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Research Article

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Seismic Analysis and Reservoir Characteristics of Boka Field, Niger Delta, Nigeria

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Abstract An integrated 3D seismic data, checkshot data and a suite of well logs for five wells located at the BOKA field, Niger Delta were analyzed with Petrel software for reservoir characterization and volumetric analysis. The method employed involves petrophysical analysis, structural analysis, volumetric analysis and reservoir ranking. Detailed well log petrophysical analysis revealed four potential reservoirs. Structural analysis showed fault assisted anticlinal structures which serve as structural traps that prevent the leakage of hydrocarbon from the reservoirs.

Keywords Boka Field, Seismic Analysis, Reservoir Characteristics

Introduction

Hydrocarbon resources remain very vital to the economy of many nations of the world. The high cost of exploration for this all-important resource makes it necessary for the attainment of high level of perfection in the methods adopted for its detection and quantification Since cost effectiveness is the driving factor in oil and gas industry, there is a great need to use effective method to quantify the reservoir with reduced level of uncertainty associated with geological models. Drilling of an oil well is a very costly venture coupled with the fact that hydrocarbon reserve are depleting. The deposits yet undiscovered are in more complex geological environments and hence it is important to exploit new development with higher resolution seismic reflection methods.

Location of the Study Area

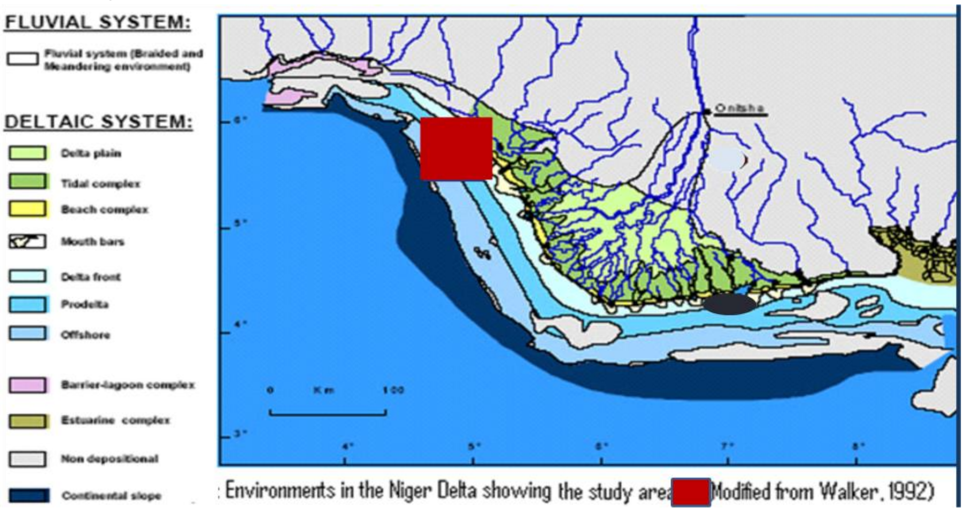

Figure 1: Location of study area (Boka Field) with respect to coordinates, fluvial and deltaic systems of the Niger Delta, Southern Nigeria.

Boka field is located within the of Niger delta in Nigeria (Figure 1). The Niger Delta is located in southern Nigeria.

Objectives of the Study

The objectives of this study include, but not limited to the:

- Determination of the seismic attributes of the Boka Field
- Identification and definition of potential reservoirs and key hydrocarbon horizons useful for field development
- Determination of fluid types and contacts in reservoirs

