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SEISMIC ANALYSIS OF THE TRANSGRESSIVE SYSTEMS TRACTS (TSTS) OF THE NIGER DELTA

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ABSTRACT

One way of identifying our MFSs is to look out for shale tops of high acoustic properties within a shale interval that corresponds to the lowest resistivity values and widest separation between neutron and density values. The TSTs culminate to a MFS as it comprises the deposits accumulated from the onset of coastal transgression until the time of maximum transgression of the coast, just prior to renewed regression (SepmStrata, 20). The seismic character of the shales within these TSTs could vary factoring the effect of depth trends, hence a need to understand the trend with increasing depth and thereby increased compaction. From generated synthetic, using the seismic responses at interfaces within the lithologies cut across by one of our HP well in the Central Swamp depobelt, a study integrating Reflectivity Pattern Analysis (RPA) and Sequence Stratigraphic analysis was carried out to understand the behavior of our shales within the TSTs. Key bounding surfaces which subdivide the strata into contemporaneously deposited sediment packages were identified from well log responses from a complete suite of logs which included Gamma Ray, Resistivity and Porosity logs. It was observed that shales in the TSTs were of higher acoustic properties compared to sales in the HSTs.

KEYWORDS

Reflectivity, Seismic Analysis, Transgressive Systems Tract, Maximum Flooding Surfaces.

1. INTRODUCTION

During the Cenozoic, until the Middle Miocene, the Niger Delta grew through pulses of sedimentation over an oceanward-dipping continental basement into the Gulf of Guinea; thereafter progradation took place over a landward-dipping oceanic basement. A 12,000 m thick succession of overall regressive, of flapping sediments resulted that is composed of three diachronous siliciclastic units: the deep-marine pro-delta Akata Group, the shallow-marine delta-front Agbada Group and the continental, delta-top Benin Group [1, 2].

Regionally, sediment dispersal was controlled by marine transgressive/ regressive cycles related to eustatic sea-level changes with varying duration. Differential subsidence locally influenced sediment accumulation. Collectively, these controls resulted in eleven chronostratigraphic ally confined delta-wide mega sequences with considerable inter¬nal lithological variation [1].

The mega sequences for¬med over time intervals of approximately 5Ma within individual accurate megastructures that laterally linked into deponents. There are 5 doublets that define the depositional sequences within the Niger Delta and they include: Northern Delta, Greater Ughelli, Central Swamp, Coastal Swamp and Offshore.

Seismic attributes provide geophysicists and seismic interpreters with useful information related to the amplitude, position, and shape of a seismic waveform compared to the conventional or more traditional ways of interpreting seismic stratigraphy. It fully utilizes the use of seismic amplitudes and3D seismic to map and visualize subsurface stratigraphy and geomorphology, geological structures, and reservoir architecture [3]. Sheriff, classified seismic attributes such as a measurement based on seismic data such as envelope, instantaneous phase and frequency, polarity, dip, and dip azimuth [4]. Taner, defined seismic attributes as the information obtained either by direct measurement of seismic data or by logical/experience-based reasoning [5]. Seismic attributes form an integral part of the qualitative interpretative tool that facilitates structural and stratigraphic interpretation. It also offers clues to lithology type and fluid content estimation with a potential benefit of detailed reservoir characterization [6]. The rapid advancement of 3D seismic data made in-depth analysis and high-resolution visualization of subsurface possible in a manner resembling surface geomorphology.

Seismic geomorphology interpretation is a primary method for mapping and viewing subsurface features as well as aiding the interpretation of seismic structures and stratigraphy, especially in areas away from well control [6-9]. Sequence Stratigraphic analysis was done using well logs and biostratigraphy data from six wells in a field in the Central Swamp deponent and the analysis revealed four 3rd order depositional sequences (SEQ 1 to 4) bounded by three erosional unconformities, Transgressive Surfaces of Erosion (TSE1 to 3) and three 3rd order Maximum Flooding Surfaces (MFS1, MFS2 and MFS3) characterized by marker shales, high faunal abundance and diversity were also delineated and dated 15.9, 17.4 and 19.4 Ma, respectively [7].

Key boundaries and genetically related sedimentary packages within them could play a role in determining seismic attributes such as the amplitudes of the traces in a seismic section. In the Chilomguembelina genetic mega sequence, the mega sequence is topped by a regional glauconitic lag deposit (13.1 Ma), recognized in well cuttings and cores grading updip into lignites which seismically form a continuous high-amplitude reflection surface [1].

