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3-D GEOLOGICAL AND GEOTHERMAL MODELING: A CASE STUDY OF USANI OFFSHORE, NIGER DELTA BASIN, NIGERIA

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Abstract
The 3-D geological and geothermal model was built using seismic data and geo-temperature data respectively. The model was used to deduce environment of deposition and their facies. The geological model serves as a pointer to locate highly permeable channels where hydrocarbons are found. The well consist of Gamma ray log (GR log), Spontaneous Potential logs (SP log), Resistivity logs, Formation density, Neutron log, Sonic log and all the well logs penetrate Agbada and the Benin Formation. The wells within the interval studied consist mainly of alternate sequence of sand and shales. The shale is rich in organic matter in the study field. The geo-temperatures values of 101.60ºC– 119.60ºCat modeled depth of 1357m- 3500m, indicating that the shale beds of Agbada Formation are within the oil generating window and is thermally matured with sufficient organic matter to generate hydrocarbon in the study field as earlier believed to be immature and cannot generate hydrocarbon. The 3-D geological and geo thermal model are the basis of establishing depositional facies and the hydrocarbon window of the Agbada Formation at depth 1357-3500m which is a useful tool in exploration and exploitation geology.

Keywords: Geological and Geothermal model, Hydrocarbon window, Thermal maturity.

Introduction
According to Short and Stauble [1], three lithostragraphic unit are recognized in the Niger Delta Basin as Akata, Agbada, Benin Formation from base to top. The aspects of the petroleum geology of the basin discussed in Merki [2]. Domkens [3] Used lithofacies to interprete sub-environments within the delta. The origin of the source rock within the Niger Delta has been a matter of debate for more than a decade. Earlier works by Weber and Daukoru [4] is of the opinion that the Agbada Formation is immature implying that the Akata Shale would have been possible source of the hydrocarbon in the Niger Delta. The objectives of this study are: To use seismic data to build 3-D fluvial depositional environment of the study field and position the hydrocarbon generating window with a view of understanding the hydrocarbon prospects in the studied field.

Study Location
The field is located at Oil Mining Lease (OML) X, offshore Niger-Delta Basin of Nigeria Fig.1.

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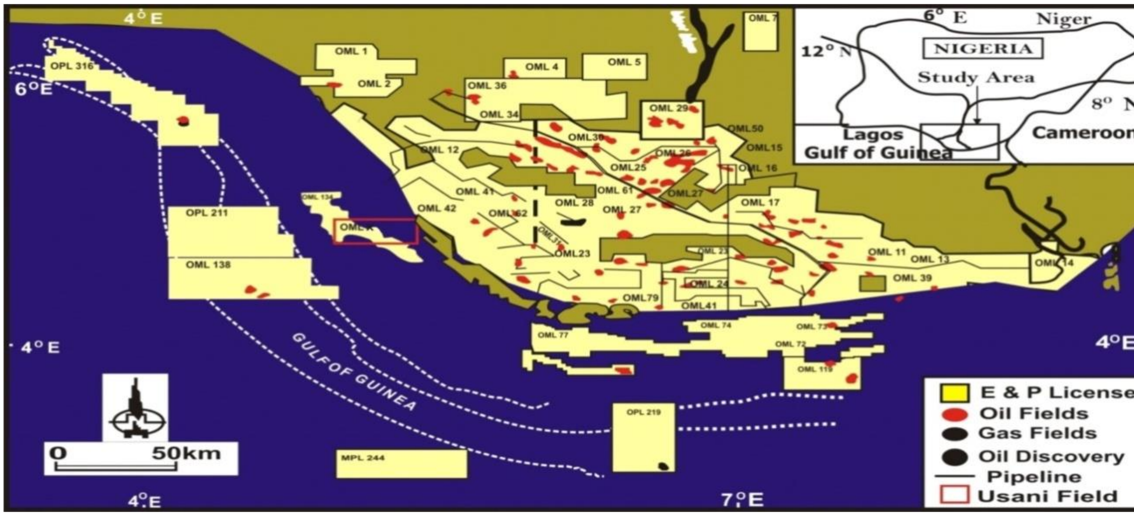