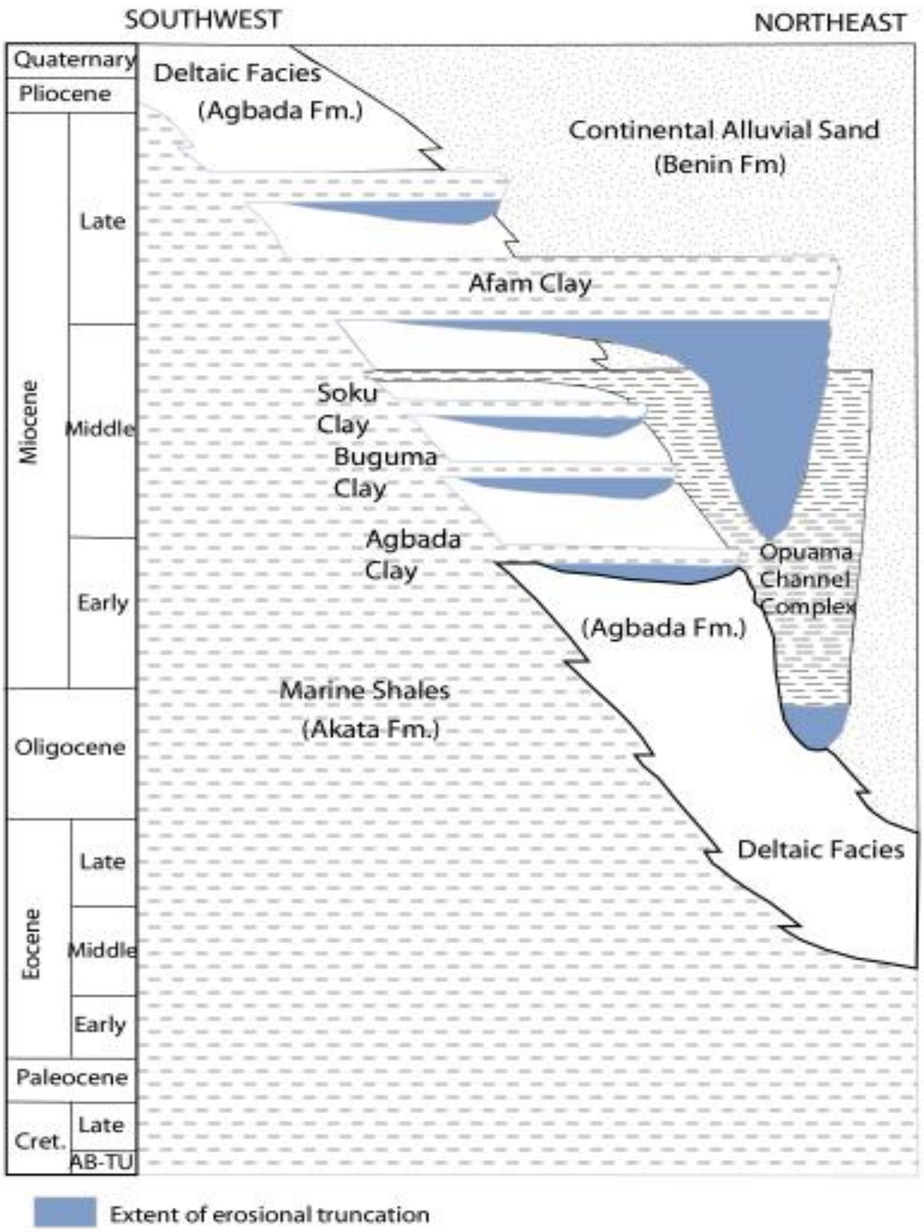

Figure 2: Stratigraphic column showing the three formations of the Niger Delta.
(Adapted From: Tuttle et al, 1999)

