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RESEARCH PAPER

AMPLITUDE VARIATION WITH OFFSET MODELLING AND CROSSPLOT ANALYSIS FOR RESERVOIR CHARACTERIZATION IN MONTERO FIELD, CENTRAL SWAMP DEPOBELT, ONSHORE NIGER DELTA BASIN, NIGERIA

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ABSTRACT
The study area is a partially appraised green field with few well counts. The recent drive to minimize the number of appraisal to save cost and still fully understand the subsurface geology underlying the field for proper characterization lead to the application and advancement of quantitative seismic interpretation techniques for field appraisals. In this study, well based Rock physics Crossplot Analysis and Amplitude Versus Offset (AVO) forward modelling feasibility were carried out in Montero Field to assess the applicability of the techniques for characterization and prospectivity of undrilled areas. Results from two conventional cross plot techniques (Vp/Vs ratio against Acoustic impedance and Lambda-Mu-Rho) gave very good lithology and fluid discrimination (that can be relied on in the absence of neutron log for fluid typing and contact definition). AVO modelling results reveals the presence of type I,II,III and IV AVO gas sand classes for sands B, B2, A2 and A respectively.

Keywords: *Gas-sand, AVO-modelling, crossplot-analysis, rock-physics, Niger-Delta*

INTRODUCTION

One of the major challenges facing quantitative seismic interpretation is data quality. An attempt to check this problem and improve the quality of interpretation results is to build models from wells that could be used to condition the interpretation of field data. Experience has shown that evaluation of geophysical anomalies such as Direct Hydrocarbon Indicator (DHI) can be used to reduce risk, and consequently, identify new prospects (Castagna and Backus 1993). The work done by Ostrander (1982) made the methodology commonly known as amplitude variation with offset analysis (AVO) very popular. Results of AVO analysis are highly dependent on the quality of seismic data produced by suitable acquisition program and special processing workflow to preserve the original amplitude. It has been demonstrated that gas sand reflection coefficient varies in anomalous fashion with increasing offset, it also displayed how to utilize this anomalous behavior as a direct indicator of hydrocarbons in relation to real data (Ostrander, 1982). Since such conditions are not always met, models can be built to condition these analyses. Seismic modeling forms the basis for understanding seismic signature. Forward modeling is seriously considered when possible direct hydrocarbon indicators are seen on the full stack seismic data (Paul and Marianne, 2006). However, in other unique situation, the modeling can provide valuable information and a good understanding of our data set. Petro-acoustic fluid substitution model is necessary to make reliable estimate of Primary wave (V_p), Secondary wave (V_s) and density, that contain information about the lithology and fluid content of the rocks (Assefa *et al*., 2003). Potential hydrocarbon accumulation had been predicted from amplitude expression observed on models generated with information on fluid saturation, production data and knowledge of acoustic properties of the various lithology facies that could serve as a potential reservoir (Eggen, 2012).

Analysis of cross plot of amplitude versus offset (AVO) attribute derived from reservoir class curves generated from the modeled synthetic gathers have been applied to characterize reservoirs. Accurate analysis is required to establish the AVO classes of reservoir present in the field under investigation. This makes it possible to concentrate quickly on some particular scenarios and perform case specific analysis. This does not ignore the fact that several types of AVO reservoirs might co-exist at the same time. Evaluating all options makes the evaluation of the AVO response more time consuming (Paul and Marianne, 2006). Several workers for example, Chi and Han (2007) worked in the Gulf of Mexico and Eggen (2012) worked in the Norwegian Sea, they applied these principles to characterize gas sands in different petroliferous basin across the world.

Some AVO class sands have been reported in the Niger Delta Basin (Ogagarue and Annie, 2016; Ohaegbuchu and Igboekwe, 2016; Uko and Emudianughe, 2014). The commonest being class (3) gas sands. This research work focuses on applying result of AVO and crossplot analysis in the Montero field in the Central Swamp of the Niger Delta Basin for lithology and fluid discrimination to characterize gas sands encountered in the Montero field.

