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Reservoir Property Distribution and Structural Styles Analysis of OML'999' 2-D Regional Line, Onshore Niger Delta Basin

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Abstract

Investigating the distribution and variation of reservoir property within a field is important for both field development plan and production optimisation. Porosity, net-to-gross, water saturation and permeability information, derived from petrophysical analysis, are controlled basically by inherent depositional settings. A sequence stratigraphic study was done to define the environment of deposition within constrained reservoir intervals in Alpha, Beta and Gamma field of OML'999' block, onshore Niger Delta by integrating log information and biostratigraphic data from three (3) wells. The analysis delineated three sequences with key surfaces generated used for correlation. These surfaces were delineated at varying depth in Maro-001 and Tegus-002 wells, suggesting the existence of fault in the block.

A comparison of the properties of the hydrocarbon bearing reservoir of Maro-001, Tegus-002 and Seyi-003 wells indicated varying petrophysical property from north to south, which can be attributed to facies change which was determined to be from fluvio-deltaic to shallow marine as we move basinward.

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The general trend of the fault in the 2-D regional line is NW- SE, while the throw direction is SW for the synthetic faults which dip basinward and NE for the antithetic faults.

The trapping mechanisms were identified to be fault dependent and are typically roll over structures, hanging wall and foot wall closures, which are the basic hydrocarbon trap associated with normal detached fault in an extensional setting.

Keywords: Sequence stratigraphy; petrophysical property; trapping mechanisms; 2-D seismic line; fluvio-deltaic; shallow marine

1. Introduction

The details of petrophysical property within reservoir intervals in wells across a field is important because, it in a large extent determine how the field behaves and also control the recovery of hydrocarbon. The reservoir architecture and geometry, which helps to determine degree of connectedness, communication and compartmentalization, is also greatly affected by the structural styles present in the field.

This study therefore aims at using sequence stratigraphy to constrain reservoir interval for petrophysical analysis and observe its spatial distribution across the entire field. Sequence stratigraphy provides the basis for correlating time surfaces between which lithofacies are distributed systematically in a predictable pattern. A more realistic image of the reservoir architecture can, therefore, be constructed by distributing lithofacies and petrophysical properties within a detailed sequence-stratigraphic framework. This study also analyse the various subsurface structural styles and hydrocarbon trapping configuration across the 2-D regional line of OML '999', onshore Niger Delta Basin while also assessing its impact on hydrocarborn storage and production.

Available biostratigraphic information, integrated with the Niger delta chronostratigraphic chart, indicates that the study area is in the Greater Ughelli depobelt of the Niger Delta basin which is Oligencene – Early Miocene in age. It contains eight (8) producing field.

1.1 Geology of the Study Area

The Niger Delta Basin occupies the Gulf of Guinea continental margin in equatorial West Africa between Latitude 3^0 and 6^0 N and Longitude 5^0 and 8^0 E. The clastic wedge of the Niger Delta formed along a failed arm of a triple junction system (aulacogen) that originally developed during the break-up of the South American and African plates in the late Jurassic [12]. It ranks among the world's most prolific petroleum producing Tertiary Deltas [3]. The stratigraphy, Sedimentology, structural configuration and paleo-environment in which the reservoir rocks accumulated have been studied by various workers. These include [7, 10, 11, 6, 3] and many others.

The Niger Delta is framed on the northwest by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif. Well sections through the Niger Delta generally display three vertical lithostratigraphic subdivisions: an upper delta top facies; a middle delta front lithofacies; and a lower pro-delta lithofacies [6]. These lithostratigraphic units correspond respectively with the Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) [7].

The Akata Formation is composed mainly of marine shales, with sandy and silty beds which are thought to have been laid down as turbidites and continental slope channel fills. It is estimated that the formation is up to 7,000 metres thick [2]. The age of the Akata formation ranges from Paleocene to Recent

The Agbada Formation is the major petroleum-bearing unit in the Niger Delta. The formation consists mostly of shoreface and channel sands with minor shales in the upper part, and alternation of sands and shales in equal proportion in the lower part. The thickness of the formation is over 3,700 metres. The age of the formation ranges from Eocene-Recent.

The Benin Formation is about 280 metres thick, but may be up to 2,100 metres in the region of maximum subsidence [12], and consists of continental sands and gravels. The age of the formation is estimated to range from Oligocene to Recent [7].

