Reservoir Delineation and De-risking using Prestack Simultaneous Inversion and Attribute studies in Mandapeta Field - A case study from Krishna Godavari Basin, East Coast India

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Key Words:

Mandapeta Sand 2 & 2A, Low Frequency Model (LFM) Building, Pre-stack Deterministic Inversion, Attribute Analysis, Facies and Fluid Prediction (FFP), Sand Probability.

Abstract:

Mandapeta field is situated in the East Godavari sub-basin of Krishna-Godavari (KG) basin. The main hydrocarbon bearing formation is Mandapeta sandstone of Lower Gondwana Group and has been assigned Permo-Triassic age. The field was discovered in the year 1988. There are mainly two producing sands in Mandapeta area, namely Sand-2/2A & Sand-2D. Apart from these two sands, Sand-1 is also a promising unit for exploration. Sand 2/2A (shallowest sand) is the most prolific pay of the Mandapeta field. Based on the drilling results, it is established that Mandapeta area is having good potential to produce commercial quantities of hydrocarbons from Mandapeta formation. However, reservoir heterogeneity and low permeability nature of reservoir sands are the main limiting factors for exploration & exploitation. To understand the lateral extent of the reservoir sands and to identify sweet spots, Pre-stack deterministic inversion studies were attempted in Mandapeta field followed by Facies and Fluid Probability (FFP) analysis. The reservoir characterization studies helped in understanding the heterogeneous distribution of the reservoir rock which was otherwise a major challenge for further field development. The present study demonstrates the effectiveness of reservoir characterization studies in de-risking the exploratory prospects and optimizing the development wells in Mandapeta field.

Introduction:

Krishna-Godavari Basin is orthogonally juxtaposed to NW-SE trending Pranahita-Godavari Graben (Fig. 1). The deposition of sediments in this part of Basin was initiated during Permian over Basement. The oldest sedimentary section, called Kommugudem Formation (Early Permian) rests on the crystalline basement. It is dominantly a coal shale sequence with subordinate sands deposited in a fluvio–lacustrine environment which marks the initiation of Gondwana sedimentation during Permian age. After a period of non-deposition, fluvial system prevailed and resulted in the deposition of Mandapeta Formation, which is dominantly arenaceous unit with shale intercalations. This was followed by the deposition of Gollapalli / Nandigama Formation of Up. Jurassic to Lr. Cretaceous in the axial lows oriented in NE-SW direction composed of mainly sandstone and shales and are deposited in a rift setting under fluvial to marginal marine conditions. The lower Cretaceous is marked by major transgression which continued up to Maastrichtian and tilting of the basin in the south-easterly direction depositing Raghavapuram shales. The south easterly tilt marks the end of the Rift fill stage and resulted in open marine conditions.

The Triassic sediments overlying the Permian sequence, were deposited in NW-SE trending Pranahita - Godavari graben, an intracratonic graben, during Lower Gondwana period before the breakup of Gondwanaland. Till Early Jurassic age, KG basin was part of intracratonic rift setup constituting the southeastern extension of NW-SE trending Pranahita-Godavari basin. Triassic sediments are litho stratigraphically named as Mandapeta Formation. Mandapeta Formation is time equivalent of Kamthi formation of Gondwana sequence as observed in the outcrops and electro log data. The Triassic sequence with dominantly sandstone comprises a high accommodation of fluvial sedimentary successions with basinal slope towards north-west in contrast to the present one. The Mandapeta graben which serves as a depocenter for Triassic sediments is bounded by Tanuku high in the North and by Darksharama high in the South. (Gupta, 2006; Khan et al., 2000)

Mandapeta Field:

Mandapeta field is located in the East Godavari sub basin, towards East of Gautami-Godavari River system of KG basin (Fig.1). The Mandapeta field led to discovery of hydrocarbons in Gondwana sediments. Mandapeta sandstone and Gollapalli sandstone are the main hydrocarbon producers in this area. In general for Mandapeta play, the main exploratory objective is to identify good quality reservoir facies which are in general characterized by low P-impedance and low Vp/Vs. There are mainly two producing sands in Mandapeta area viz. Sand-2/2A & Sand-2D. Apart from these two sands, Sand-1 is also a promising unit for exploration. Sand-2/2A in Mandapeta is the shallowest sand within Mandapeta and largely it coincides with Mandapeta top.