Fig.1: Concession map showing study field

Materials and Method

The materials used in this investigation include: Seismic data, well log data which consist of GR log, SP log, resistivity log, caliper log and geo-temperature data from Usani wells 1-4. Correlation of the wells across the field, processing and interpretation of seismic data, were all done using petrel software. The plot of formation temperature against formation depth was used to generate a mathematical model. This model generated was used to position the hydrocarbon window of the field.

The plot of formation temperature against formation depth is a linear function (Fig.2) and the first step for generating the hydrocarbon thermal maturity model is to determine the geothermal gradient (equation 1) [5, 6].

Table 1 Geo-temperature data for the wells

Wells	Reservoir	Depth(m)	Reservoir temperature (ºC)
	A	2946-2982	110.00
1	B	2994-3138	112.00
	C	3162-3293	116.00
2	A2	3066-3012	115.00
	B2	3126-3263	115.00
	C2	3293-3413	116.00
3	A3	2994-3054	115.20
	B3	3126-3257	116.10
	C3	3269-3434	116.20
4	A4	3054-3434	116.80
	B4	3246-3341	117.50
	C4	3372-3532	118.50

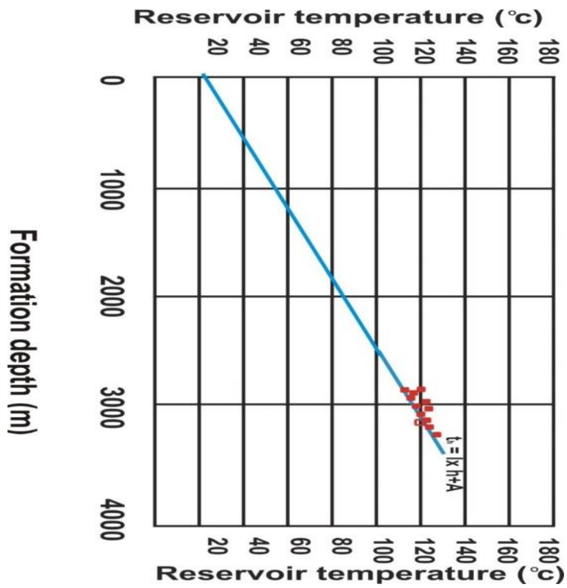

Fig.2: Plot of reservoir temperature against formation depth(m) in the wells

Geothermal gradient (I) = $\frac{\Delta T}{\Delta D}$ (1)

Geo-temperature Analysis

From the plot of temperature against depth (Fig. 2)

$$A_o + Ih = t_h \qquad (2)$$

Simple model for positioning oil and gas windows for the field of study.

$$h = \frac{t_h - A_o}{I_a} \qquad (3)$$

Results and Discussion

Correlation in the wells

The litho-section were drawn to a scale of 1cm-100m, (Fig. 3). The GR log were used to delineate lithologic section of the wells

