DOI:10.24996/ijs.2018.59.3B.10

ISSN: 0067-

Seismic Facies Analysis for Lithofacies Prediction, Okam Field of Niger Delta, Nigeria

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Abstract

Seismic facies analysis constrained with well log information have been used to predict lithofacies distribution across the Okam Field of Niger Delta. Density and gamma ray logs were cross-plotted and the seismic section was subdivided vertically into different seismic facies. The delineated lithologies, from well logs were correlated with seismic facies signatures using lines of intersection across the wells. Gamma ray and resistivity logs were used to identify the interfaces between the lithofacies and correlated across the field. Structural interpretation was carried out. Time slices were generated and examined at different intervals within the identified reservoirs. Stratigraphic related attribute and envelope were extracted on these time slices. Three seismic facies type (facies A, B and C) were identified based on reflection amplitude, reflection patterns and continuity. Seismic facies A represents the undisturbed sediments in the Uppermost Benin Formation (parallel continuous, moderate to high reflections). Seismic facies B corresponds to the sand-shale pairs of the Agbada Formation which is diagnostic of moderate to high amplitude subparallel-parallel discontinuous reflections. The chaotic seismic facies signature (facies C) beneath this represents the overpressured mobile deformed Akata shales. The time slices show lateral variation in amplitude from high amplitude continuous reflections to low amplitude chaotic reflections from the southwest to northeast direction of the field. The extracted stratigraphic related attribute and envelope show lateral changes in amplitude from the northeast direction depicting increase in shaliness towards the northeast direction. The lateral variation in lithofacies across the field suggest varied and spatial changes in key reservoir parameters such as porosity and permeability that suggest changes in reservoir qualities across the field.

Keywords: Seismic facies; Niger Delta; stratigraphy

Introduction

For several decades of hydrocarbon exploration and exploitation in Niger Delta, attention has been centred on structural traps. Most of the identified structural closures on the shelf and upper slope have been drilled and the search for hydrocarbon is becoming increasingly more difficult and expensive [1]. Combination of geophysical well logs and 3-D seismic stratigraphy technique has proven to be effective exploration tools to delineate lithology, lithofacies, depositional environment and hydrocarbon reservoirs [2]. Great deal of economic significance are associated with proper understanding of facies architecture. Changes in sea level cause large lateral shifts in the depositional patterns of seafloor sediments. The lateral shifts in deposition create alternating layers of good reservoir quality rock (porous and permeable sands) and poorer-quality mudstones (capable of providing a reservoir "seal" to prevent the leakage of any accumulated hydrocarbons that may have migrated into the sandstones) [2]. Hydrocarbon prospectors look for areas where porous and permeable sands are overlain by low permeability rocks, and where conditions are favourable for hydrocarbon generation and migration into traps [3].

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Mitchum et al. (1977), [4] demonstrated how facies analysis as an effective tool in seismic stratigraphic analysis, can be employed to recognize seismic facies units, define their limits and map their areal associations. They noted that facies analysis are interpreted in order to express certain stratification, lithologic and depositional features of the deposits that generated the reflections within the units.

Heinio and Davies (2006), [5], [6] interpreted three-dimensional seismic data of the toe-slope region in deep water Niger Delta. They showed how stratal architectural features such and sediment deposits can be interpreted from seismic character in the absence of borehole data. This study integrated well logs and seismic facies analysis with a view to enhancing the prediction of lithofacies distribution.

Regional Geologic Setting

The Niger Delta basin is located in the Gulf of Guinea Figure-1 and extends throughout the Niger Delta Province [7]. From the Eocene to the present, the delta has prograded southwestwardly, forming depobelts that represent the most active portion of the delta at each stage of its development [8].These depobelts form one of the largest regressive deltas in the world [9].

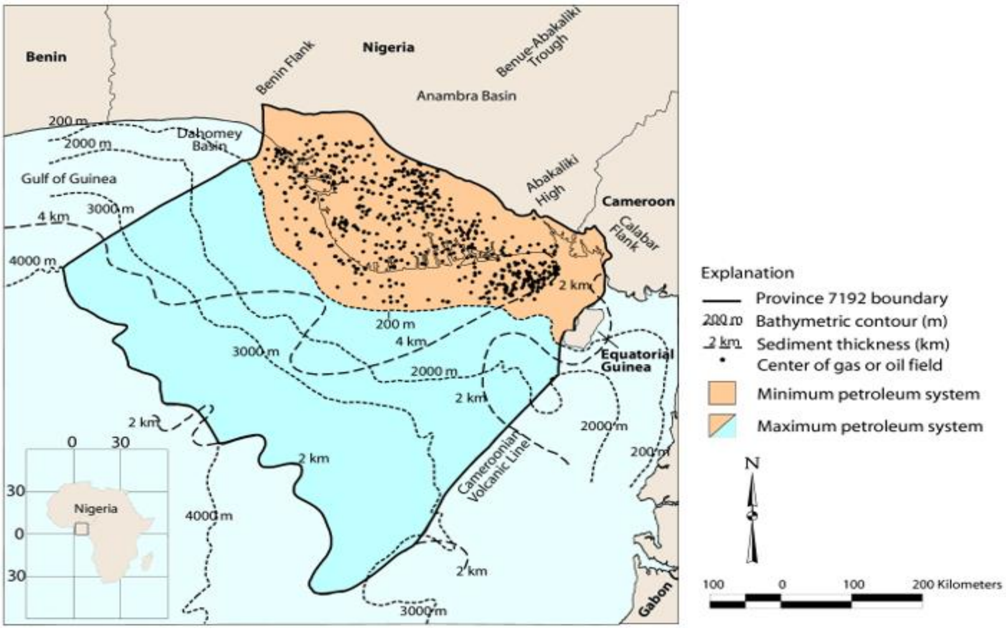

Figure 1-Map of the Niger Delta Showing Provincial Outline, Bounding Structural Features [10]

