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P-impedance Inversion - A fit for purpose technique delineates reservoir distribution and aids in field development (Mangala Field, India)

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Summary

Barmer Basin located in NW of India in state of Rajasthan is a Tertiary rift basin, predominantly consisting of Paleocene-Eocene sediments. Till date more than twenty discoveries have been made, Mangala being the largest discovery in this basin. The main reservoir unit in the Mangala field lies in Fatehgarh Group. The group has been sub-divided into Lower Fatehgarh Formation (FM-3 to FM-5) dominated by well-connected sheet flood and braided channel sands, and the Upper Fatehgarh Formation (FM-1 and FM-2) dominated by low sinuosity, fluvial channel sands. The Upper Fatehgarh reservoir has around 46% average net to gross whereas Lower Fatehgarh has ~95 net to gross consisting of high quality quartzose fluvial sandstone. The objective of this study was to discriminate the lithology primarily in Upper Fatehgarh and also in Lower Fatehgarh Formation in Mangala field. The rock physics feasibility study indicates that, the P-impedance of Fatehgarh sands is significantly lower than the intervening flood plain mud/shale units. Both density and velocity of the Fatehgarh sands are lower compared to shale in the same zones. Hence, lithology discrimination using P-impedance is realistic. However, the rock-physics is less suitable for AvO analysis as reservoirs show similar AvO responses irrespective of brine, oil and gas scenarios.

Although P-impedance inversion is an old tool that has been used for many decades in the oil industry, the presented paper highlights its relevance in Mangala Fatehgarh reservoir in Barmer Basin. The post stack P-impedance inversion is identified as the most suitable attribute for lithology discrimination and reservoir characterization in Mangala field. The inverted impedance volume has been successfully used for to validate the well locations which were drilled in pattern mode. This paper illustrates how a successful well based feasibility study of P-impedance inversion followed by full inversion work and its analysis can help in discriminating lithology for reservoir characterization.

Keywords: *Rock physics, P-impedance, depth trends, scenario modeling, reservoir characterization, inversion QC*

Introduction

Mangala Field is located in the northern part of Barmer Basin of the Rajasthan State, India (Figure-1). This field was discovered in 2004 by targeting a series of tilted fault blocks plunging to the east south-east (ESE). Mangala structure was formed by interaction of two high angle normal faults of different age oblique to each other on the north-west side. The throw along these main bounding fault increases towards south. Low angle gravity collapse (splay) faults are developed at the crest of the field (Figure-2a) from the main bounding faults. In 2007, High Density 3D was acquired in Mangala field covering a total area of 120 sq km and full fold coverage of 88 sq km. The seismic data quality varies from "good" over the flanks of the structure to poor adjacent to the main bounding faults at the crest of the field (Figure-2b).

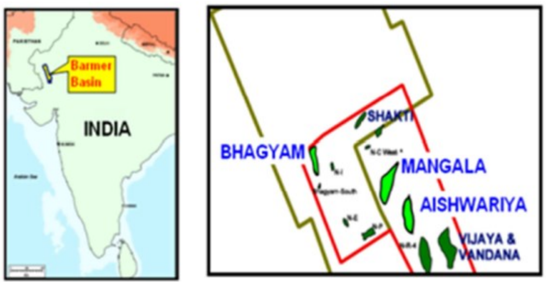

Figure-1. Location map of Barmer Basin and Mangala Fields

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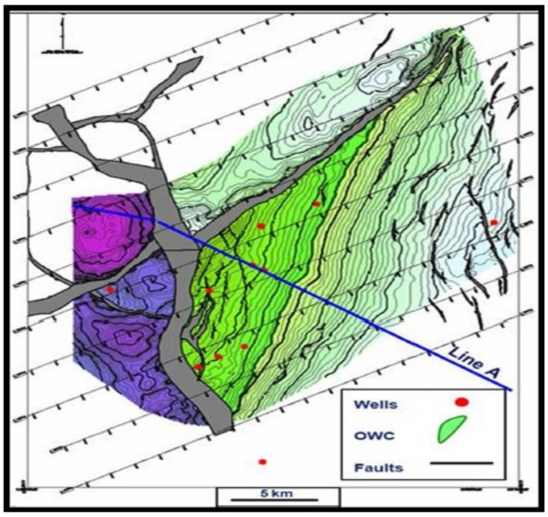


