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AVO FLUID INVERSION (AFI) TECHNIQUE AS A TOOL TO PREDICT RESERVOIR FLUID CONTENT USING DATA FROM FD FIELD, ONSHORE NIGER DELTA NIGERIA.

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Abstract

The AVO Fluid Inversion (AFI) procedure is used to calculate reservoir fluid probability and it helps to reduce the uncertainty in conventional AVO techniques. By the use of Shuey's AVO gradient and intercept theory, Monte-Carlo simulation, Biot-Gassmann fluid substitution, and Bayesian estimation fluid probability maps was built. Burial depth of interest is between 800m to 2300m. The result from AFI shows that areas penetrated by the wells have gas and oil probability greater than 0.4. The results gave a measured level of confidence that can guide any oil and gas investor to evaluate their chance of drilling success.

Keyword: AVO, Fluid Inversion, Stochastic model, Probability, FD field, Niger Delta.

1.INTRODUCTION

Amplitude versus offset (AVO) analysis has become a fundamental and familiar tool for both exploration and production (Qu & Bian., 2012). In consideration to this, it has come a long way from the early days when the reputation of the method oscillated wildly between excessive expectations and total rejection. AVO was introduced as a methodology to provide additional information so as to more accurately predict the rock and fluid properties of the earth (Gao et al., 2006). In geophysics, Amplitude variation with offset (AVO) is the general term for referring to the dependency of the seismic attribute or amplitude with the offset (Smith & Sutherland., 1996). The method that geophysicists use to evaluate seismic data in other to determine its rock's fluid content such as porosity, density or seismic velocity, shear wave information and fluid indicators is call AVO analysis (Rutherford & Williams., 1989). AVO is primarily based on the relationship among the reflection coefficient and the angle of incidence and has been understood for that reason since the early 19th century when Zoeppritz Karl came up with the zoeppritz equations in 1919. According to Xu and Bancroft, (1997), AVO is just one method in a whole range of methods providing a small but important addition to our knowledge of the prospect or reservoir. Although, predictions from AVO are probability statements and have a lot of uncertainties, inversion from AVO models can reduce the uncertainty and provide the basis for the decision-making in the oil exploration and development (Cardamone & Corrao., 1999).

AVO fluid inversion technology have been widely used nowadays to estimates the fluid uncertainties from AVO predictions (Aigbedion & Okogbue., 2017). AVO Fluid Inversion (AFI) uses AVO gradient and intercept theory, Monte-Carlo simulation, Biot-Gassmann fluid substitution, and Bayesian estimation to build fluid probability maps where these maps can be used to make a quantitative analysis for best probable exploration success (Qu & Bian., 2012). The establishment of the conventional AVO model is more complicated. The Monte-Carlo stochastic forward model shown in Figure 1 is used to characterize mudstones (Castagna., 1995).

The Monte-Carlo stochastic model explains that, if the distribution for V_p, known as the P-wave velocity of a shale body have a very large scatter, then the resulting models will have a correspondingly large range of shale velocities (Dan et al., 2004). According to Hampson and Russell., (1990), this distribution law for Sandstone are characterized by brine modulus, brine density, gas modulus, gas density, oil modulus, oil density, matrix modulus, matrix density, modulus of dry rock, permeability, porosity, modulus of shale, water saturation and thickness while the distribution law for Shale is characterized by Vp, Vs and density. Most of this parameter can be measured by logging curve and a range of variation (Dan et al., 2004).