The Niger Delta Province contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata - Agbada) Petroleum System [1]. The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank, an east-northeast trending hinge line south of the West Africa basement massif [1]. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey to the west, and the two-kilometer sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest [1].

The lithostratigraphy of the Niger Delta Basin consists of three main stratigraphic units Figure-2 of Cretaceous to Holocene origin [11]. These units represent the prograding depositional environments [12].

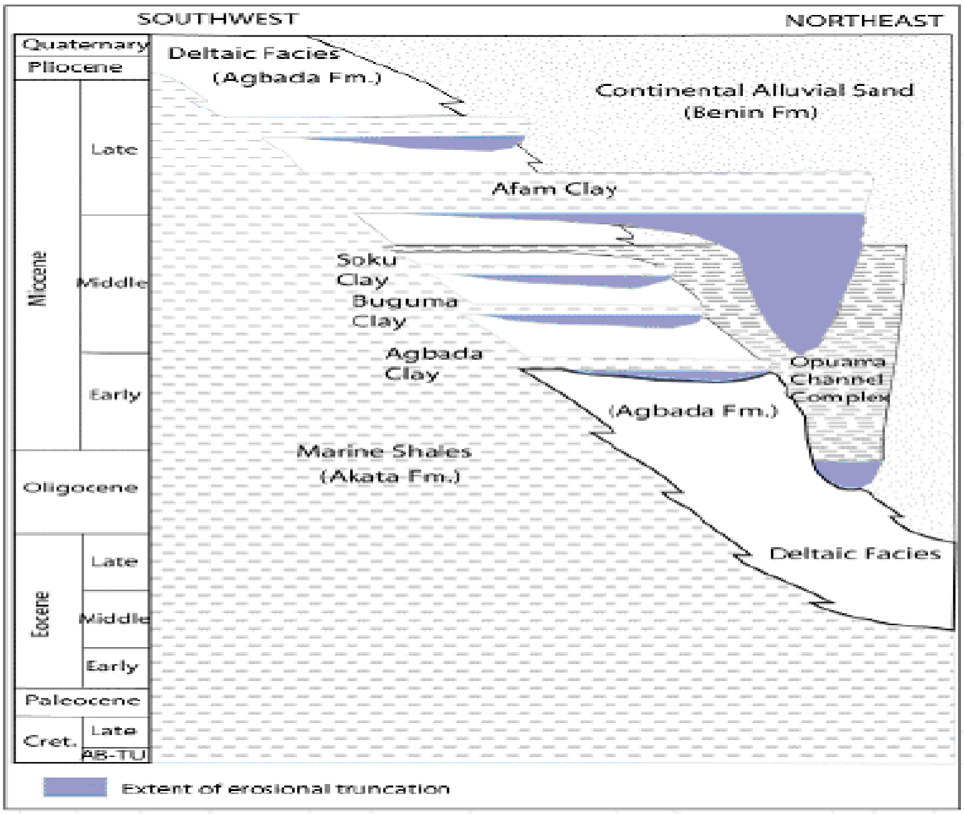

Figure 2-Stratigraphic column of Niger Delta (After Doust and Omatsola, 1990)

At the base of the system is the Akata Formation, a sequence of planktonic foraminifera-rich undercompacted transgressive Paleocene-to-Holocene marine shales, clays, and silt [8]. The Akata Formation is conformably overlain by a paralic sequence of alternating Lower Eocene to Pleistocene sandstones and sand bodies with shale intercalations, which is known as the Agbada Formation [8]. The Agbada Formation is in turn overlain by the Benin Formation which consists of late Eocene to Holocene. Agbada Formation is characterized by massive, porous and unconsolidated freshwater bearing continental deposits, including alluvial and upper coastal-plain deposits that are up to 2000 m [11].

Materials and Methods

Base map, check shot, 3D seismic data and a suit of well logs were available from the field.

The seismic section was subdivided vertically into different seismic facies. Table-1 summarizes the different seismic facies; their interpretation and geologic significance. Distinct seismic facies were defined using their corresponding seismic characteristics. The delineated lithologies were correlated with seismic facies signatures using lines of intersection across the wells.

Table 1-Seismic facies interpretation model [13]

Amplitude	Reflection pattern	Reflection continuity	Inferred Depositional environment
High	**Parallel**	**Continuous**	**Shelf setting, uniform deposition**
Low-moderate	**Parallel**	**Discontinuous**	**Low energy depositional setting**
Low	**Chaotic**	**Discontinuous**	**Soft sediment deformation or high energy depositional setting**

Well logs (gamma and resistivity) were used to identify the interfaces between the lithofacies (sand and shale) and correlated across the field.