In this study, within the well section of our interest, we would use the seismic responses from our stack trace to analyze the behavior of shales in the TSTs identified from sequence stratigraphic analysis using basically well responses. The seismic trace is the convolutional model comprising a reflection coefficient series convolved with a time series representation of the seismic pulse in the zone of interest [9, 10]. This pulse is often called the seismic wavelet. Before we start to assign significance to the troughs and peaks of seismic data the interpreter needs to establish the form of the wavelet in the data.

The question posed in discussions of seismic interpretations is what the phase (shape of the wavelet) is and polarity (the sign [positive or negative] of the dominant part of the wavelet that relates to a particular contrast of acoustic impedance)? The motivation behind asking these questions is the need to know if and how the data can be used to reliably indicate hard and soft reflections, and what signature or response should be expected from different reflection types which may be slightly more sophisticated if there is also an AVO component to the model. In data processed for the purpose, the form of the AVO response maybe diagnostic of lithology or fluid type. Understanding the wavelet shape is therefore a critical starting point in amplitude interpretation logic.

For a symmetrical wavelet with a dominant loop, polarity describes whether it is the red or blue or the trough or the peak that represents a particular reflection type (hard or soft). The seismic data that has undergone processing could either be normal or reverse polarity depending on which convention (European or US) is being adhered [7,11,12]. European convention normal polarity (indicating an increase in acoustic impedance or hard kick) is negative number on tape which is represented as trough as shown in the figure below. European convention reverse polarity is the opposite.' US convention normal polarity is same as European reverse polarity.

In this work, zero phase European normal convention was used and more importantly in this work, is the generation of the AVO component of our already generated stack trace adhering to the non-SEG or European normal convention. We hope to initiate the possibility of assigning seismic character to surfaces identified from Sequence Stratigraphic analysis. It is important to note that basically, different geologic environments tend to favor different types of contrasts, for example;In shallow young rocks the sands tend to be lower in impedance than the shales and the resulting AVO type values tend towards the higher numbers (3's, 4's and5's). With depth the sands generally become faster than the shales and the AVO types will decrease to 1's and 2's. Similarly, the expected AVO types in geo pressure areas are 1's and 2's. AVO types 3 and 4 may be found in deeper over pressured sections.

AVO typing is also controlled by lithology; Sands that display a low ratio of compressional velocity to shear velocity will tend to be conforming AVO types. This type of sand is generally non-cemented or lightly cemented, but still granular in nature. If the sands are well-cemented or if a carbonate is encountered the AVO type will generally be negative (non-conforming) [10,12,13]. Coals always show a much slower compressional velocity than either sands or shales as a result coals tend to be types 4 and 5. The presence of compressible fluids, especially gas, has the effect of lowering the impedance; the effect can be emphasized with offset. Usually P and G both shift in a negative direction with the addition of compressible fluids. Gas and light oil tend to cause the AVO type to be positive; a shift to the AVO type from negative to positive, if the sand is very well-cemented the effect may be slight. A wet type 2 AVO sand may show a transition up-dip into a type 3 AVO with the addition of gas. In this study, within the well section of our interest, we intend to use the seismic responses from our stack trace to analyze the behavior of shales in the TSTs identified from sequence stratigraphic analysis using basically well responses. To this end, we firstly generate our stack trace from where we identify the responses on our reservoir tops. Then we use complete suite of logs to carry out a Sequence Stratigraphic analysis of the well section of our interest comparing the results to their equivalent seismic responses on the stack trace. Finally, an AVO component of the stack trace is done to better understand the seismic character of the reservoir tops and surfaces identified from Sequence Stratigraphic Analysis.

2. LOCATION AND GEOLOGY

The Niger Delta sedimentary basin evolved following the Early Cretaceous break up between the South American and the African plates. The tectonic framework, stratigraphy and sedimentation pattern of the Niger Delta sedimentary basin is well reported in several literatures [14-18]. Several episodes of transgressions and regressions accounted for the sedimentary units in both the Cretaceous and Tertiary Southern Nigerian sedimentary basins [19]. The delta covers an area extent of about 100,000 km2 and represents the regressive phase of the third cycle of deposition in the southern Nigeria sedimentary basins, which began during the Paleocene and has continued to the present day. The area of interest is located at the northwestern end of the Central Swamp Depobelt of the Tertiary Niger Delta that lies between Latitudes 5°N and 6°N and Longitudes 5°E and 6°E, covering an aerial extent of about 675 km2.

The field is characterized by a dual culmination WNW/ESE trending rollover anticline; and part of a larger complex structure of fault/roll-over structures within the Central Swamp megastructure.