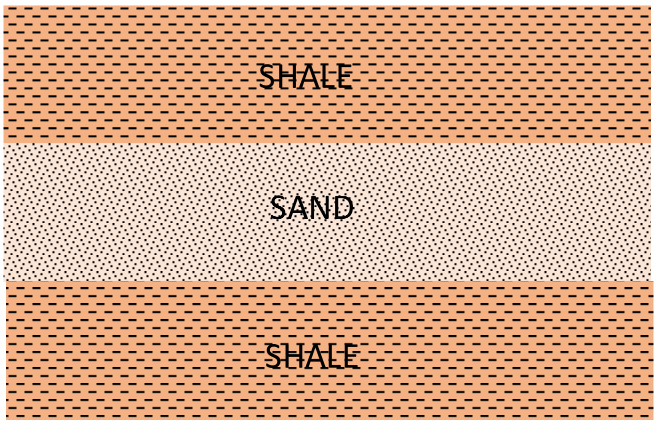


Figure 1: Monte-Carlo Stochastic forward model

The AVO intercept and gradient process is applied to obtain a detailed analysis at a well location (Ross., 2000). The basis of AVO theory is that when the angle of incidence is zero, only reflection longitudinal waves are transmitted but when the incident angle is not zero then, reflected longitudinal waves and transverse waves are transmitted (Ostrander., 1984). The relationship between the amplitude and the incident angle is given in Zoeppritz equation expressed below.

$$\begin{bmatrix} R_p \\ Rs \\ T_p \\ T_s \end{bmatrix} = \begin{bmatrix} -\sin\theta_1 & -\cos\phi_2 & \sin\theta_2 & \cos\phi_2 \\ \cos\theta_1 & -\sin\phi_1 & \cos\theta_2 & -\sin\phi_2 \\ \sin 2\theta_1 & \frac{Vp_1}{Vs_1}\cos 2\phi_1 & \frac{\rho_2 V^2 S_2 Vp_2}{\rho_1 V^2 S Vp_2}\cos 2\phi_1 & \frac{\rho_2 V S_2 Vp_1}{\rho_2 V^2 S_1}\cos 2\phi_2 \\ T -\cos 2\theta_1 & \frac{Vs_1}{Vp_1}\sin 2\phi_1 & \frac{\rho_2 Vp_2}{\rho_1 Vp_1}\cos 2\theta_2 & -\frac{\rho_2 VS_2}{\rho_1 VP_1} Sin2\phi_2 \end{bmatrix}^{-1} \begin{bmatrix} Sin\theta_1 \\ Cos\theta_1 \\ Sin2\phi_1 \\ Cos2\phi_1 \end{bmatrix}$$

(1)

Equation 1 is the equation for the reflection and transmission coefficients as a function of incident angle and the media elastic properties. (after Aki and Richards, 1980).

The four unknown values R_P, R_S, T_P and T_S are the reflected p-wave, reflected s-wave, transmitted p-wave and transmitted s-wave amplitudes. V_{P1}, V_{S1} and ρ_1 represents the p-wave velocity, s-wave velocity and density for medium 1. While V_{P2}, V_{S2} and ρ_2 represents the p-wave velocity, s-wave velocity and density for medium 2. The angles $\theta_1, \theta_2, \phi_1$ and ϕ_2 represents the incident p-wave angle, transmitted p-wave angle, reflected s-wave angle and transmitted s-wave angle respectively. However, knowing only how the amplitudes change with offset is not sufficient to uniquely solve these equations.

But under certain assumptions and physical parameters, Shuey (1985) simplified the equation to:

$$R_{pp}(\theta_1) \approx A + BSin^2\theta_1 \qquad (2)$$

where Θ_1 = incidence angle (°), $A =$ AVO gradient and B is the AVO slope or "gradient."

But when the sandstone contains different fluids, the obtained AVO intercept and gradient is also different, which can be determined according to the fluid replacement theory of the AVO model Intercept and gradient (Castagna & Swan., 1997; McGregor., 2007).

Another AVO Fluid Inversion (AFI) model for probability mapping is the Fluid replacement modeling based on the Biot-Gassmann's equations given as

$$K_{sat} = K_{dry} + \beta_m^2$$

This model assumes the following conditions:

- The shear wave modulus is not affected by the pore flow Influence of the volume.
- The pore shape of the reservoir is spherical.
- The velocity does not vary with frequency changes.
- There is a differential movement between the rock skeleton and the fluid.

