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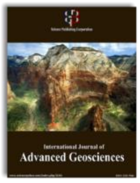

Application of model-based inversion technique in a field in the coastal swamp depobelt, Niger delta

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Abstract

Considering the heterogeneity of the reservoir sands in the Niger Delta basin which are primary causes of low hydrocarbon recovery efficiency, poor sweep, early breakthrough and pockets of bypassed oil there arises a need for in-depth quantitative interpretation and more analysis to be done on seismic data to achieve a reliable reservoir characterization to improve recovery, plan future development wells within field and achieve deeper prospecting for depths not penetrated by the wells and areas far away from well locations. An effective tool towards de-risking prospects is seismic inversion which transforms a seismic reflection data to a quantitative rock-property description of a reservoir. The choice of model-based inversion in this study was due to well control, again considering the heterogeneity of the sands in the field. X-26, X-30, and X-32 were used to generate an initial impedance log which is used to update the estimated reflectivity from which we would obtain our inverted volumes. Acoustic impedance volumes were generated and observations made were consistent with depth trends established for the Niger Delta basin, inverted slices of Poisson impedances validated the expected responses considering the effect of compaction. This justifies the use of inversion method in further characterizing the plays identified in the region.

Keywords: *Amplitude; Reflectivity; Acoustic Impedance; Model-based Inversion; Poisson's ratio.*

1. Introduction

Seismic is sensitive to impedance which is a function of velocity and bulk density. Seismic reflection occurs at a boundary between layers of different impedances. Reflection amplitude is proportional to contrast in impedance rock property which determines the value of our reflectivity. A seismic section is our approximate measurement of the earth's reflectivity convolved with an input signal pulse (the wavelet) which is the convolution model. Seismic inversion thus tends to reverse the process going back from the convolution model to the reflectivity and finally to the impedances.

From the classic inversion theory by (Oldenburg, et al 1984,), the impedance at any point in the subsurface is a function of the first layer and the sum of the reflectivity all the way down to that layer of interest. So, seismic inversion is a sum of reflectivity all the way down the trace.

Sheriff, (2002), define inversion as deriving from field data a model to describe the subsurface that is consistent with the data. It could be explained as determining the cause from observation of effects, it also means solving for a special distribution of parameters, which could have produced an observed set of measurements.

PendreL 2006, reiterates the relevance of seismic inversion as an effective tool in reservoir characterization. The paper posited that quantitative rock properties derived from inversion facilitates better estimation of reservoir properties such as porosity and net pay.

For any seismic inversion, well ties are a critical step; it establishes the relationship between the reflectivity and rocks. Well ties for seismic inversion demands a higher precision than that used for seismic interpretation. We avoid stretch and squeeze operation in well ties for inversion process for accurate phase estimation. Seismic inversion methods may be grouped based on certain geophysical assumptions that divide them into; Relative impedance inversion, colored inversion, Deterministic inversion and Stochastic Inversion. Deterministic Inversion is good for getting a regional understanding of reservoir properties and for simplifying the stratigraphic interpretation by wavelet removal. It models the earth as a sparse blocky layered model replacing the assumption of modelling the earth as having continuous reflectivity. The use of well-control in carrying out the inversion process will help remove tuning giving us a representative model of the earth.

The Niger Delta basin has for long been recognized as one of the world's major hydrocarbon provinces and as exploration is done further to tap the over 36 billion barrel crude oil reserves in the shallow to deep offshore there arises a need for more analysis (quantitative interpretation) to be done on seismic data thereby reducing the cost in drilling more exploratory wells. This study focuses on the need to achieve a cost effective, fast and reliable reservoir characterization of the reservoir sands onshore Niger Delta to better understand the lateral reservoir architecture considering its heterogeneity (which are the primary causes of low

ydrocarbon recovery efficiency, resulting in poor sweep, early breakthrough, and pockets of bypassed oil) and to improve recovery, planning of future development wells in this region and achieve deeper prospecting in areas not penetrated by wells. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15metres to 10% having greater than 45 metres thickness (Evamy, et al, 1978). Based on reservoir geometry and quality, (Kulke, 1995,) describes the most important reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. Edwards, and

Santogrossi, (1990), describe the primary Niger Delta reservoirs as Miocene Paralic sandstones with 40% porosity, 2 darcys permeability, and a thickness of 100 metres. The lateral variation of the reservoir thickness is strongly controlled by growth faults; the reservoir thickens towards the fault within the down-thrown block (Weber, and Dakouru, 1975).