From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development [2]. These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km2 [13] a sediment volume of 500,000 km3 and a sediment thickness of over 10 km in the basin depocenter.

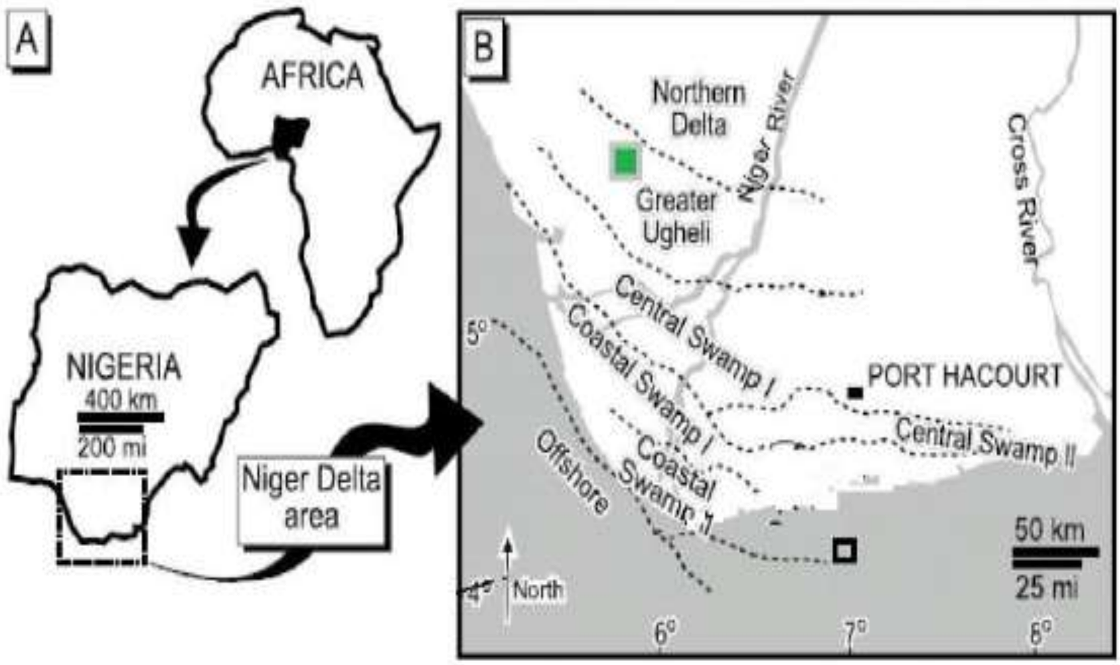

Figure 1: Map of Niger Delta and depobelts showing location of study area

2. Materials and Method

In order to achieve the project objective, an integrated asset workflow was designed, which also summarily captured the adopted methodology. Petrel 2013 and Techlog 2013 software was used. The methods followed these summarized steps:

- Data loading and QC
- Seismic interpretation on 2D regional line (synthetic generation, faults and horizon interpretation)
- Structural styles analysis
- Build a robust sequence stratigraphic framework
- Gross Depositional Environment definition within reservoir intervals
- Petrophysical analysis
- Reservoir property characterization