MATERIALS AND METHODS

This research was carried out using well data and the Hampson Russell subsurface interpretation software. The well logs were quality checked (edited and filtered) to improve the quality of result from rock physics crossplot and AVO modelling.

Shear wave log and neutron log were not available. Hence, Castagna relationship was used to estimate Shear wave log from the available compressional wave log (Castagna and Backus 1993). AVO modelling was done using the simplified two term Aki-Richards Model (Aki and Richards,1980).

RESULTS AND DISCUSSIONS

Rock physics cross plots analysis

Results of crossplot analysis of Sand A are presented in figs1-4 to test sensitivity of variation in rock properties to changes in lithology and fluid using two convectional techniques; crossplots of Vp/vs ratio against Acoustic-Impedance and lambda-rho against Mu-rho. For crossplots in Figs 1-4, the black circle on the cross plot corresponds to the black shaded areas in the well logs (especially Gamma-ray in the third tract and Resistivity log in the fourth tract) by the left of the panel, the blue circle corresponds to the blue shaded area in the logs and represent brine sand, the red circle corresponds to the red shaded areas in the well logs and represent Oil Sand and the green circle corresponds to the green shaded areas in the well logs and represented Gas Sand.

Figs 1 and 2 show cross plot done between shale layers above and below the reservoir of interest to discriminate lithology mainly because the sand is very clean. The results indicate that both crossplots are good discriminator of lithology. In Fig.1, despite the large range of thickness plotted, the crossplot was still able to discriminate two fluids i.e. separation between hydrocarbon Sand and Brine Sands. The cross plot of Lambda-Rho vs Mu-Rho for the same depth interval was able to further discriminate between Gas Sand and Oil Sand. This shows that the Lambda-Mu-Rho technique is more sensitive to fluid changes and would give better results in unique cases.

To better appreciate the fluid discrimination using the aforementioned crossplot techniques, we narrowed down to plot just the reservoir interval. In figs. 3 and 4, both crossplot gave very good cluster separation. It was observed that the separation between Brine Sand and Oil Sands was not distinct. This is due to the small contrast in impedances that exist between water and sand. Therefore, crossplot plot analysis have been demonstrated to be a very dependable tool for fluid typing and delineation of hydrocarbon fluid contact in the absence of neutron log.

AVO modelling and Crossplot analysis

AVO analysis practice mainly involves adopting Reflection Coefficient (RC) versus offset angle plots and the intercept versus gradient plots modified by Castagna and Swan 1997 to define and classify hydrocarbon gas sand into different classes. The response from the top reservoirs are categorized based on their amplitude behavior as a function of offset on a Common Depth Point gather, when filled with hydrocarbons, and also dependent on the competency of the overlying shale layer. Typical result of AVO analysis of Montero field are presented in this work.

Sand A

The cross plot of Sand A at a depth of 8520ft shows variation of acoustic properties as a result of fluid and lithology changes. The plotted parameters have good relationship with reflected amplitude. Hence, it's expected that these properties and reflected amplitude should vary with offset. Figs. 11 and 12a is the generated synthetic gather at the top of Sand A and the zero offset amplitude. The response shows a highly negative amplitude that becomes less negative in absolute value with offset, defined as a diming effect (off structure diming effect) that could be seen as dim spot on a high resolution full stack reflectivity seismic data, and a positive gradient typical of a Class IV Gas Sand. The intercept versus gradient plot in fig. 12b validates the gas sand definition in fig. 12a. This AVO response is typical of a geological condition were a competent shale is overlain by a very loose sand and commonly found at shallow depth were unconsolidated sands predominates.

