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The Impact of Seismic Facies Analysis on the Reservoir Architecture of "CHARLIE" Field in the Niger Delta

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Abstract:

The seismic facies technique was used to analyse the "CHARLIE" Field to better understand its impact on the reservoir architecture of the field. The field which has undergone extensive faulting is located onshore Niger Delta basin and comprised of only two drilled wells. Well correlation done with Petrel software to delineate the different reservoir sands in the field. The seismic facies analysis of "CHARLIE" Field involved the integration of seismic reflection characters/attributes towards the interpretation of the energy of deposition of the sediments, environments of deposition and thus make inferences on the lithologic composition of the field and its source rock, reservoir and seal potentials. The seismic reflection attributes which include reflection amplitude, reflection continuity, reflection geometry and seismic frequency were used to delineate the different depositional sequences observable on the seismic sections and these sequences are adjudged as seismic facies units. From the results of well correlation, ten reservoir sands were correlated with four of them being hydrocarbon bearing. Also, from the results of seismic facies analysis, seven (7) seismic facies units designated as Ai, Bi, Ci, Di, Ei, Fi and Gi were delineated and described based on the observed seismic attributes. Thus, it was observed that reservoir architecture is anticlinal in structure, and the depositional environments ranged from fluviatile–deltaic– beach settings. The energy of deposition of sediments showed low energy as in the case of facies units Bi and Ci, while Ai, Di and Gi exhibited variable energy, and the facies units Fi and Gi were deposited in high energy setting. The lithologic composition discerned showed an alternating sequencing of sands and siltstone intercalation and shale/mud stratigraphy. From the foregoing, the "CHARLIE" Field presents good source rock, seal and reservoir potentials.

Keywords — Seismic facies analysis, "CHARLIE" Field, Niger Delta, Seismic Facies units, depositional environment, energy of sediment deposition, reservoir architecture.

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I. INTRODUCTION

With the increasing demand for energy due to the teeming population growth, there is thus the need to revisit petroleum fields that have once undergone exploration in the past and study them critically to be able to make decisions on the current potential of such fields using new and improved technology.

Consequently, this study integrates seismic facies analysis in the evaluation of “CHARLIE” Field in the Niger Delta, and the impact of this technique on the field’s reservoir architecture. The study area (“CHARLIE” Field) lies in the Coastal Swamp depobelt of the Niger Delta as shown in Fig. 1. The depobelts have been subdivided into three provinces (North, Central and Distal provinces) [1], and described based on their structures. A good knowledge of the sequence stratigraphic model of the Niger Delta as it pertains to oil and gas prone environment is very pertinent [2]. Gas is trapped in the Niger Delta mainly within the sands of the transgressive system tracts, but the sands of the Lowstand system tracts prefer oil, while the sands of the Highstand system tracts in parts of the Western Niger Delta are thus more receptive to oil and gas accumulation [2], [3]. Documented findings have shown the reliability and use of seismic stratigraphy and sequence stratigraphic models to delineate the fundamental building blocks of the Niger Delta succession [4], [5]. The Niger Delta petroleum province is one of the most explored petroleum provinces in the world, with major discoveries made over the past decades. The province comprises of several fields including “CHARLIE” Field, and with over five thousand wells drilled, yielding an estimated reserve of over 36 billion barrels of oil. Seismic facies analysis is the description and geologic interpretation (environmental setting, lithofacies, etc.) of seismic reflection parameters.

The seismic facies unit is a mappable, 3-dimensional seismicunit composed of groups of reflections whose parameters differ from those of adjacent facies units. These units of depositional sequences are three dimensionally traced and they consist of areas where specific reflection characteristics are detected [6]. The seismic reflection parameters include seismic amplitude, reflection geometry, reflection continuity and wavelet frequency. These seismic attributes can be used to predict the environments of deposition (EODs) that influenced the types of deposits (e.g., a beach where clean sands may have been deposited), and seal potentials available in the field.

II. AIM AND OBJECTIVES

The aim of the study is to employ the technique of seismic facies analysis to help understand the reservoir, seal and source rock potentials within the “CHARLIE” Field, Onshore Niger Delta. The objectives of this study shall include the followings;

To delineate the different depositional sequences which can be adjudged to be the seismic facies units that are existent in the field.
To study and describe these seismic facies units in the field using the different seismic reflection attributes/bounding surfaces.
To describe the geometric relations and reservoir architecture of the field.
To infer and interpret the energy of the deposition during sedimentation and depositional environment viz-a-viz the lithologic composition. To evaluate the source rock, seal and reservoir potentials of the field.
To carry out comparative analysis of the seismic and well data.