. The workflow is as seen in Figure 2 below

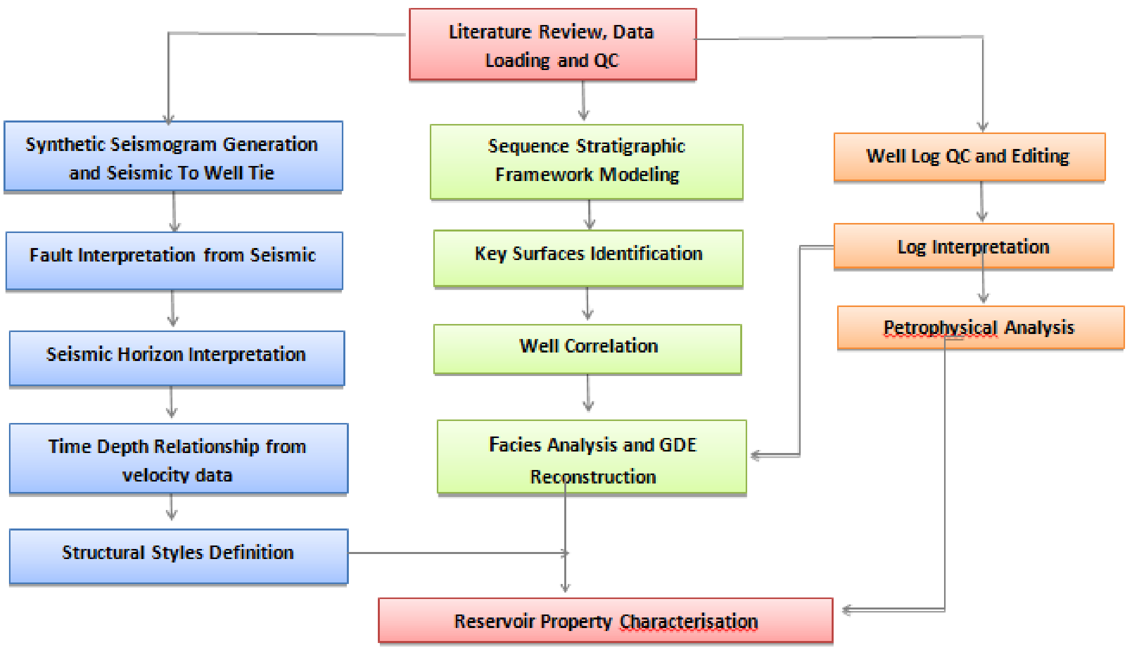

Figure 2: Generalized project workflow

3. Results

3.1 Structural interpretation

The study area is characterized by a passive phase where there has been a relatively tectonically quiet regime and an extensional regime which starts at about TWT= 1.5s below the base continental. The extensional regime is characterized by intense faulting on the Agbada formation showing major faults with some having associated synthetic faults.

Faults were interpreted from Alpha field in the North to Gamma field in the south. The faults are labelled F2, F4, F5, F7, F9, F10 and F11. The major boundary down-to-basin faults delineating different fields are designated F1, F3, F6 and F8. (Figure 3)

The general trend of the fault in the 2D regional line is North West- South East (NW-SE), while the throw direction is South West (SW) for the synthetic faults, which dip basinward and North East (NE) for the antithetic faults. Each field within the given OML is separated by a major growth fault.

Some of the DHIs identified on the regional line are flat spot, on and off structure brightening and amplitude anomalies.

The trapping mechanisms were identified to be fault dependent and are typically roll over structures, hanging wall and foot wall closures, which are the basic hydrocarbon trap associated with normal detached fault in an extensional setting.