Sand A2

Sand A2 AVO results are presented in Figs 9 and 10. The reservoir occur at depth 9820ft. It is defined by a negative zero offset reflection

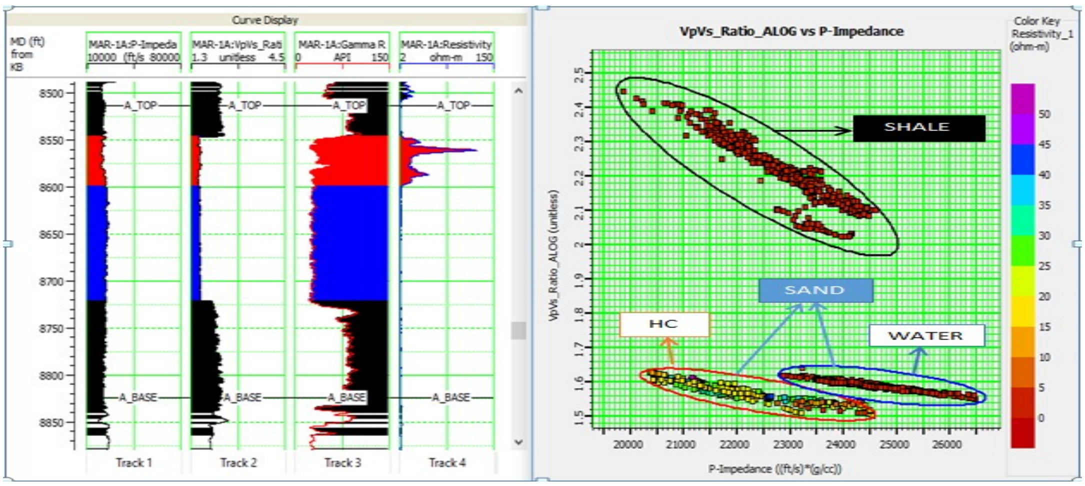

Fig. 1: Crossplot of V_p/V_s ratio versus P-impedance in Sand A for lithology discrimination

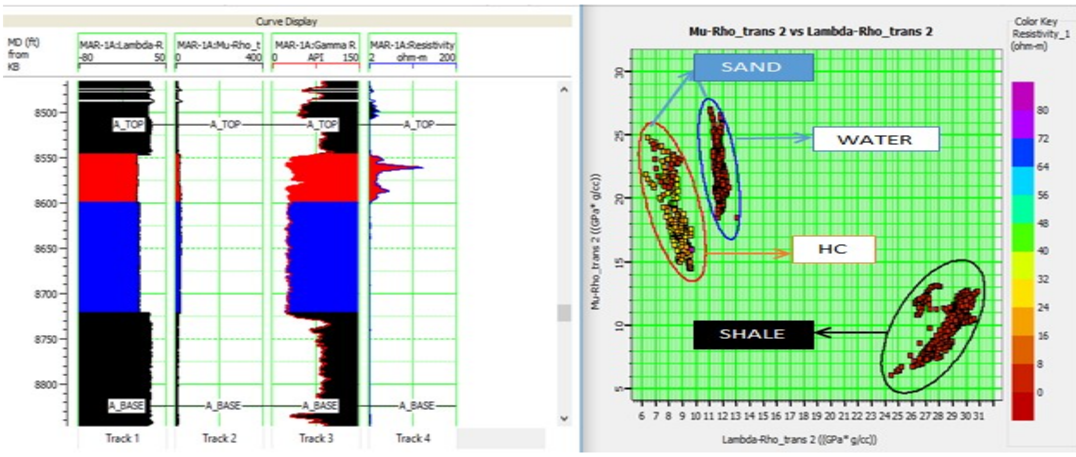

Fig. 2: Crossplot of Lambda-rho versus mu-rho in Sand A for lithology discrimination