With the help of checkshot the well was tied to the seismic section and the structures and seismic reflection patterns mapped across the seismic volume. The identified pay sand was correlated from the well to the seismic and mapped across the seismic cube. Faults were mapped across the seismic sections cutting through the pay sand.

3D view of the structural map was generated to facilitate the understanding of the nature of the trapping mechanism.

Time slicing was performed across the seismic section with a view to observing the lateral variation of lithologic properties across the field.

Instantaneous frequency attribute was carried out to validate the spatial variation of different lithologies at different depth of the field of study.

Results and Discussion

The crossplot of density and gamma ray logs Figure-3 shows lateral variation of litholofacies. The lothofacies include sandstones that is characterised by low gamma and density values that ranges from 2.08-2.4g/cm^3. The heteroliths/shaly sand is characterised by intermediate gamma readings and density values that ranges from 2.08 to 2.32g/cm^3. The shale facies is characterized by high gamma and density values that ranges from 2.16 to 2.60g/cm^3. The shaly facie is associated with high gamma due to the presence of radioactive material.

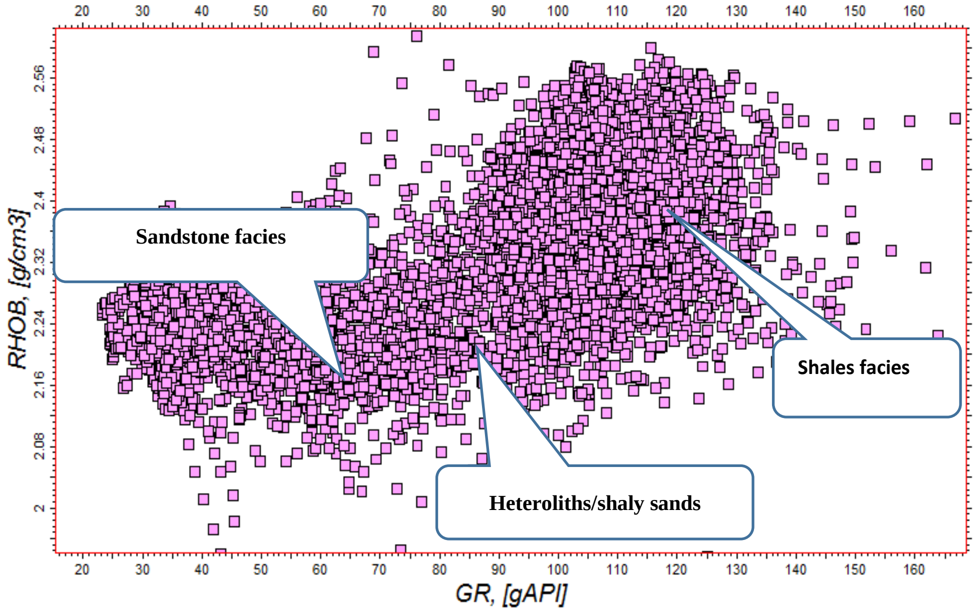

Figure 3-Crossplot of density/gamma ray logs from well A4

Figure-4 shows the seismic facies A that extends from the surface to -880ms down the seismic section. It is characterised by parallel/subparallel, continuous, moderate to high amplitude seismic facies. This seismic facies signature is indicative of relatively stable/undisturbed uniform deposition affected by little or no tectonism/diapirism of the mobile Akata shales and hence represents sediments in the most recent and uppermost Formation of the Niger Delta (Benin Formation).