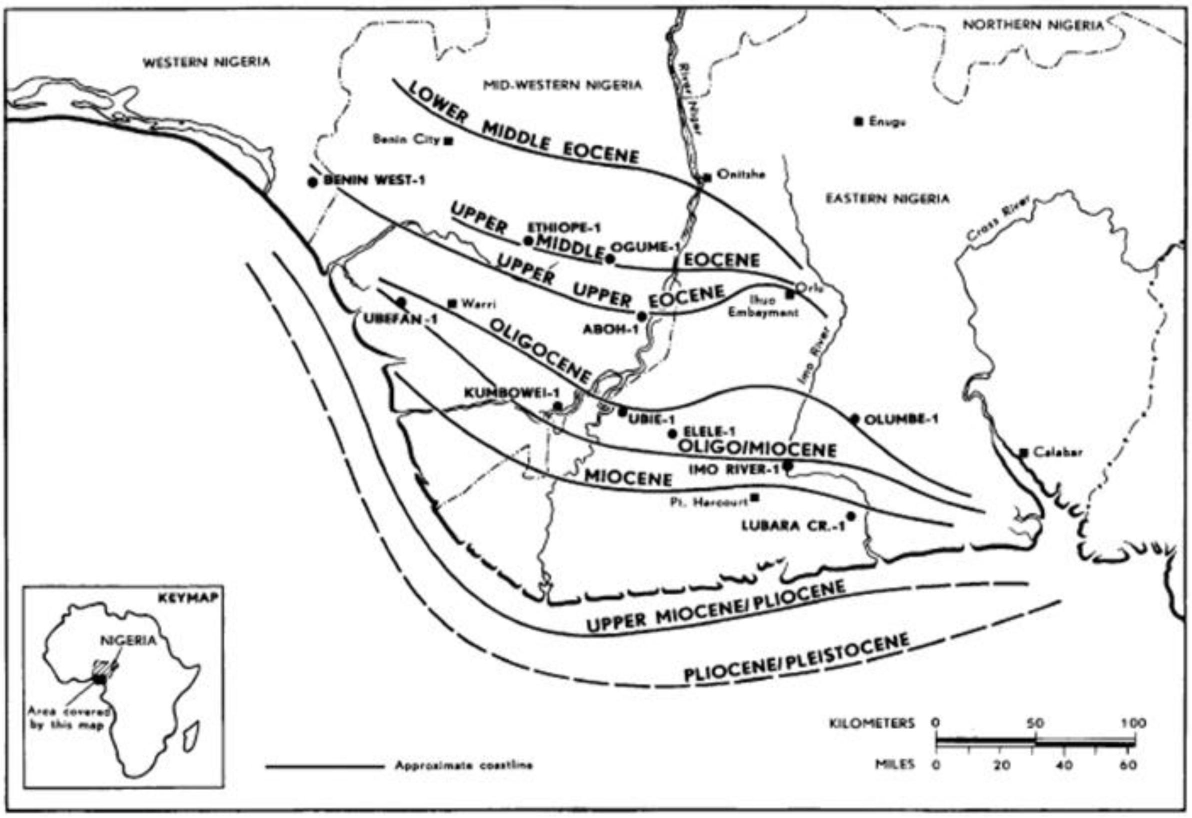

Figure 3: Palaeogeography of Tertiary Niger Delta showing stages of delta growth and progradation of coastline / shoreline from Early Eocene to Pleistocene with corresponding shift in depobelt southerly (Adapted from Short and Stauble, 1967).

Methodology

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Data Sets

The following data sets were obtained and used for this study:

- Base map of the field
- A suite of wire line logs of five wells
- 3D Seismic sections
- Check shot data
- Biofacies data

The analytic procedure was aimed at bringing out the lithology, reservoir, its area extent, complexity, productivity, and the type and quantity of fluid it contains [1]. The results were used to locate and estimate the economic prospects of the wells already drilled. Qualitative log interpretation in this work is based on the visual observation of the logs to determine zone of interest [2]. These are primarily concerned with shape, characteristic signature and physical model of the relevant well log. It involves the identification of permeable and impermeable beds. Also bed thickness and depth to various fluids can also be determined. Generally, the litho-stratigraphic correlation is a visual process which provides knowledge of the general stratigraphy of an area. Based on the available logs, the parameters that were evaluated include; lithology identification, identification of reservoir and well log correlation [3].