In the outer portion of the delta complex, deep-sea channel sands, lowstand sand bodies, and proximal turbidites create potential reservoirs (Beka, and Oti, 1995).

Petroleum occurs throughout the Agbada Formation of the Niger Delta. However, a southeast-northwest trending belt that cut across the depositional and structural trends of the delta form an "oil-rich belt" having the largest field and lowest gas-oil ratio (Evamy, et al., 1978; Ejedawe, 1981; Doust, and Omatsola, 1990,). The belt comprises the central, easternmost, and northernmost parts of the delta. Hydrocarbon distribution is attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil).

We attempt to show the application of model-based inversion in characterizing two reservoirs of interest in the field.

2. Geology of the study location

The onshore portion of the Niger Delta where the coastal swamp depobelt is situated is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank, an east-northeast trending hingeline south of the West Africa basement massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakiliki High and further east-southeast by the Calabar flank, a hinge line bordering the adjacent Precambrian. The offshore boundary of the Niger Delta is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin to the west, and the two-kilometre sediment thickness to the south and southwest. The province covers 300 000km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System (Tuttle ,et al.,1999).

X-field is located some few kilometers southwest of Port Harcourt within the Niger Delta Basin as shown in Fig. 1.1. The Niger Delta lies between latitudes 3° N and 6° N and longitudes 5° E and 8° E. The structure is a complex collapsed crest, rollover anticline, elongated in an E-W direction. The zone of interest is typically a sand/shale/sand sequence.

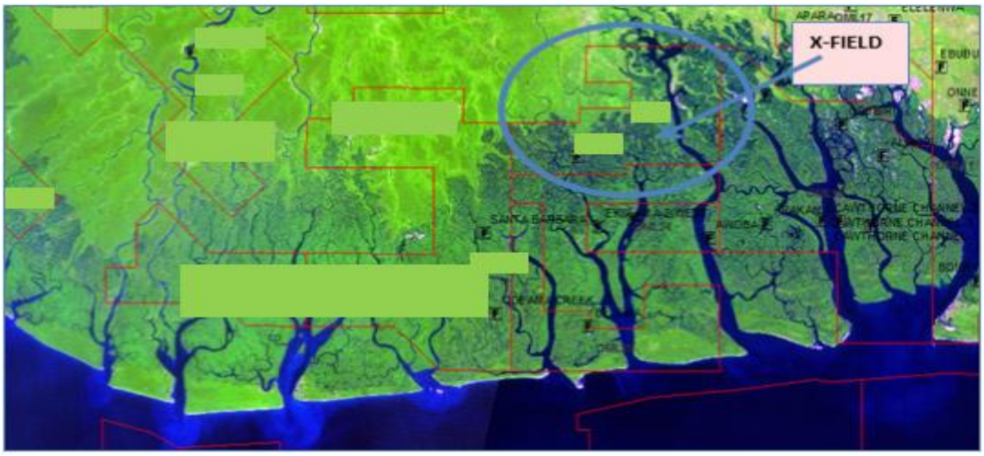


Fig. 1.1: Location Map Showing X Field in the Niger Delta (SPDC 2005).