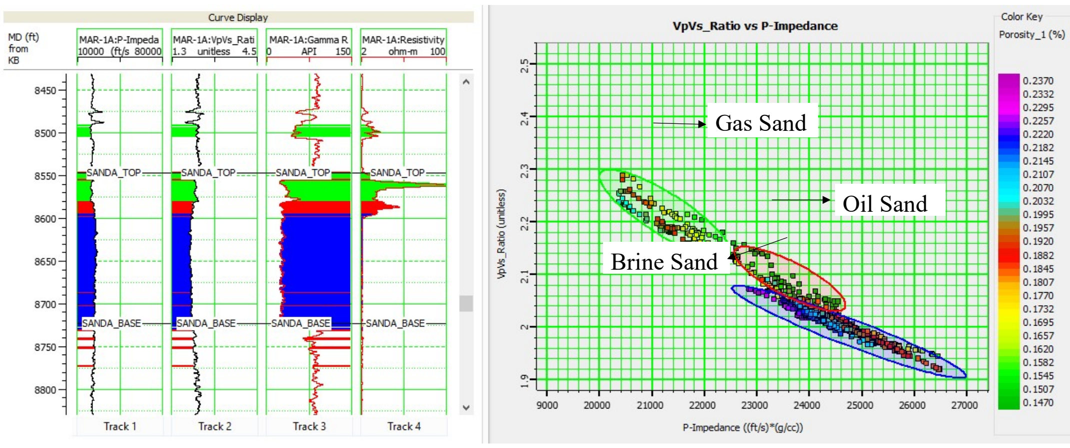

Fig. 3: Crossplot of Vp/Vs ratio versus P-impedance in Sand A for Fluid discrimination