For lithology identification, sand and shale bodies were delineated from the gamma ray log signatures. Sand bodies were identified by deflection to the left due to the low concentration of radioactive minerals in it. The gamma ray log was set to a scale of 0-150 API. The scale increased from left to right, with a central cut off of 65 API units (less than 65 API units was interpreted to be sand while greater than 65 API units was interpreted as shale). Reservoirs are subsurface formations that contain water and hydrocarbon [4]. They were identified by using the log signatures of both gamma and resistivity logs. Intervals that have high resistivity are considered to be hydrocarbons while low resistivity zones are water bearing intervals. The logs were activated and displayed on the well section window,

The quantitative interpretation in this study involves the use of empirical formulae to estimate the petrophysical parameters such as porosity, permeability, volume of shale and hydrocarbon saturation. In addition to that volumetric analysis was carried out in order to determine the volume of hydrocarbon in place.

Table 1: Geological significance of seismic attributes (*After Schlumberger, 2009*)

Seismic attribute	Geological significance
Amplitude	Lithological contrast
	Bedding continuity
	Bed spacing
	Gross porosity
	Fluid content
Instantaneous frequency	Bed thickness
	Lithological contrast
	Fluid content
Reflection strength	Lithological contrast
	Bedding continuity
	Bed spacing
	Gross porosity
Instantaneous phase	Bedding continuity
Polarity	Polarity of seismic
	Lithological contrast

Determination of Petrophysical Parameters

Gamma Ray Index and Shale Volume

The Gamma Ray Index (I_{gr}) option (equation (2.1)) below was employed to determine the volume (percentage) of shale, and implicitly, the dominant lithology. This was achieved by determining the clean sand line and maximum thickest shale line from the Gamma ray log for each well. Correction was made on the gamma ray index to compensate for the unconsolidated sands of the Tertiary Niger Delta. The volume of the shale (V_{sh}) was computed using an expression after Larionov (1969) here stated as equation (2.2). The parameter also served as an input data in the porosity and saturation model for shaly sand.

$$I_{gr} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad --- \quad --- \quad --- \quad (2.1)$$

$$V_{sh} = 0.083(2^{3.7(I_{gr})} - 1.0) \quad --- \quad --- \quad --- \quad (2.2)$$

Where,

GR_{log} = Gamma ray of formation measured from log

GR_{min} = Least Gamma ray in zone of interest

GR_{max} = Maximum gamma ray reading in formation of interest

I_{gr} = Gamma Ray Index

V_{sh} = Volume of shale

Porosity (φ)

The porosity of the various units was determined from the neutron and density logs. Density porosity (φ_D) was obtained from the log-derived bulk density using equation (2.3) after Rider (1986) while Neutron porosity was read directly from the neutron log after which it was corrected for shale effect within the sandy reservoir units.

$$\Phi_D = \frac{\rho ma - \rho b}{\rho ma - \rho f} \quad --- \quad --- \quad --- \quad (2.3)$$

Where,

φ_D = Density porosity (effective)

ρ_b = Bulk density

ρ_{ma} = Matrix (grain) density

ρ_f = Fluid density

The matrix (grain) density (ρ_{ma}) and fluid density (ρ_f) were assumed that of sand (2.65 g/cm^3) and salt-based mud (1.1g/cm^3), respectively. This was in compliance with Asquith and Gibson (1982) who state that electrode tools such as Dual Laterolog require salt-saturated drilling mud to determine accurate true resistivity (R_t) values whereas Dual Induction tools require fresh water based mud.

