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Pore pressure effects on AVO and Prestack Inversion attributes: A case study of Western Offshore Basin

Sonu Prasad[1], Honey Abraham
[1]Email: prasad_sonu@ongc.co.in, Oil and Natural Gas Corporation Limited

Keywords

Pore pressure, AVO, Inversion, Shale velocity modelling

Abstract

Tapti-Daman Block of the Mumbai Offshore Basin having potential gas reservoir and also one of the thrust areas for exploration and development along the west coast of India. Early Oligocene Mahuva Formation and Late Oligocene Daman Formation having good hydrocarbon accumulation in the West coast of India. In this area, the most of the gas bearing sands show bright amplitude due to the impedance contrast, but some of the gas bearing pay sands do not generate clear bright amplitude at the interface. The reason behind could be the high pore pressure in the overlying shale intervals which cause the reduction in impedance contrast of shale sand intercalations. The present study analyses the high pore pressure effects on seismic amplitude response to distinguish the hydrocarbon bearing sand when the overlying shale is over-pressured. The observed seismic AVO (amplitude variation with offset) response at the reservoir interface has been modelled with different fluid pressures of the shale seal by well based modelling of elastic parameters at shale-sand boundary. This analysis brings out the importance of considering the Pore pressure while interpreting AVO and Prestack Inversion (PSI) attributes. In this study, A non-linear relationship is adapted between pore pressure & impedance with reference to the well sites and the same is used to map the over pore pressure zones. Combined analysis of elastic attributes & pore pressure is useful in reservoir characterization.

Introduction

The objective of this study is to quantify the change in AVO response and inversion attributes due to effect of pore pressure in Tapti Daman Area of Western offshore Basin as shown in Fig1. Due to development of new acquisition and processing techniques, AVO analysis is now established as an effective hydrocarbon detection tool in exploration. The AVO response is an interface property which depends on the elastic properties of the interfacing layers. When there are intercalations of sandstone & shale layers in clastic environment they results in different Classes of AVO responses (Rutherford & Williams, 1989).

In Tapti-Daman Area –Mahuva formation is over - pressured and is drilled with mud weight of 16 to 17.8 ppg. Some of gas bearing plays in Daman & Mahuva are observed to show Class 2 and Class 2p AVO response in spite of the hydrocarbon potential, which is anomalous considering the depth and porosity of the formations. The pore pressure gradient in impermeable shale seals are envisaged causing deviation in the AVO response due to the effective change in impedance contrast. The seismic amplitude variation in different pressure regimes has been quantified for Niger delta field (Ogagarue et.al. 2019). This method is used to model elastic parameters in different pressure regimes and corresponding synthetic gathers has been generated to observe the seismic response at shale sand interface. These seismic responses at the interface of shale –sand boundary has been used to categorize the AVO response of the study area.

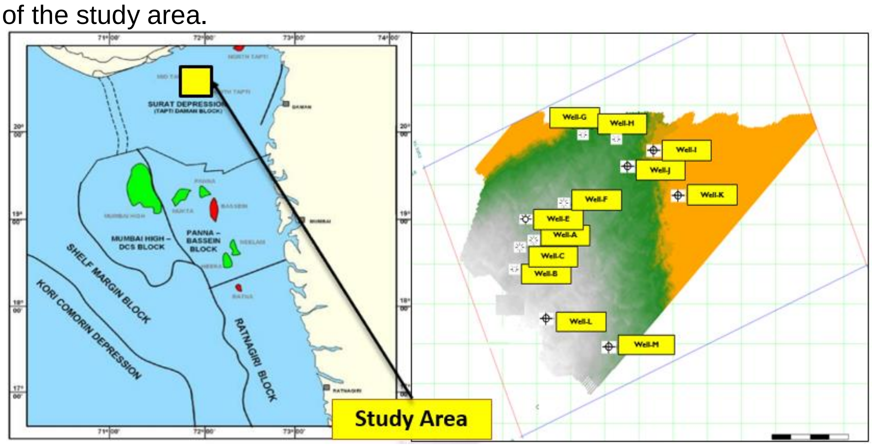

Fig1 Location map with study area

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Geology of the area

Tapti Daman area is located in northwest portion of Mumbai. This is area comprise of different blocks like south Tapti, mid Tapti and north Tapti. The structural style in the area is dominated by NE-SW trending anticlinal folds and nosal features. These folds are formed due to inversion of rift grabens. The tectonic episode resulting in these features occurred during Early to Middle Miocene. In the study area pertaining to central part of Tapti-Daman, the Oligocene deltaic sands of Daman as well as Mahuva Formations are potential reservoirs charged from Paleocene clastic Panna source rocks of older syn-rift sequence (Fig.2).