III. MATERIALS AND METHODS

The seismic facies analysis of “CHARLIE” Field was carried out to be delineate the reservoir architecture of the field. The Schlumberger Petrel software was used for the seismic interpretation, well correlation, study and delineate the seismic facies in the reservoir sections of the field. A Petrel project was created for the purpose of this work, with the accurate Coordinate Reference System (CRS) selected for the location which is the Nigeria Minna Mid-belt. Also, the data was carefully checked for fitness and the units were carefully selected as a basis for all data loading and projection. The data available and used for the study are all secondary data and include: 271sqkm 3D seismic reflection data, Well logs data for the two wells (“CHARLIE” 001 and “CHARLIE” 002), Well tops data, Checkshot data for the two wells, Directional survey data. The well log correlation was carried out to determine the number of reservoir sand units in the field as shown in Fig. 3. Seismic-to-well tie was done with the aim to tie the available seismic data to the well data, hence, giving an indication of the depth. The seismic interpretation was carried out by the picking the fault at interval of 10 on the inline axis, and same was done in the X-line during the horizon mapping.

Then, the seismic facies analysis was carried out on the selected seismic section of IL 5414 at the XL 2310 containing the wells; "CHARLIE" 001 and "CHARLIE" 002 were partitioned into ante-, syn- and post-kinematic faulting episodes as shown on Fig. 2. Subsequently, the seismic section was used to generate seismic wiggles, so as to ensure better resolution of the seismic to be able to delineate the depositional sequences properly. Then, it was followed with dividing each of the depositional sequence into seismic facies units on a selected seismic section on the basis of their characteristic seismic reflection attributes. Variations in both the depositional sequence and seismic attributes were adjudged as different seismic facies. However, the major emphases were laid on the portions of the seismic that show to house the hydrocarbons which are correlative from the well logs and through the well-to-seismic ties that had been carried out. In the end, seven seismic facies designated as Ai, Bi, Ci, Di, Ei, Fi and Gi, were delineated as shown in Fig. 4. This was followed by the description of the internal reflection configuration and terminations of each seismic facies' unit, i.e., sigmoid, parallel, amplitude as shown in Table 1. Hence, the seismic facies descriptions from seismic sections was transferred to a shot point map of each sequence.

At this juncture, the well data with seismic facies distribution were integrated as a correlative measure to ensure uniformity of the data. Furthermore, the interpretation of the seismic facies units in terms of depositional settings (environments) such as marine or non-marine, water depth, basin position, energy, transport direction, or any other depositional aspects was carried out and thereafter used the information to estimate the lithology and make inferences on the source rock, reservoir and seal potentials of the field.

IV. RESULTS AND DISCUSSIONS

The well log correlation was carried out with view to establish lateral continuity and relationship for the delineated lithologic sands of interest across the 2 "CHARLIE" wells. Ten sand bodies were correlated with tops and bases and designated as A, B, C, D, E, F, G, H, I and J as shown in Fig. 2. However, sand bodies A, B, F, and I were observed to be hydrocarbon bearing based on the readings from the resistivity and density logs. The seismic facies analysis was carried out on the seismic section of IL 5414 and XL 2310. The seismic section was first divided into episodes that occurred before, during and after the fault took place. The depositional sequences observed on the section which are adjudged as seismic facies units were delineated based on the similarities in the internal reflection characteristics. The various seismic facies units are designated as Ai, Bi, Ci, Di, Ei, Fi and Gi as delineated on the seismic section. The seismic facies unit were then described using the seismic attributes such as the reflection configuration, seismic frequency, seismic amplitude and reflection continuity, in conjunction with their bounding relationships as shown in Table 2. These described seismic attributes on the sections are then used to infer the depositional environment of the field.

A. Seismic Facies Unit Ai

This seismic facie unit consists of continuous, sub-parallel seismic character, with low amplitude and medium frequency, and thus restricted at the top of the anticline. The amplitude and continuity signify that the sediments were deposited in a variable energy setting and may also be suggestive of the rapid changes in energy level (probably a braided or meandering river system on a floodplain).

B. Seismic Facies Unit Bi

It consists of continuous subparallel character, with a show of waviness and contortion. It has high amplitude and medium frequency and occurred at the crestal portion of the anticline. The high amplitude and continuity can be likened to an interbedding of high and low energy setting.