Figure-2 (a). Top Fatehgarh reservoir depth structure map

The main reservoir i.e. the Fatehgarh group is subdivided into five Fatehgarh members (FM-1 to FM-5). The Upper Fatehgarh comprises of two members i.e. FM-1 and FM-2 (FM-1 being the youngest part of Fatehgarh Formation). FM-1 reservoirs mostly consists of low sinuosity single storey and multi storey fluvial channels bars and associated other fluvial depofacies like, channel margin sands, heterolithic channel fills and crevasse splays. FM-2 is a mudstone rich unit which comprises of isolated channel sands. The mudstones in FM-2 are reddened and frequently contain immature soil profiles; they represent flood plain shales subjected to exposure. Lower Fatehgarh reservoirs are dominated by well-connected sheetflood and braided channel sands.

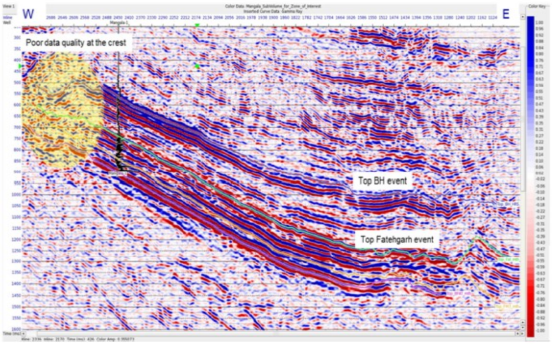


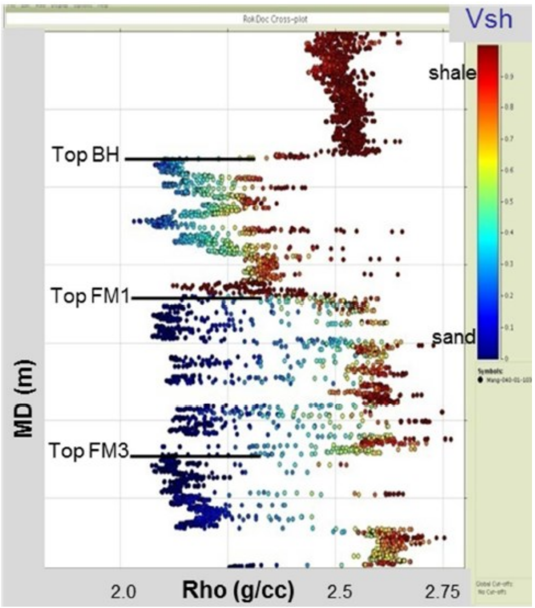
Figure 2(b): PSTM seismic profile (Line-A) showing better data quality at flanks compared to the crest of the structure.

Lithology and Fluid Discrimination

Rock-physics analysis was undertaken for the Mangala Fatehgarh rocks to understand elastic rock properties and their seismic responses. Rock-property analysis helped in deciding which seismic inversion attribute is more suitable for dependable reservoir characterization within the zones of interest. As demonstrated by the following paragraphs, feasibility study has clearly established the link between log and seismic data in order to ascertain the lithology and fluid discrimination.

Depth Trend Analysis

The depth trend analysis unravels the compaction history of the basin and also helps in determining the fluid and lithology discriminators. Each formation is clearly distinguishable by its own depth trend. The expected contrast in elastic properties between the Fatehgarh reservoir sands and inter-bedded shale helps to understand their seismic responses as a function of depth. Figure-3 shows the velocity, density and total porosities trends with depth. The average density of reservoir sandstone and nonreservoir shale in Fatehgarh is nearly 2.15 g/cc and 2.55 g/cc respectively whereas the average velocities of the same lithologies are roughly 3200m/s & 3700m/s in that order. This leads to the conclusion that density is a good discriminator whereas velocity is a moderate discriminator of the lithology in the Fatehgarh Formation.