The use of Biot-Gassman fluid replacement model is basically to obtain models separately which corresponds to oil-bearing sandstone, gas-bearing sandstone and water-bearing sandstone. The process is repeated many times, that is, obtaining intercept-gradient intersection of multiple points (Clusters).

Finally, with these clusters, the uncertainties in AVO can be obtained numerically using standard statistical algorithm, known as Bayes Theorem (Cardamone & Corrao., 1999). This Bayes theorem tells us that some new point that is not on the clusters may belongs to each of the fluid types (Brine, oil or gas). According to Bayes Theorem, the mutually exclusive finite number (n) of an events $A_1, A_2, A_3, \ldots A_n$, is exactly 1. The probability of each occurrence of each A_i is called the prior probability. The mathematical expression of the prior probability is $P(A_1), P(A_2), \ldots, P(A_n)$, The mathematical expression of the posterior probability is $P(A_1|B), P(A_2|B), \ldots, P(A_n|B)$. Assumptions, $A_1, A_2, \ldots A_n$ are mutually exclusive and $A_1 + A_2 + \ldots + A_n = U$, then, the total probability formula will be:

$$P(B) = \sum_{i=1}^{n} P(B|A_i)P(A_i)$$

(4)

By the probability multiplication theorem, $P(A_i|B)P(B) = P(B|A_i)P(A_i)$, therefore, the posterior probability is:

$$\mathrm{P}\ (A_i \mid \mathrm{B}) = \frac{P\ (B \mid A_i)\ P\ (A_i)}{\mathrm{P}\ (\mathrm{B})} = \frac{P\ (B \mid A_i)\ P\ (A_i)}{\sum_{i=1}^{n} P\ (B \mid A_i)\ P\ (A_i)}$$

(5)

By using the Bayes' posterior probability formula to calculate for the intercept-gradient intersection graph, the possibility that any of the above points belong to oil, gas, and water will be as follows:

$$P(\mathrm{F}\ |\mathrm{I,G}) = \frac{P\ (I, G \mid F)\ P\ (F)}{\sum_K P\ (I, G \mid F_K)\ P\ (F_K)}$$

(6)

where P (F|I, G) is the point on the intercept-gradient intersection graph belonging to a certain types of fluids; P (I, G|F) is a fluid intercepted by the distance-gradient graph; P (F) is the fluid Possibility; P (I, G|F_k) is the score calculated from the random simulation output; P (F_k) is the Possibility of a phase in oil, gas and water; F is Samples of real seismic data on the intercept-gradient graph; k is a phase in oil, gas and water; F_k is a fluid obtained from the model sample points on the intercept-gradient graph

2. THE STUDY AREA

The study area is FD field located with the Niger Delta of Nigeria. The Niger Delta region is positioned in the southern part of Nigeria (Fig. 2), and lies between latitudes 4° N and 6° N, and longitudes 3° E and 9° E. It was formed from interconnected body of rivers, which drain from central and northern Nigeria through a landmass into the Atlantic Ocean. The Niger Delta is known to be the second largest delta in the world with a coastline spanning about 400 km terminating at the Imo River entrance (Short & Stäuble., 1965).
The region spans over 20,000 km2 and it has been described as the largest wetland in Africa, covering an area of about 70,000 km2 and consists mainly of freshwater swamps, mangrove swamps, beaches, bars and estuaries. This delta has prograded southwestward during the Eocene to present, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). These depobelts made up one of the largest regressive deltas in the world with sediments volume of 500,000 km3 and a sediment thickness of over 10 km in the basin depocenter (Kulke., 1995).