C. Seismic Facies Unit Ci

It comprised of reflection free character and restricted at the right lobe, and thinning away from the anticline. This unit coincides with zone where the acoustic impedance contrasts are weak or lacking and thus maybe suggestive of a homogenous gross lithology of either sands or thick shales deposits.

D. Seismic Facies Unit Di

Facies Di comprised of discontinuous, hummocky clinoforms with a representative chaotic character and this can indicate the presence of cut-and-fill geometry and/or contorted bedding. It also has medium amplitude and high frequency and restricted at the crest of the anticline which is thought to house the hydrocarbon. The clinoform shape may have originated from prograding slope systems in standing bodies of water.

E. Seismic Facies Unit Ei

This facies unit is comprised of chaotic character with low/variable amplitude, and shows shale diapirism at the base of the depositional sequences. The shale diapiric body is due to the presence of over-pressured shales. The internal reflection character signifies a variable energy setting.

F. Seismic Facies Unit Fi

The seismic facies unit Fi consist of disrupted and oblique seismic character, with a characteristic low amplitude and low frequency, and grading vertically to the anticlinal limb. This is reflective of higher energy slope system and area of sedimentbypass with the depositional environment thought to be a deltaic or beach deposits.

G. Seismic Facies Unit Gi

This seismic facie unit consist of continuous and parallel-oblique reflection, with high amplitude and medium frequency with the bounding surfaces truncating at the base of facies unit Fi. This geometry normally also reflects a high-energy slope system and the depositional environment can be a delta environment.

Depositional Environment and their Corresponding Lithology and Architecture

The "CHARLIE" Field comprised of different depositional episodes. The environments of deposition which were interpreted from the different seismic facies ranged from fluviatile – deltaic – beach environments. The sediments were deposited at varying energy levels and can be observed from the internal reflection characters on the seismic sections and the interval travel velocity read off from the sonic logs and seismic-to-well tie that the depositional sequences which show low energy of deposition are likened to be very fine grained lithofacies. However, depositional sequences that exudes variable energy of deposition tend to have intercalations of maybe sandstones and silts, while the higher energy of deposition can be attributed to the sediments with coarser grains sizes. The reservoir architecture of "CHARLIE" Field is anticlinal in structure. This was done with the view to describe the reservoir and seal potentials that are prevalent in the "CHARLIE" Field, and the architecture of the reservoir.

Source Rock, Seal and Reservoir Potentials Inference from Seismic Facies

From the seismic facies analyses carried out, it can be seen that the "CHARLIE" Field is endowed with good petroleum play elements such as source rock, reservoir and seal. Within the Akata -Agbada petroleum system observable from the seismic, it can be shown that the petroleum play elements occur in an alternating sequence of caprock-reservoir-bottom seal-reservoir- and the bottom seal which also doubles as the source rock for the hydrocarbon generation in the field as stated in Table 3.

Discussions

Seismic facie is an aerially definable, 3-dimensional unit composed of seismic reflections whose elements, such as reflection configuration, amplitude, continuity, frequency and interval velocity, differ from elements of adjacent facies units [7]. The seismic facies were analyzed with the view of interpreting the environment of deposition, energy of deposition, lithology of the different facies and hence, make inferences on the reservoir, seal and source rock potentials of the field. The seismic facies unit Ai which showed that the sediments were deposited in a variable energy setting and coincided with the basal part of the Benin Formation. This was followed by a depositional sequence that ranged from a high to low energy that may signify the intercalation of sand and silt; which may likely show a thickness that has good reservoir potential as shown in Table 3. Apparently, this facies unit was immediately followed by a facies unit that clearly shows a reflection free seismic character designated Ci, which may likely signify a mud that may also seem to have good seal potential. This is also immediately followed by a seismic facies unit Di which has significant reflection character that can be attributable to a lithofacies with a good reservoir potential.

This facie is thus being underlain by a chaotic seismic facie unit of Ei and maybe thought to serve as a source rock seal to the overlying reservoir; this represents the zone of the over-pressured shale. Adjacent to this facies unit, are the facies unit Fi which showed a characteristically low amplitude, high frequency and appreciably continuous which may be adjudged to be a good seal to the reservoir units bounding it above and below, and then facies unit Gi, which is a new reservoir delineated from the analysis. Facies Gi shows a high amplitude, continuous with low frequency.

