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Reservoir Prediction and Prospectivity of Omos Field Onshore Niger Delta Basin, Nigeria

[1*]OGBAMIKHUMI, A; [2]EDEGBAI, AJ

Department of Geology. University of Benin, Benin City, Edo state, Nigeria

***** *Corresponding Author Email: alexander.ogbamikhumi@uniben.edu*
**ORCID: https://orcid.org/0000-0001-6022-7918*
**Tel: +2348032722203*

Co-Author Email: aitalokhai.edegbai@uniben.edu

ABSTRACT: Reservoir prediction and prospectivity are performance indices of the oil and gas field development planning and reserves estimation which depicts the behaviour of the reservoir in the future; its success is dependent on accurate description of the reservoir rock properties, fluid properties, rock-fluid properties and flow. Hence, the objective of this paper was to investigate and predict the reservoir and prospectivity of Omos Field, Onshore Niger Delta Basin, by integrating appropriate standard methods. Results obtained from rock physics attribute map analysis revealed very high Mu-Rho values between 13.0-16.2 Gpa, that is expected for sand presence, and this agrees with the good quality reservoir sands predicted from sequence stratigraphy study.Lambda-Rho values obtained ranges between - 1 to 9.5 GPa, with a much lower value between -1 to 4.3 in the prospective zone that indicates the presence of hydrocarbon bearing sand. These results agree with the results of structural and amplitude maps analysis. Hence the prospective reservoir has a very good hydrocarbon potential in this zone and should be a target for further appraisal for development and production purposes

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Reservoir facies prediction is paramount for conceptual modeling as it also serves as a key element required for a robust static modeling. One of the most reliable techniques commonly adopted to predict reservoir facies continuity is the application of sequence stratigraphy concepts. Such predictions are necessary especially in the prospective undrilled area of hydrocarbon fields with a good potential of hydrocarbon presence, to predict the possibility of having good quality sands. Several authors have defined and explained the application of this concept (Van Wagoner, *et al.*, 1990; Vail, *et al.*, 1991; Mitchum, *et al* 1997; Emery and Myers, 2009). According to Catenuanu, *et al.*, (2009), sequence stratigraphy study is distinctively focused on analyzing changes in geologic facies, geometric and ultimately reservoir properties characteristics of strata and predicting these changes across field. Slatt (2006) showed that at the reservoir development scale, the application of this technique will result in fine scaled correlation and predictions of various stratigraphic facies that are genetically related. The genetic characteristics can constitute either distinct or a combination of the following rock characteristics; fossil content (biofacies), lithology (lithofacies), seismic character (seismic facies) or electric log signature, electro-facies (Allen and Allen, 2013). Another technique recently being adopted for reservoir presence prediction in undrilled area of a field is the application of rock physics attributes

***Corresponding Author Email:** *alexander.ogbamikhumi@uniben.edu*
**ORCID: https://orcid.org/0000-0001-6022-7918*
**Tel: +2348032722203*

derived from both wells and seismic inversion. The inversion process removes the effect of wavelet on seismic data and present rock properties that can be interpreted as stratigraphy facies or fluid change. Such interpretation is commonly done for field evaluation and its accuracy is based on our familiarity with the geology of the study area and the seismic reflections correlation or similarity with well-log Data. Avseth *et al.*, (2016) demonstrated the importance of integrating rock physics techniques with a very good understanding of geological and sequence stratigraphy control of facies variation across field during field evaluation. This is partly due to the fact that the accuracy in the application of the sequence stratigraphy concept to predict reservoir facies changes and build conceptual models is dependent on the available data and subjective to the geo modeler's experience. Hence such models are accompanied by some uncertainties and errors. To reduce such uncertainties, this study integrates both sequence stratigraphy concept and rock physics analysis to evaluate and predict the presence of good quality reservoir facie across field to the prospective undrilled area of the OMOS field of the Niger Delta Basin, and also to evaluate the possibility of having hydrocarbon presence in this prospective area of the field. The field is structurally bounded by a major synthetic fault at the north and at the south eastern part by a minor synthetic fault, with an intra-reservoir fault in between both bounding faults. The exploited region of the field with well penetration is a simple anticline where production is currently ongoing. The prospective undrilled area defined by a rollover anticline trapped on the southern bounding fault. A major producing reservoirs in the field; D2 reservoir level, was selected for this study to evaluate the possible hydrocarbon potential in the undrilled area by predicting the reservoir and possible hydrocarbon presence for further appraisal as a development opportunity for future production. Therefore, the objective of this paper was to investigate the reservoir prediction and prospectivity of Omos Field Onshore Niger Delta Basin, Nigeria.