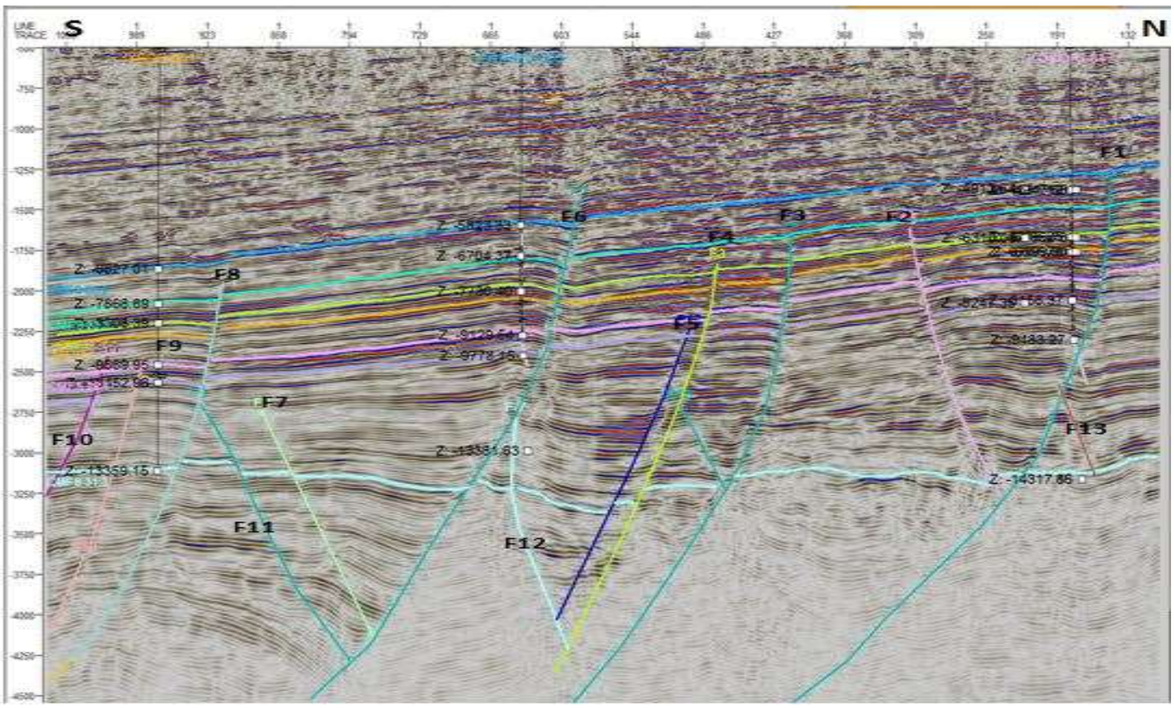

Figure 3: Interpreted Faults and Horizon on 2D Line

3.2 Sequence stratigraphic studies and gross depositional environment reconstruction

A detailed sequence stratigraphic framework was built on Maro-001 well (Gamma field). Key surfaces (MFS and SB) were picked using log shapes, stacking patterns, and biostratigraphic information. Correlation was done using the identified constrained chronostratigraphic surfaces, in the dip direction. Evidence of faulting was noticed, as the surfaces occurred at varying depth down dip across the wells.Three depositional sequences were identified. Each depositional sequence is bounded above and below by a maximum flooding surface. The details is as summarized in Table 1 and 2.