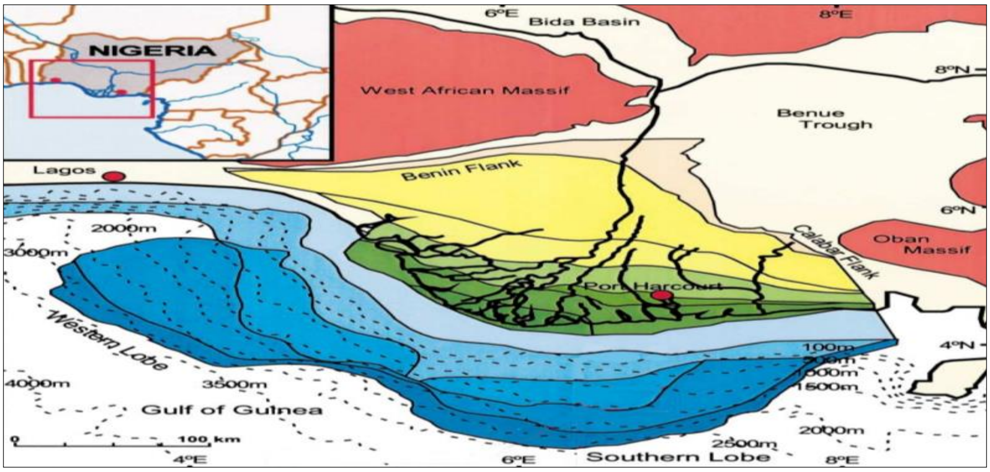


Fig. 1.2: Location Map of the Niger Delta Showing The Depobelts and Geologic Features that Bounds the Delta (Tuttle, Et Al., 1999).

3. Data and methodology

The data used in this work is a well log data and a 3D full stack seismic data from "X" field in the Coastal Swamp depobelt within the Niger Delta Basin. The data consist of a suite of well logs from X-26, X-30, and X-32 located towards the northwestern part of the field. This data was analyzed using Hampson Russell software (HRS).

Because deterministic inversion can work well in thin sand intervals within stacked reservoirs where lateral thickness changes gradually and provided there is good well control, model-based inversion is applied to characterize the identified reservoirs in the field.

The model-based deconvolution was used to invert the stacked sections to pseudo-velocity sections.

The model-based inversion derives the impedance profile which best fits the modelled trace and the seismic trace in a least squares sense using an initial guess impedance. Basically, this inversion resolves the reflectivity from an objective function and compares its RMS amplitude with the assumed reflectivity size. The wavelet is then scaled to compensate for the difference. This iterative process for updating the estimated reflectivity requires an initial impedance value. The initial impedance logs were obtained from the sonic and density logs of the wells X-26, X-30, and X-32. Each value of the mean impedance log obtained from the three wells corresponded to the arithmetic sum of the individual impedance values for each well divided by the factor 3. During this process each well was stretched for matching the principal impedance contrasts with the formation tops associated with the Horizon 1 Formation at the tie location.