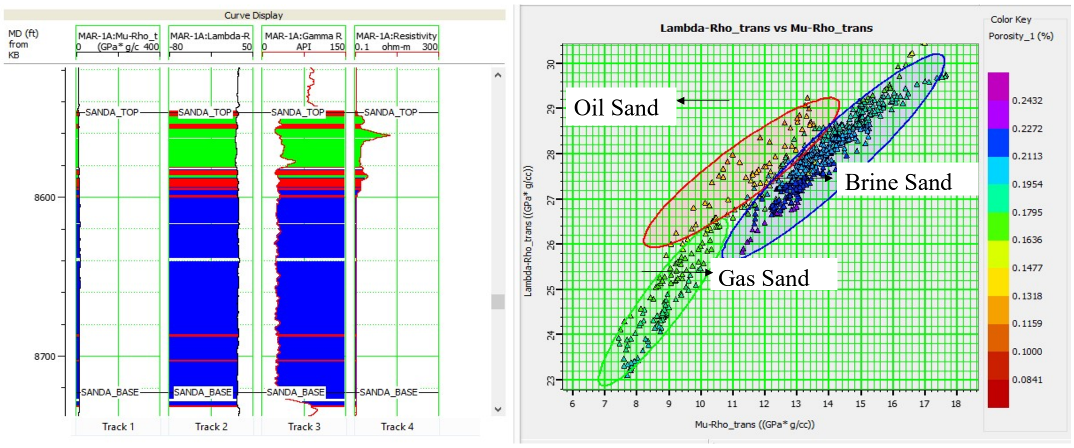

Fig. 4: Crossplot of Lambda-rho versus mu-rho in Sand A for Fluid discrimination

Results on AVO modelling and Crossplot analysis

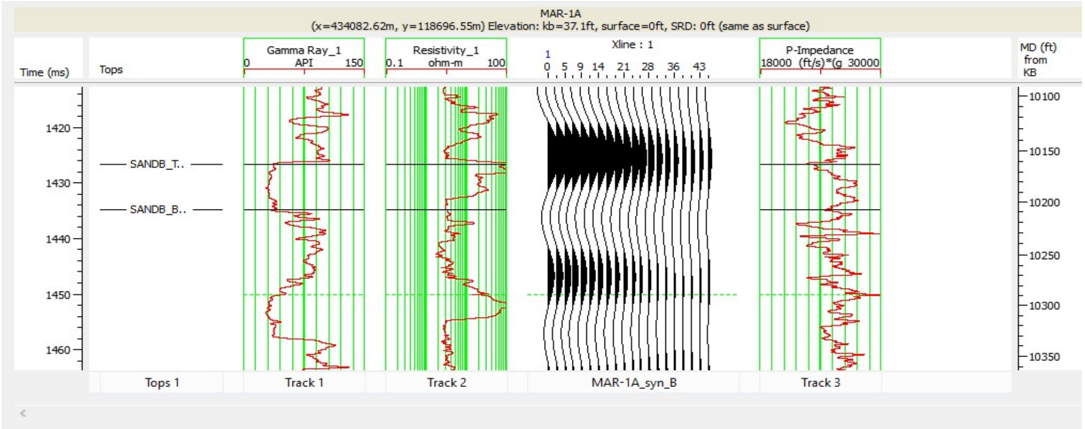

Fig. 5: Well logs and Synthetic gather at the top of Sand B reservoir

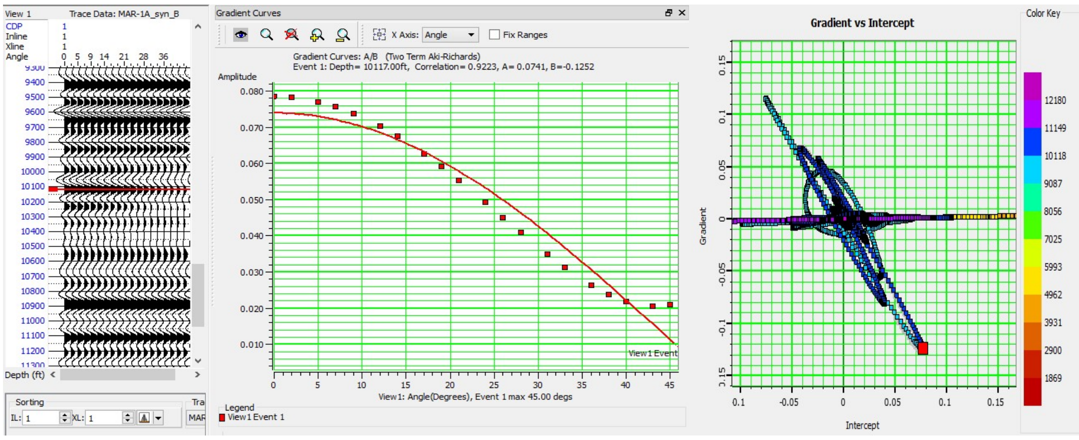

Fig. 6: a) Amplitude versus offset angle plot showing a typical Class 1 Gas sand curve for Sand B
b) AVO gradient versus intercept plot of Sand B top indicating Class 1 Gas Sand