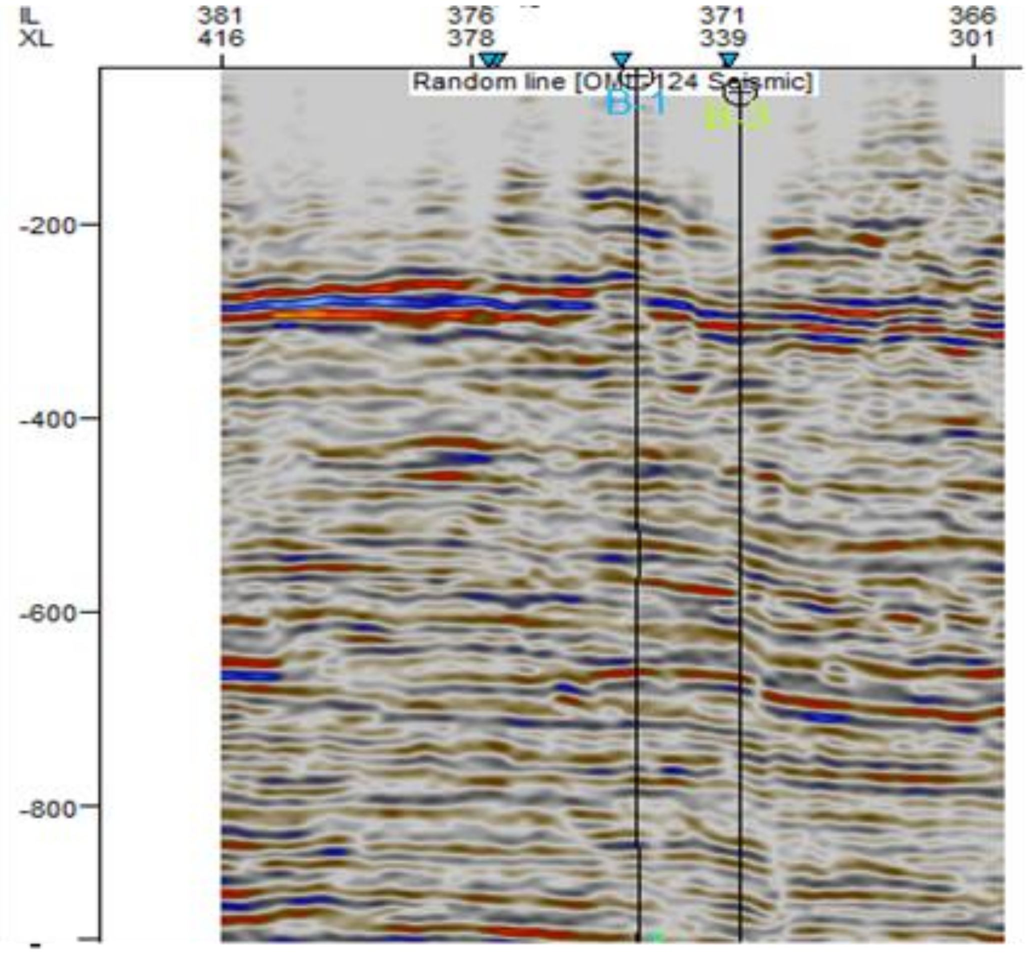

Figure 4-parallel-subparallel continuous seismic facies a

Figure-5 shows the seismic facies B that extends in time from -880ms to -2375ms. It is characterised by moderate to high amplitude and parallel to subparallel, discontinuous seismic facies. There is an observable high resistivity kicks that indicates the presence of hydrocarbon in some of these sandstones.

The moderate - high amplitude discontinuous seismic facies correlates to sand-shale intercalations from the gamma ray readings in most wells. This seismic facies signature is indicative of sand-shale pairs of the Agbada Formation. The discontinuities of the seismic events are caused by deformations due to gravity sliding and shale diapirism that results in listric and growth faults with associated rollover anticlines. The sand-shale intercalation and structural framework of the Agbada Formation enables conditions favourable for the trapping and accumulation of hydrocarbons. The trapping mechanism in the field includes rollover anticlines and fault related anticlines.

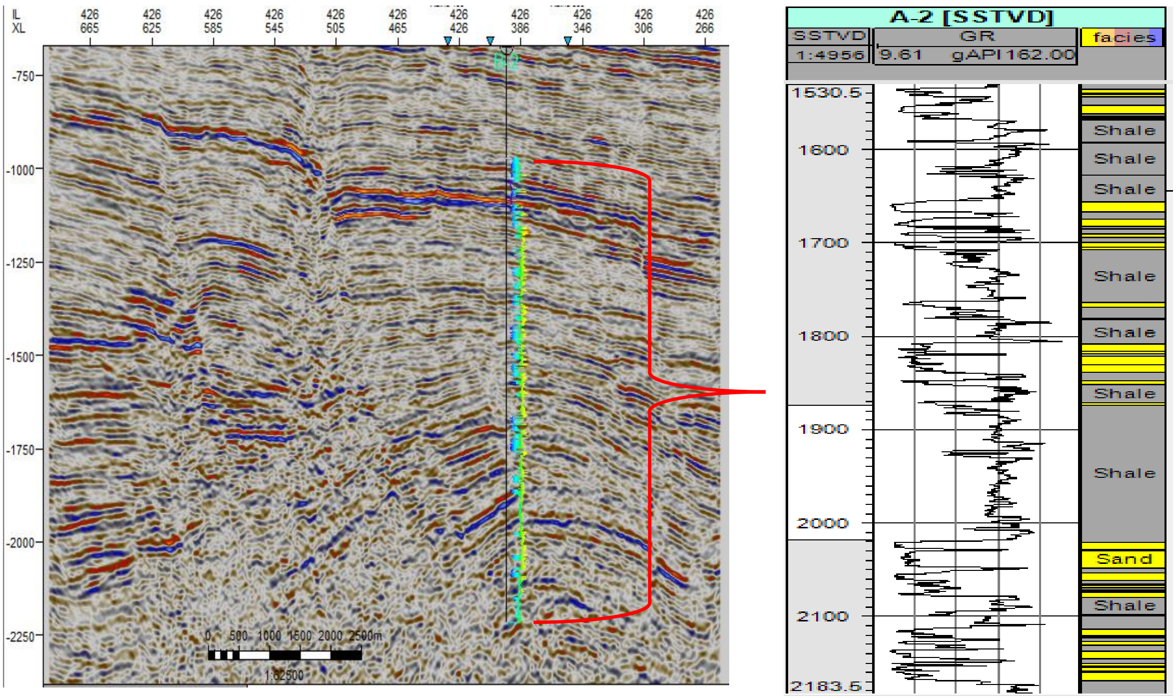

Figure 5-Parallel-subparallel discontinuous seismic facies B

Figure-6 represents the basal seismic facies of that extends from -2375ms to -3500ms. It is characterised by low to moderate amplitude chaotic seismic facies. This is indicative of the overpressured mobile Akata shales.