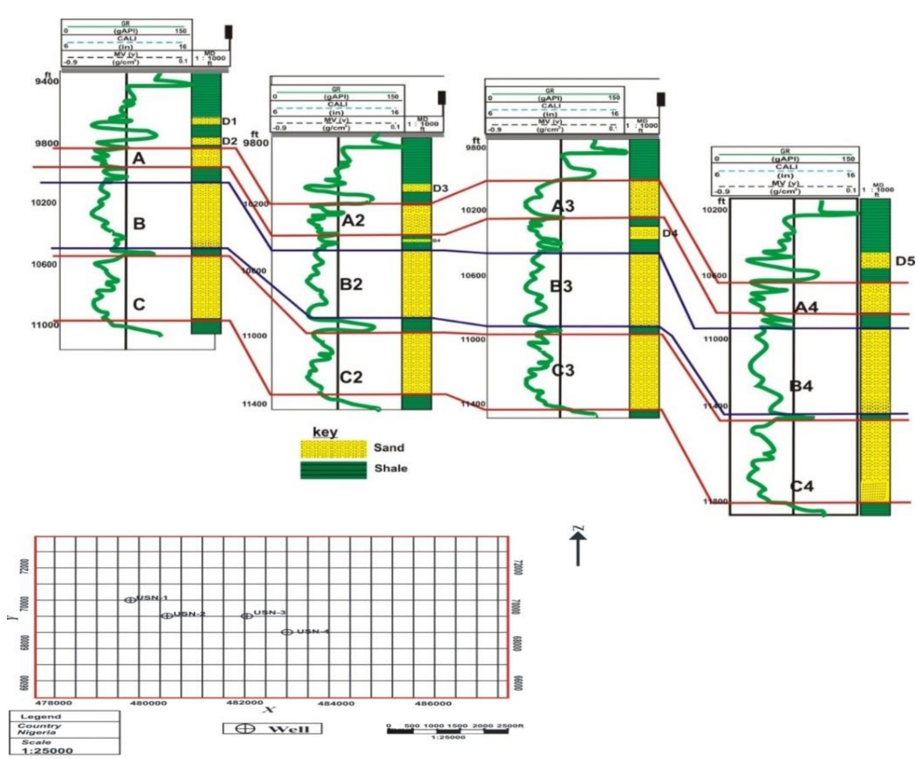

Fig. 3: Correlation in well 1, 2, 3 and 4 in NW-SE direction.

and the shale units were properly delineated from the sand bodies. The correlation was done on the wells to determine the shale thicknesses (Fig.3). Geothermal equation was used to determine the thermal maturation potentials for shales intervals in the Agbada Formation because all the wells penetrate the Agbada Formation.

From the 3-D geological model of the fluvial depositional environment (Fig.4) obtained from the stochastic model. It shows that the depositional facies are mainly of sands, shale, flood plain (mixed deposits – mainly of mud and silts), leeve sand, crevasse splay, point bar deposits. This is a typical fluvial/deltaic facies. The wells are located in the channels containing high quality sands.

The estimated temperatures and geothermal gradient values were estimated for all the wells in Tables 2-5, using equation 1&2.