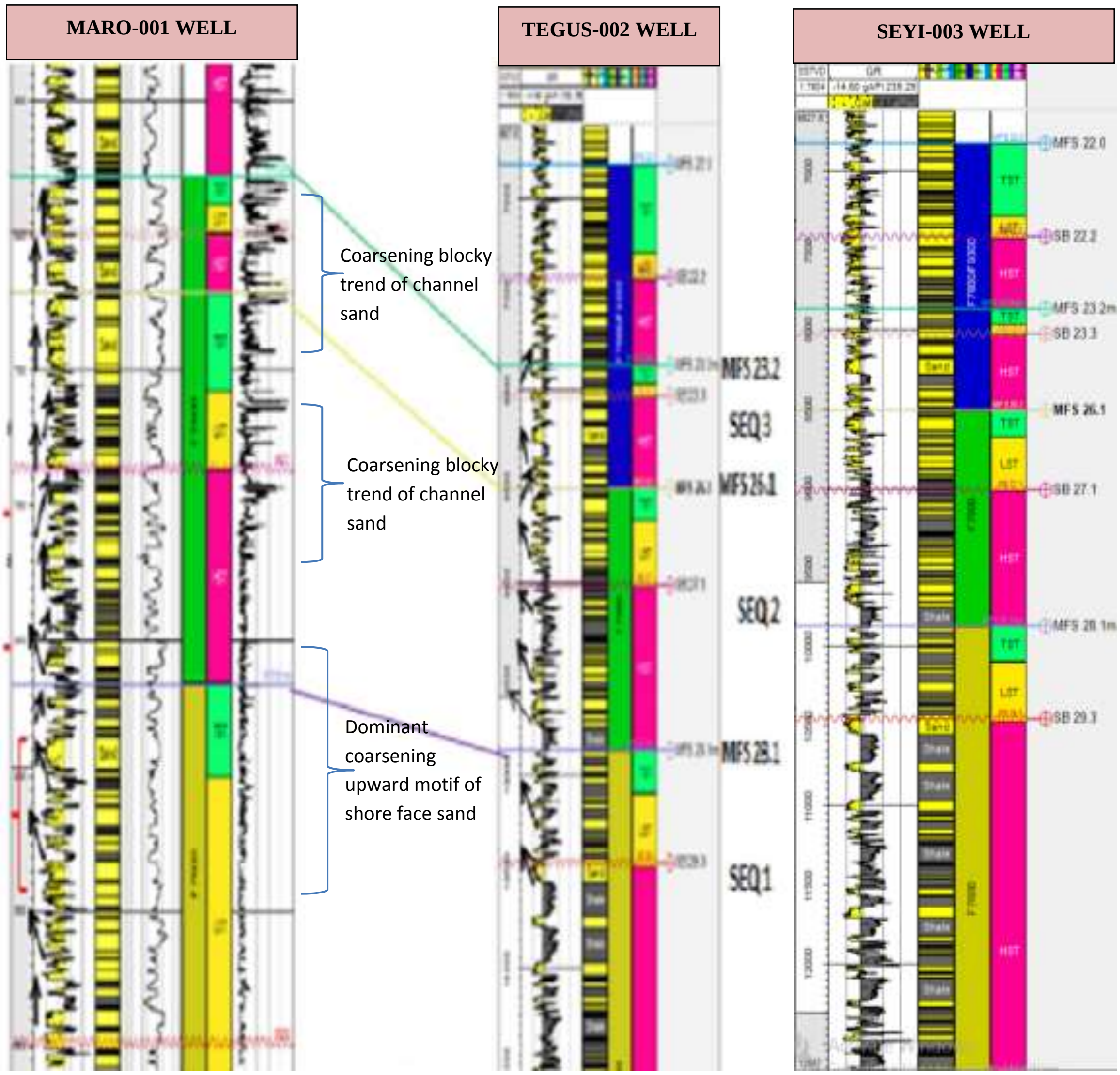

Figure 4: Stratigraphic framework on Maro-001 and log motif interpretation

The gross depositional environment was achieved through the integration of sequence stratigraphy, structural stratigraphic framework and the interpretation of log motifs (stacking patterns of facies) within and the across field.

The blocky gamma ray log patterns at the upper part of the well are interpreted to be fluvial channel fills, (coastal plains). Prograding, coarsening upwards, parasequence patterns located in the lower parts of the wells are interpreted to be shoreface deposits within shallow marine environments. As a whole, the stratigraphic successions within the field is a progradational succession of clastic sediments, although there are fining upward sequences of fine grained sediments deposited during periods of relative sea level rise and landward movement of the shoreline.

On a gross scale, the characteristic log shape within the sequences varies laterally across the wells from blocky shape with less developed shale interval (Alpha field) - typical of fluvio-marine environment, to funnel shape with well-developed shale interval (Beta and Gamma field)-which is characteristics of a shallow marine environment. The dominant depositional environment within each chronostratigraphic interval, trend from coastal plain to shallow marine within the shelf environment, which is depicted in the decrease in net to gross from the proximal to distal end of the basin.

Table 1: Interpreted MFS information picked on study wells

		DEPTH (ft.)		
MFS	AGE	MARO-001 WELL	TEGUS-002 WELL	SEYI-003 WELL
MFS1	22.0 Ma	--	--	6830
MFS2	23.2 Ma	6280	6700	7800
MFS3	26.2 Ma	6700	7740	8300
MFS4	28.1 Ma	8790	9020	9850
MFS5	31.3 Ma	--	--	13400

Table 2: Interpreted SB information picked on study wells

		DEPTH (ft.)		
SB	AGE	MARO-001 WELL	TEGUS-002 WELL	SEYI-003 WELL
SB1	22.2 Ma	5600	6020	7440
SB2	23.3 Ma	6500	7000	8020
SB3	27.1 Ma	7400	8000	8940
SB4	29.3 Ma	9500	--	10460

3.3 Petrophysical evaluation

The objective of this evaluation is using the gamma ray, resistivity, neutron and density logs to determine lithologic units, differentiate between hydrocarbon bearing and nonhydrocarbon bearing zone(s) within identified reservoir(s), define reservoir geometry by means of well to well correlation and determination of the petrophysical parameters value of zones of interest in the field such as porosity, permeability, gross thickness and water saturation

Three prominent hydrocarbon bearing reservoir intervals were identified across Maro-001, Tegus-002 and Seyi-003 wells. These reservoirs were picked based on their characteristic low neutron, low density and high resistivity value. The identified reservoirs are mainly stacked channel sands and shoreface sands of LSTs and HSTs.

The table 3 summarizes the results of petrophysical properties from the reservoir interval from the studied wells.