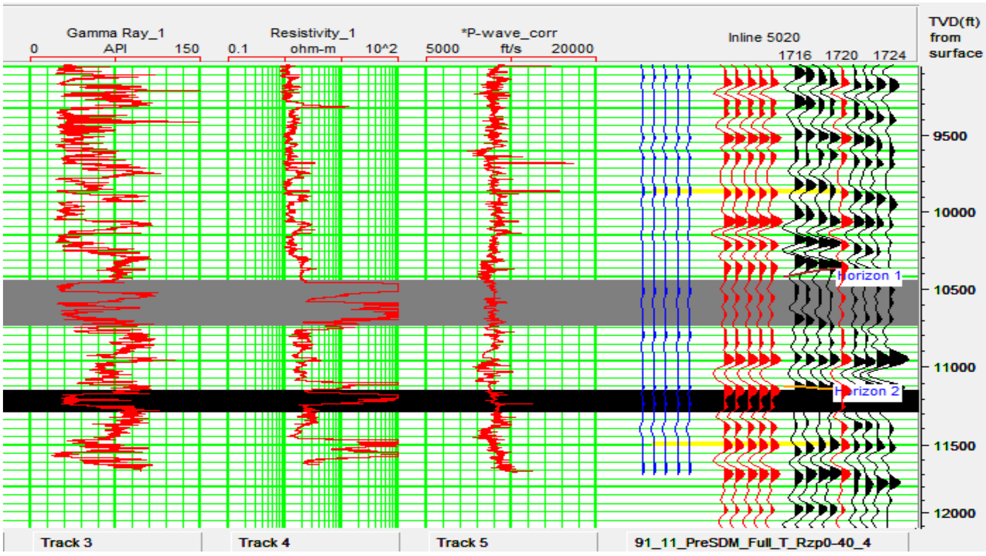
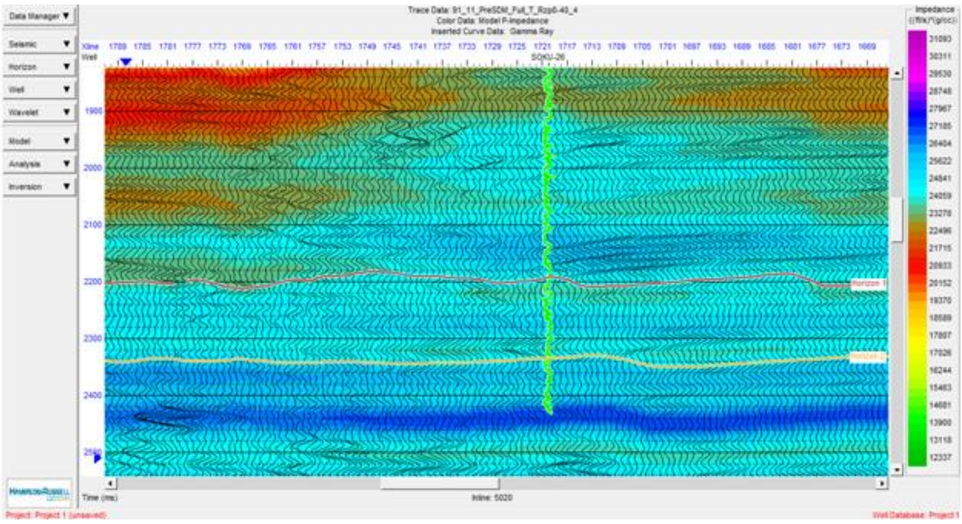


Fig. 1.4: Well to Seismic Tie for Well X-26 Showing to the Right, Synthetic Trace (Blue) Extracted from the Baseline Seismic, Seismic Trace (Black), And Composite Trace (Red). Horizon 1 and Horizon 2 Was Delineated from the Gamma Ray, Resistivity and Sonic Logs.



Fi. 1.5: Low Frequency Acoustic Impedance Model with Computed Impedance Value at X-26 Overlain on It.

4. Result and discussion

In the model based inversion method, to make impedance estimates absolute, we must add the missing low frequency. Fig. 1.5 shows the low frequency acoustic impedance model obtained from combining the seismic wavelet amplitude spectrum with the reflectivity spectrum from the wells to produce the bandlimited reflectivity shown below, from which we get our inverted volumes.

The inverted acoustic impedance volume at well location X-26 and X-30 is shown below in Fig. 1.6 and 1.7 below. Observe steady increase in acoustic impedance values with increase in depth and compaction. But the impact of depth trends cannot be neglected. This is consistent with (Olowokere and Ojo 2011) investigation on porosity-depth trends of sand and shales, identifying shales as having a parabolic form (relatively decreasing in acoustic impedance with increased depth), and sands having a linear trend with its impedance gently increasing with depth. The sands also show an exponential trend and generally this increase in impedance in sands especially from depths below 2km in the Niger Delta can be attributed to cementation in the sands as we go basin ward.

From the foregoing, we can see that the impact of phase change for the lithologies as a result of depth trends is observed from 2200ms. Notice the seeming similarities in acoustic impedance values from this point for the stacked sand/shale interval as opposed to how distinct they were above in the inverted volumes shown below.

The footwall of the regional fault which is supposed to be more compacted due to longer periods of burial shows relatively higher impedance values than their lateral equivalent on the hanging wall. Horizon 1 and Horizon 2 were relatively good inversion targets despite how thin their interval was.