MATERIALS AND METHODS

A field wide full stack 3D reflectivity seismic data with dimension approximately 226sqkm was available for the study. Eight wells were also available; three of them have biostratigraphy data and four has checkshot data. Well 25 has only Foraminifera data, well 2 has only palynological data while Well 60 has both foraminifera and palynological data. The spread of the wells with biostratigraphy data were good enough to build a workable sequence stratigraphic framework and correlation of our defined reservoir across field. Only six of the eight wells possessed the required acoustic logs and checkshot data for well to seismic match and the inversion process; wells 1, 6, 34, 61, 42 and 53. The basic well logs required was at least available in all six wells; Caliper, Gamma ray, Resistivity, Density and velocity logs. The logs were initially processed and conditioned for spurious readings and passsed ok for the objective of the project. However further quality check were conducted to quality check the logs and improve upon the quality. These include; median filtering, Depth Matching and De-spiking.

Sequence Stratigraphic Analysis and conceptual Modeling: Biostratigraphy analysis using biostratigraphy data and log motif were carried out in wells with the required data to identify and define regional markers (Maximum Flooding Surfaces (MFS) and Sequence boundary (SB)) and ultimately, to develop a sequence stratigraphic framework for the Omos Field. These markers were correlated between wells with biostratigraphy data and away to wells with no biostratigraphy information.

These biostratigraphy information included P- and F-zones, foraminifera abundances and diversity, last occurrence depths of marker fossils, amongst others, which were key to identifying the likely positions of Maximum Flooding Surfaces (MFS) and corresponding Sequence Boundaries (SB) to define our stratigraphic framework. While SBs were identified using information about scantiness of fossil and lithology types, maximum flooding surfaces were picked in shales with high diversity and abundance of fossils, and dated in correlation with the Niger Delta chronostratigraphic chart. Similarities in log motifs, neutron density separation and thickness of shales were used to correlate the MFSs across wells with no biostratigraphy data.

In the absence of core data, log motif models proposed by Cant (1992) were adopted to define our reservoir facies from well logs. Selley, (2000) described the interpretation of depositional facies based on these well-log curves, and gave credence to the technique in un-cored sections, where there have been calibrations of log patterns to well-understood depositional facies successions in outcrop and or cores.

The identified prospective reservoirs were correlated across the field using the already defined regional markers as control. An important check was to ensure that the reservoir tops and bottoms correlation didn't criss-cross different timelines. The position of the wells relative to structure considering the effect of faults between wells during correlation was also noted on time slice from semblance volume attributes.

Seismic inversion and Rock Physics Analysis: Seismic inversion is a process of extracting from seismic, the underlying geology that gave rise to the seismic. It attempts to estimate the earth rock properties of geological subsurface model that utilizes seismic data as input and well data as a control by removing the effect of seismic wavelet (Lines and Levin, 1990; Sukmono, 2002). It is an inverse modeling process that undo the effect of the forward modeling acquisition process. In this study, model based inversion technique was employed since it requires a lot of input data to serve as constrain for the result to represent the subsurface geology as much as possible thereby reducing the associated uncertainties. The major input data include but are not restricted to; a 3D full stack seismic data, a deterministic wavelet, interpreted surfaces of the desired interval, low frequency model from acoustic logs etc. A deterministic wavelet was extracted using wells and the seismic data within the time interval of interest. It is important to state here that the frequency was band limited. Hence, one of the advantages of the model based inversion is that the very low frequency end can be compensated for by low frequency model built from well log data. Model based inversion analysis was carried out by converting the trace closest to the selected wells and inverts them to their corresponding Acoustic impedance log and compared with the well derived Acoustic Impedance logs. The error recorded for well 1 and 61 were high (Fig. 5b), hence they were excluded from the inversion process proper. Rock physics analysis was conducted both on wells and seismic to evaluate the inversion results for the reservoir of interest. Rock physics is the bridge that relates inversion derived elastic rock properties to litho-types and reservoir properties such as porosity, shale volume and water saturation (Chi and Han 2009; Kumar et al. 2016; Alvarez et al. 2017). Rock properties such as the Lame parameters; incompressibility (λ), rigidity (μ), and density ($\boldsymbol{\rho}$), can enhance the ability to point out reservoir zones (Sohail and Hawkes 2020). Goodway *et al.,* (1997) demonstrated that the Lamé parameter terms λ and $\mu\boldsymbol{\rho}$ to be good pore fluid and lithology indicators respectively. For clastic rocks. Li (2004) shows that $\lambda\boldsymbol{\rho}$ reduces with an increasing porosity, increasing gas content and a decreasing shale content.