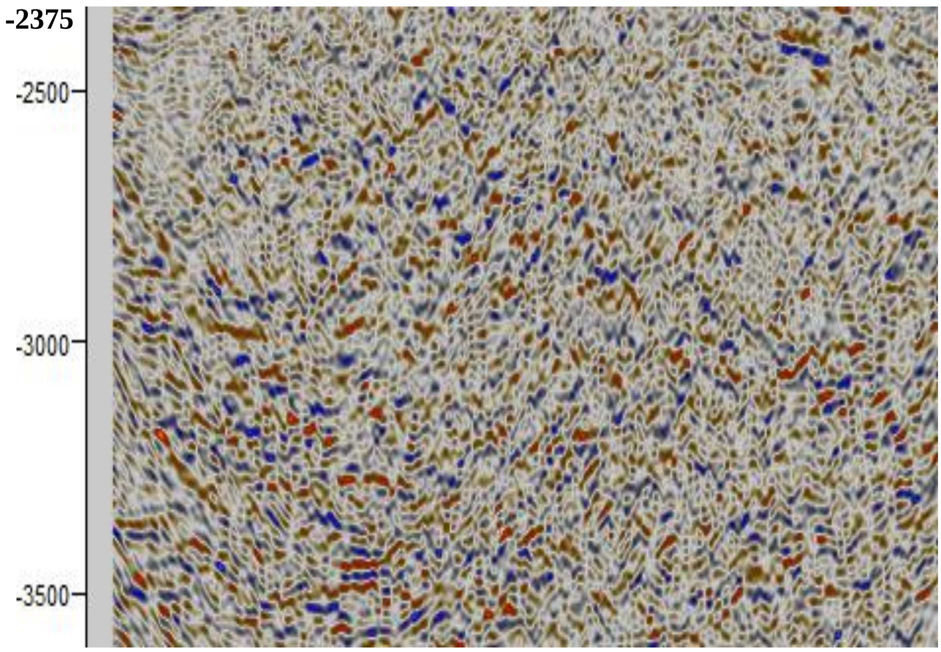

Figure 6-Chaotic seismic facies C

Table 2-Summary the different seismic facies of okam field, their interpretations and geologic meaning

Seismic facies	**Interpretation**	**Geologic meaning**
A	Moderate-high amplitude and Parallel-subparallel continuous seismic facies Figure-4	The reflection characteristics represent that of a uniform deposition affected by little or no tectonism. This is indicative of sediments in the recent Benin Formation.
B	Moderate-high amplitude and Parallel-subparallel discontinuous seismic facies. Figure-5	Gamma ray log information from this sections indicates intercalation of sand and shale and also observable high resistivity kicks indicating the presence of hydrocarbon in some of these sandstones in the Agbada Formation.
C	Low-moderate amplitude chaotic seismic facies Figure-6	Overpressured mobile Akata shales.

Figure-7 (a) shows the result of the well log interpretation of the well B-1 and well B-3. The yellow interval along the gamma and resistivity logs show the hydrocarbon bearing B sands of the field of study within the Agbada Formation. The thickness of the B sand varies from well B-1 to well B-3. It is thicker in well B-1 and thinner in well B-3. The sand column is bounded on top and base by shale confirming the intercalation of shale and sand within the Agbada Formation. Figure-7 (b) shows the interpreted B Horizon (Top of Paysand) across inline 386. The red horizontal lines shows the top and base of the B Sand. The shape of the sand reveals the present of anticlinal trap caused by the underlying Akata Shale. This section also shows the two major faults (F1 and F2).

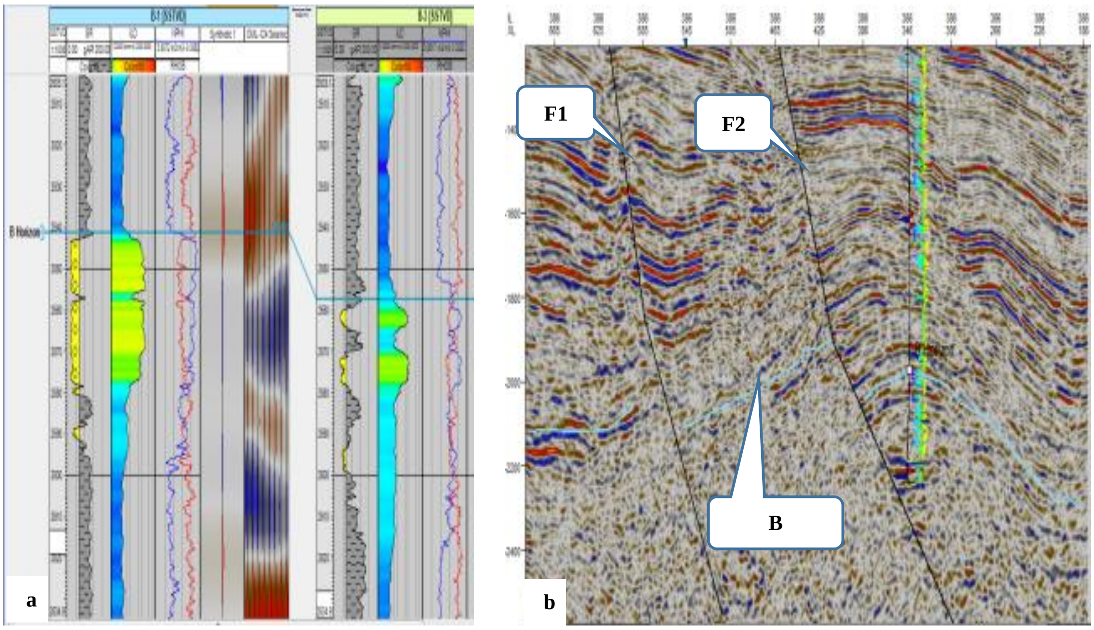

Figure 7 (a)-Well log interpretation showing hydrocarbon bearing sands in the Agbada Formation. 7 (b): interpreted B Horizon (top of paysand) across inline 386.