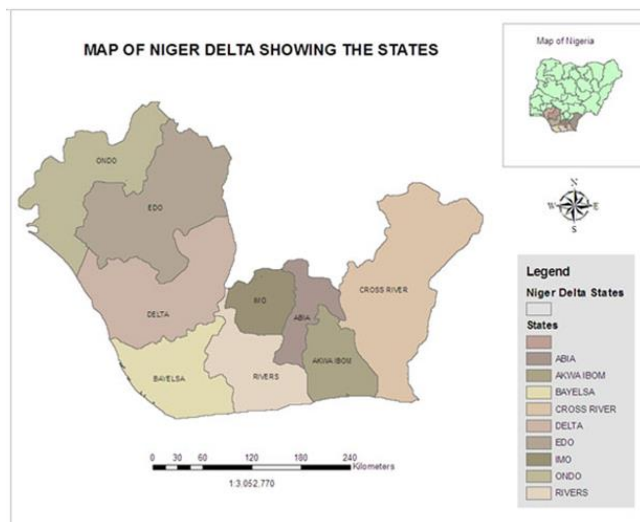


Fig.2. Map of Niger Delta showing states of the Niger Delta. (Source: GIS Development).

During first period of the Cenozoic era for the Niger Delta, three formations was formed namely, Akata, Agbada and Benin. These formation represents prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The Lithology of the Niger Delta have be detailedly described in various papers since the 60's in the likes of Short and Stäuble (1967), Avbobvo (1978); Doust and Omatsola, (1990); Kulke, (1995); Burke, (1972); Stacher, (1995); Haack, et al, (1997). Ejedawe, et al (1984); Ekweozor, and Daukoru, (1984).

3. MATERIALS AND METHODS

The software used for this study is an open source software and the methodology adopted for the study involves four steps:

I. Establish a Monte-Carlo simulation model from logging curves.
II. Get the synthetic data using Biot-Gassman theory as the fluids are oil ,gas, and water in the model.
III. Get intercept and gradient using Shuey's function, then, compare the intercept and gradient values from the seismic data with the model values.
IV. And finally, determine the probability of oil and gas using Bayesian theory.

4. DISCUSSION OF RESULTS

Buried depth of Interest ranges between 800m to 2300m with thickness of about 1500m and our horizon was picked at 1600m. Trend analysis was carried out and results were then used as input to the AVO Stochastic Model. The result from the trend analysis of P-wave shale against buried depth and P-wave wet sand against buried depth cross-plot show the Standard Deviation of shale velocities as a function of depth (figures 4a – 4b). The wet simulated acoustic impedance logs were compared to each of the wells used with the aim of finding a common trend with burial.