RESULTS AND DISCUSSIONS

Prospect Identification: Prospect identification involves observations made to detect seismic response that can be related to hydrocarbon presence. In this case, structural maps and amplitude maps of the three reservoir levels were analyzed to identify potential prospect in both the exploited and undrilled areas of the field. Hydrocarbon reservoir is considered to be a potential prospect if they are trapped within structural traps such as fault blocks or stratigraphic traps (Ogbamikhumi *et al.,* 2017a). The D2 reservoir structural map in figure 4 have six interpreted faults; one major fault to the north and five intra reservoir faults which is typical of the structural configuration of the field. From the legend, the structural map indicated that the exploited zone is a structural high, where hydrocarbon has accumulated due to buoyancy effect. It is bounded at the north by the major synthetic faults and by several intra reservoir faults at the south. At the prospective zone also, the legend shows that the zone is a structural high bounded by one of the intra reservoir faults. Reservoirs in the field at this zone might be a good prospect as it is bounded by fault blocks that can serve as hydrocarbon trap. The traps defined in the field are anticlinal which may or may not be fault supported. Amplitude maps are perceived as a direct hydrocarbon indicator on which hydrocarbon response can be identified (Das and Chatterjee, 2016). The Root Mean Square (RMS) Amplitude extracted on structural maps points out with some level of certainty hydrocarbon prospect as long as the amplitude response conforms to structure. The amplitude expression of the D2 reservoir at the exploited zone reveals bright amplitude confirmed as hydrocarbon expression, similar to espression at the potential prospective zone, which could also indicate hydrocarbon presence (figure 1). Hence, evaluation of this prospective region to predict presence of good quality reservoir and confirm hydrocarbon presence was subsequently conducted.

Sequence Stratigraphy Analysis and Reservoir Correlation: The Sequence stratigraphy concept aided in defining stratigraphic framework for the correlation of facies changes across fields. The established correlated regional markers act as constraint that helps restrict the correlation of defined reservoir tops. The framework is paramount for the correlation of our prospective reservoir across field within the exploited zone, and also for the prediction of the presence of potential good quality facies sand within the prospective zone. The available biostratigraphy data in wells 25, 60 and 2 were utilized to build the stratigraphic framework for the field. Data for fauna and flora diversity and population were used to define P-zones, F-zones and depositional environments. The P-zone defined includes P650 and P670 while the defined F-zones were F9300 and F9500. Both the P and F-zones were integrated with the Niger delta Chronostratigraphic chart to define the following key regional markers; Maximum Flooding Surfaces

(MFS) 15.0, 15.9, 17.4, 19.4 and 20.7 and Sequence Boundaries (SB) 15.5, 16.7, 17.7 and 20.4. (Figure 2). Correlation of the developed stratigraphic framework, reservoir tops and facies changes ran from the north western part of the field to the eastern region as shown in the correlation map at the bottom right corner of the figures. The correlation of our reservoirs of interest is presented in figure 3, using the correlated stratigraphic framework as constrain. Correlation of the prospective D2 reservoir was constrained within MFS 15.9 ma and SB 16. The defined regional markers were integrated with the Niger delta Chronostratigraphic chart to define the age of the field as Early to Middle Miocene and the location of the field to be in the Central Swamp Depo-Belt of the Niger Delta Basin.