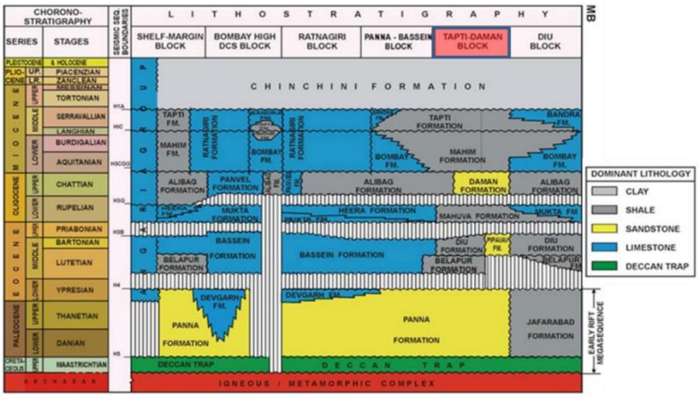

Fig.2: General stratigraphy of Mumbai offshore

Theory and Methods

Pore pressure of impermeable shales are associated with many geological processes. The main causes for pore pressure are due to under compaction, unloading and fluid expansion and even diagenesis, which is reflected in interval velocity as well as in density as a characteristic reduction (Hoesni, 2007). Acoustic impedance, product of the velocity and density will also have proportional reduction in shales under abnormal pressure. AVO response being dependent on relative impedance contrast of shale-sand interface, the reduction in velocity and density of over-pressured shale might alter an expected class 3 AVO anomaly to class 2 or class2p.

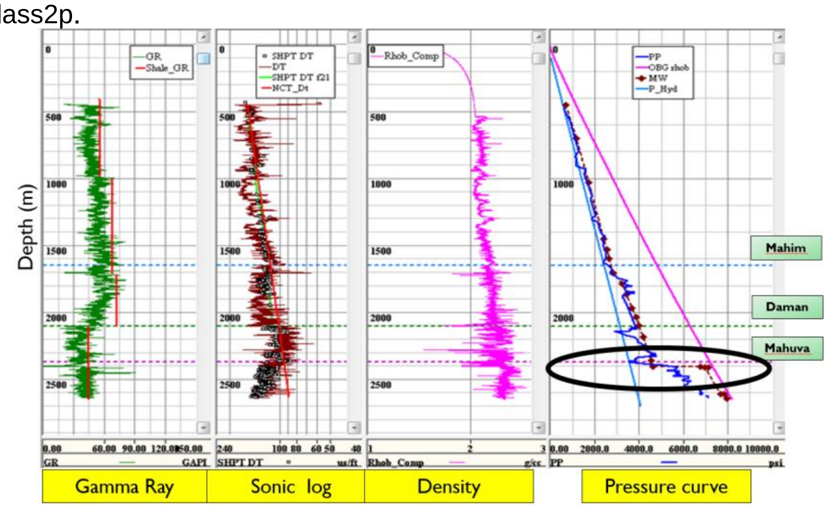

Fig.3: OBG, PP computation in representative Well A

[GR (Gamma Ray), Shale_GR (Shale line), DT (Sonic curve) & SHPT DT (Shale points), SHPT_DT f21 (Smooth Shale points), NCT_Dt (Normal Compaction Trend); Rhob_comp (Density), PP (Pore Pressure), P_Hyd (Hydrostatic Pressure Curve), MW (Mud weight curve), OBG_rhob (Overburden Pressure curve)]

In present study, AVO response has been generated in relation to pore pressure by substitution of shale end members. In this modelling shales were progressively over-pressured while the reservoirs were kept at in situ pore pressure condition. The first step of modeling is to compute the overburden pressure (OBG) in the area using bulk density (rho) logs.

OBG = rho*g*h ------------ (1)

And then calculated pore pressure using sonic logs and calibrated it with formation pressure test data.

From Terzhagi's relation of OBG, Effective stress (Ves) and Pore pressure (PP) equation 2.

PP=OBG-Ves ------------------- (2)

Then using equation 2 effective stress (Ves) is calculated.

Ves= OBG-PP ------------ (3)

Using Bowers equation (equation 4), between shale velocity (Vp_{shale}) and effective stress (Ves) is utilized to compute shale velocity in different pressure regimes.

