

Seismic Reservoir Characterization of Pay Sands Encountered in Chandrika South Area, Offshore, KG-PG Basin, India – A Case Study

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Summary

Commercial gaseous hydrocarbon has been discovered in well A-1 Chandrika South area, KG-PG basin. The Pliocene hydrocarbon reservoirs comprises of multi-stacked channel sandstones with a net pay thickness of 55 m.

This discovery, first time in NELP area shallow offshore, has given impetus to accelerate probing similar prospects in the block. A few more locations were identified and released to probe similar pay zones in the study area. An inversion study has been undertaken with an objective of delineating the reservoir's lateral and vertical distribution, and also for identifying lithology and fluid thereby validating the proposed locations in the area.

Rock physics modeling were carried out for better understanding the relationship between the petrophysical and elastic properties of the reservoir and non-reservoir zones. The cross plot of P-impedance & Vp/Vs shows clear separation between gas sand and brine sand.

Simultaneous Inversion of AVO/AVA in seismic data has been carried out to derive P-impedance and Vp/Vs volumes. The results of the inversion were analysed through horizon attributes, cross plots and body capture. The channel configuration was brought out through attributes of P-impedance similar to the channel and Fan system obtained from traditional seismic attributes. The probability of occurrence of identified gas charged zones within Pliocene sequence has been evaluated through Bayesian inference (Pendrel, 2006). These results were interpreted in terms of gas sand thickness and mean gas sand probability in the reservoir zone. Using these inputs inplace volumes was estimated. The results of the studies were useful in validating the proposed locations in the block. It was found that a few proposed locations fall outside the gas sand reservoirs. The leads given by this study are likely to give a much needed fillip to mitigate the risk in the exploration efforts in the area.

1. Introduction

The objective of this paper is to better delineation of pay sand discovered in well A-1 to identify its vertical & lateral extension and understand the associated rock properties. Discovery well, A-1 is located in shallow water offshore block of KG-OSN-2004/1, KG-PG Basin. Fifteen wells have been drilled in the vicinity of the KG-OSN-2004/1 block. Consequent upon the discovery of gaseous hydrocarbons from multi stacked channel system in Pliocene for the first time in the NELP-IV block KG-OSN-2004/1, it has assumed greater importance to find out similar features in and around the Block.

Three exploratory locations, A-1, B-1 and C-1 were released to explore the Mio-Pliocene prospectively and two wells A-1, B-1 were drilled and proved to be hydrocarbon bearing from Mio-Plio sequences. A-1 was drilled down to 2368m and tested gaseous hydrocarbons on conventional testing from two objects from Pliocene sequence and second well B-1 (TD: 1930m) tested gaseous hydrocarbons on conventional testing

The block (Fig.-1) is covered by 3D Seismic data (Q Marine 3D survey and shallow water 3D seismic data with water depth of ~8m.). The most prospective play fairways within the 3D data area are of Pliocene and Miocene age, amplitude supported, channel plays, of which the Pliocene Chandrika Channel system and Mio-Pliocene channel system of well B-1 have already proved to be gas bearing. A number of prospects and leads have been identified in these plays at target depths varying between 1500 and 2500m.

2. Geological setup and Basin Evolution

The Krishna-Godavari basin is underlain by an Archaean and Proterozoic Cratonic Basement, consisting of complex gneissic and meta-igneous tectonostratigraphic units. The basement hosts a series of poorly exposed and poorly understood pre-rift, Palaeozoic and Mesozoic basins, which may host source intervals.

Marine incursions become more common in younger parts of these sequences until fully open marine conditions are developed throughout the basin at a regional transgression in the Aptian-Albian. This major transgression is

associated with the final stage of rifting between India and Antarctica. High quality, marine source rocks are developed during this transgression.

A major unconformity marks the end of the Cretaceous across the basin and is associated with a major regional regression and basin ward shift of facies belts. The major delta systems are rejuvenated and thick, progradational; deltaic sequences begin to fill the basin. These Paleocene and Eocene aged pro-delta shales and silici-clastic delta tops are particularly well developed in the KG-OSN-2004/1 block and are associated with both reservoirs and source intervals.

The Plio-Pleistocene sedimentation is dominated by slope shales and associated slope channel and fan systems in the KG-OSN-2004/1 block. Sedimentation is locally controlled by accommodation developed by major gravitational growth faults. Shale diapirism and compression tectonics are commonly associated with these growth faults

Geographically, the block KG-OSN-2004/1 is located off the Narsapur Coast and falls in the inter riverine area of the major drainage systems of Godavari and Krishna. The block is South and Southwest of IA-IF PEL blocks at bathymetry ranging from 0 to >350m. The Northern part of the block defined by the coast line and adjoins the onland ONGC nomination block of 1B PEL. Block is bound to the South/South east by deep water ONGC nomination of block of KG-OS-DW-III and by the G-1-Vashista PML to wards east. The sedimentary cover comprises of syn-rift sediments overlain by Tertiary sediments.