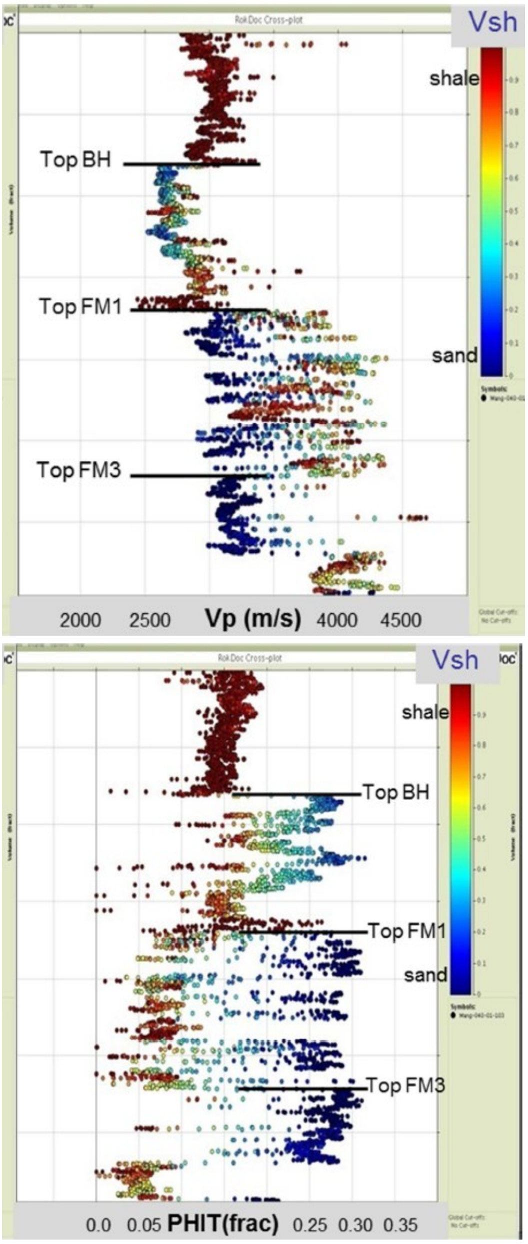


Figure-3: Velocity, density and total porosity trends with depth, Notice the lithology discrimination through density and velocity trends for Mangala wells.

During burial, the total porosities of the reservoir sands are preserved up to 30pu whereas shale porosities are decreasing faster compared to sand with increasing burial depth up to 5pu (refer figure-3). Figure-4(a) shows cross-plot between P-Impedance and Gamma Ray for Fatehgarh Formation. Due to significantly low density and reasonably low velocity, sands are significantly softer compared to encasing shale units. This resulted in remarkably low P-impedance for sand compare to shale and suggesting that Pimpedance can be used as a good discriminator of lithology. However, there are scatter between sand and shale which possibly indicates low energy fluvial depofacies like channel margin sands and crevasse splays. This provides the encouragement to extend the rock physics work to carry out the P-impedance inversion for reservoir characterization in Mangala field.

Dry rock modeling and Gassmann fluid substitution indicate that Fatehgarh rocks are less sensitive to fluid change. There is little variation in Vp, Vs and Rho for oil and brine scenarios. Although the P-impedance of oil reservoir is slightly lower than the brine one, discriminating the oil reservoir from brine is not possible due to large P-impedance overlap (refer Figure-4b).

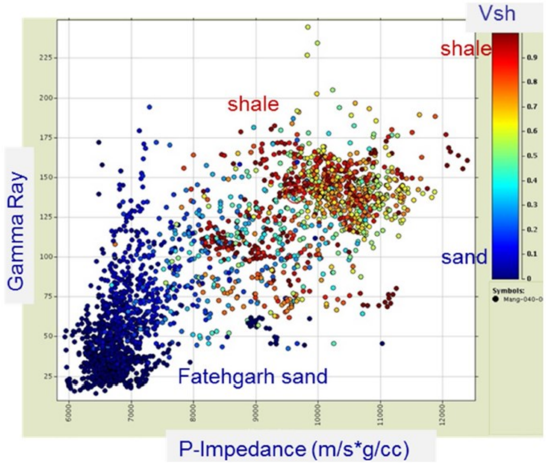


Figure-(4a): Gamma ray and P-impedance cross plot high lighting the lithology discrimination on the basis of P-impedance.