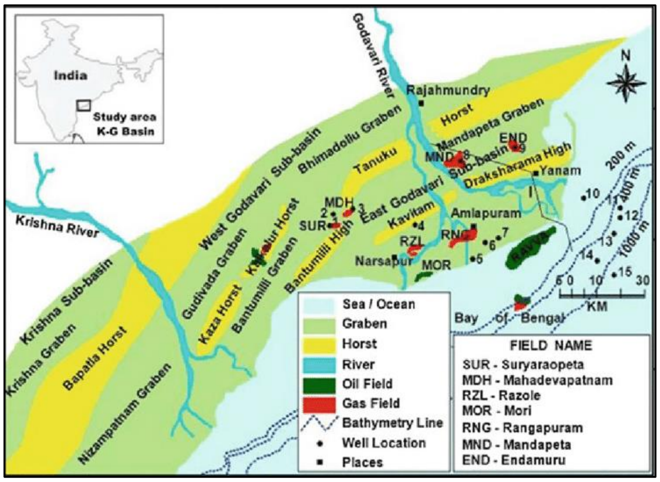

Fig.1: Tectonic map of KG Basin showing the study area

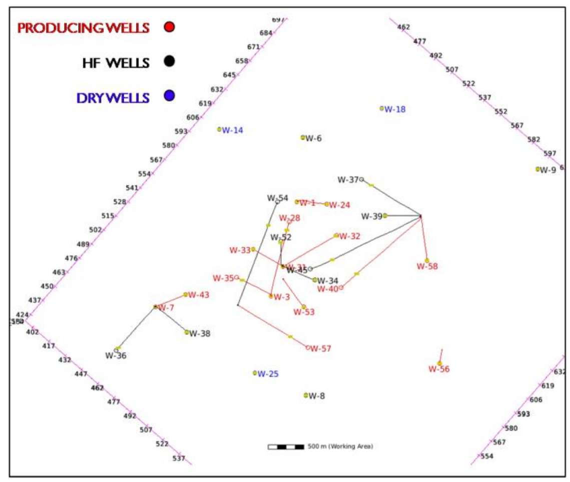

Fig.2: Base Map showing drilled wells in the study area

Most of the wells in the Mandapeta field are Gas bearing. The wells producing from good quality sands are annotated with red colour, wells with tight reservoir facies are denoted with black colour and the water bearing wells are shown in blue colour. (Fig. 2). The average gross reservoir thickness in Mandapeta main field is ~200m. Sand proportion of 2/2A is ~ 0.60 in the main field. An electro log correlation profile along wells W-36, W-7, W-43, W-35 & W-40 depicting the structural disposition and sand distribution is shown in Fig. 3.

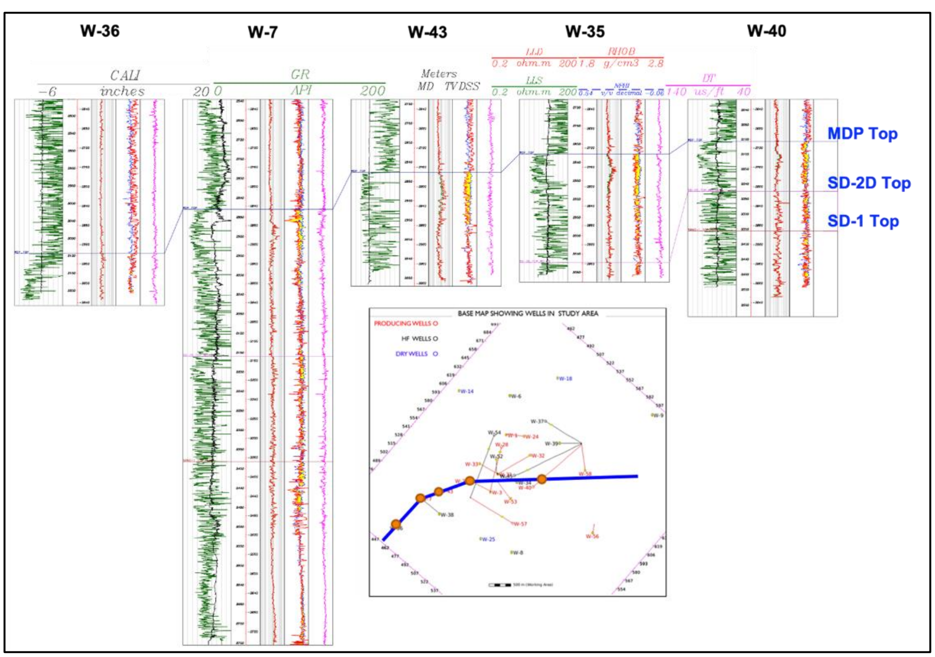

Fig.3: Log correlation profile connecting drilled wells W-36, W-7, W-43, W-35 & W-40 through the main field