Consequent upon this, the environment of deposition thus interpreted ranged from fluviatile – deltaic – beach environments. The energy of deposition also ranged from low energy to high energy for the different seismic facies. The energy of deposition act as play for the lithology of the depositional sequences.

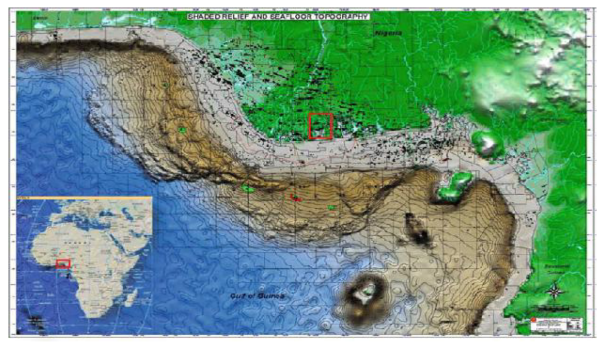


Fig. 1. An insert map of Niger Delta in map of Africa showing the study location [8].

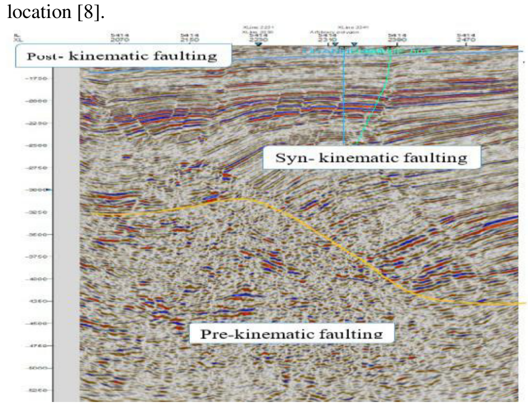


Fig. 2. Seismic section of IL 5414 and XL 2310 showing the different fault episodes (Adapted from Petrel).

Finally, the lithofacies description of the field which focused on the reservoir section showed that there are alternating sequences in the depositional models and thus, aided the petroleum system elements of the field. It can therefore be said that the field shows an alternating sequence of seal and good reservoir stratigraphy as can be exemplified in the Table 3.

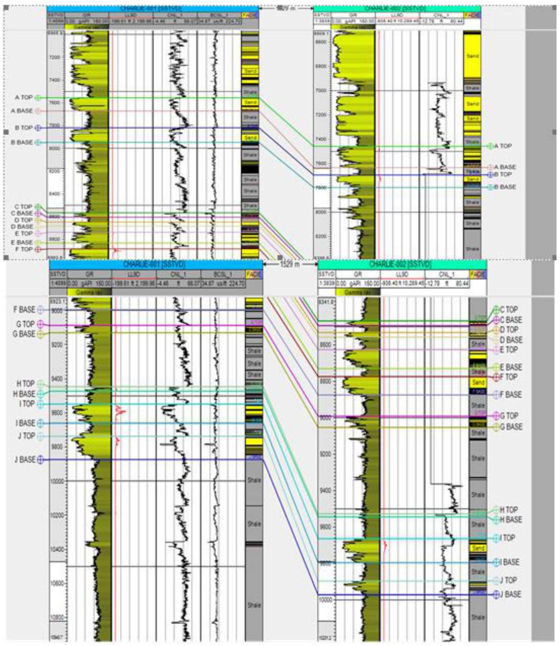


Fig. 2. Well section window showing the well correlations in the "CHARLIE" Field (Adapted from Petrel).

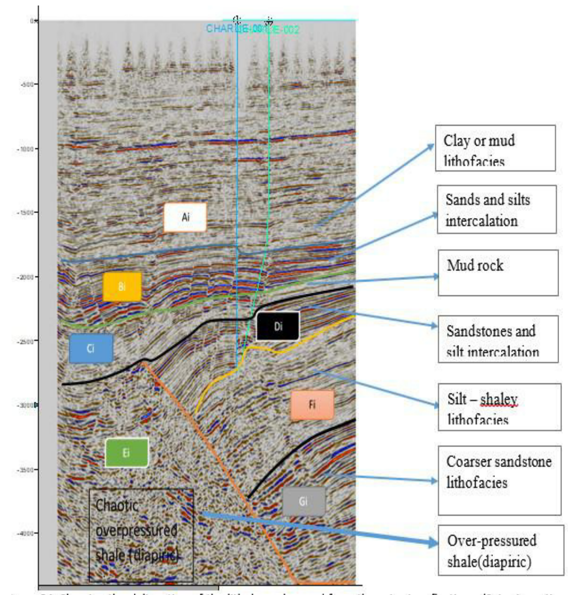


Fig. 4. Seismic section showing the delineated seismic facies units on Inline 5414 and XL 2310 (Adapted from Petrel).