3. DATA AND METHODOLOGY

Well log data suites provided for the study included Gamma Ray (GR) Logs, Caliper Logs, Resistivity Logs, and Porosity Logs. The nDI AVO Model was used in carrying out the RPA. Well logs basically needed include: Sonic, Density, Shear (can be generated from the sonic logs), Gamma Ray (or lithology) required for Shear creation and Gassmann substitution, Caliper - optional, always should be consulted as a quick Q.C. tool, Resistivity/SP - optional, helpful to know where hydrocarbons are. The Checkshot is necessary for building overburden model and calculating reflection angles. Workflow for generating our stack traces from the nDI AVO Model as shown in Figure 2 and Figure 3 below can be summarized as follows:

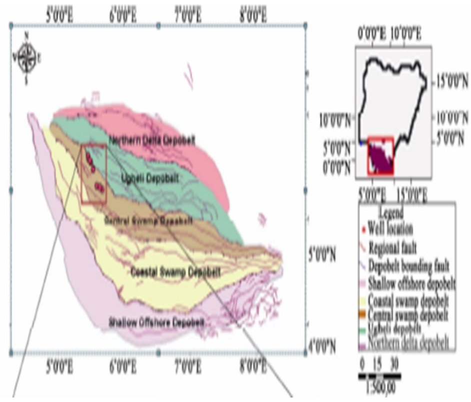

Figure 1: Map showing the depobelts and area where field of interest is located

1. After starting our nDI AVO Model, we smoothen our velocity function obtained from the check shot used.

2. Then we load our well logs carefully selecting the units of measurement and view defining minimum and maximum values, fill parameters, Polarity, Color, for each log as needed.

3. The next step is to generate an Overburden model and afterwards in the absence of Shear data, we then need to generate Sand fraction log to enable us to calculate the shear velocities from the compressional velocities. The sand fraction data helps us calculate porosities within the shale intervals used in estimating the shear velocities.

4. Finally, using the Zoeppritz function algorithm, we generate the stack trace which is angle dependent.

The basic concept behind generating our stack traces from the nDI AVO Model as shown in Figure 2 and 3 below involves convolving the zero-phase wavelet with the reflectivity series generated from the acoustic impedance log inbuilt in the nDI AVO Model factoring the effect of overburden. For the Sequence Stratigraphic analysis, key bounding surfaces which subdivide the strata into contemporaneously deposited sediment packages were identified from well log responses from a complete suite of logs which included Gamma Ray, Resistivity and Porosity logs.

Firstly, flooding surfaces were identified from logs by locating the point of maximum separation between the neutron and density porosities which corresponds to the lowest shale resistivity. Key bounding surfaces such as SBs or MFSs were identified based on observing trends of increasing flooding surface resistivity values and decreasing flooding surface neutron porosity values corresponding to forward-stepping (progradation) of the delta cycles and vice versa corresponding to retro gradational cycle [20].

Highest relative neutron-porosity values and the corresponding lowest resistivity values relative to the other surrounding flooding surfaces correlated to MFS, and SBs were identified based on points that correlated with maximum forward-stepping of the delta cycle. The systems tracts were then identified and compared to the stack traces obtained from the reflectivity pattern analysis workflow.

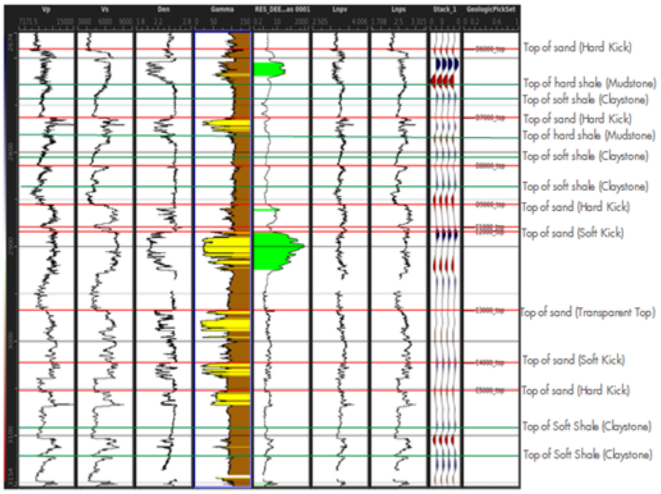

Figure 2: Reflectivity Pattern Analysis of well 'X' (Upper Section)