The combined neutron-density porosity uncorrected for shale effect was computed using expression (2.4) below:

$$\Phi_{nd} = \sqrt{\frac{\Phi_N{}^2 + \Phi_D{}^2}{2.0}} \quad --- \quad --- \quad --- \quad (2.4)$$

Where,

φ_{nd} = Neutron-density porosity

φ_N = Neutron porosity

φ_D = Density porosity

Porosity values obtained from bulk density log was corrected for shale effect using equation (2.5).

$$\Phi_{dc} = \Phi_D - (\frac{\Phi_N\ Shale}{0.45} \times 0.13 \times Vsh) \quad --- \quad --- \quad (2.5)$$

Where,

Φ_{dc} = Density porosity corrected

Φ_D = Density porosity

φ_{Nshale} = Neutron porosity of adjacent shale

V_{sh} = Volume of shale

The effective neutron porosity (φ_{nc}) was further deduced by introducing the shale volume percentage into the equation. This help to correct for shale effect. In correcting for shale effect, a formula after [14] was used. This is given as:

$$\Phi nc = \Phi_N - (\frac{\Phi_N\ Shale}{0.45} \times 0.30 \times Vsh) \quad --- \quad --- \quad --- \quad (2.6)$$

Where,

φ_{nc} = Neutron porosity corrected (Effective)

φ_N = Neutron porosity

φ_{Nshale} = Neutron porosity of adjacent shale

V_{sh} = Volume of shale

From the corrected neutron porosity (φ_{nc}) and density porosity (φ_{dc}) values, the corrected neutron-density porosity ($\varphi_{N\text{-}DCorr}$) [the later generally referred to as porosity (φ)] was computed using the expressions below:

$$\Phi_{N\_DCorr} = \sqrt{\frac{\Phi nc^2 + \Phi dc^2}{2.0}} \quad --- \quad --- \quad --- \quad (2.7)$$

Where,

$\Phi_{N-DCorr}$ = Neutron-density porosity corrected

φ_{dc} = Density porosity corrected

φ_{nc} = Neutron porosity corrected

On the basis of the stated approach, the porosity for various reservoir sand units was evaluated. The interpretation of the porosity values was based on the classification scheme established by [8]

Results and Discussion

The results of this study were discussed based on qualitative interpretation, quantitative interpretation, statistical, structural, and volumetric analysis.