Based on the drilling results, it is established that Mandapeta field is having good potential to produce commercial quantities of hydrocarbons from Mandapeta formation, particularly Sand-2/2A. However, reservoir heterogeneity and low permeability are the main limiting factors for development & exploitation. Reservoir characterization study was carried out to identify the sweet spots for exploitation from Sand 2/2A. The area of study is around 200 SKM covering the main Mandapeta field and its Southern part.

Methodology:

Data Conditioning:

Pre-stack seismic inversion can be utilized for predicting fluid and lithology properties of subsurface of the earth (Hampson et al., 2005). To get good quality inversion output, the input seismic should be good enough with higher Signal to Noise ratio. Therefore rigorous data conditioning efforts were made to prepare the datasets for carrying out Reservoir Characterization studies. The seismic data was acquired using a bin size of 20m x 20m with 120 fold having a record length of 7 sec and sample interval of 2ms. The data was processed and utmost care was taken to suppress the multiples up to a possible extent. VSP corridor stacks were also analyzed and it is found that the events in VSP corridor stack and conditioned seismic gathers are correlatable within the zone of interest. Four partial angle stacks, Near (03-14 deg), Mid (12-23 deg), Far (21-32 deg) & Ultra Far (30-42 deg) were generated and used in the inversion studies. As per spectral analysis the dominant frequency is around 15 Hz.

Interpreted horizons corresponding to Gollapalli Top (Late Jurassic to Early Cretaceous), Mandapeta Top (Permo Triassic) & Kommugudem (Permian) Top and sand level horizons were conditioned and loaded in Jason software platform. An arbitrary seismic line (full stack) connecting drilled wells W-7, W-43, W-35 & W-40 is shown in Fig. 4. Bright amplitudes within Mandapeta indicate gas bearing zones whereas high amplitudes within Kommugudem represent coal shale – sand alterations.

Well data corresponding to around 60 wells was loaded in the project. However, P-Sonic, S-Sonic and Density logs within the zone of interest was available in 16 wells and were used for carrying out pre stack inversion studies.