Table 3: Estimated petrophysical parameter values for hydrocarbon bearing sand across the studied wells

MARO-001 WELL								
Sand	Top (ft)	Base (ft)	Gross (ft)	Net(ft)	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
A	6283	6417	134.00	107.20	80	25.75	69.22	4925.96
B	6587	6707	120.00	98.40	82	26.69	75.00	3926.05
C	7787	7807	20.00	17.00	85	30.43	72.71	5883.63
TEGUS-002 WELL								
Sand	Top (ft)	Base (ft)	Gross (ft)	Net(ft)	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
A	7660	7732	72.00	53.28	74	27.09	67.11	5754.03
B	8065	8101	36.00	28.80	80	29.96	68.78	4054.03
C	8600	8725	125.00	103.75	83	35.43	71.71	6314.03
SEYI-003 WELL								
Sand	Top (ft)	Base (ft)	Gross (ft)	Net(ft)	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
A	10115	10140	25.00	17.75	71	26.75	67.00	5925.96
B	10145	10175	30.00	24.00	79	28.85	80.40	4326.05
C	10230	10290	60.00	48.00	80	31.38	58.56	6083.63

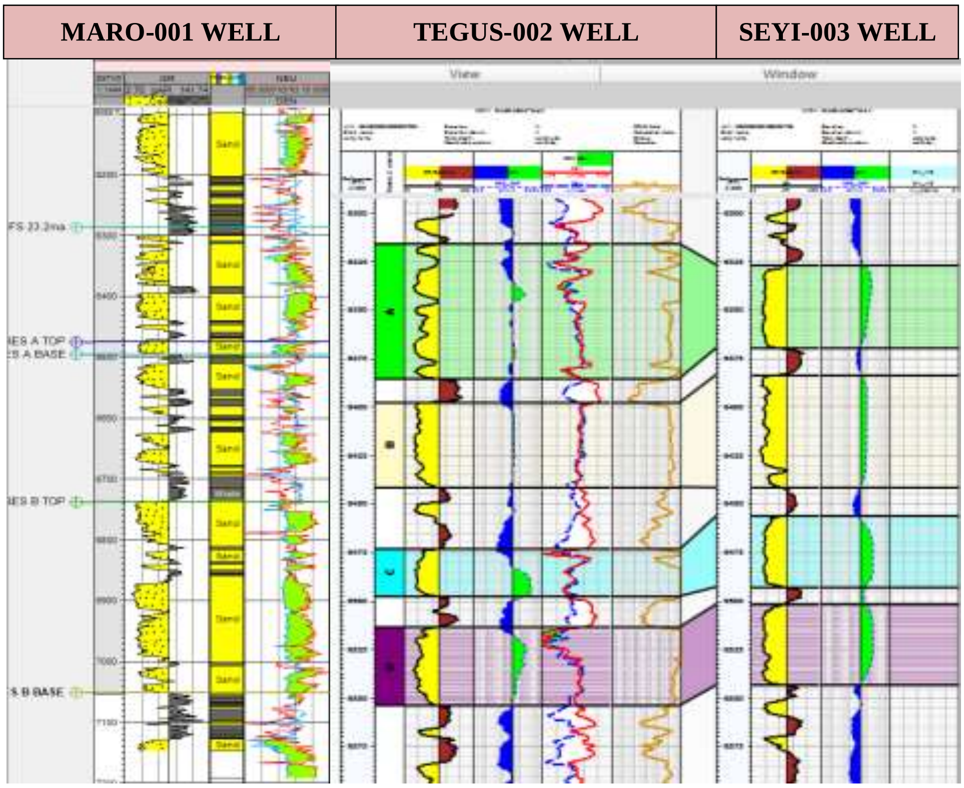

Figure 5: Delineated hydrocarbon bearing reservoirs

3.4 Reservoir property distribution

Reservoir sand A was interpreted to be channel sand occurring at depth 6283 - 6417ft in Maro-001 well, 7660 - 7690ft in Tegus-002 well and 10115 - 10140ft in Seyi-003 well with an average net thickness of 59.41ft. Net-to-gross value was observed to be decreasing slightly from Alpha field in the north to the more basinward Gamma field in the south with an average value of 75%, suggesting increasing distance away from sediment source. Porosity value ranges from 25.75 – 27.09%with an average of 26.42%. Relatively lower permeability value was observed which averaged at 5534.67mD. The water saturation value which ranged from 67 – 69.22% have an average value of 67.78%.