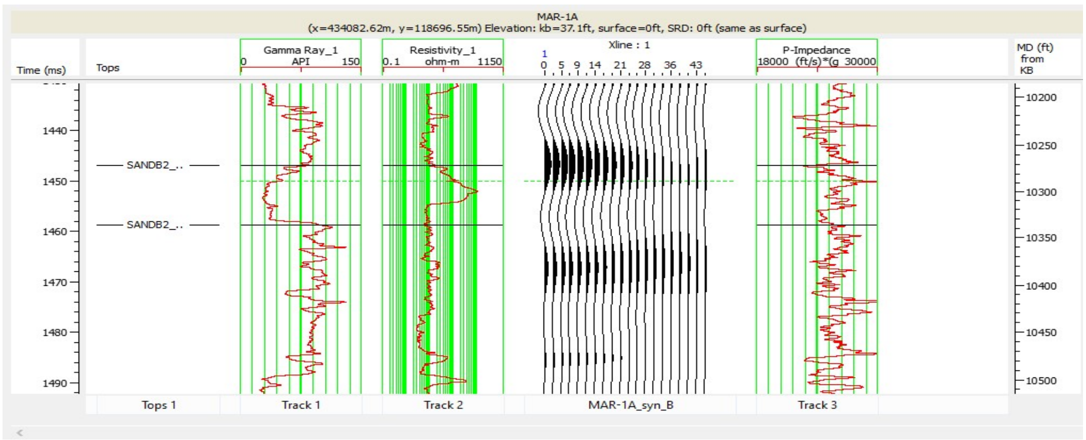

Fig. 7: Wells logs and Synthetic gather at the top of Sand B2 reservoir

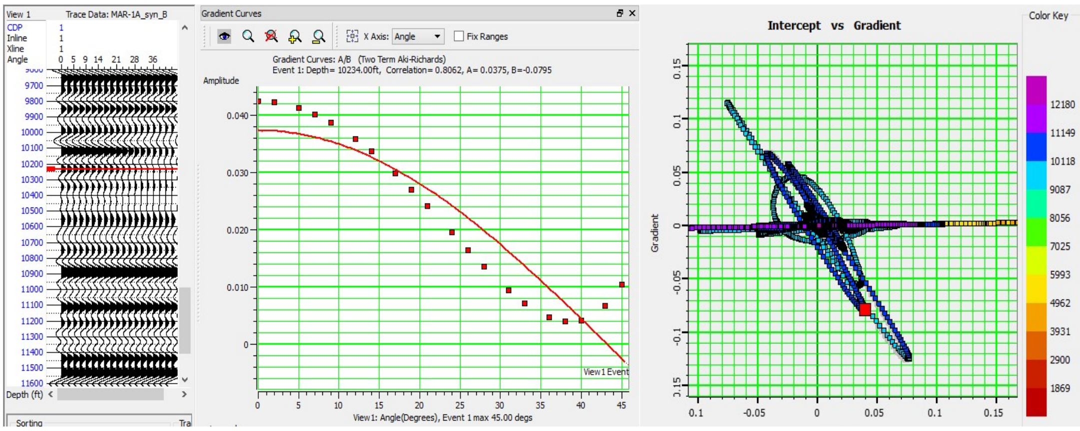

Fig. 8: a) Amplitude versus offset angle plot showing a typical Class II Gas sand curve for Sand B2 b) AVO gradient versus intercept plot of Sand B2 top indicating Class II Gas Sand