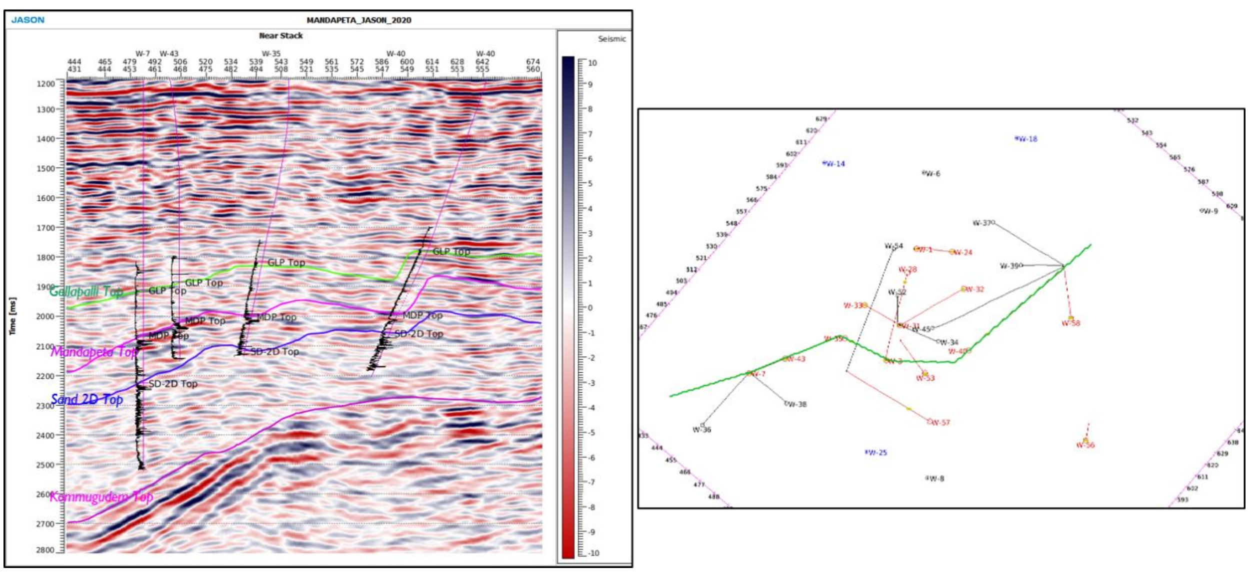

Fig.4: RC line through wells W-7, W-43, W-35 & W-40 (Seismic full stack)

Rock Physics Analysis & Feasibility Studies:

Feasibility studies, in terms of cross plot and histogram of elastic property logs (P-impedance & Vp/Vs), were carried out to assess the adequacy of wells to fulfil the inversion objective. Facies logs (FC3) were generated with three facies viz., Gas Sand, Brine Sand & Shale based on cutoffs suggested by petro-physical evaluation. Cross plots between P-impedance and Vp/Vs demonstrates a good separation between reservoir and non-reservoir facies. The hydrocarbon bearing sands are characterized by relatively low to moderate P-Impedance and low Vp/Vs.

To demonstrate the reservoir heterogeneity within the area of study, P-impedance vs Vp/Vs cross plot, coloured with fluid curve (FC3) for Sand-2/2A is shown in Fig. 5. The points representing the hydrocarbon bearing zones of sand-2/2A of good producing wells are highlighted in the cross plot (Fig. 5a). These points are absent in the P-Impedance vs Vp/Vs cross plot of tight/HF wells (Fig. 5b) indicating the heterogeneity of the reservoir within the same zone. The cross plot of P-impedance, Vp/Vs and effective porosity colored with fluid curve (Fig. 6) also show that the good producing wells with better effective porosities are having relatively low P-impedance, low Vp/Vs values when compared to tight/HF wells.

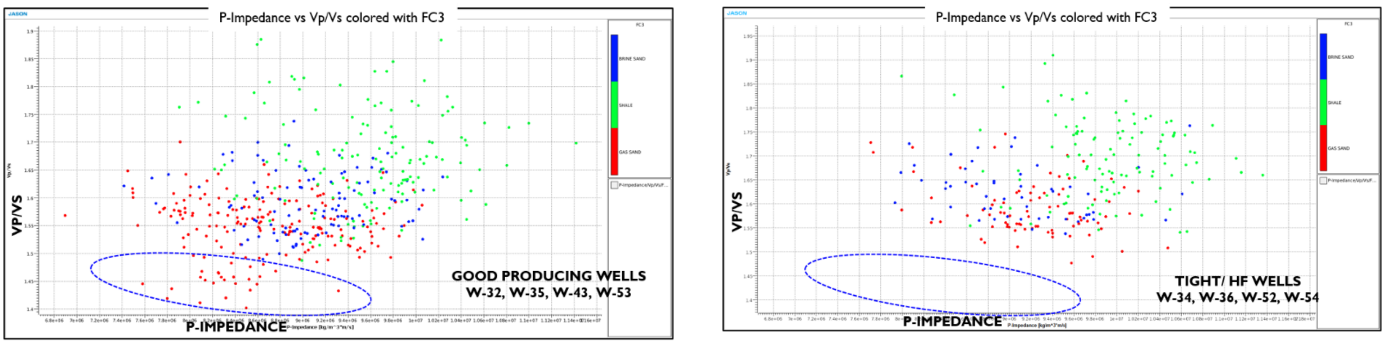

Fig.5: P-Impedance vs Vp/Vs Cross plot (colored with FC3) for a) Good Producing Wells b) Tight/HF Wells