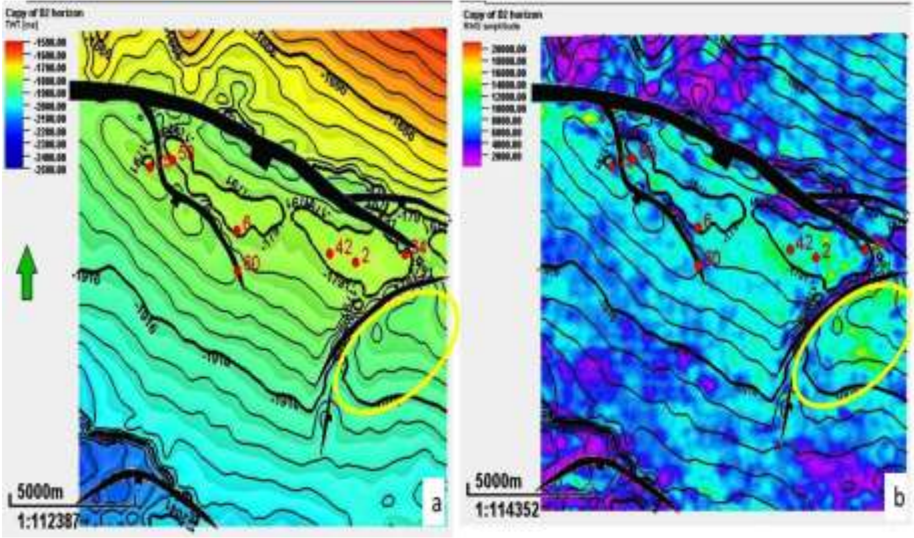

Fig 1: (a) Structural map of top of D2, (b) Amplitude map of D2 reservoir overlaid on top of its structural map for prospect identification

Facies Definition and Conceptual Modeling of the Prospective D2 Reservoir: Correlation of facies types across field gives an excellent idea of the reservoir quality and the potential geometry. Facies analysis for the prospective D2 reservoir was performed using Cant *et al.,* (1987) log motif signature. Five facies type were defined; Shale, Lower Shore face, Upper Shore face, Channel sands and Channel heterolith (figure 4). The reservoir is of good quality at the western part of the field as it is predominantly made up of channels and shoreface sand. This quality reduces towards the eastern part of the field due to an increase in channel heterolith. To understand the nature of the reservoir in the prospective area, this information was projected across field with the knowledge of the interaction of various depositional processes, and the application of Walthers's law of facies succession (Middleton, 1973**)** (figure5). The prospective zone was observed to also have a good quality reservoir, dominated by channel and upper shore face sand. Hence, alongside the presence of structural trap, the zone has good potential for hydrocarbon accumulation.

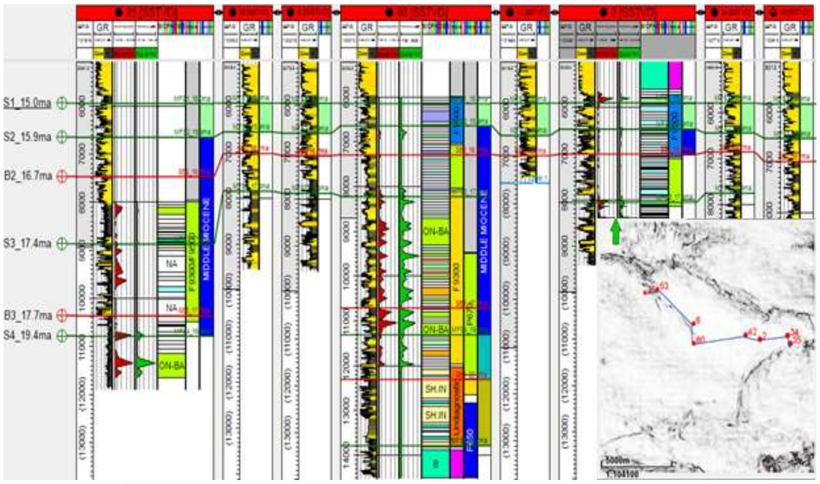

Fig 2: Definition and correlation of regional markers using biostratigraphy data and age determination for the field using the Niger Delta Chronostratigraphic Chart