TABLE 1: The Descriptions of the Seismic Facies Units Using their Seismic Reflection Attributes

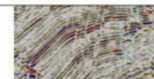
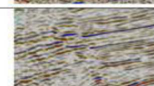
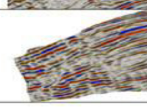
Seismic facies	Seismic facies units representations	Reflection continuity and geometry	Reflection amplitude and frequency	Bounding relationship
Ai		Continuous, semi-parallel seismic character,	Low amplitude and medium frequency	Restricted at the top of the anticline
Bi		Continuous, semi-parallel, with a show waviness and contortion.	Higher amplitude and medium frequency	Occurs at the crestal portion of the anticline
Ci		Continuous and parallel reflection	Reflection free character	Restricted at the rightlobe, and thinning away from the anticline
Di		Discontinuous, hummocky clinoforms with chaotic character	Medium amplitude, high frequency	Restricted to the crest of the anticline
Ei		Chaotic character	Low amplitude	Shale diapirism at the base of the depositonal sequences
Fi		Disrupted and oblique seismic character	Low amplitude and low frequency	Grading vertically to the anticlinal limb
Gi		Continuous and parallel oblique reflection	High amplitude and medium frequency	Truncating at the base of facies Fi

TABLE 2: Showing the Reservoir Tops and Bases of the "CHARLIE" Wells and their Reservoir Thicknesses

Reservoir tops and bases	Wells		Reservoir thickness(ft)	
	CHARLIE 001	CHARLIE 002	CHARLIE 001	CHARLIE 002
A TOP A BASE	7558 7673	7457 7633	115	176
B TOP B BASE	7821 7951	7695 7796	130	101
C TOP C BASE	8567 8604	8468 8495	37	27
D TOP D BASE	8650 8684	8531 8558	34	27
E TOP E BASE	8736 8833	8626 8730	97	104
F TOP F BASE	8884 8995	8774 8876	111	102
G TOP G BASE	9086 9130	8990 9068	44	78
H TOP H BASE	9446 9474	9526 9544	28	18
I TOP I BASE	9549 9661	9664 9796	112	132
J TOP J BASE	9740 9876	9896 9972	136	76

TABLE 3: Showing Facies Units with Source Rock, Seal and Reservoir Potentials.

Seismic Facies Units	Impact on the field's economics	Lithology
Facies Unit Ai	Good seal potential	Mud
Facies Unit Bi	Good reservoir potential	Sands and silt intercalation
Facies Unit Ci	Good seal potential	Mud
Facies Unit Di	Good reservoir potential	Sandstone
Facies Unit Gi	Good reservoir potentials	Permeable sands
Facies Unit Ei	Good seal/ source rock potential	Over-pressured shale

V. CONCLUSIONS

From the research work that have been carried out on the seismic facies analysis of "CHARLIE" Field and its impact on the fields reservoir architecture, the following concluding statements can be drawn:

a. That the different seismic facies units identified are characteristically distinct from those bounded above and below them. Some exhibits either high or low amplitude, continuous or discontinuous reflection, low or high frequency, parallel or sub-parallel geometry. Others show either chaotic or reflection-free character.

b. That the seismic facies units' characteristics show that the sediments that make up of the "CHARLIE" Field and at a larger scale, Niger Delta basin were deposited at different times with varying energies of deposition which can be likened to base level changes. These energies of sediment deposition played important roles in the grain sizes of sediments and hence, their lithology.

c. That the environments of deposition ranged from fluviatile (braided/meandering river system) – deltaic – beach environments.

d. That the lithology of the sediments of the field shows an alternating sequence owing to the amplitude and frequency variations due to the eustatic sea level changes. The stratigraphy shows sands and silts intercalations alternating with shale/mudstones across the seismic sections.

e. That the lithofacies make-up of the field showed that the "CHARLIE" Field are comprised of good source rocks of mainly the over-pressured shales at the lower part of the seismic sections, with the reservoirs alternating with the sealing materials in the middle part of the reservoir.

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