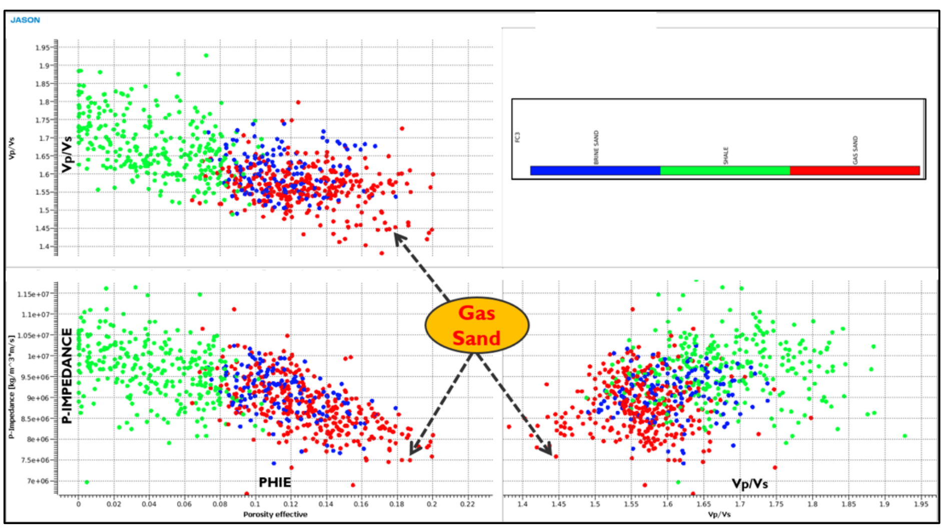

Fig. 6: P-impedance, Vp/Vs & PHIE Cross plot (colored with FC3) for Sand-2/2A

Wavelet Extraction and Well-to-Seismic Tie:

Well to seismic tie was done for all the wells considered in the study. To begin with, an initial well tie is established with a statistical wavelet. Using this initial TD relationship, angle dependent wavelets were estimated within the target zone of interest with a deterministic technique. Wells having consistent wavelet were used for multi well wavelet estimation. These estimated wavelets were then used to update the final well-tie for each well.

Low-frequency model building:

As the seismic data is band limited in nature, to derive the full spectrum of inversion results, a low frequency model is required for incorporating in the inversion engine. In other words, LFM incorporates the compaction trend into the inversion results which are missing in the seismic amplitude data (Contreras et al., 2006). First, a structural framework is modelled using the horizons interpreted at the tops of the main geologic formations. In the present study, horizons close to Gollapalli top, Mandapeta SD-2/2A top, Mandapeta SD-2D top and Kommugudem top were used to generate the structural framework. Subsequently, the geological framework is populated with available well log data (Zp, Vp/Vs, and Density) using inverse distance weighted technique. This model is then high cut filtered at the merge cut off frequency to generate the required low frequency model.

CSSI Simultaneous inversion:

Constrained Sparse Spike Inversion (CSSI) was attempted using Jason's Rock Trace module. It starts with determining various inversion parameters viz, seismic misfit signal-to-noise ratio, contrast misfit uncertainty, wavelet scale factor, merge cut off frequency. It involves checking the sensitivity of these parameters and QC'ing the prior and inverted outputs along with cross correlation between synthetic and recorded seismic amplitude data. Using these optimized parameters along with the estimated angle dependent wavelets, all four partial angle stacks are inverted simultaneously to generate P-Impedance, Vp/Vs & Density volumes. The P-Impedance and Vp/Vs sections along RC line through wells W-7, W-43, W-35 & W-40 is shown in Fig. 7. To QC the inversion results, pseudo logs were extracted from inversion output at well locations. These extracted pseudo logs show very good match with the original elastic logs filtered to seismic bandwidth.

