The Application of Seismic Velocity Pseudo Section in Interpreting Subsurface Stratigraphy in Offshore Niger Delta, Moonstone Field

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Abstract: Record sof offshore seismic lines from Moonstone Oil-field Niger Delta have been interpreted for the observed structures, anticlinalhorizons and faults present. Porosity and velocity Pseudo Sections were constructed and interpreted for the observed structures. Velocity pseudo section was used to identify hydrocarbon accumulation zone by checking for sudden reduction (velocity break and discontinuities) in its value, and regional compactation trends was deduced since interval velocity increases with depth. The Porosity Sections for seismic lines M-016, M-020, M029, and M-031 show changes in porosity variation with depth. For line M-016, porosity discontinuities are seen at 4000-5000m, for line M-020 porosity discontinuities are seen at 3000m and 5000m respectively. The Porosity Sections for seismic lines M-029 and M-031 show the changes in porosity with depth and discontinuities at 3500m and 4000m respectively. Horizons were picked wherever there are lithological Changes. Velocity pseudo section for LinesM-016, M - 0 2 0 , M - 0 2 9 , and M - 0 3 1 , delineated four (4) layers. Layer 1 with velocity ranging from 1490m/s to 2248m/s, is characterized by relatively strong and continuous reflection amplitudes. This layer consist of loose and porous sands of the Benin formation. Layers 2 and 3 are similar in their reflection patterns, but with strongeramplitude reflections, most of which are discontinuous. The velocity within these layers vary from 217m/s to 3532m/s and this section does not show the faults characteristic of the Agbada formation since geologic features are concentrated down dip. However, a porosity range from 20-35% was obtained within these layers and is consistent with the established porosity values within the Agbada formation in the Niger Delta. The fourth layer occurring at depth of about 3000m is characterized by irregular and discontinuous reflections with velocities ranging from 2547m/s to 3200m/s. The nature of the reflection is characteristic of shales, indicating a change in lithology from sandy shales to the base of layer 3 into shales of layer 4, this layer is the Akata formation. The velocities of the layers increases with depth which is asa result of the increasing compaction, depth of burial and age. The Pseudo-sections were compared with with the Seismicamplitude sections of the Sono (M-016, M-020, M-029 and M-031) and the results obtained show a good match between these sections. The seismic record show results of a subsurface geology that has three major subdivisions which is Agnewment with the established subsurface geology of the Niger Delta. The results obtained in this study are very useful in the siting of appraisal and development wells however, it should be carried out on the entire field.

Keywords: Seismic amplitude, Velocity sag, porosity discontinuity, pseudo-section.

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I. Introduction

Modern technique of extracting velocity data from seismic traces, their interpretation and advances in seismic data processing, makes it possible to estimate lithology and identify hydrocarbon location on a seismic line before a well is drilled. Accurate prediction of abnormal Pressure zone before drilling is vital. The drilling engineer and team with the lithology extracted from the velocity data, is an invaluable service to reservoir engineering (Fitch, 1976). The application of seismic interval velocity to hydrocarbon detection defines the identification of hydrocarbon location in seismic data in terms of abnormal velocity variation (pull-down). Exploration objectives include mapping subsurface geological structures, detection of hydrocarbon accumulations, estimation of total energy reserve, formation of a model of the reservoir, and reservoir monitoring (Water, 1997).
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1987). A key indication of the presence of hydrocarbon is bright spot (high amplitude anomaly); other indications include velocity pull-down or sags, diffraction patterns, polarity reversal at the edges of gas sands, ordim-spot (low amplitude or attenuation effects with selective absorption of high frequency components), (Dobrin, 1988; Fowler, 1984; Fagin, 1991; and Hilterman, 1975). Direct detection of oil has been achieved in the location of gas accumulation which considerably reduces the seismic velocity of the sedimentary rocks in which they occur (Hubral and Krey, 1980).