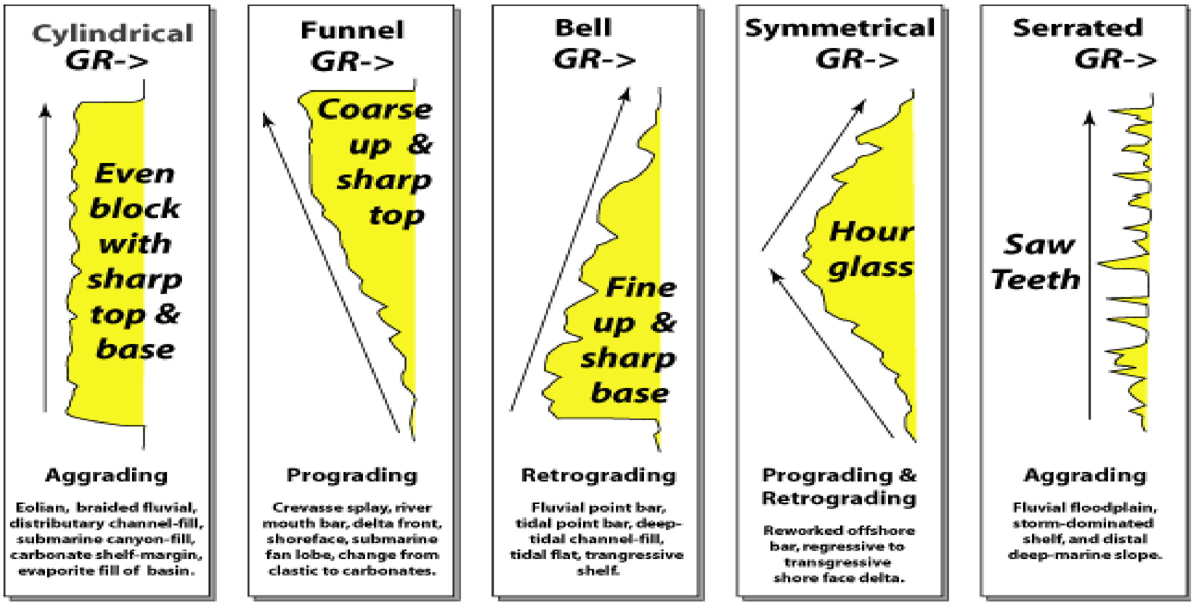

Figure 4: General gamma ray responses to grain size variations showing stacking pattern and depositional environment (Adapted from Emery and Myers, 1996).

(a) Qualitative interpretation

For the log interpretation, its litho-stratigraphic correlation furnished knowledge of the general stratigraphy of the study field.

Well Correlation Panel across Boka *a* and *e* showing the Top & Base of Reservoir a, b and c (values are in feet). The litho-stratigraphic correlation is a visual process which provides knowledge of the general stratigraphy of an area. Two lithologies; sand and shale, were identified using the gamma ray log. From the lithology log, the interval colored blue is sand, while the interval coloured grey is shale. three sand bodies were mapped as reservoirs; Reservoir **a, b, c**, which are correlated across the field. The results obtained from this study are based on both the petrophysical analysis and seismic interpretation [5]. The well correlation panel is showing the top and base of the reservoirs. The five reservoirs cut across Boka . **a, b and c** occur at depth 3670 m, 3975 m and 4387 m respectively.

The analysis showed that each of the sand units extends through the field and varies in thickness. Some units occurred at greater depth than their adjacent units, which is possibly an evidence of faulting. The shale layers were observed to increase with depth along with a corresponding decrease in sand layers. This pattern in the Niger Delta indicates transition from Benin to Agbada formation. From the analysis of this study, particularly the resistivity log, all the three delineated reservoirs were identified as hydrocarbon bearing units across the five wells.