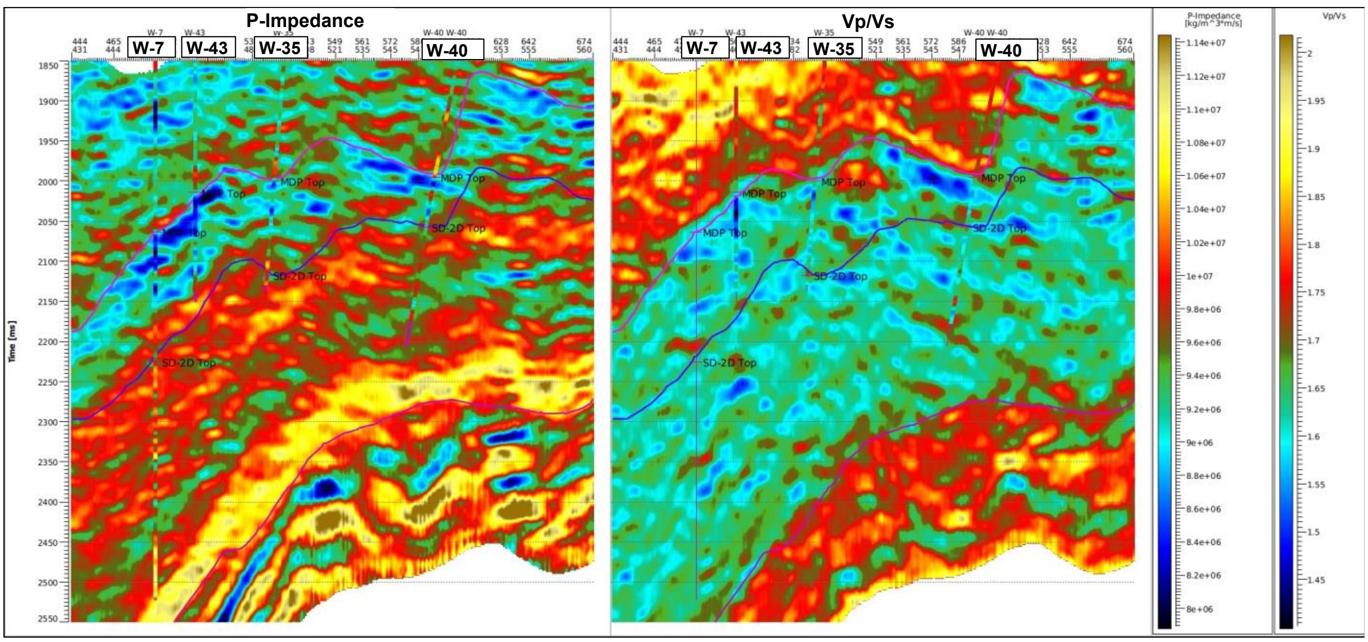

Fig. 7: RC line through wells W-7, W-43, W-35 & W-40 showing P-Impedance and Vp/Vs

Attribute Analysis:

Inversion results viz., P-Impedance, Vp/Vs and Density (volumes) were analyzed. Horizon and layer-based attributes were extracted to understand the possible extent of the reservoir facies and geometry. The P-Impedance and Vp/Vs attributes extracted for Sand-2/2A are shown in Fig. 8 & 9 respectively. Most of the producing wells are located within areas characterized by low P-Impedance and low Vp/Vs, which is in concurrence to our understanding from well log analysis. Further, Facies and Fluid Probability (FFP) study was attempted to understand the probability of occurrence of reservoir sands (Sand-2/2A).