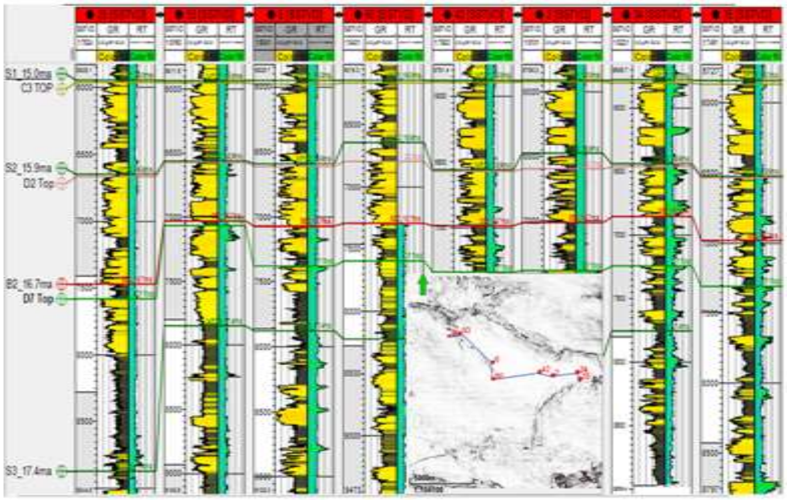

Fig 3: Definition and field wide correlation of reservoirs of interest using the correlated regional markers.

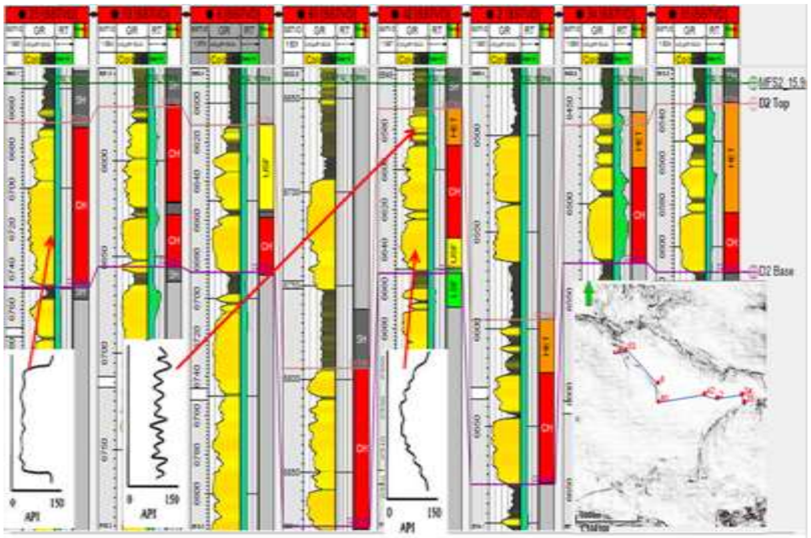

Fig 4: Facies Definition and field correlation of D2 reservoir facies for conceptual modeling using log motive signature of Cant 1987

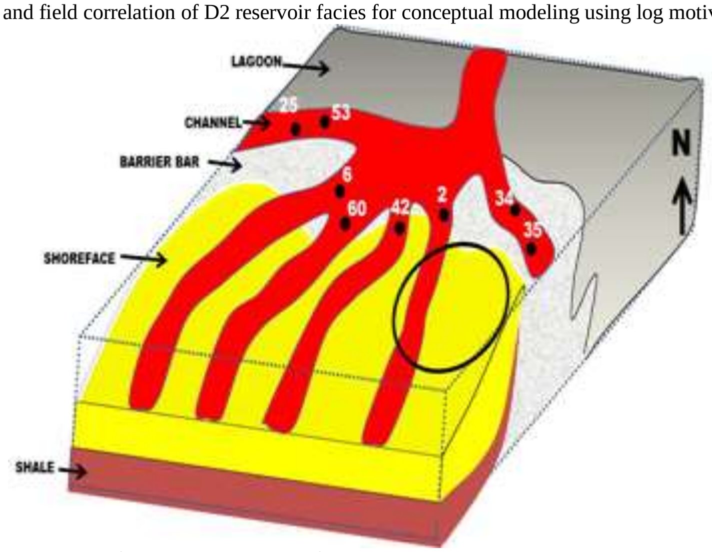

Fig 5: Conceptual depositional model of the prospective area of the D2 reservoir showing a predicted channelized shoreface depositional environment (Black Ellipse)