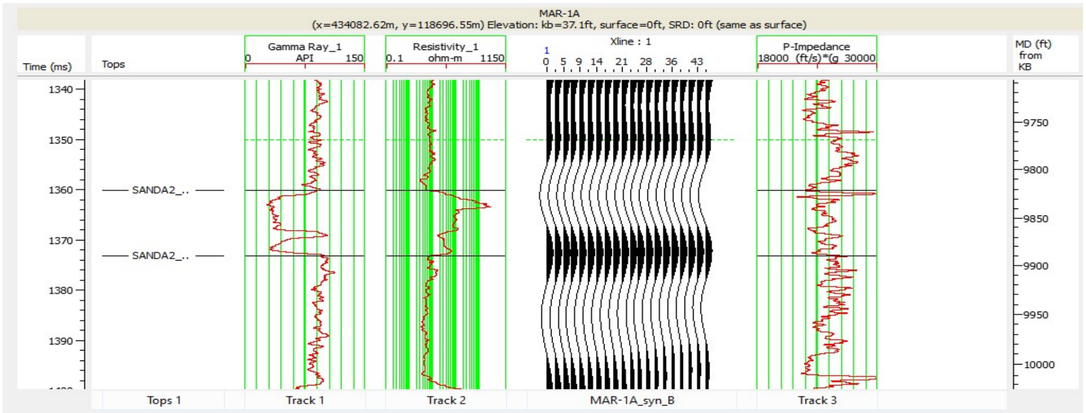

Fig. 9: Wells logs and Synthetic gather at the top of Sand A2 reservoir

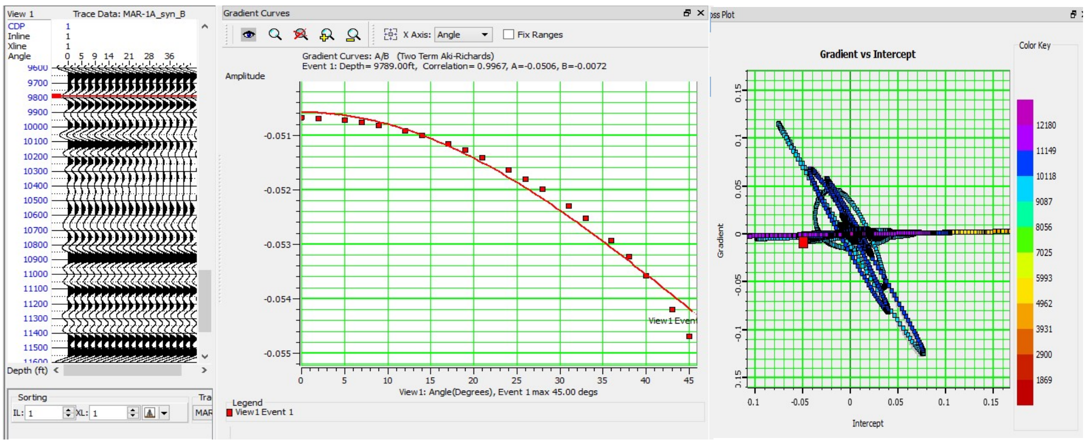

Fig.10: a) Amplitude versus offset angle plot showing a typical Class III Gas sand curve for Sand A2 b) AVO gradient versus intercept plot of Sand A2 top indicating Class III Gas Sand