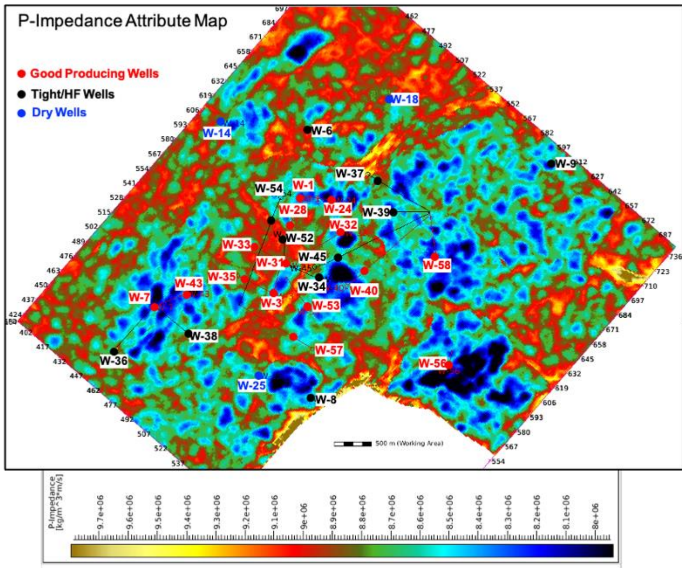

Fig. 8: P-impedance attribute map extracted for Sand-2/2A

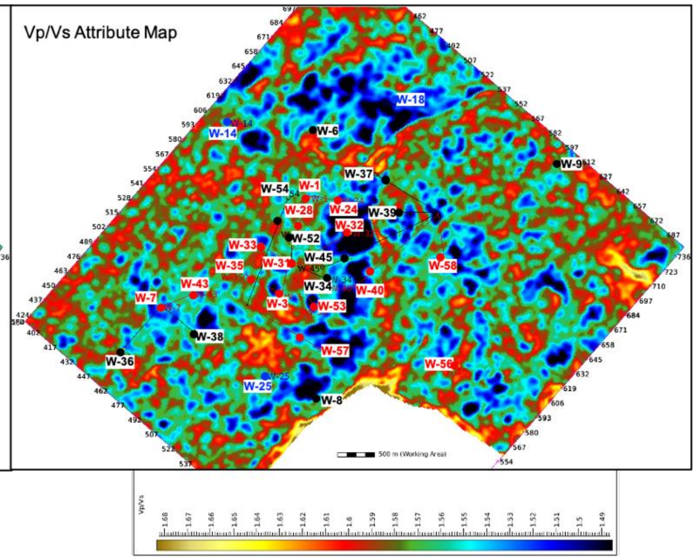

Fig. 9: Vp/Vs attribute map extracted for Sand-2/2A

Facies and Fluid Probability:

Facies and Fluid Probability (FFP) has been carried out to generate sand probability volumes. The Probability Density Functions (PDFs) for each facies were modelled using the cross-plots and histograms of P-Impedance and Vp/Vs as shown in Fig. 10. Accordingly, uncertainty and likelihoods were estimated and using the Bayesian estimates, posterior probability of each facies were determined. It gives facies and fluid probability volumes for each facies (viz., gas sand, brine sand and shale) as well as the most probable facies volume.

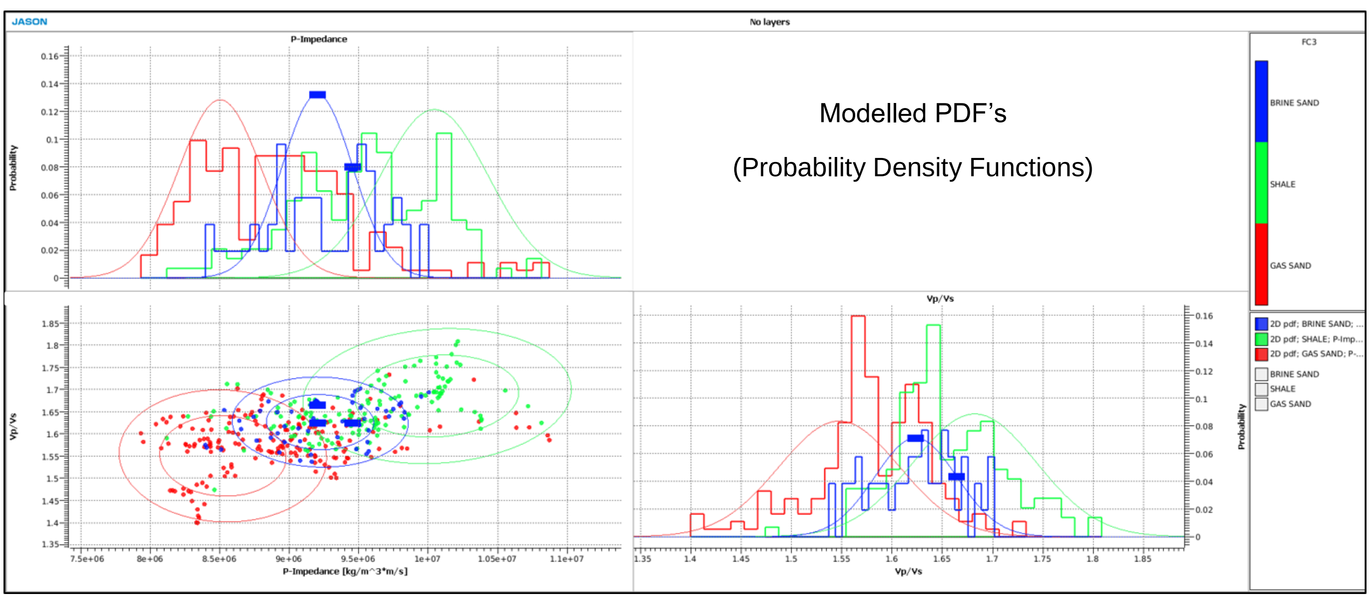

Fig. 10: Probability density functions defined for Facies & Fluid Prediction

Results and Discussions:

Layer based attributes were extracted for Mandapeta Sand-2/2A from gas sand probability volume. 60% and 80% probability cutoffs were applied on the gas sand probability volume to know the most possible and most probable extents of the reservoir facies with varying confidence (Fig. 11 & 12). The areas with more than 80% gas sand probability are having relatively higher confidence in terms of reservoir quality. The sweet spots were identified based on the attribute maps and gas sand probability maps. Based on the attribute studies and derived gas sand probability maps, the subsurface positions of several development locations were optimized. Additionally, the study opened up the areas of exploratory focus in sand-2/2A.