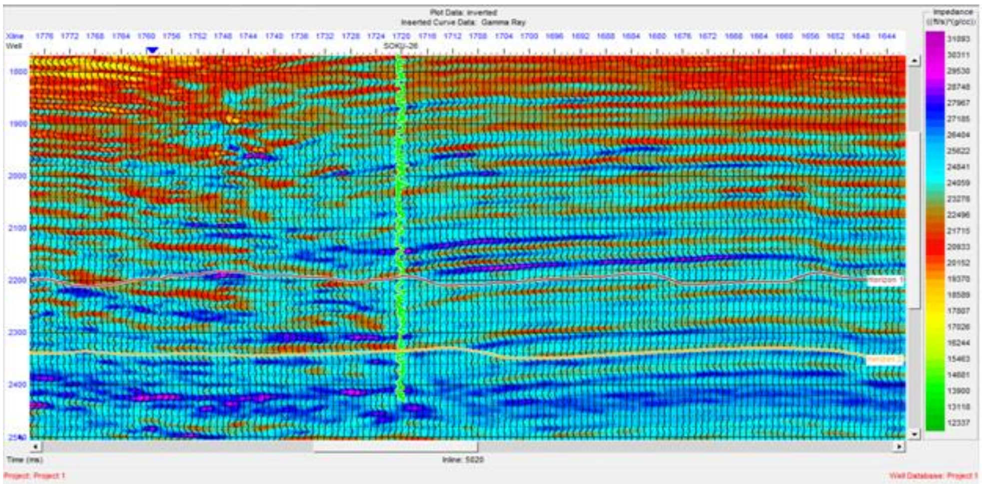


Fig. 1.6: Inverted Impedance Section at X-26 Well Location.

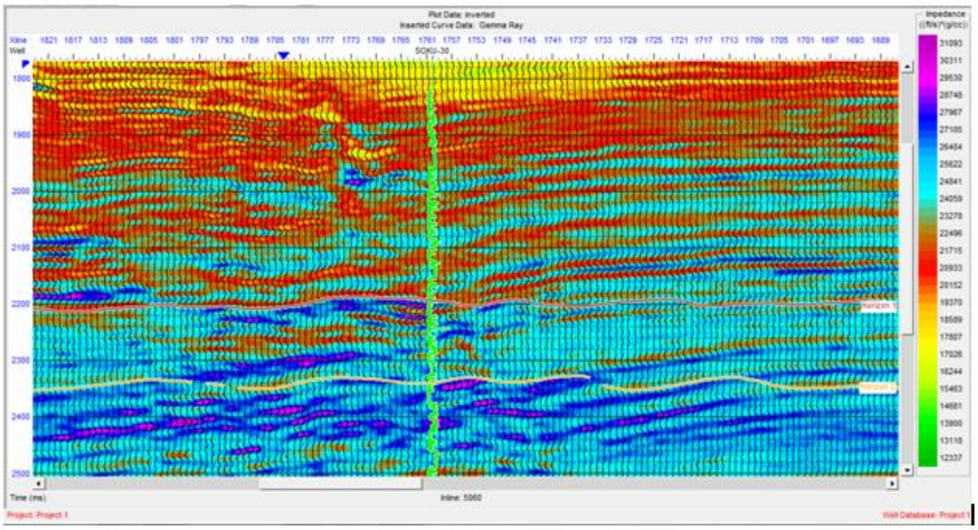


Fig. 1.7: Inverted Impedance Section At X-30 Well Location.