Rock Physics Attribute Analysis for D2 prospect: Rock physics analysis was conducted to integrate its results with sand prediction presented in the conceptual model at the prospective area of the field, and to confirm the possible hydrocarbon expression suggested by the amplitude map at the prospective undrilled area. Goodway *et al.,* (1997) have established that the Lamé parameter terms λρ and μρ serves as good pore fluid and lithology presence indicators respectively. λρ reduces with a change of lithology from shale to sand. A greater reduction is expected when oil and or gas content are increased within a reservoir (Ogbamikhumi *et al.,* 2018; Khaden et al., 2020;). Sand has a greater μρ values than shales since sand matrix exerts greater resistance to shearing than shale matrix. Shale matrix behaviour is not affected by the nature of fluid in the pore spaces, hence the value for brine and hydrocarbon fill sand are expected to remain relatively constant. Lambda-Rho on the other hand is a P-wave derived parameter, since fluid contributes to the total resistance exerted by a rock to compression, a change in fluid type will determine the incompressibility of a rock (Ogbamikhumi and Igbinigie, 2020; Khoshdel et al., 2022; Plemo-daniels et al., 2024). A systematic change in fluid type from brine to oil then to gas will lead to significant gradual reduction in the incompressibility of a rock (Azeem *et al.* 2017; Ogbamikhumi *et al.* 2017b; Guo et al., 2021).

Well based Rock attribute analysis for reservoir facies and hydrocarbon indication: In an attempt to further evaluate the D2 reservoir, rock attributes where cross plotted to discriminate the reservoir into the respective facies types as defined by the conceptual model (Figure 6&7). To achieve this, both Lambda-Rho and Mu-Rho were cross plotted against each other and against Gamma ray log in two wells. This is to show if these rock attributes can be applied to conveniently discriminate reservoir lithology into various facies types, which could suggest its application on seismic for the same purpose (Ogbamikhumi and Omorogieva, 2021, Waqas et al., 2023). In the first well (Figure 11), where three facies were initially defined (shale, channel heterolith and channel sands), three zones were delineated, with the black zone interval having very high Lambda-rho and Gamma ray values, indicative of shale. A second zone is defined by a moderately low value for Lambda-Rho and low values for Gamma ray, define as channel sands. A hydrocarbon bearing third zone is defined as channel heterolith has the lowest value for both parameters (Figure 11c and d). A clear definition between the shale facies with channel heterolith and channel sand facies was obvious. Although cluster separation was evident between the channel heterolith and channel facies, we can confidently conclude here that the very low value of lambda rho was as a result of hydrocarbon presence only within the heterolith depth interval as indicated by the Resistivity log. Hence, it will be difficult to discriminate between channel heterolith and channel sands facies on seismic in the field. But the reservoirs facies can easily be discriminated from the non-reservoir shale facies.