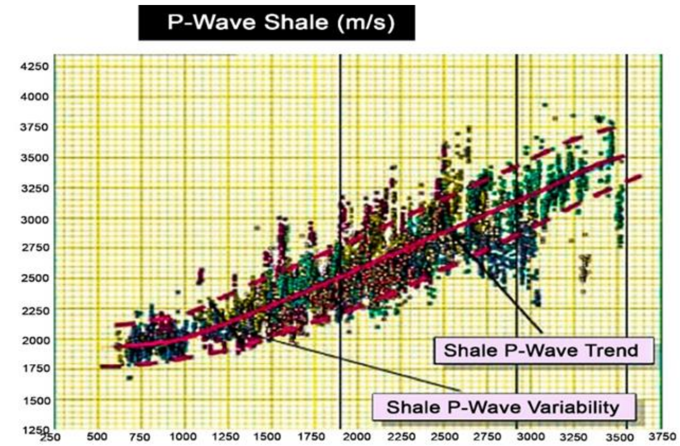


Figure 4a: P-Wave Shale trend

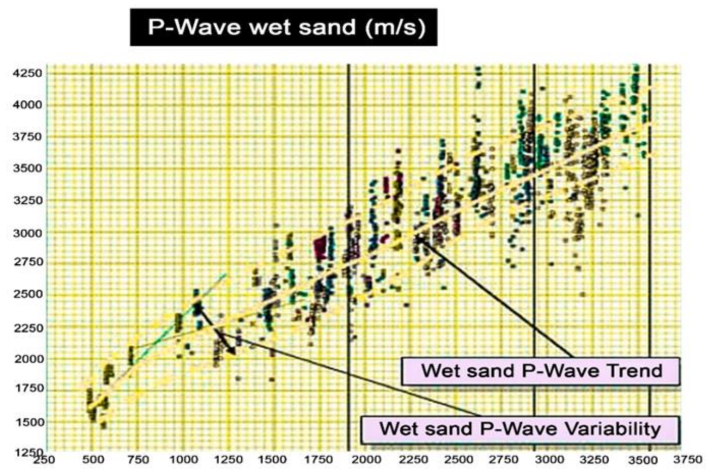


Figure 4b: P-Wave wet sand trend

The AVO stochastic model covers burial depth spanning between 800m and 2300m by 100 m step (Figure 5a – 5b). The result shows that between burial depth of 800m and 1100m, AVO class IV – Class III reservoir sand was observed. According to Castagna and Swan (1997), the class IV sand plots in the 2nd quadrant with negative intercept and positive gradient while class III sands plots in the 3rd quadrant located far away from the background trend. The AVO class III sand is normally associated with bright spots and they are relatively soft sands saturated with hydrocarbons. Also, they are easily detected on seismic data. Class IV anomalies are relatively rare, but occur when soft sands with gas are capped by relatively stiff cap-rock shales and characterized by V_P/V_S ratios slightly higher than in the sands (i.e., very compacted or silty shales).

From burial depth 1200m to 1900m show AVO class II reservoir sand. Class II represents transparent sands with hydrocarbons that often show up as dim spots or weak negative reflectors on the seismic (Castagna & Swan., 1997). However, because of relatively large gradients, they show up as anomalies in an A-B cross-plot, and plot off the background trend with weak intercept but strong negative gradient. These can be hard to see on the seismic data, because they often yield dim spots on stacked sections.

From burial depth 2000m to 2300 m, AVO class II - class I reservoir sand. Class I plots in the 4th quadrant with positive intercept A and negative gradient B. This represents relatively hard sands with hydrocarbons, with relatively high impedance and low V_P/V_S ratio compared with the cap-rock. These sands tend to plot along the background trend in intercept-gradient cross-plots. Moreover, very hard sands can have little sensitivity to fluids, so there may not be an associated flat spot. Hence, these sands can be hard to discover from seismic data.