For the Sequence Stratigraphic analysis, key bounding surfaces which subdivide the strata into contemporaneously deposited sediment packages were identified from well log responses from a complete suite of logs which included Gamma Ray, Resistivity and Porosity logs. Firstly, flooding surfaces were identified from logs by locating the point of maximum separation between the neutron and density porosities which corresponds to the lowest shale resistivity. Key bounding surfaces such as SBs or MFSs were identified based on observing trends of increasing flooding surface resistivity values and decreasing flooding surface neutron porosity values corresponding to forward-stepping (progradation) of the delta cycles and vice versa corresponding to retro gradational cycle [1,21,22]. Highest relative neutron-porosity values and the corresponding lowest resistivity values relative to the other surrounding flooding surfaces correlated to MFS, and SBs were identified based on points that correlated with maximum forward-stepping of the delta cycle. The systems tracts were then identified and compared to the stack traces obtained from the reflectivity pattern analysis workflow.

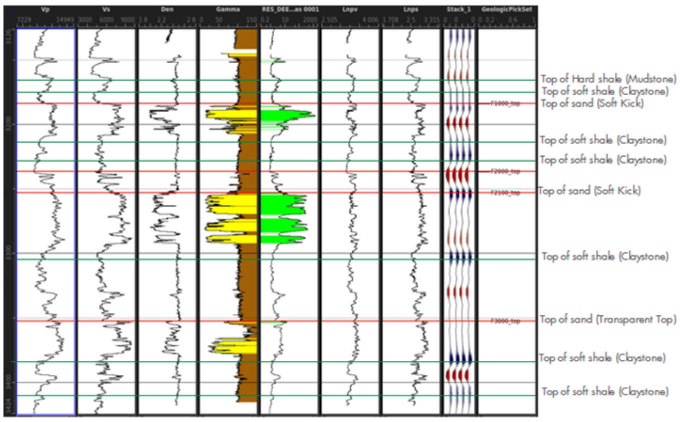

Figure 3: Reflectivity Pattern Analysis of well 'X' (Lower Section)

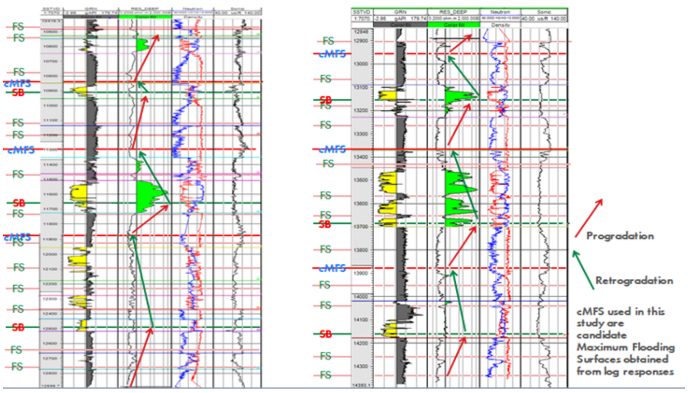

Figure 4: Identification of bounding surfaces from logs from upper section to lower section (L-R)

4. RESULTS AND DISCUSSIONS

From Figure 5 and 6, 6 candidate Maximum Flooding Surfaces (cMFSs) identified had the lowest resistivity value and maximum separation between neutron and density values relative to surrounding flooding surfaces. Hence, six transgressive systems tracts (TST 1- TST 6) were identified. On comparison of the TSTs to the seismic responses observed within them from the RPA, there was a consistency in identifying the MFS that terminates the TST interval as having a moderate to high positive reflectivity or a hard kick. At intervals where we saw low positive reflectivity and a transparent top which were in TST 6 and TST 5 accordingly, the thickness of the shale column terminating the transgressive interval was not thick enough to generate the observed response in other TSTs. Also the missing data just above TST 5 could also account for the transparent response of the MFS capping it.

Another observation was that the thick shales within the TSTs that accumulated just before MFS, were seen to display high acoustic properties. They generated soft kicks at points where they interface with underlying sand deposit, but there were exceptional cases which we shall explain further. A first exception to the observation of soft kicks at interface between thick transgressive shales over sand deposit was first observed in TST 1. Here it was a transparent response seen at the top of the sand, and this was because they were high gamma sands. High Gamma Sands having high gamma values but no appreciable density neutron separation and are part of the TST, and the high gamma could be as a result of the formation of glauconite in the sand pore spaces, giving rise to the high gamma values. This is common in the Niger Delta and so we need density neutron to see them. Based on this theory, the cementation in the sands had made the sands of high acoustic property proportional to the acoustic property of the thick transgressive shale deposit just above them resulting in the transparent top observed.