These seismic methods of geophysical exploration utilize the fact that elastic waves travel with different velocities in different rocks. The principle is to initiate sound waves at a point and determine the number of points that time of arrival of the energy (signal) that is refracted or reflected by the discontinuities between different rock formations. This then enables the position of the discontinuities to be deduced (Parasnis, 1986). There are two distinct seismic techniques, one making use of the reflection and the other the refraction of elastic waves in rocks. The reflections and refractions are recorded by detecting instruments responsive to ground motions, these are geophones for land survey and hydrophones for marine work. Velocity is linked between seismic data and geology, however depth sections are not always coincident with migrated time sections. For a constant velocity layer, the traveltime curve is a function of offset set is a hyperbola. The time difference between the traveltime at a given offset and a zero-offset is called normal move-out (NMO). The velocity required to correct normal move-out (NMO) is called the normal move out velocity (Mayne, 1967). The interval velocity is the average velocity in an interval between two reflectors. Several factors influence its velocity within a rock unit with a certain lithologic composition these are, pore space, pore pressure, pore fluid saturation, confining pressure, and temperature etc. In this study, seismic interval velocity data were used in prospect zone identification and in the knowledge of regional stratigraphy. This study utilizes the interval velocity data generated from velocity analysis points on the seismic reflection sections obtained from Moonstone field, offshore Niger Delta to create pseudo-section of porosity and velocity for the delineation of reservoir zones and subsurface geology using the pseudo sections created, as well as the lithological characteristics of the field. The significance of this study is that it utilizes the sensitivity of seismic velocity to analyze lithofacies and reservoir parameters like porosity, pore fluid type, saturation and pore pressure, with theoretical need to quantify seismic to rock-properties and then to interpret amplitudes for hydrocarbon detection, reservoir characterization and monitoring.

II. Geologic Setting

The Moonstone Oilfield is located in offshore Niger Delta in the southern part of Nigeria. The field is located within latitudes 4°N and longitude 7°E. It is located at about 75Km southeast of Port Harcourt with an area of about 742Km². The Niger Delta is situated on the Gulf of Guinea in the West coast of Africa. It is located at the southeastern end of Nigeria, bordering the Atlantic Ocean and extends from Latitude 4° to 6° North and Longitude 3° to 9° East. The tectonic framework of the Niger Delta is related to the stress that accompanied the separation of the African and South American plates (as proposed by Alfred Wegner), which led to the opening of the South Atlantic. The Niger Delta Basin is the largest sedimentary basin in Africa with an area of about 75,000Km², and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences (Stacher, 1995). The proto Delta developed in the Northern part of the Basin during the Campanian transgression and ended with the Paleocene transgression. Sedimentary deposits in the Basin have been divided into three large-scale lithostratigraphic units namely: (a) the basal Paleocene to Recent pro-delta facies of the Akata Formation, (b) Eocene to Recent paralic facies of the Agbada Formation and (c) Oligocene to Recent, fluviatile facies of the Benin Formation (Short and Stauble, 1967; Evamy et al., 1978 and Whiteman, 1982). These formations became progressively younger into the basinward, recording long-term progradation (seaward movement) of depositional environments of the Niger Delta into the Atlantic Ocean Passive Margin. The stratigraphy of the Niger Delta is complicated by the syndepositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluviatile Benin Formation.

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III. Materials and Method

The dataset used in this study was obtained from Moonstone Oilfield offshore Niger Delta, and consists of four Seismic sections and Velocity analysis data from four lines labelled as M-016, M-020, M-029, and M-031. Where M-016, M-020 represents the strike lines which runs NE-SW, and M-029, M-031 represents the dip lines which runs NW-SE. The sections show a common midpoint display (CMD) of seismic responses in the form of wiggles.

From each seismic section, three (3) time horizons H1, H2, and H3 were identified based on amplitude and continuity of the reflections. The horizons are anticlinal on the strike sections.

H1 was picked between two way time 1.2 – 1.6 second to the left of the section; H1 underlies a stratum marked by strong continuous reflections which likely contains the Benin Formation. The second and third horizons are both marked by stronger reflections. The reflection is likely due to the strong acoustic impedance of the sand and shale sequences of the Agbada Formation.