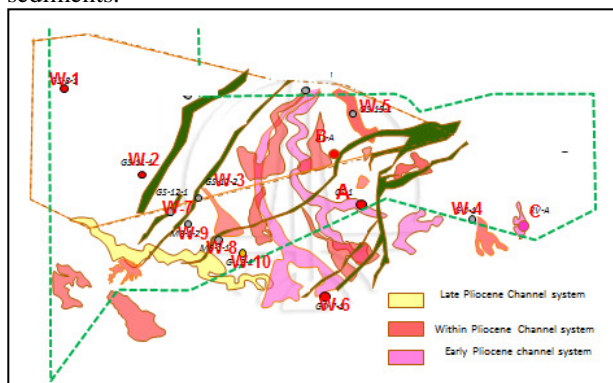


Fig.-1: Location map of block under study

3. Stratigraphy

The stratigraphic frame work of the block consists of sequences ranging from Late Jurassic to Early Cretaceous (Albian – Aptian) Gollapalli to Pleistocene to Recent sediments overlying the Archean basement of varied composition. The NW part of the block falls in the inter riverine area of the Godavari and Krishna rivers and forms the part of the Masulipatnam Bay.

The entire stratigraphic sequence from Lower Jurassic to Recent sediments is preserved and mappable on seismic data, but however, none of the wells could explore the complete Cretaceous sequence and only Upper part of the Upper Cretaceous representing Chintalapalli shale was probed.

4 Input Data

Three wells, viz. A-1, W-8 & W-3 falling in the study area have been considered for the reservoir characterization study. Out of these three wells, A-1 is a gas producer from stacked channel of Pliocene sequence. In rest of the wells, reservoir facies are poorly developed. Both acoustic and shear sonic data are recorded in well A-1, while in other wells only P-sonic was recorded.

The study area is covered with 200 Sq.Km of 3D Q-marine seismic data with 3 angle stacks (0-15, 15-29 and 28-42 degrees). The seismic horizons corresponding to top of MTC and top of horizon within Pliocene sequence were considered for generating the low frequency model for inversion.

5 Methodology

5.1 Data QC, Conditioning & Feasibility study

Quality of seismic data is very important for faithful reproduction of elastic properties. Therefore QC of seismic data, well log data and interpretation data was done to assure quality input for inversion study. It was observed that well data needs some conditioning to remove bad data at some places and fill the patches in density logs. Logs were conditioned before using them for rock physics modeling and low frequency modeling (Figure.-2). QC of seismic data was done to observe the frequency content of seismic data, clipping of seismic data or any other processing artifacts. Seismic angle stacks found suitable for performing inversion.

In order to effectively map pay sand using inverted elastic properties, it is required that pay sand should show separation with other lithology on P-Impedance and V_p/V_s crossplot. In this study, Pay sand is showing good separation from other lithologies (Figure.-3).

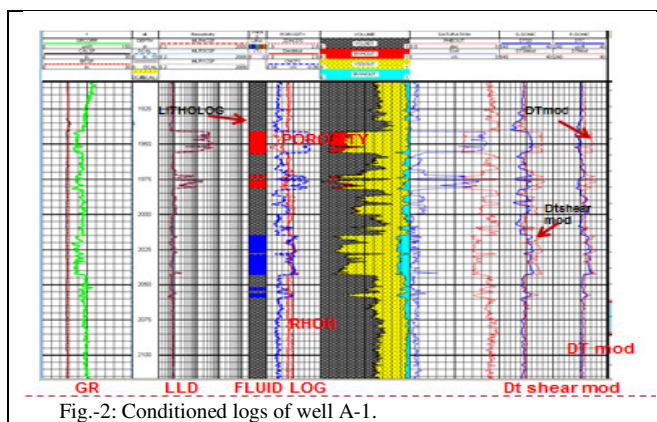


Fig.-2: Conditioned logs of well A-1.

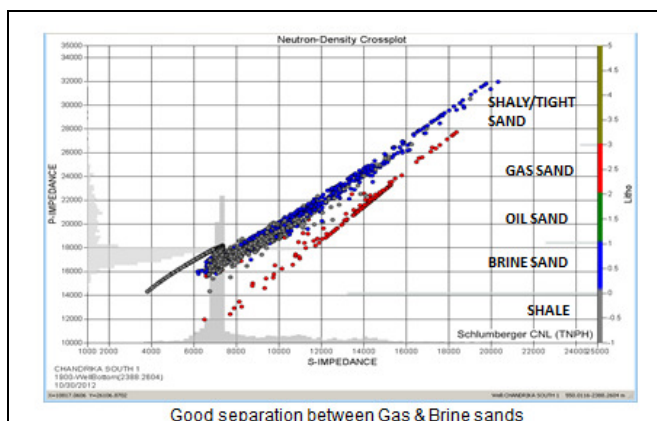


Fig.-3: Cross plot well: CS-1 (P-Impedance Vs. S-impedance)
Indicates good separation between pay and non-pay in crossplot of P-impedance versus S-Impedance