Figure-8 shows the 3D view of the top of the E sand with two listric faults (F1 and F2) delineated in the seismic facies B of the seismic section. The trap is a fault assisted closure/rollover anticline. This is a possible hydrocarbon prospect.

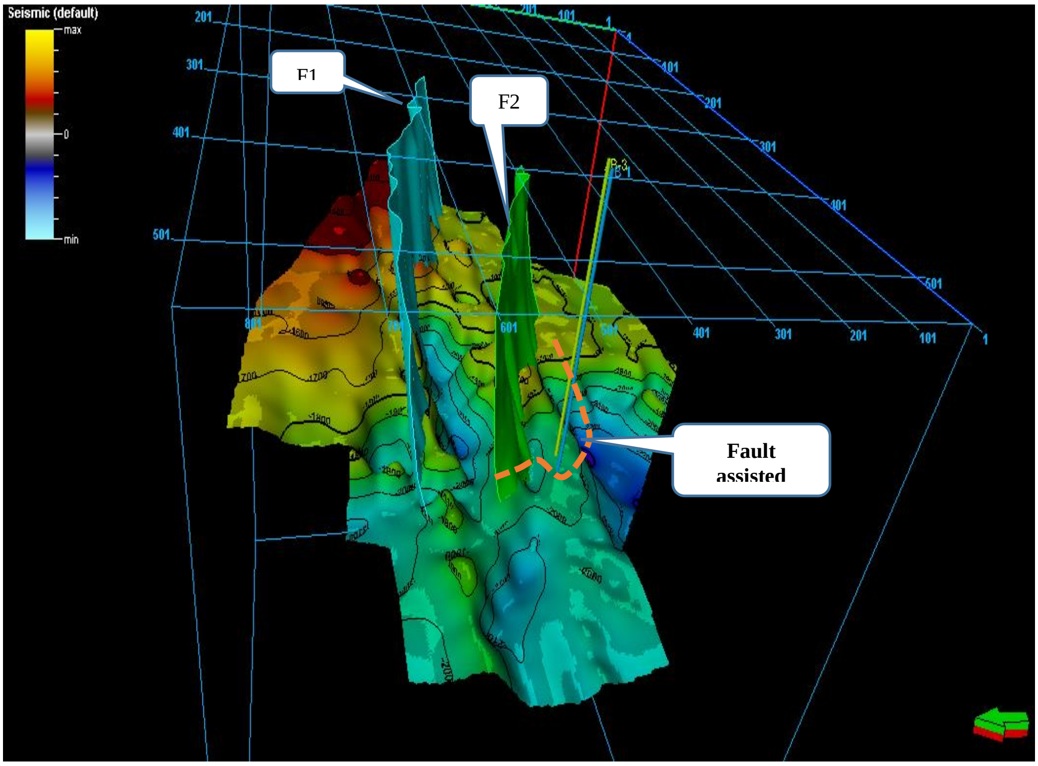

Figure 8-3d view of the top of the sand b with two listric faults (faults F1 and F2)

Figure -9(a, b) show the time slices extracted from the seismic cube within the seismic facies B. There is a characteristics lateral variation in seismic facies signature from moderate-high amplitude that characterizes sand to low amplitude chaotic signatures of shale. There is an observable lover sand/shale ratio at the 2000m interval compared to the slice of 1800ms indicating increase in shaliness with depth.

The time slices reveal lateral alternation of sand and shales from the northwest to the southeast direction. The sand/shale ratio decreases from southwest to northeast direction. The dotted red arrow shows the direction of increase in shaliness.