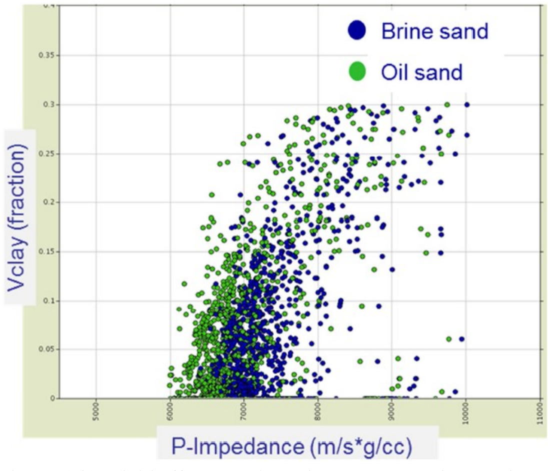


Figure-(4b): Fluid effect on P-impedance suggests that Fatehgarh reservoirs are less sensitive to fluid change.

Forward and Fluid Scenario Modeling

Lithology and fluid discrimination analysis was carried out for number of wells; results are presented for a representative well. Gassmann fluid substitution has been performed to create different fluid scenarios in study well. To match the seismic frequency, a Ricker wavelet with 30Hz dominant frequency and SEG normal polarity (increase in acoustic impedance is peak and represented in blue colour) has been used to create the AvO synthetics. The objective was to study the impact of brine, oil and gas scenarios on the acoustic logs and hence on seismic amplitudes (Figure 5). As there is a little change in the acoustic properties (Vp, Vs, Rho) of oil and brine reservoirs, Fatehgarh rocks are least sensitive to fluid change. These reservoirs show decreasing of amplitudes with increasing offsets suggesting normal AvO responses for brine, oil and gas scenarios. In general, brine amplitudes are weaker than oil and gas amplitude responses.

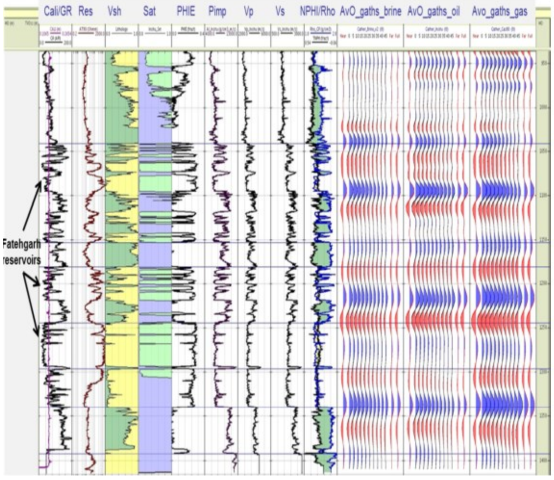


Figure 5: Well composite display showing the fluid scenario modeling; observe the varying seismic response for the brine, oil and gas scenarios.

Inversion Results

Following the successful feasibility study high density 3D seismic data was inverted to deliver the P-impedance volume. The HD 3D time migrated (PSTM) data used for inversion was good quality towards the flank and fair at the crest of the Mangala structure. The dominant frequency in the data was observed around 30 Hz. As the shale is acoustically harder than the sand, all the sands are marked by the trough at the top and peak at the base of the reservoirs. The low P-impedance is related to the Fatehgarh sand and high P-impedance to the non-reservoir lithology mostly flood plain muds. Notice the excellent match between the inverted and measured P-impedances at well location (Figure-6). Most of the Fatehgarh reservoirs are delineated by P-impedances, however, the reservoirs with sand thickness 5 to 7m, are producing the integrated response and cannot be discriminated individually. This is the limitation of the any deterministic inversion technology.