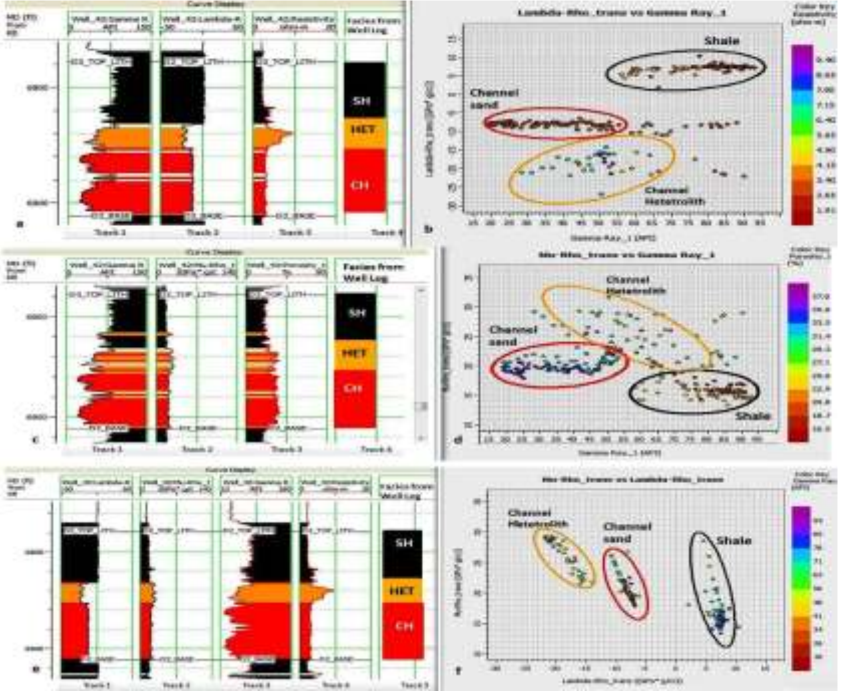

Fig.6 Plot of Lambda-Rho versus Gamma ray(a&b), Mu-Rho versus Gamma ray(c&d) and Mu-Rho versus Lambda-Rho(e&f) for D2 reservoir facies discrimination in well 42

The cross plot of Mu-Rho against Gamma ray (Figure6 c and d) also gave a clear separation of these three facies types with the shale interval having the lowest Mu-Rho values. Comparing the cluster behavior of channel heterolith and channel sands facies, the separation in this case is clearly not fluid related but matrix related. Since S-wave derived Mu-rho values is not affected by fluid difference, the high shale volume in the channel heterolith resulted generally in higher gamma ray and Mu-rho values. Hence, this template can be adopted to discriminate the three facies on seismic. The cross plot of Lamda-Rho Vs Mu-Rho in In figures 6e and f, defines three clearly defined cluster zones. It is observed that when both rock properties are plotted together compared to using them separately as presented by the two previous plots, both fluid and lithology facies cluster separation and discrimination are more apparent. Hence can be relied upon to discriminate both fluid and litho-facies on seismic. The cross plot in the second well (figure7) attempts the discrimination of shale, channel and shoreface sands. The cross-plots successfully discriminated all three facies, especially the reservoir from the non-reservoir facies. The clusters analysis of the cross plots in both figures 6 and 7 revealed Lamda-Rho as a better reservoir fluid discriminant than Mu-rho, but Mu-rho attribute appear to be the better attribute to discriminate litho-facies. In conclusion, a combination of both rock attributes present better discrimination of both litho-facies and reservoir fluids. Hence the earlier observed amplitude expression on seismic can be further evaluated using both rock properties. As such, Maps of both rock attribute were generated from the inversion result to predict the presence of a good quality sand for hydrocarbon prospectivity in the undrilled area of the reservoir.