Fault mapping was done on each time section using the criteria proposed by Dobrin and Savit (1988).

From the velocity analysis data, transit time was obtained for the various velocity analysis points by taking the inverse of the velocity at each point using:

$$\Delta t = \frac{1}{\Delta V} \tag{1}$$

The interval transit time was then plotted against depth to acquire a transit time log. This was done over all velocity analysis points of the four seismic sections.

Porosity of each of these seismic sections was determined using the empirical formula based on field observations (Schlumberger, 1989). The equation is given as:

$$\Phi_S = C \frac{t_{log} - t_{ma}}{t_{log}} \tag{2}$$

Where

C = 0.67 (correction factor);

$$\Phi_S$$ = sonic porosity;

$$t_{log}$$ = transit time as calculated from the reciprocal of interval velocity;

$$t_{ma}$$ = transit time of the matrix material (taken to be 55.5μs/ft for sandstones).
This relation was preferred because of its applicability to the uncompacted sands like those of the Niger Delta. The porosity along the velocity analysis points was obtained for each of the four sections, from which four porosity pseudosections were generated corresponding to each seismic section. Also, the reflectivity coefficient series was calculated using the Zeoppritz equation

\[ R_c = \frac{Z_2 - Z_1}{Z_2 + Z_1} \]  

Where

\( Z_1 \) = acoustic impedance of layer 1 (the upper layer) and \( Z_2 \) is that of layer 2.

If \( Z = \rho v \), where \( \rho \) is the density of the rock and is assumed to be negligible or equal to unity (1). This simplifies the Zeoppritz equation, becomes reduced to the form;

\[ R_c = \frac{V_2 - V_1}{V_2 + V_1} \]

Where;

\( V_1 \) = the interval velocity of the spatially upper layer; and \( V_2 \) = the interval velocity of the spatially lower layer.

The reflectivity coefficients were plotted against depth on the velocity analysis points on each seismic section and this was also compared with the seismic sections provided. The obtained interval transit time, porosity and acoustic reflectivity coefficient sections obtained from the four velocity analysis points were matched with the surface seismic section on which the velocity analysis point data was obtained. From the above procedures, interpretation of the subsurface geological structures, delineation of the different lithologies within the study area was facilitated. The research design used for this work is summarized in the flow chart (Figure 2).

Procedure / Workflow

![Flow chart showing the research workflow.](Figure 2)
IV. Results, Interpretation and Discussion

1.1 Porosity Section

Porosity pseudo Section which show changes in porosity with depth for the particular line for which it was measured were plotted and from the section, horizons can be identified and picked where there are lithological changes. This was done for lines M-016, M-020, M-029, and M-031.

![Porosity pseudo section for seismic line M-16](image1.png)

**Figure 3:** porosity pseudo section for seismic line M-16.

![Porosity pseudo section for seismic line M-20](image2.png)

**Figure 4:** porosity pseudo section for seismic line M-20.
1.2 Velocity Section

Velocity pseudo sections show the same variations over the lithologies as the Porosity sections above. Interval velocities are expected to increase with depth almost linearly. However, sudden velocity responses called velocity pull-downs or sags, which occur at the edges of gas sands or on the top of overpressures, can be used as indicators of zones of hydrocarbon occurrence. Figures 7–10, shows the Velocity pseudo sections created for analysis.
Figure 7: Velocity pseudo Section for Line M –16

Figure 8: Velocity pseudo Section for Line M –20.
1.3 Analysis and Discussion of Results

The Porosity Section for seismic line M-16 (figure 3) shows the changes in porosity variation with depth for line M-16 for which it was measured. Horizons can be picked where there are lithological changes. From the Porosity Section of line M-20 (figure 4), we observe that the change in porosity for which we picked our H1 from Section M-16 has shifted from a depth of about 1000 m to nearly 2200 m. Since both sections are dip sections, it implies that the horizon dips in a NW-SE direction. The Porosity Section for seismic lines M-29 and M-31 (figures 5 and 6) show the changes in porosity with depth for both lines and horizons can be picked where there are lithological changes. Between Horizons 1 and 2 for both lines, there are discontinuities between the plots obtained at the different points. This indicates the faulted nature of the layer and it corresponds in depth to the bottom of Agbada and top of Akata formations of the Niger Delta. However, the discontinuities so delineated are much more evident on line M-31 than that observed on the Section of M-29.