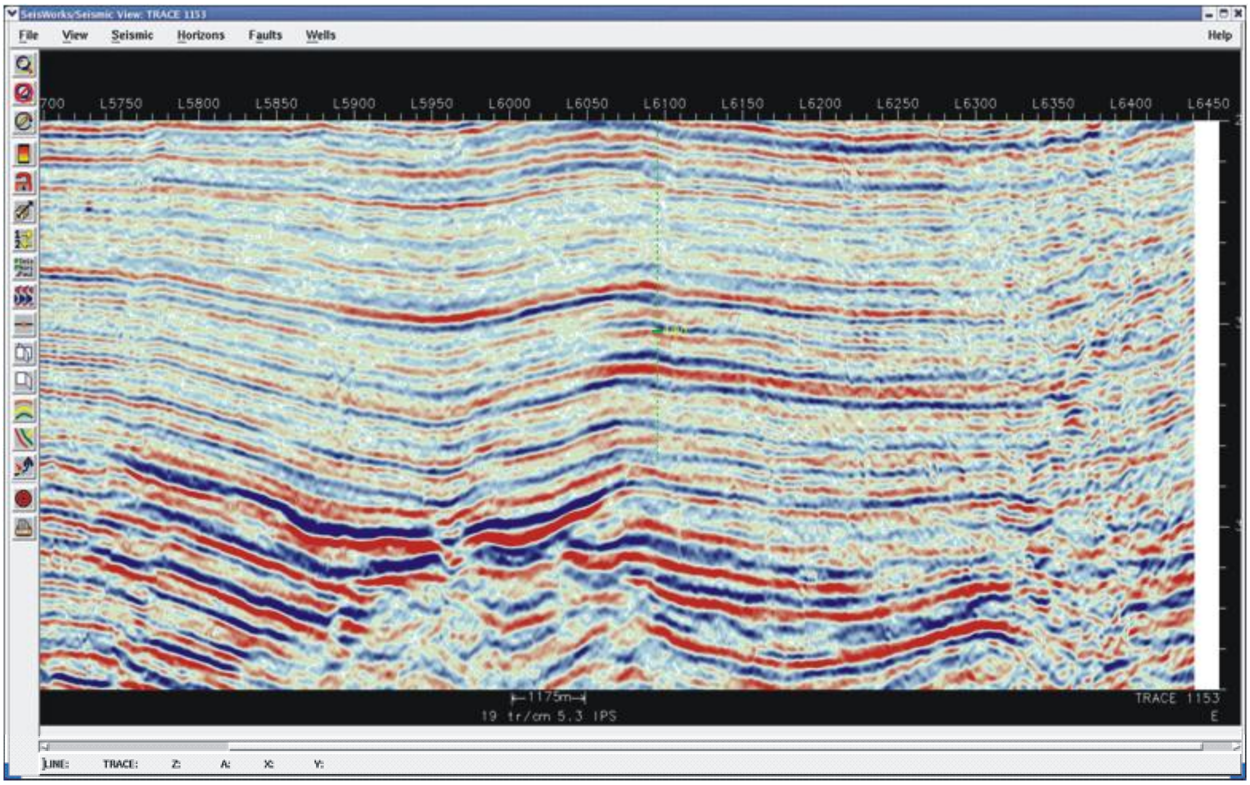

Figure 5: 3D-Seismic of Boka Field

The porosity values obtained across all the five wells in reservoir **b** indicated good to very good values which are slightly less in quality when compared to reservoir a and this complement the fact that porosity decreases with depth [6].

Furthermore, the permeability showed an excellent value for well **a** and very good values for all the other wells. The ratio of the hydrocarbon to water saturation indicated that this reservoir contain both water and hydrocarbon, with hydrocarbon slightly higher than water saturation.

Table 2: Summary of reservoir sand properties at Boka Well

Sand	**Depth (ft)**	**Thickness**	**% Vsh**		**Φ (%)**	**K (mD)**	**Sw (%)**	**Swirr**	**Sh (%)**	**BVW (%)**	**Fluid Type**	**Nature of formation water**
			Range	**Aver**								
a	12400-13962	552	0.9 – 28.1	7.2	26.22	119.27	24.68	7.66	75.32	6.48	Oil	Not at irreducible
b	12025-12375	350	0.9 – 8.3	5.0	25.65	70.39	23.65	7.69	76.35	6.05	Oil and Gas	Not at irreducible
c	12575-12810	235	0.9 – 28.1	11.8	27.11	102.13	14.94	7.23	85.06	4.08	Oil and Gas	Not at irreducible
d	12875-13175	300	0.9 – 57.6	7.1	27.14	111.04	9.68	7.31	90.32	2.50	Oil and Gas	Not at irreducible
e	13425-13600	175	1.8 – 57.6	22.8	27.31	127.17	8.13	7.43	91.87	2.13	Oil and Gas	Not at irreducible