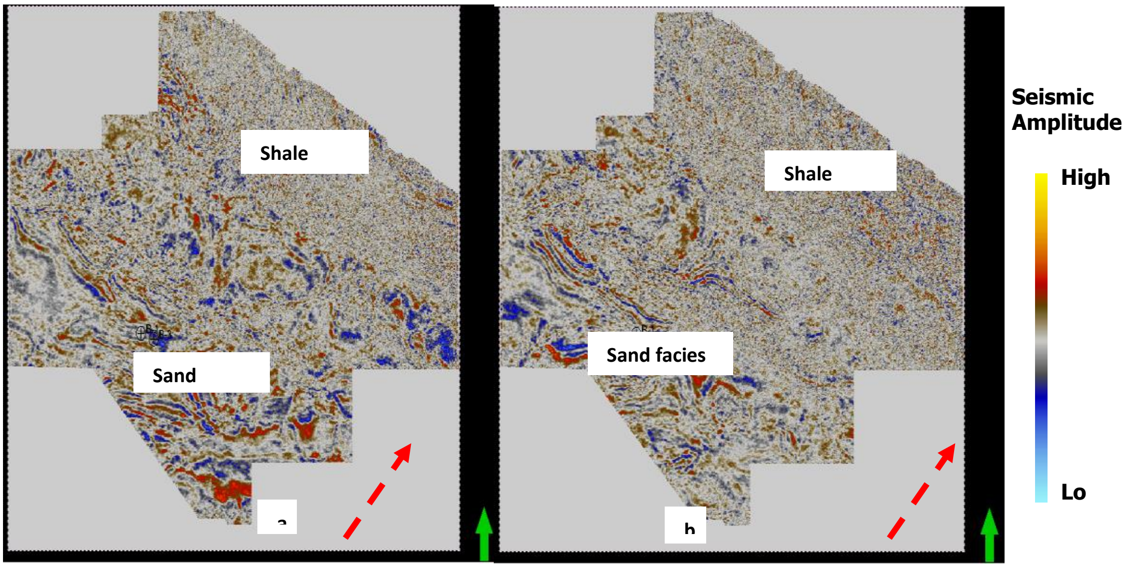

Figure 9-time slice 1800ms and 2000ms showing lateral variation in seismic amplitude and configuration.

Figure-10 shows stratigraphic related attribute (variance) that is generated as a volume attribute. Distinct lithofacies are discriminated based on seismic velocities. Sand (denoted by whitish colour) is associated with high amplitude and low velocity, and shales (redish colour) has relatively lower seismic amplitude and high velocity. This lateral variation in the amplitude indicates spatial variation in lithofacies. This lateral variation in lithofacies suggests the possibility of reservoir heterogeneity in terms of grain sorting which might affect spatial distribution of porosity and permeability. The variation of reservoir qualitys inhibit the flow and recovery of hydrocarbon across the reservoirs. The quality of reservoirs would decrease from southwest to northeast as the shaliness tends to increase in this direction. The amplitude variation across the southwest to north-eastern direction is a strong indication of lateral change in lithofacies across this direction (dotted arrow)

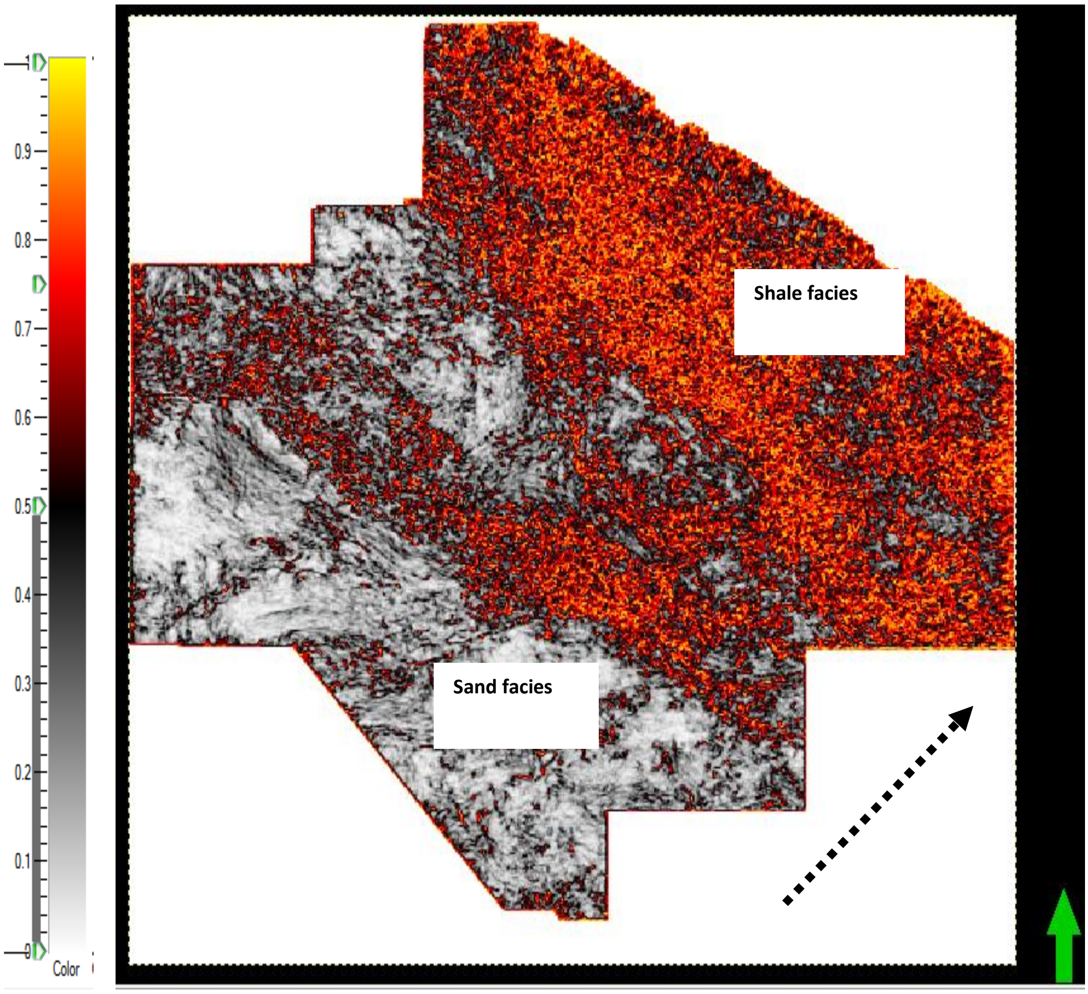

Figure 10- time slice (2000ms) extracted from the variance cube showing the trend of lithofacies variation across the field.