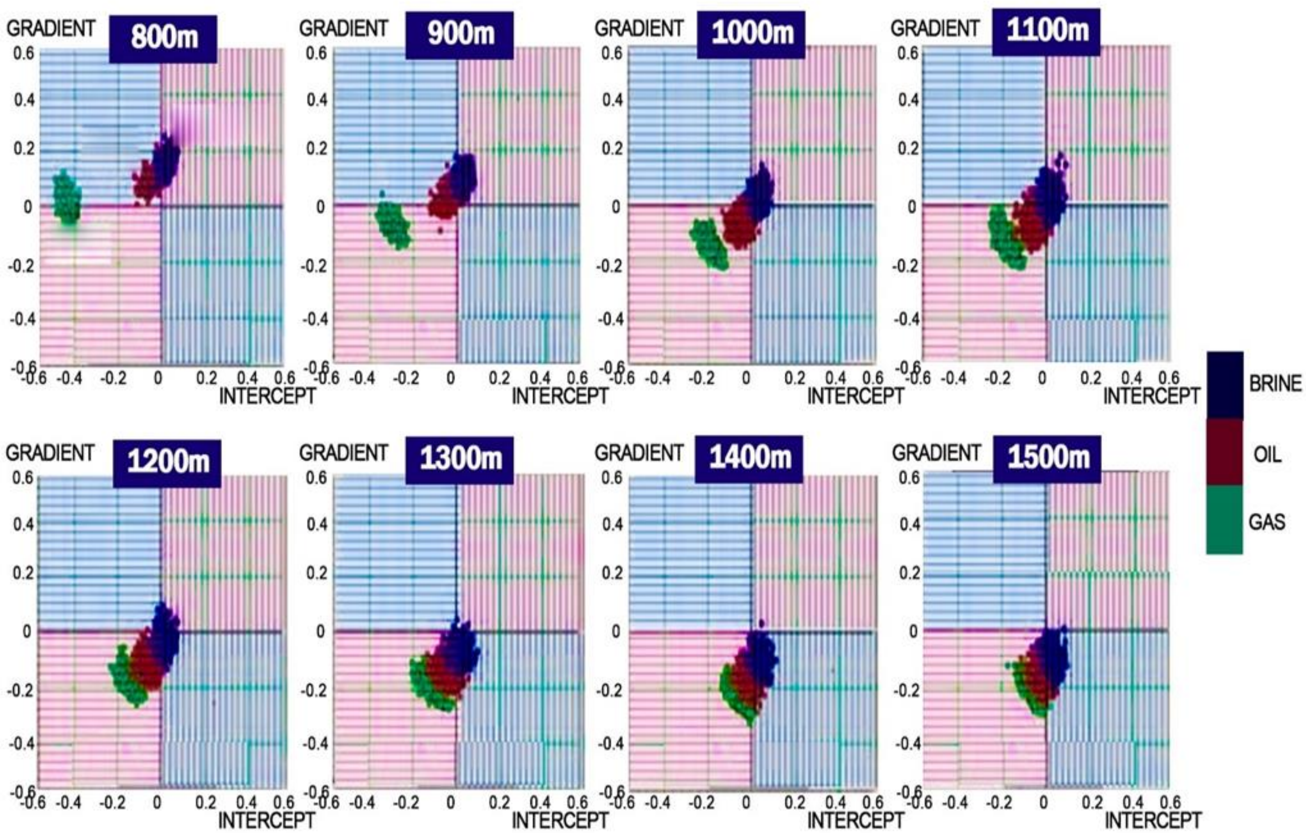