$Vp_{shale} = Vo + A^{*} (Ves)^{B}$ ----------- (4)

Where Vo is compressional velocity at the sediment top which equals the water velocity, and A and B are Bower's parameters determined by calibrating compressional sonic velocity picks in shales with the measured pore pressure data using Bower's equation, in all available wells in the study area. The value of the coefficient A & exponent B is 14.7 and 0.68 respectively.

The present study uses the following modified form of the Bowers equation which provides a relation between the p-wave impedance and the effective stress, where α = A*rho:
$Ip = Ipo + \alpha^{*}(Ves)^{B}$ -----------------------(5)

The above equation is inverted in terms of pore pressure:

$PP = OBG - ((Ip - Ipo)^{B})/\alpha)$ -----------------(6)

In addition to this Castagna relationship (Castagna et.al, 1985) between compression and shear velocity is used to computed Shear velocity and for density using Gardener relationship in non-reservoir zone i.e. in shales respectively. Pore pressure is also computed at Well A falling in the study area as shown in Fig 3.

Results and Discussions

AVO responses have been generated in three different scenarios Normal pressure, Mild Pressure, Overpressure. The shale velocity has been computed using equation 4, for three pore pressure regimes: a hydrostatic (in situ) regime, mild overpressure regime and high overpressure regime, with pore pressure gradients of 0.434psi/ft, 0.59psi/ft and 0.67psi/ft, respectively for modelling.

Fig 4 shows the elastic parameters generated through shale end members substitution in different scenario of pressures for Shale gas sand model. The velocity of shale in normal pressure regime is more than the gas sand. The primary cause of over pore pressure is the disequilibrium compaction of shale which is caused by under-compaction dewatering in Mahuva formation.

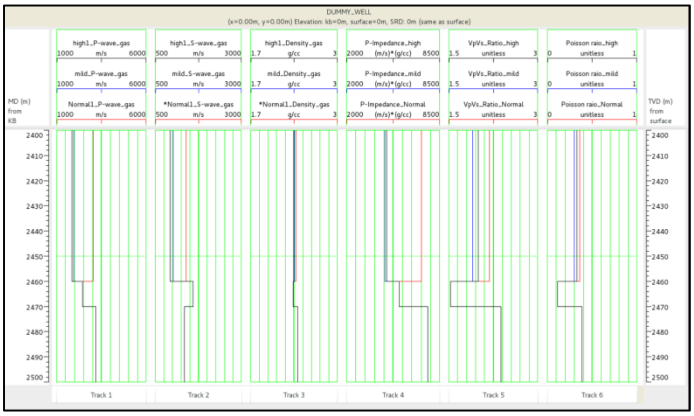

Fig 4 Elastic parameters generated from Shale end members substitution in different scenario of pressures for shale gas sand model

The AVO response has been generated on synthetic gathers of different pressure scenarios (Fig.5). In normal pressure regime, amplitude increase with the offset. In mild pressure regime, amplitude decrease with offset and then there is change in the polarity of the amplitude. In high pressure scenario, amplitude decrease with offset. So pore pressure changes the scenario from positive AVO to negative AVO even in the presence of hydrocarbon. (Lindsay & Towner, 2001).

In the field analyzed in Tapti-Daman area, overpressure is encountered in Mahuva formation. Representative Well-A, with gas bearing sand in Mahuva and with reduced impedance contrast at reservoir interface (Fig.6) has been selected for its Pore Pressure and AVO response analysis (Fig.3 & 5).

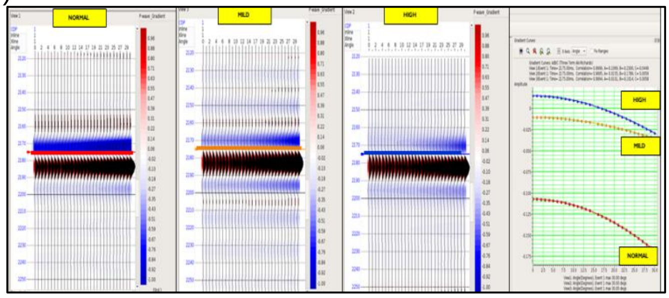

Fig 5 AVO response of synthetic gather generated through elastic parameters on normal, mild and high-pressure scenario in shale -gas sand model.