Figure-11 shows the lateral variation of instantaneous frequency. Shale has higher instantaneous frequency than sand thus there is an increase in instantaneous frequency (the red arrow) from south-western to north-eastern direction. This is as a result of increase in shaliness (shale has higher instantenous frequency than sand). The result also supports the lateral lithologic variations. The dotted red arrow shows the direction of increase in shaliness.

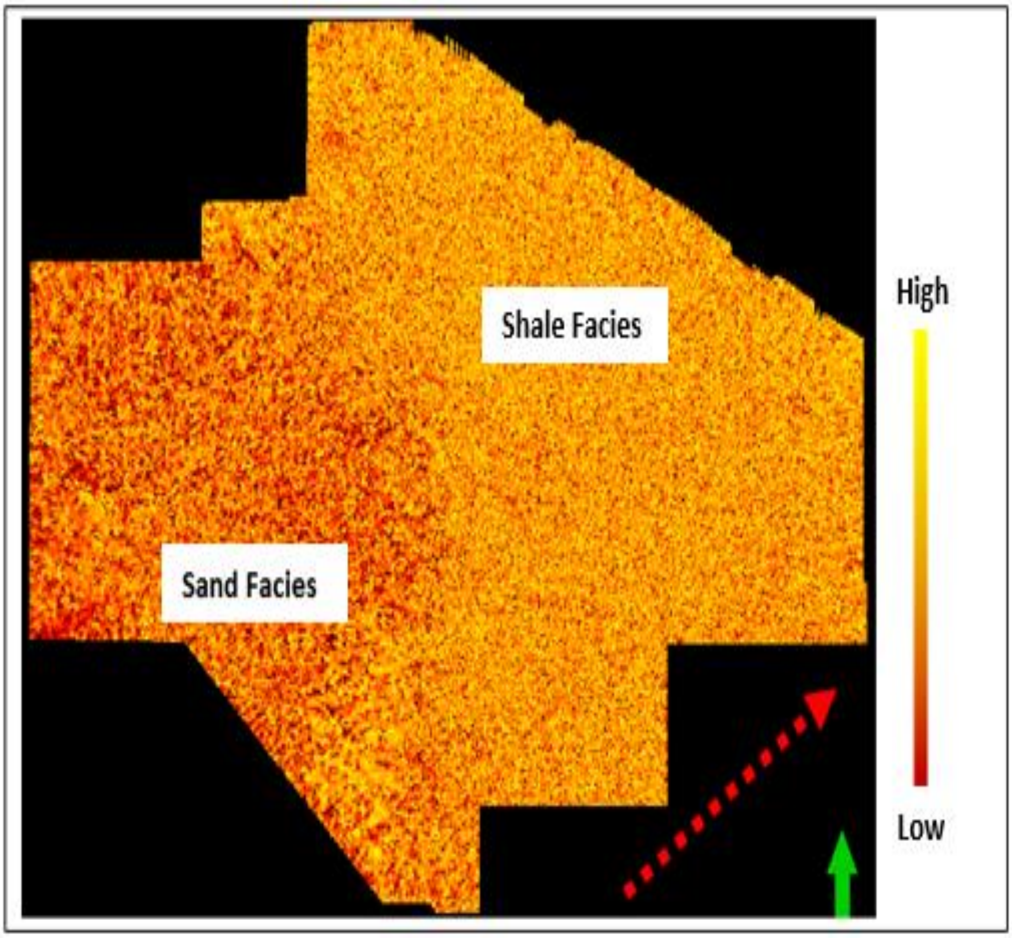

Figure 11-instantaneous frequency attribute showing variation in lithologic properties

Conclusion

Seismic facies analysis constrained with well log information have been used to predict lithofacies distribution both vertically and laterally across the Okam Field. Vertically, seismic sections intersecting wells showed three major seismic facies type; which are facies A, B and C, based on reflection amplitude, reflection pattern and continuity. Seismic facies A is the undisturbed sediments in the Uppermost Benin Formation (parallel continuous, moderate to high reflections). Seismic facies B corresponded to the sand-shale pairs of the Agbada Formation which is diagnostic of moderate to high amplitude subparallel-parallel discontinuous reflections. The basal chaotic seismic facies signature is the overpresurred, mobile deformed Akata shales of Niger Delta.

Laterally, time slices cut at intervals within the identified reservoir (B Sand) in the Agbada Formation showed lateral variation in amplitude and pattern basically from high amplitude continuous reflections to low amplitude chaotic reflections in the southwest to northeast direction. The stratigraphic related attribute variance and envelope extracted on these time slices showed changes in amplitude laterally in these direction given a strong indication of increase in shaliness (high amplitude-sandstones and low amplitude-shales) in the northeast direction across the field toward the north-eastern direction. This lateral variation in lithofacies across the field suggest varied and spatial changes in key reservoir parameters such as porosity and permeability hence decrease in reservoir quality in this north-eastern direction.

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