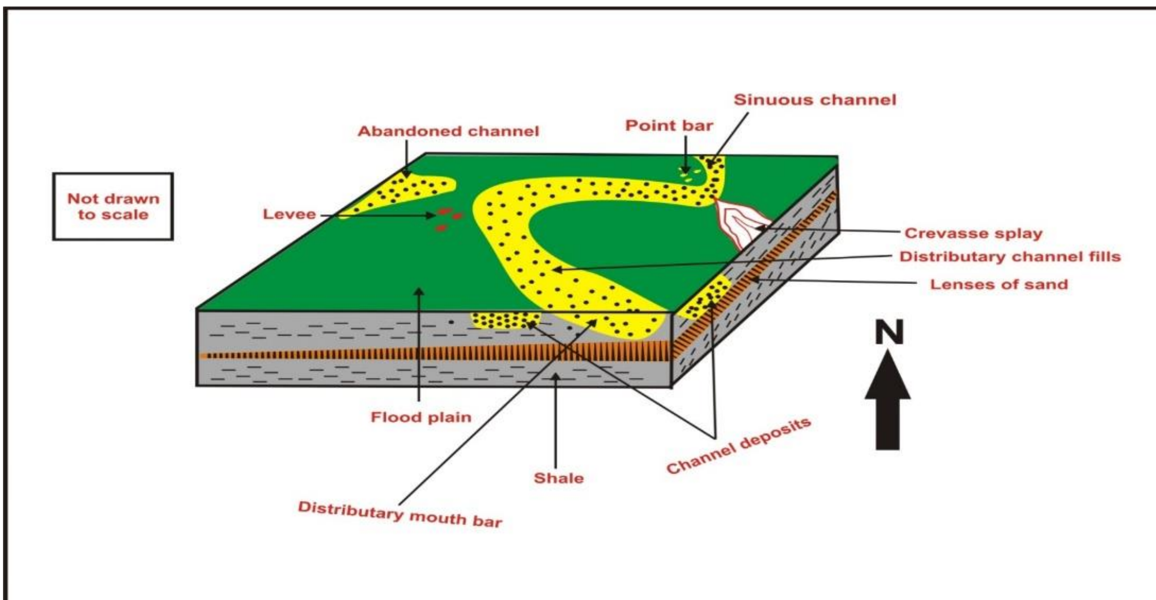

Fig. 4: 3-D Geological model of fluvial/deltaic depositional environment obtained by stochastic modeling method

Table 2: The results for estimated temperature values for shale bed in well 1

S/N	Depth (h) (ft)	Depth (h) (m)	Shale thickness (m)	Geothermal gradient (I) °C/m	Mean annual surface temp. °C	Temp. at depth of interest (t_h) m
1	9400 – 9640	2814 – 2886	72	0.028	22.00	101.80
2	9680 – 9760	2898 – 2922	24	0.028	22.00	103.48
3	10520 – 10560	3150 – 3162	12	0.028	22.00	110.36

Table 3: Temperature results for shale bed in well 2

S/N	Depth (h) (ft)	Depth (h) (m)	Shale thickness (m)	Geothermal gradient (I) °C/m	Mean annual surface temp. °C	Temp. at depth of interest (t_h) m
1	9800 – 10120	2934 – 3030	96	0.028	22.00	105.49
2	10120 – 10200	3030 – 3054	24	0.028	22.00	107.17
3	10280 – 10320	3078 – 3090	12	0.028	22.00	108.35
4	10460 – 10580	3132 – 3168	36	0.028	22.00	110.20
5	10880 – 10960	3257 – 3281	24	0.028	22.00	113.44
6	11400 – 11520	3413 – 3449	36	0.028	22.00	118.06

Table 4 Temperature results for shale bed in well 3

S/N	Depth (h) (ft)	Depth (h) (m)	Shale thickness (m)	Geothermal gradient (I) °C/m	Mean annual surface temp.°C	Temp. at depth of interest (t_h) m
1	9800 – 10120	2934 – 3030	96	0.28	22.00	105.49
2	10120 – 10200	3030 – 3054	24	0.28	22.00	107.17
3	10280 – 10320	3078 – 3090	12	0.28	22.00	108.35
4	10460 – 10580	3132 – 3168	36	0.28	22.00	110.20
5	10880 – 10960	3257 – 3281	24	0.28	22.00	113.44
6	11400 – 11520	3413 – 3449	36	0.28	22.00	118.06

Table 5: Calculated temperature values for shale bed in well 4

S/N	Depth (h) (ft)	Depth (h) (m)	Shale thickness (m)	Geothermal gradient (I) °C/m	Mean annual surface temp. °C	Temp. at depth of interest (t_h) m
1	10160 – 10240	3030 – 3066	36	0.29	21.90	110.29
2	10500 – 10580	3143 – 3168	25	0.29	21.90	113.40
3	10620 – 10660	3180 – 3192	12	0.29	21.90	114.29
4	10960 – 10840	3221 – 3245	24	0.29	21.90	115.65
5	11320 – 11350	3389 – 3398	10	0.29	21.90	120.31
6	11760 – 11860	3521 – 3551	30	0.29	21.90	120.49