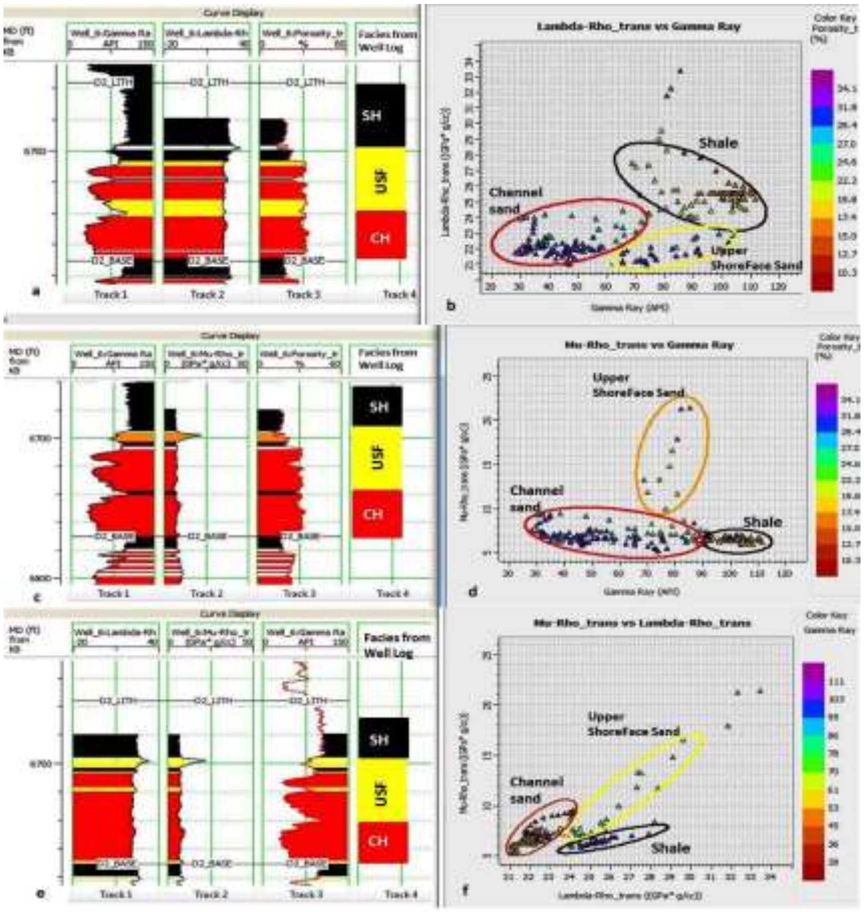

Fig. 7: Plot of Lambda-Rho versus Gamma ray (a&b), Mu-Rho versus Gamma ray(c&d) and Mu-Rho versus Lambda-Rho(e&f) for D2 reservoir facies discrimination in well 6

Seismic Attributes maps: The Mu-rho map was generated to determine the presence of reservoir response in the prospective zone and compared with the prediction of the conceptual model, to confirm and appreciate the area extent of the sand. The Mu-Rho map generated for the prospective reservoir is presented in figure 8. As seen in the legend, the prospective zone (in black ellipse) has Mu-Rho value between 13.0-16.2 Gpa, indicative of very high value expected for a reservoir facies response. This response confirms the presence of good quality sands as earlier indicated by the prediction from conceptual facies model. Map for lambda-Rho extracted from the model based inversion result is presented in figure 8. For sands, Lambda-Rho is expected to generally have low values. But For hydrocarbon bearing reservoirs, the value is expected to be much lower. Lambda-Rho values observed on the map ranges between -1 to 9.5 GPa. But within the prospective zone a much lower response with value between -1 to 4.3 exists, defining the presence of hydrocarbon within the sand. One of the evidences confirming that the low response is indicative of hydrocarbon is the fact that the response lies within the structurally highest region of the anticlinal structure as indicated by the structural map and this agree strongly with the amplitude map earlier presented.

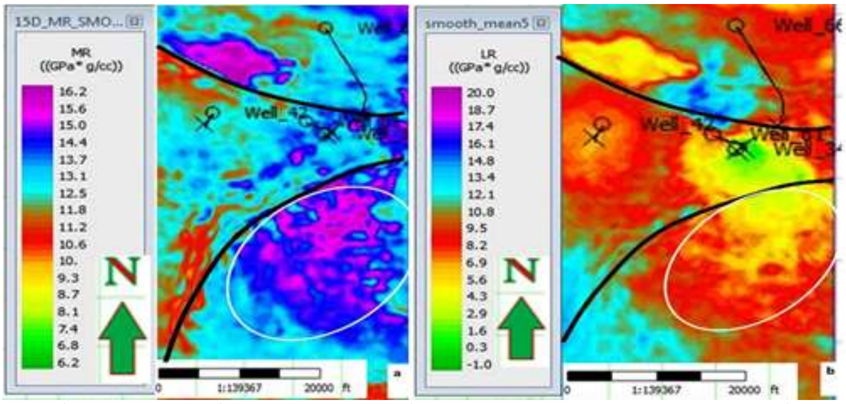

Fig 8: (a) Mu-Rho map of D2 reservoir confirming the presence of good quality sand, (b) Lambda-Rho map of D2 reservoir showing the possible extent of hydrocarbon accumulation.

Conclusion: The study attempts to predict the presence of hydrocarbon bearing reservoir in parts of the OMOS field, by integrating sequence stratigraphy techniques with seismic data. Results from sequence stratigraphy analysis and conceptual facies deposition modeling revealed the presence of channelized surface sand within the prospective region of the field. The Analyzed rock attribute maps clearly confirmed that the expression earlier identified on amplitude maps is an indication of the presence of a good quality hydrocarbon sands at this prospective zone.

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