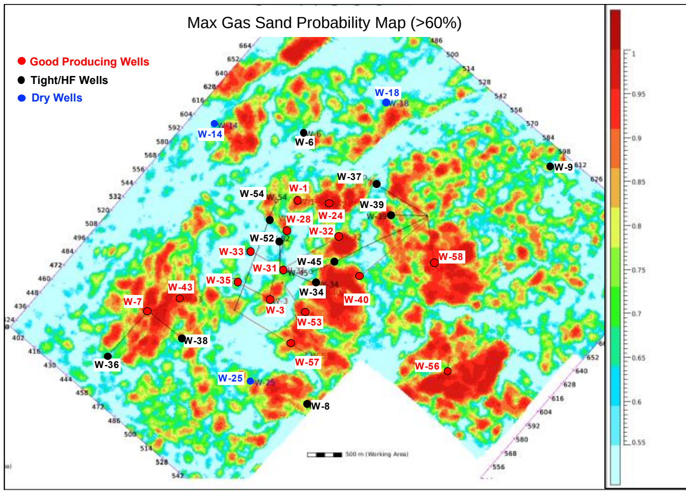

Fig.11: Maximum Gas Sand Probability (>60%) map

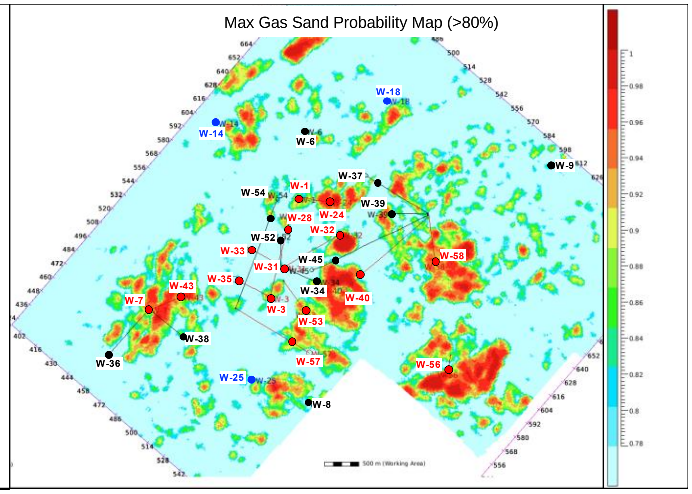

Fig. 12: Maximum Gas Sand Probability (>80%) map

Conclusion:

The reservoir characterization studies carried out in Mandapeta field show that the gas bearing sands are characterized by low to moderate P-impedance and low Vp/Vs. As analyzed in the cross plots of P-Impedance and Vp/Vs, the low P-Impedance and low Vp/Vs areas are relatively good locales for exploration & further exploitation. These areas are largely captured in gas sand probability attributes prepared by combining elastic properties through probability density functions.

Two gas sand probability attribute maps (with 60% & 80% probability cutoff's) were derived and analyzed with the drilled wells, which gave a correlatability of the order of 75%-80%. In terms of confidence, locales with gas sand probability >80% may be considered as the immediate locales for development, followed by locales with gas sand probability >60%. The areas which are dominantly poor facies/shaley are demarcated through very less gas sand probability (probability < 60%).

The study brought out areas where the probability of occurrence of good sand facies is more in terms of gas sand probability attributes. After completion of the study, two development locations were drilled and the results were very close to the predictions.

The attribute studies (viz., P-Impedance, Vp/Vs & gas sand probability) not only helped in optimally placing the development locations but also opened up areas of future exploration potential, especially for Mandapeta Sand2/2A. Integration of reservoir characterization studies with other available geo-scientific data/studies can provide enormous value addition for updation of reservoir model and for future development activities in Mandapeta field.

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