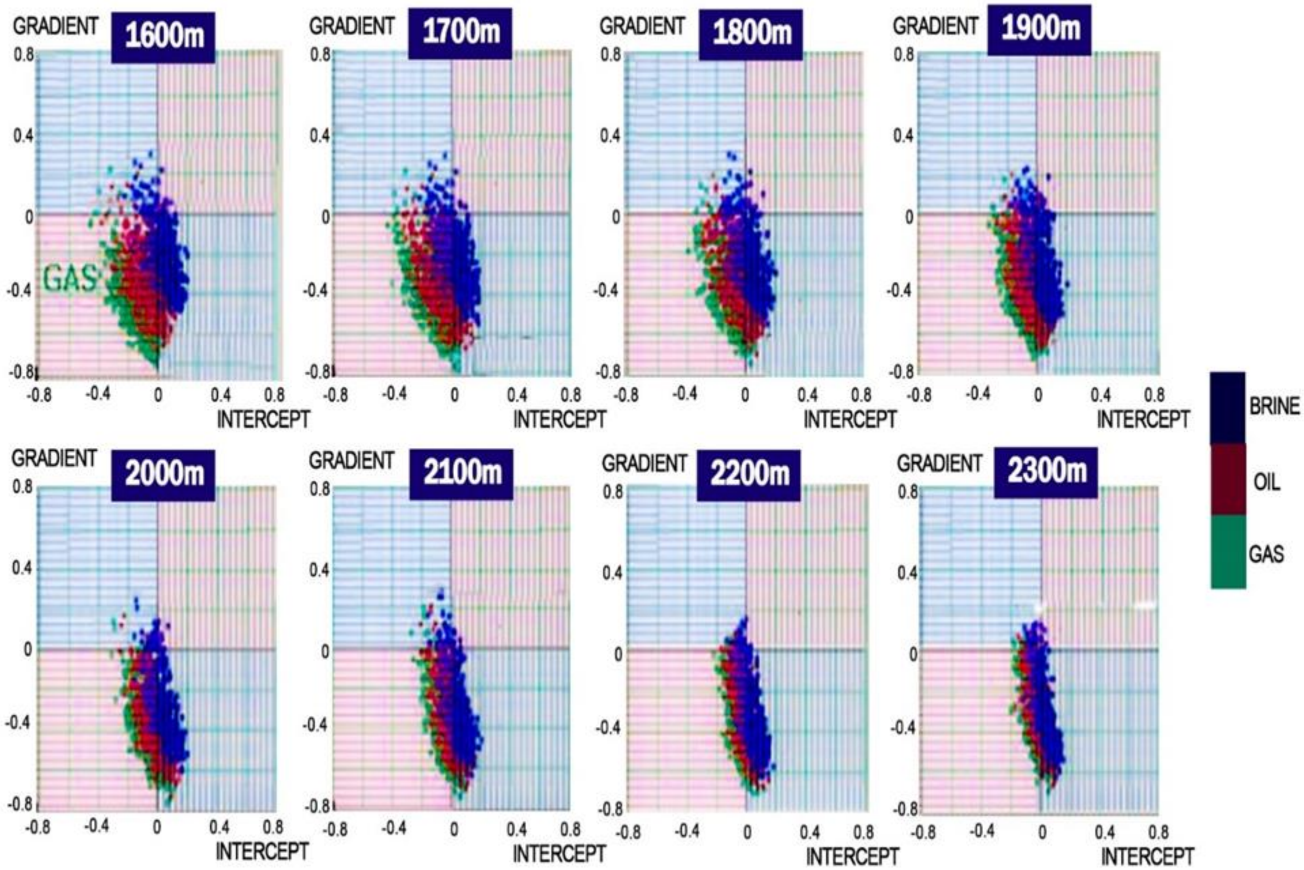