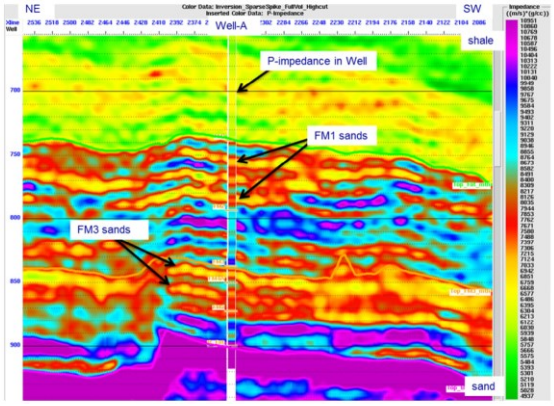


Figure-6: 2D QC of the inversion results at the well location, Notice the excellent match between the inverted and measured P-impedances.

Many wells have been drilled after this inversion study, Figure-7 illustrates the inversion QC at one such blind well location. There is reasonably good match for lower and upper Fatehgarh reservoirs. This well encountered more than 50m thick FM-2 reservoir intervals.

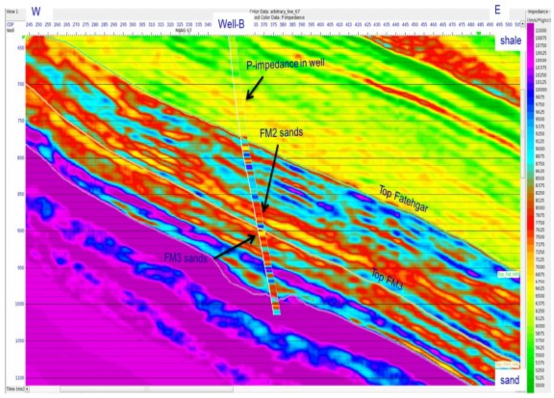


Figure – 7: Blind well test at Well-B, Notice the good match between the lower and upper Fatehgarh reservoirs.

To map the extent of the Fatehgarh reservoirs, horizon slices of P-impedance at reservoir tops have been computed. Figure-8 is one such example, illustrating the extent of FM-3 reservoir distribution. OWC is plotted in dotted blue lines. The crest of the structure is dominated by low P-impedance values suggesting that FM-3 reservoirs are more continuous which has been verified by well control. The low P-impedance area extending beyond the OWC is indicating the presence of the reservoir and not the hydrocarbon. In Mangala field, as P-impedance is only lithology and not the fluid indicator, it is not necessary that low impedance region will follow the structural contours.

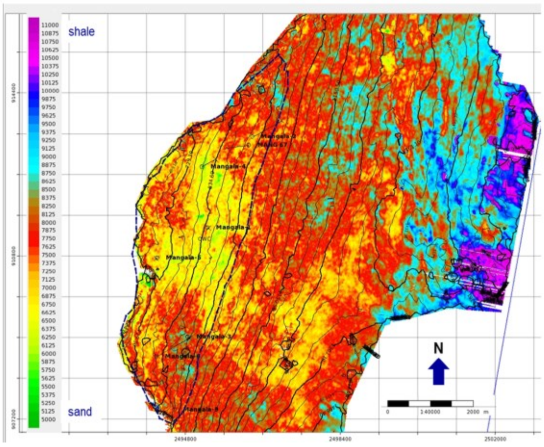


Figure-8: Average P-impedance measured within the 8ms window at FM-3 reservoir level. Within the OWC, the crest of the structure is pre-dominantly marked by the low impedance values.

Conclusions

At log resolution P-impedance was able to discriminate the lithology but not the fluid type and hence can be used as a reservoir predictive tool. Within the known OWC, reservoir prediction helps to validate the well locations in Mangala field. Due to the good correlation between the inverted rock physics results and well log data, inverted volume is being used as an effective development tool, reducing sub-surface uncertainties for reservoir characterization, and optimizing the well locations during field development campaign. Careful integration of rock physics, seismic, petrophysics and geological data can thus be used to delineate reservoirs even in a Class-I AvO scenarios where the reservoirs are least sensitive to fluid change.

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