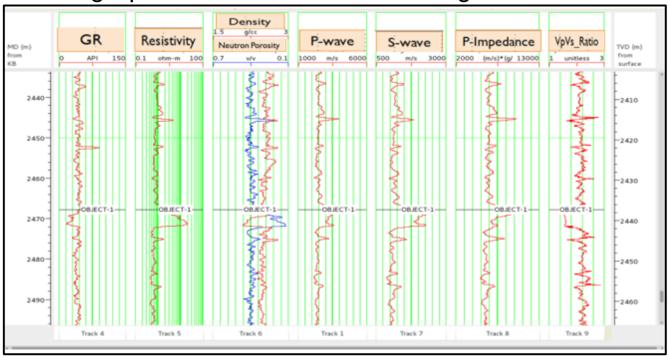

Fig 6 Recorded logs of Well A with computed Impedance log.

Synthetic gathers have been generated in Well-A using recorded elastic logs. In this well, shear log was not recorded so it has been modeled through fluid replacement modeling in the reservoir zone using petrophysical parameters having average porosity 24%, water saturation of 39% and shale content of 30%. And in non-reservoir zone using multi attributes regression relationship. AVO response has been calculated (Aki & Richards, 1980), which shows amplitude variation with polarity change after the angle 20 deg (Fig. 7).

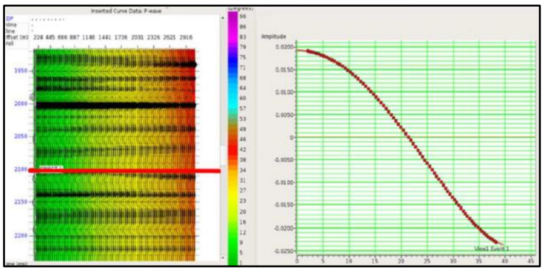

Fig. 7 Gradient analysis on synthetic generated at the from recorded (actual) logs

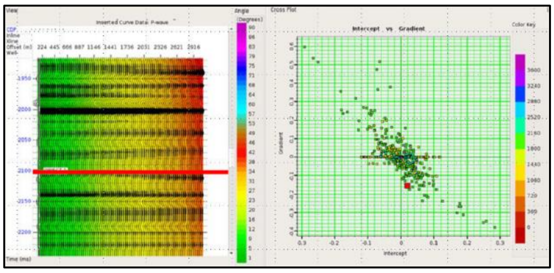

Fig. 8 Crossplot of intercept and gradient Top of gas sand on synthetic generated from actual logs

The cross plot of intercept and gradient (Fig.8) shows that top of gas sand fall in Quadrant II near to gradient axis which represents class 2p of AVO. By definition, in Class 2p AVO response the impedance of reservoir and cap rock or seal rock are very similar.

The Product of intercept and gradient (Fig.9) of AVO shows dim spot in reservoir zone. The scaled Poisson Ratio is also positive at top of reservoir which make it difficult to distinguish reservoir from non-reservoir zone with AVO attribute alone.

Cross plot of Impedance versus VpVs ratio for Well-A (Fig.10) shows that cap rock or Overlying shale having very close impedance with the hydrocarbon bearing sand. The color scale shown in pressure implies that shale having high pressure.

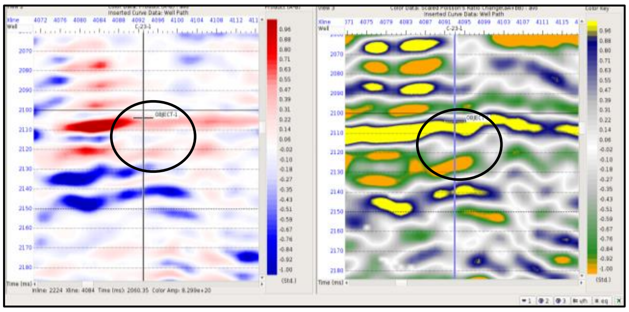

Fig. 9 Product of Intercept and gradient (left) and Scale Poisson ratio (right)

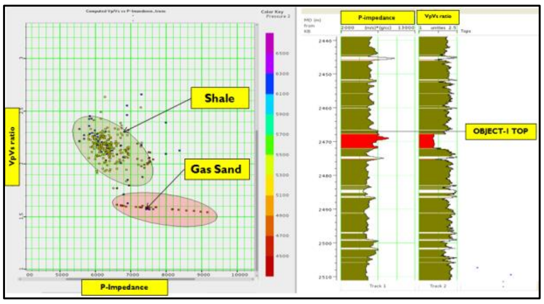

Fig 10 Crossplot of P-impedance vs VpVs ratio in Well-A shows high pressure in shale.