Table 6: Computed values for the linear model

T_h	60°C	120 °C	225°C
h(m) $h = \frac{t_h - A_o}{I_a}$	1357m	3500m	7250m

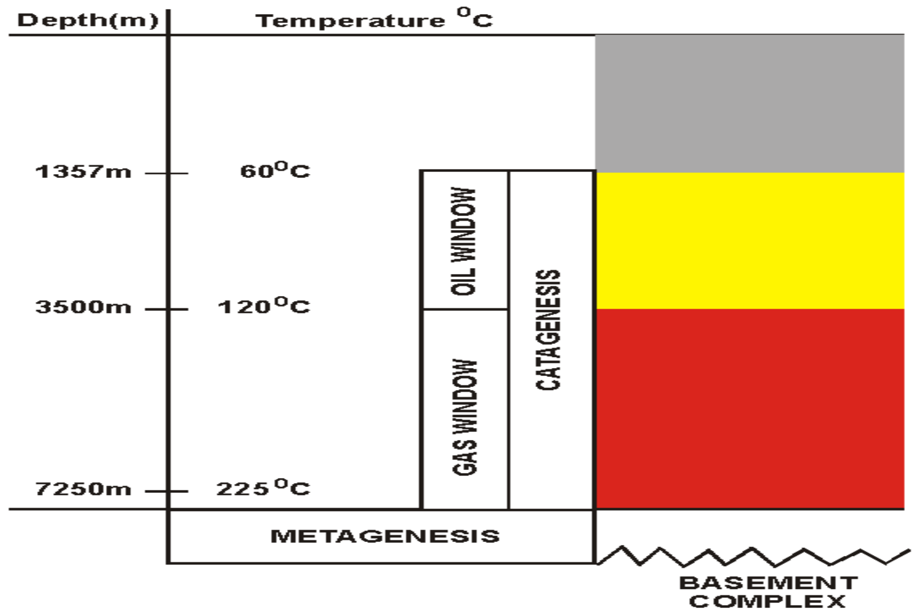

Fig. 5: Catagenesis and metagenesis in the field

Hydrocarbon window of the field

From the plot of formation temperature against formation depth, a linear model was generated. This model was used to estimate the thicknesses/depths of the formation that house the hydrocarbon in the field from 1357m-3500m (Fig. 5 and Table 6).

The Agbada Formation ranges in thickness from about 2000m to 4000mShort and Stauble [1]. The rock facies from the 3-D geological model are good to harbor the hydrocarbon in the field. The estimated thickness of 1357- 3500m in this study fall within the range of Short and Stauble [1]. The calculated geothermal gradient values and temperature values of Agbada Formation in the southern offshore parts of Niger Delta Basin calculated by Avbovbo [7] were 3.3 - 4.7°C/100m and (105°C – 119°C) respectively. The estimated geothermal gradient of (0.03°C/M) and temperature values 101°C – 120.5°C respectively in this study fall within the range Avbovbo [7]. Evamy *et al* [8] estimated the temperature range of the Agbada shale bed of the study field for hydrocarbon generation to be 115°C -118°C in southern Niger Delta Basin, Nigeria and position the hydrocarbon window to be about 115°C. This study was able to position the hydrocarbon window at about 101°C – 120°C, which fall on the range of Evamy *et al.*[8].Evamy *et al.* [8], Selley [9]stated that hydrocarbon generation for any sedimentary basin begins at 60°C and stops at 120°C. The temperature model for the study starts above 50°C and ends at 225°C and the temperature values fall within the range of Evamy *et al*. [8]. It is important to note that temperature and thicknesses/depth are important factors for geothermal modelling and flow simulation model. From all indication the thermal analysis showed that the Usani shale beds are thermally matured, oil and gas generation start at 60°C – 120°Cand ends at 120°C – 220°C respectively in the Usani field. The study also, shows that the basal part of the Agbada Shales are responsible for the expulsion of the hydrocarbon from the field and this supports the work of Lambert-Alkhionbare and Ibe[11]. The hydrocarbon generation starts from 1350m and ends at 3500m in the study field.

Conclusion

The model generated was used to determine thermal maturity of Usani shale beds of the Agbada Formation that is thermally mature and the 3-D depositional model was also used as a basis to establish the depositional model of the field.

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