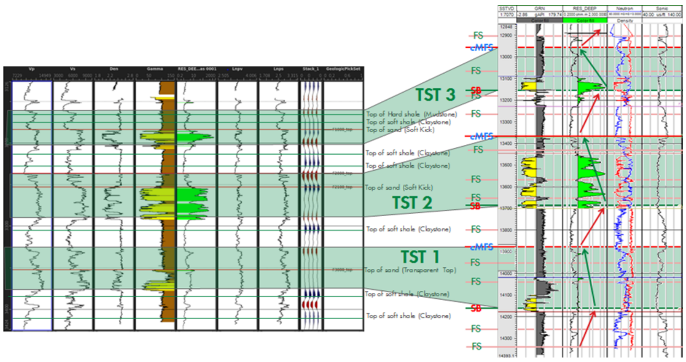

Figure 5: Comparison of TSTs with the seismic response from RPA for lower section of the well

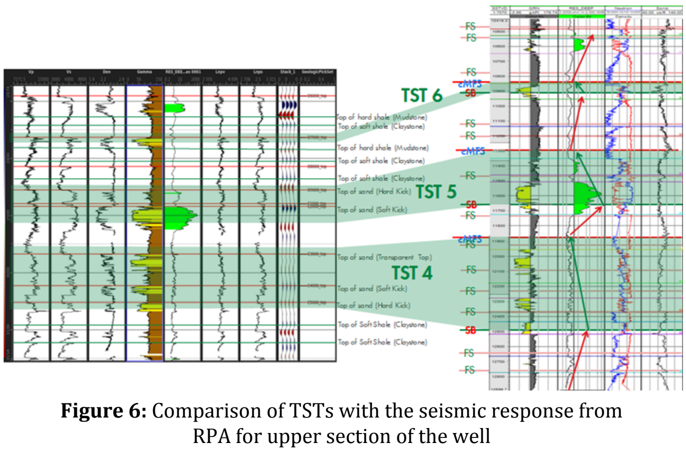

Figure 6: Comparison of TSTs with the seismic response from RPA for upper section of the well

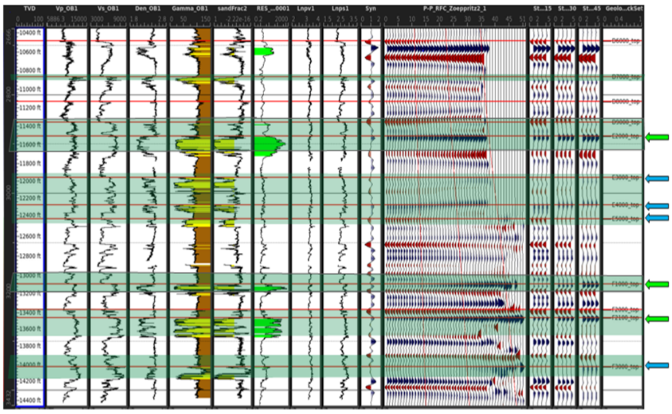

Figure 7: AVO Modelling for the entire well section

Again, the TST 6 would not be consistent with the above observation due to the thickness of the overlying shale. An observation of a soft kick within the shale interval of TST 3 was consistent with top mudstone/top marine shale (claystone) response.

AVO observations of sand tops show Type 3 AVO for hydrocarbon sands beneath the shales in the TSTs and Type 2 AVO for water bearing sands. Also, the all MFS tops show decrease in positive amplitude with offset excepting for MFS top 2 which maintained its high positive amplitude value with offset.

5. CONCLUSION

We have shown using just a well section how seismic responses from surfaces and reservoir tops help us to understand the behavior of shales across the entire well section. Our findings being that, shales within the TST intervals exhibit high acoustic responses than those in the HSTs. AVO response of MFSs were consistent having high positive amplitude decreasing with offset. We propose that on a larger scale, there should be a link between seismic amplitude responses (including their AVO component) to stratigraphy and further studies on analyzing the relationship of elastic parameters of seismic may form the basis of predicting stratigraphy in frontier basins which would derisk prospect evaluation in such areas to a high degree.

One way of identifying our TSTs is to look out for shale tops of high acoustic properties within a shale interval that corresponds to the lowest resistivity values and widest separation between neutron and density values. Anomalies aside from expected responses from sand-shale top responses factoring the effect of depth trends would require stratigraphic analysis. The relationship between elastic properties from rocks which can be inferred from seismic and their expected behavior after a clear understanding of their stratigraphy from sequence Stratigraphic analysis is a concept for further study as it simplifies further prospect identification and analysis in frontier fields especially in offshore seismic dataset.

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