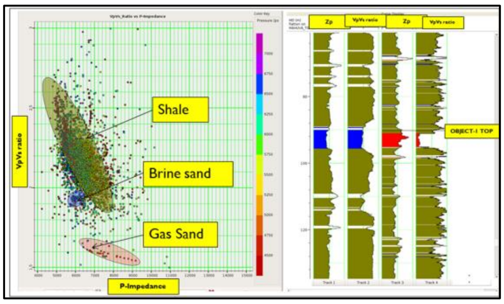

Fig. 11 Cross plot of P-Impedance vs VpVs ratio in Well-A (gas bearing) & Well-B (water bearing) showing high pressure in overlying shale as compared to water bearing sand and gas bearing sand

Impedance of cap rock i.e. shale over water bearing sand and gas bearing sands are similar (Fig.11) so that impedance alone could not distinguish the contrast between shale and sand. VpVs ratio help in distinguishing shale sand as well as water bearing and gas bearing sands.

Pre-stack simultaneous inversion has been carried out to distinguish the gas sand in high pressure regime (Fig.12 &13). The Well-O is gas bearing from Mahuva sand so it has been considered as a blind well to test the inversion and over pressure outputs. The P-impedance of reservoir is higher as compared to the overlying shale seal. VpVs ratio is low in reservoir and high in overlying shale. Variation in VpVs ratio value depends on the compaction and effective stress of the rock. The VpVs ratio for gas is around 1.58 to 1.6. It increases slightly beyond this value in unconsolidated sands and at low effective stress regimes (RV Rao, 2004). VpVs ratio is a least affected attribute of prestack inversion in high pressure zone (Prasad, 2002).

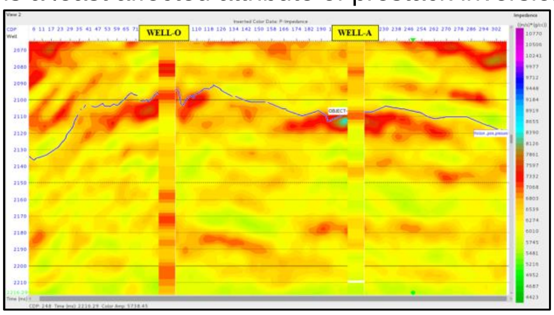

Fig 12 P-Impedance section along over-pressure Well-A and Well-O.

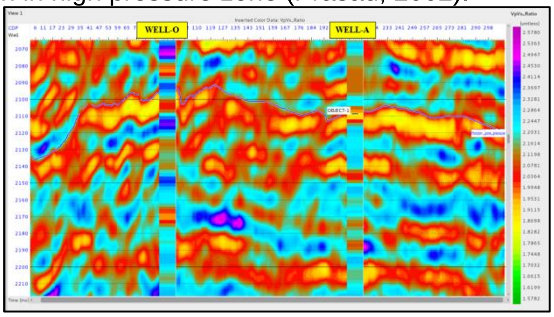

Fig 13 VpVs ratio section along over-pressure Well-A and Well-O

The nonlinear relation between pressure and impedance is established as mentioned in Equation 6 to generate high resolution pore pressure volume, which matches with the actual pressure log of the Well A (Fig.14).

High resolution pore pressure must be generated in such scenario to de risk the hydrocarbon exploration and exploitation.

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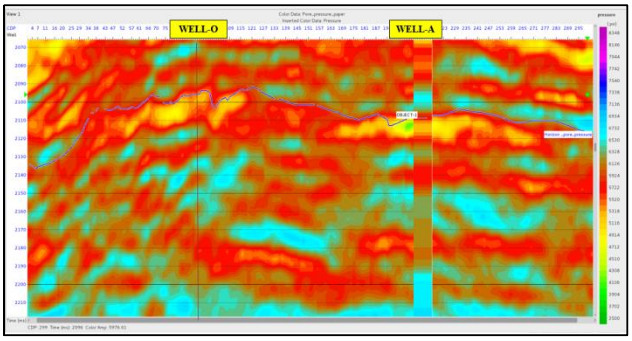

Figure 14 Pore pressure section along over-pressure Well-A and Well-O.

Conclusions

The paper has demonstrated clearly that high pore pressure has effect on seismic amplitude response and therefore AVO analysis/attributes may not give satisfactory results in high pressure zones. For better interpretation, Prestack inversion attributes must be considered such as P-Impedance, S-Impedance, VpVs ratio and Density. The study also brought out the importance of considering the pore pressure regime while interpreting AVO and Prestack Inversion (PSI) attributes. VpVs ratio is useful attribute of Prestack inversion to identify the gas bearing sands in over pressure regime.

Pre-drill AVO modeling and Prestack inversion taking into account the pressure gradient in the zone can help to reduce the risk of drilling seismic anomalies.

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