Reservoir sand B have slightly similar properties as sand A, occurring within same environment (channel sand). It occur at depth 6587 – 6707ft in Maro-001 well, 8065 – 8101ft in Tegus-002 well and 10145 – 10175ft in Seyi-003 well. Net-to-gross decreases from the proximal to the distal well with an average of 81%. Porosity value ranges from 26.69 – 29.96% averaging at 28.5%. Permeability value ranges 3926.05 – 4326.05mD with an average of 4102.04mD. Water saturation value ranges from 68.78 – 80.4% having an average of 74.73%.

Reservoir sand C was interpreted as Shoreface sand occurring at depth 7787 - 7807ft in Maro-001 well, 7660 - 7690ft in Tegus-002 well and 10115 - 10140ft in Seyi-003 well. Results for net-to-gross show increase in value from 85% in Maro-001, 83% in Tegus-002 well to 80% in Seyi-003 well with an average value of 84%. Porosity value ranges from 30.43 to 35.43% while permeability and water saturation have an average value of 6093.76mD and 67.67% respectively.

There is an observed general increase in porosity, water saturation and permeability from the Alpha field in the north towards Gamma field in the south while overall results indicate a close relationship between depositional facies and petrophysical properties

Table 4: Estimated petrophysical parameter values for hydrocarbon bearing sand across the studied wells

SAND A (HYDROCARBON BEARING)

Well	Top(ft)	Base(ft)	Facies Type	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
MARO-001	6283	6417	Fluvial Channel Sand	80.00	25.75	69.22	4925.96
TEGUS-002	7660	7732	Fluvial Channel Sand	74.00	27.09	67.11	5754.03
SEYI-003	10115	10140	Fluvial Channel Sand	71.00	26.75	67.00	5925.96

SAND B (HYDROCARBON BEARING)

Well	Top(ft)	Base(ft)	Facies Type	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
MARO-001	6587	6707	Fluvial Channel Sand	82.00	26.69	75.00	3926.05
TEGUS-002	8065	8101	Fluvial Channel Sand	80.00	29.96	68.78	4054.03
SEYI-003	10145	10175	Fluvial Channel Sand	79.98	28.85	80.40	4326.05

SAND C (HYDROCARBON BEARING)

Well	Top(ft)	Base(ft)	Facies Type	NtG(%)	AV_POR(%)	AV_SW(%)	AV_PERM(mD)
MARO-001	7787	7807	Shoreface Sand	85.00	30.43	72.71	5883.63
TEGUS-002	8600	8725	Shoreface Sand	83.00	35.43	71.71	6314.03
SEYI-003	10230	10290	Shoreface Sand	80.00	31.38	58.56	6083.63

4. Conclusion

The properties of each reservoir were observed to follow unique pattern which were visibly controlled by the distinct environment of deposition. This is because different depositional settings imply different reservoir qualities in terms of architecture, connectivity, heterogeneity and porosity-permeability characteristics. This assertion can be confirmed from tables 3 and 4 which computes the trend of the petrophysical properties. Fluvial channel sands in the Gamma and Alpha field (Maro-001 and Tegus-002 wells respectively) depicts almost similar characteristics which are typically distinct from the property of Shoreface sand in the Beta field (Seyi-003 well). It can therefore be asserted that the geological interpretations from the results above serves as constraints for petrophysical property trend.

Structural traps, which are closures formed most commonly by faulting, structural uplift and differential compaction (structural movements within the Earth) were mapped. Faulted structures are very common in the 2-D regional line and they form most reservoirs mapped in the studied area. The types of faults observed and mapped include normal, reverse and listric (growth) fault

Conclusively, for optimal management of a producing reservoir, a detailed understanding of property variation and trend and also subsurface structural pattern is required, and this has been clearly captured in the defining objective of this research work.

4.1 Recommendation

During primary production areal variation of properties such as permeability, porosity, thickness, and sand continuity influence both oil recovery and its distribution in the field. It is therefore highly recommended that a robust and holistic 3-D studies be done. This will further validate the inferences drawn from the 2-D regional line since an accurate internal, three-dimensional (3-D) variation of reservoir rock properties description is essential to effective reservoir management.

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