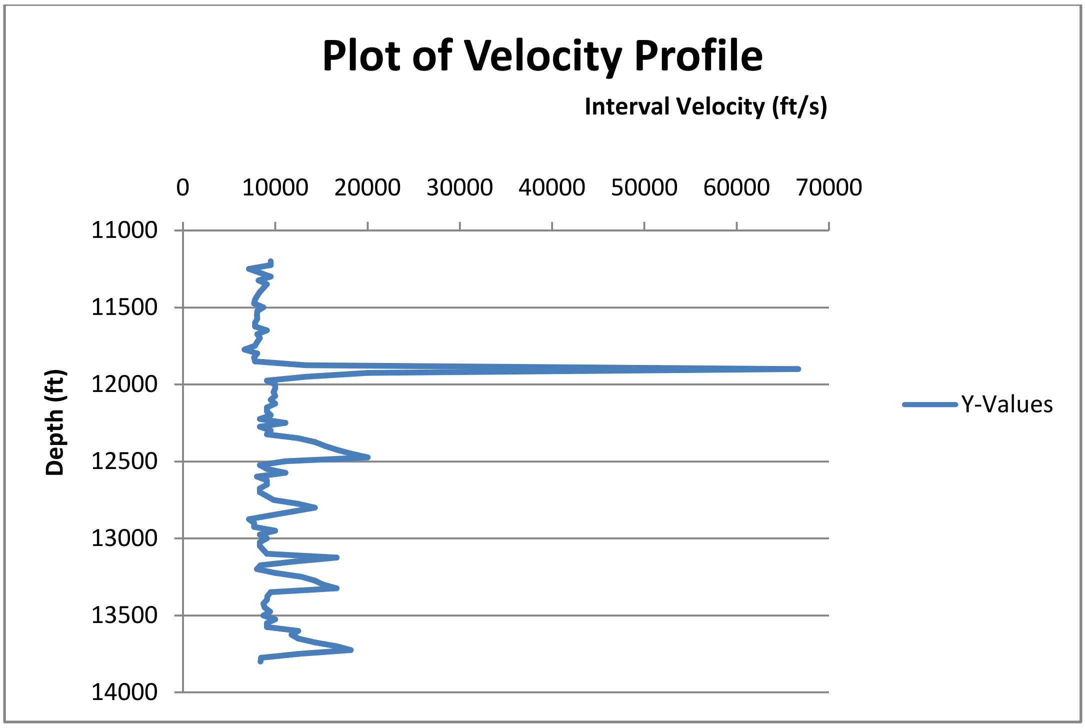

Figure 6: Interval velocity profile with depth at Boka c

Well **a** reservoir sand was found to contain 82.30% hydrocarbon saturation and 17.70% saturation water at depth 11325 - 11858ft. Gas column was up to (GUT) 11325ft, with Gas-Oil contact (GOC) at 11375ft and Oil-Water contact (OWC) at 11600ft. This reservoir sand, with an average Volume of Shale (Vsh) of 9.0%, average porosity of 22.79 and average permeability of 54.24mD was found to be irreducible at approximately 4% Bulk Volume Water (BVW), an indication that more oil and gas will be produced than water [9] and [10].

Reservoir sands **b** and **c** encountered at Well **c** location were also at irreducible while sand **e** had 76.15% hydrocarbon saturation and 23.85% water saturation; oil up to (OUT) 12000ft and oil-water contact (OWC) at 12300ft. Three horizons corresponding to the tops and bottoms of the four reservoirs and three faults were mapped as horizon **a** (Ha), horizon **b** (Hb), horizon **c** (Hc) and fault **a** (Fa), fault **b** (Fb) and fault **c** (Fc) respectively across the seismic section for this analysis. To ensure a good tie, wells with their tops were superimposed on the seismic sections that intersected each other.
Some of the reservoir tops and bases coincided with the peaks and troughs on the seismic section. Mapped horizons and the generated fault polygons were used to generate time structure maps for the five reservoirs [11] and [12]. The map showed an anticlinal structure at the centre of the surfaces which is a structural trap. The two growth faults seen on the seismic section is also displayed on the surfaces. Although a time map is compressed in its deeper parts and stretched out in its shallow areas because of the general increase in velocity with depth, the highs and lows are normally in the right places [13].
The time structure maps were then converted into depth maps using the check shot data obtained from the area which is an important parameter in the determination of the hydrocarbon in place. The depth structure maps also showed the anticlinal structure and the two faults. The depth structural maps were then used to quantify the oil in place. The area extents of the reservoirs were mapped to be 35,639 m^2 for a, 8,585 m^2 for b and 12,655 m^2 for c. The above obtained values were then multiplied by the gross thickness of the reservoir in order to obtain the volume of the hydrocarbon in place in each reservoir.

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