Velocity pseudo section on line M-016 delineated four (4) layers. Layer 1 is about 1220 m thick, with velocity ranging from 1490 m/s to 2248 m/s. It is characterized by relatively strong and continuous reflection amplitudes.
This layer is more likely to consist of loose and porous sands of the Benin formation. Layers 2 and 3 are similar in their reflection patterns and amplitudes. They are marked by stronger amplitudes of reflections, most of which are discontinuous. The strata are 1400 m thick and velocity within these layers vary from 2317 m/s to 3532 m/s. This section does not show the faults characteristic of the Agbada formation since geologic features are concentrated downdip. However, the porosity range from 20–35% is consistent with the established porosity values within the Agbada formation in the Niger Delta. The fourth layer occurring at a depth of about 3000 m is characterized by irregular and discontinuous reflections. It has velocities ranging from 2547 m/s to 3200 m/s. The reflection is characteristic of shales, in this case a change in lithology from sandy shales at the base of layer 3 into shales of layer 4. This layer is the Akata formation. Also, velocity pseudo section on Line M-029, delineated four (4) layers. Layer 4 is about 1225 m thick. It begins at a depth of about 1200 m on the left, rises to about 1682 m and falls back to 1342 m on the right. It has velocities ranging from 1490 m/s to 2248 m/s. It is characterized by relatively strong and continuous reflection amplitudes. This layer is more likely to consist of loose and porous sands of the Benin formation. Layers 2 and 3 are similar in their reflection patterns, amplitudes, thickness and velocity range as that in line M-016 discussed above. The noticeable difference is in the fault pattern in these layers within their depth of occurrence. These fault zones are recognized on the porosity and velocity pseudo sections as highly irregular responses. These responses show the stratigraphical variations within the individual layers. The anticlinal structures are displayed on the pseudo sections as displaced events as one moves from the left to the right of the sections. The fourth layer occurring at a depth of about 3000 m is characterized by irregular and discontinuous reflections, and is similar in characteristics with the fourth layer delineated in line M-016. The velocities of the layers increase with depth which is a result of the increasing compaction, depth of burial and age. The seismic records show results of the subsurface geology that has three major subdivisions which is in agreement with the established subsurface geology of the Niger Delta. A comparison was made between Porosity and Velocity Sections for Seismic lines M-016 and M-029 with the original Seismic section to show correlation of the major formations of the Niger Delta, as well as delineation of the reservoir formation. Two sections were picked, a dip and strike section each.

**Figure 11:** Line M-016 (a) Sonic Porosity, (b) Original Seismic section, (c) Velocity. Horizons H1, H2, and H3 are seen running across the various discontinuities observed in a and c. This correlates with amplitude anomalies observed in the seismic section in (b).
Figure 12: Line M-029 (a) Sonic Porosity. (b) Original Seismic section, (c) Velocity. Horizons H1, H2, and H3 are seen running across the various discontinuities observed in a and c. This correlates with amplitude anomalies observed in the Seismic section in (b).

V. Conclusion

We have interpreted recordsoffourseismiclinesfromMoonstone Oilfield Niger Delta forthe structures, anticlinalhorizonsand faults present. Pseudo Sections of Porosity and Velocity were also constructedand interpretedfor the observed structures andreservoirparameters. Velocity pseudo section was used to identify hydrocarbon accumulationzoneby checking for sudden reduction (velocity break and discontinuities) in its value, also regional compaction trend was deduced from interval velocities since its value increases with depth and topof the over pressured shale mass can be identified from sudden change in compaction trend. The Pseudosections were compared with the seismic amplitude sectionsof the four lines, and the results obtained in this study are very usefulinthefindingof appraisal anddevelopment wells however, it should be carried out on the entire field.

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