Fig.5a: AVO stochastic model, 800m – 1500m



The association of AVO intercept and gradient easily discriminates between hydrocarbons and brine until 1500m and between gas and oil until 1500m. Distinction of wet sands from hydrocarbon bearing ones below 1800 m burial is tricky and it is almost impossible below 2100 m. in essence, we can see a gradual shifting of the clusters from a clearly Class IV behavior at 800 m depth to a class II behavior at 2300 m depth.
The results of AFI are clean and they suggest oil and gas presence on the probability distribution map. The AFI maps below (Fig. 6a) shows that Probability figures for the oil map is good while that of the Gas map is moderate (Figure 6b). The result also shows that in areas penetrated by the wells have gas and oil probability greater than 0.4 indicated in red colour. It shows that FD field have good Oil and gas probability distribution with its main area dominated by oil.

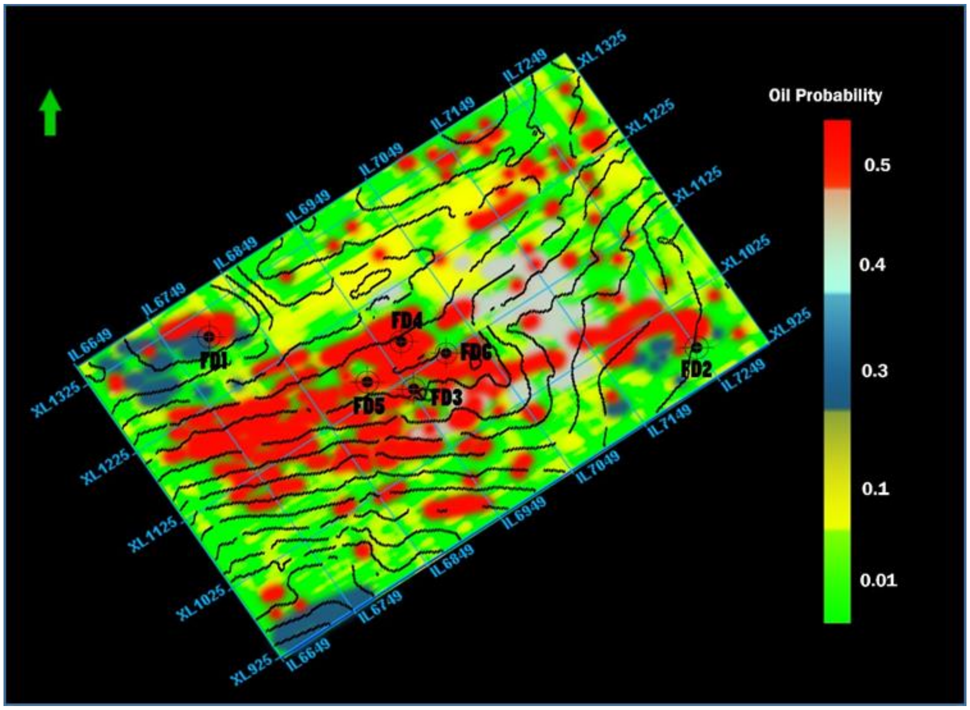


Fig.6a: Probability distribution map for oil in FD field.

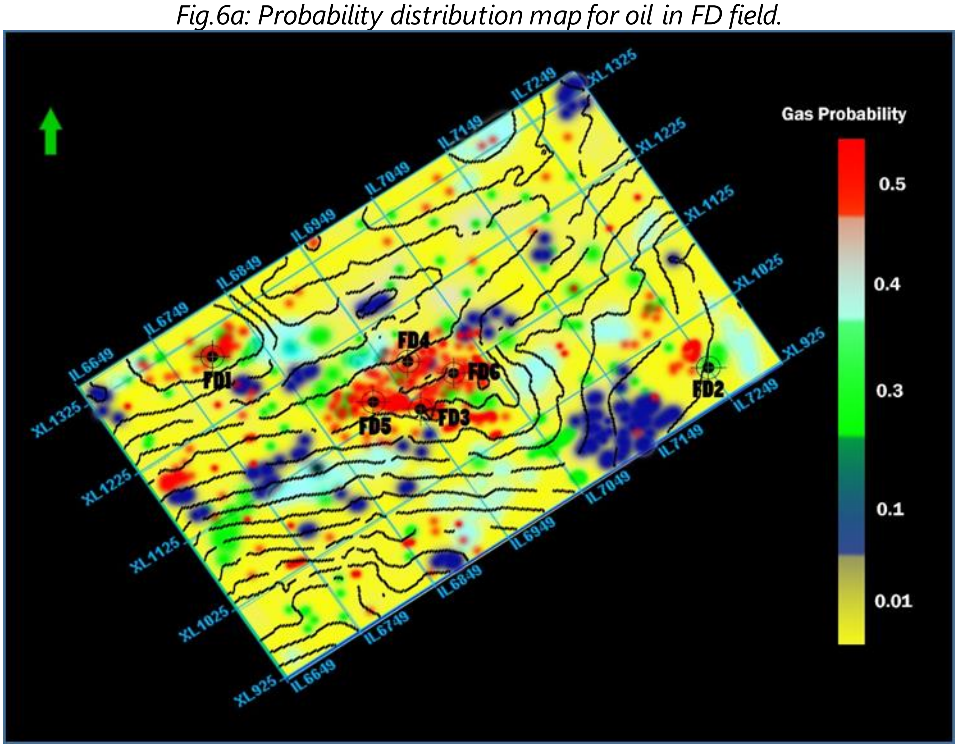


Fig.6b: Probability distribution map for gas in FD field.

5. CONCLUSION

AVO Fluid Inversion (AFI) procedure gives a strong and modest strategy for recognizing potential hydrocarbon-filled reservoirs and gives a quantitative evaluations of the vulnerabilities in the prediction. Thus using Bayes theory the probability distribution maps of fluids with different properties can be obtained. Therefore, in the absence of any well penetration to the target reservoirs, the AVO Fluid Inversion (AFI) technique can be used to predict oil and gas presence in the reservoirs of a given study area.

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