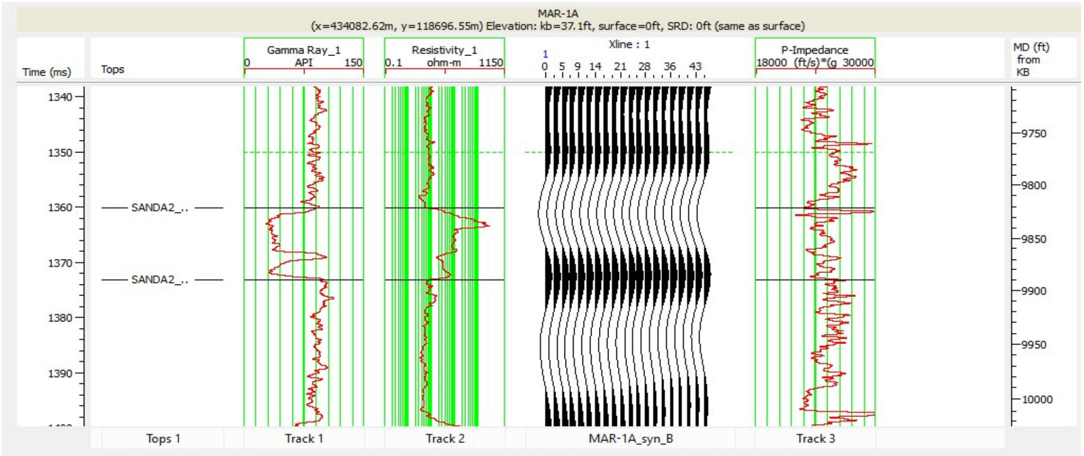

Fig. 11: Wells logs and Synthetic gather at the top of Sand A reservoir

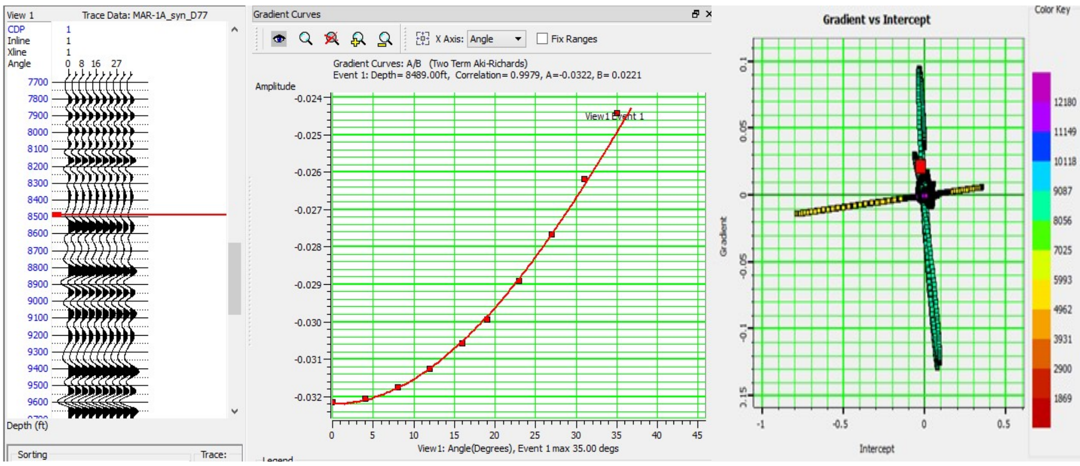

Fig. 12: a) Amplitude versus offset angle plot showing a typical Class IV Gas sand curve for Sand A b) AVO gradient versus intercept plot of Sand A top indicating Class IV Gas Sand

coefficients (amplitude) that become more negative with offset, described as bright spot DHI on full stack seismic reflectivity data (On structure Brightening), with a negative gradient, typical of a type III AVO gas sand. AVO attribute crossplot on fig. 10b validates the Sand A definition as a class III AVO Gas sand. This is typical of the geologic condition common were a very competent shale overlies an acoustically softer sand. According to Uko and Emudianughe (2014), class III gas sand is the most common in the Niger Delta Basin.

Sand B

Generated Synthetic gather and AVO modelling results for sand B in figs. 5 and 6a reveals a gas sand with a large positive zero offset reflection coefficient that reduces with offset typical of class I AVO gas sand. AVO attribute crossplot in fig. 6b also confirm that sand B is a class I Sand. This is a classical geologic condition common at depth where the overlying shall be very incompetent when compared with the underlying reservoir having a greater acoustic impedance value. Care must be taken when evaluating Class I gas sand for field with highly under compacted shales because at great depth, the geologic conditioned at an interface defined by an acoustically harder sand overlying a softer shale can be mistaken for a hydrocarbon bearing class I sand, since it gives similar response to the geological condition described earlier, typical of a class I AVO Gas Sand.

Sand B2

Sand B2 is the deepest reservoir of the four and occur at a depth of about 10270ft. Results of the generated synthetic gather in figs. 7 and 8a reveals a small positive zero offset reflectivity that becomes less positive with offset and could cross the zero origin with further increase in offset (polarity flip/reversal), defined by a negative gradient is typical of a Class II AVO Gas Sand. In the Castagna and Swan (1997) AVO attribute crossplot, modified after Rutherford and Williams 1987, there are two types of class II gas sand. The second is also known as a Class IIP AVO Gas Sand, defined as having a very small negative zero offset reflectivity that experience a reduction in absolute value with offset. AVO attribute crossplot in fig. 8b confirms Sand B as a class II gas Sand. A typical class II AVO gas sand are common at depth were the shales are slightly incompetent, and the acoustic impedance value of the overlying shale and the underlying reservoir are similar or slightly different. They are described as dimming/brightening effect on seismic data.

CONCLUSION

Rock physics cross plot analysis reveals that Vp/Vs versus Acoustic Impedance and Lambda-Mu-Rho techniques especially, gave very good results that conveniently discriminate lithology and fluid from well data even in the absence of acquired shear wave velocity log, indicating the dependability on Castagna equation for shear wave estimation. In the absence of neutron log, it has been demonstrated that results from rock physics crossplot can be used for fluid typing and hydrocarbon contact (Gas Oil Contact) definition. Hence seismic based quantitative interpretation for field characterization and prospectivity from inversion will give good results due to the observed cluster separations. The separations are as a result of variations in rock properties in response to lithology and fluid changes which could show up as DHIs on full stack seismic data. AVO modelling results reveals the presence of all four AVO class Gas Sands, with Class III and IV occurring at a relatively shallower depth than Class I and II. Hence, results from AVO study of field data are expected to give good results for prospect identification and evaluation in undrilled areas in the field.

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