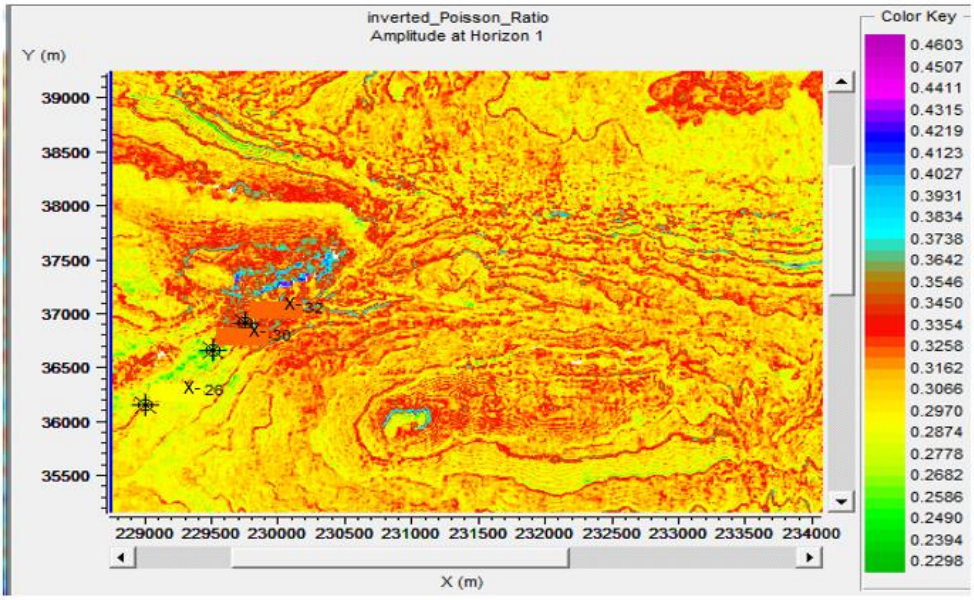


Fig. 1.8: Inverted Poisson Impedance Slice A Horizon-1.

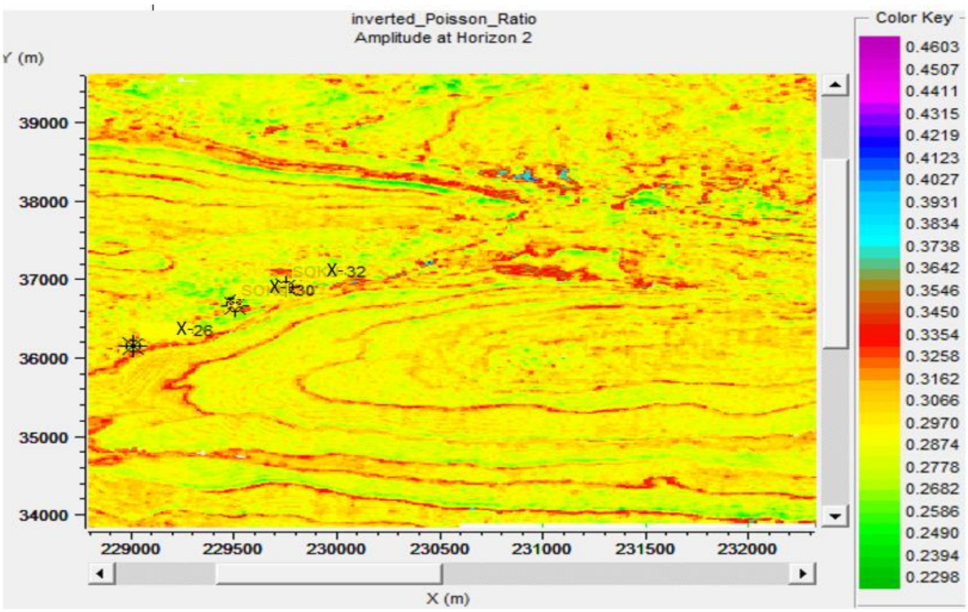


Fig. 1.9: Inverted Poisson Impedance Slice A Horizon-2.

Shuey, 1985 showed that using least squares inversion the contrast in Poisson's ratio (Aσ) at the interface between two lithologies could be extracted. Following modifications of Shuey, 1985's approximation with assumptions, least squares inversion can be used to extract normal incident reflectivity, S-wave velocity reflectivity and Poisson's ratio reflectivity (Castagna, and Swan, 1997, Hilterman 2001).

Taking Poisson impedance slices across the horizons, we see generally higher Poisson impedance values shallower in Fig. 1.8 which are consistent with fluid discrimination using inversion being done readily for shallower intervals of lower acoustic impedance compared to deeper intervals of higher acoustic impedance. So, we see lower Poisson impedance in Fig. 1.9 because due to increased compaction going deeper, which makes us characterize the fluids less readily.

5. Conclusion

Model-based inversion has been used to characterize thin sand intervals in heteroliths prevalent in the Niger Delta despite tuning due to good well control around the field of interest. Observations were consistent with theories on depth trends studied from the Niger Delta basin.

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