5.2 Log correlation

Well log correlation of W-1, W-2, W-3, CS-1, W-4, W-5, AL-1, W-6, W-7, W-8, W-9 and W-10 have been carried out along dip & strike lines. The correlation in all these profiles indicate that Channel pay sands encountered in well A-1 is isolated and confined to around the well. In well B-1, discovery of gaseous hydrocarbon is from sub-conformity set up of Miocene sequence. Barring these two wells, in no other wells equivalent channel sands are seen developed. In general in all the wells reservoir facies are poorly developed or absent. The reservoirs encountered in well A-1 is characterised by Resistivity of 30-50 Ohm-m, porosity: 26%, Sw: 37% and produced gas @ 1,27,116 m³/d (16/64") and the interval 1972-1974 & 1975.5-1978.5: resistivity: 3-15 ohm-m, porosity : 21-23%, Sw: 55-61% and produced gas @ 1,72,000 m³/day through 20/64" choke.

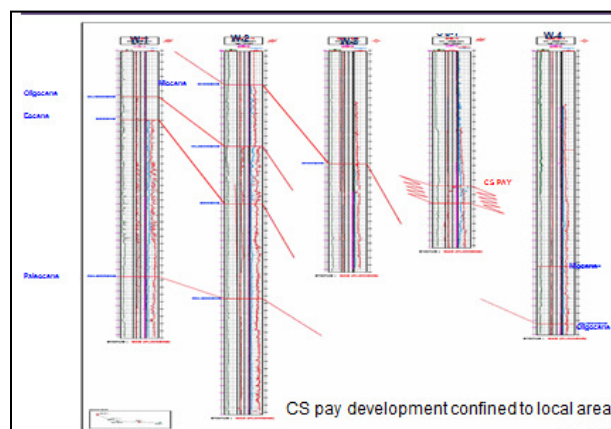


Fig.-4: Electro log correlation of wells W-1, W-2, W-3, A-1 & W-4

5.3. Petrophysical study

Using the conditioned logs, Petrophysical evaluation of the zone of interest (MTC Base to Pliocene Top) was done based on deterministic method. The attribute logs such as acoustic impedance, shear impedance, V_p/V_s ratio were generated and used to produce cross plots colour-coded by Litho log. Fig.- 3 shows a cross plot between P-impedance and V_p/V_s . A good separation is indicated between gas sand facies and other (brine, shale) facies.

5.4 Lithology Definition

Based on the detailed petrophysical study, lithological Definition was made and gas sand & brine sands have been clearly demarcated

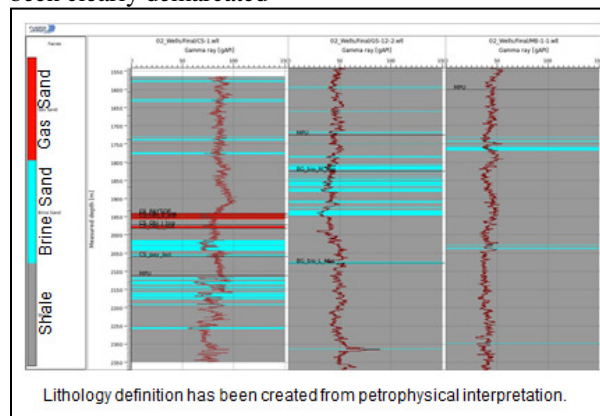


Fig.-5: Lithology definitions

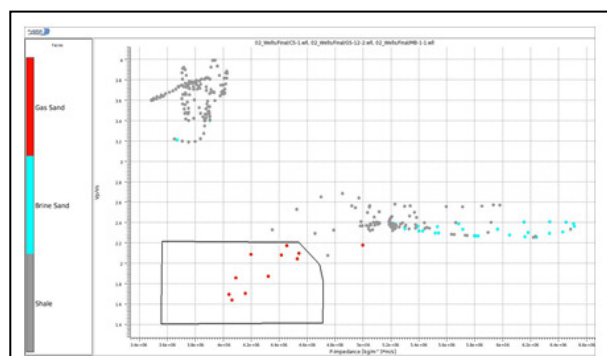


Fig.-6: Cross plot between P-impedance & Vp/Vs in A pay zone depicting good separation between Gas sand & brine

5.5 Low Frequency Model:

The horizons were conditioned by removing kinks, filling gaps, interpolation and smoothening. These horizons were used to prepare a structural framework through which well properties, viz. P-impedance, Vp/Vs and density were interpolated to generate low frequency model (LFM). Figure.-7 shows the LFM for P-impedance.

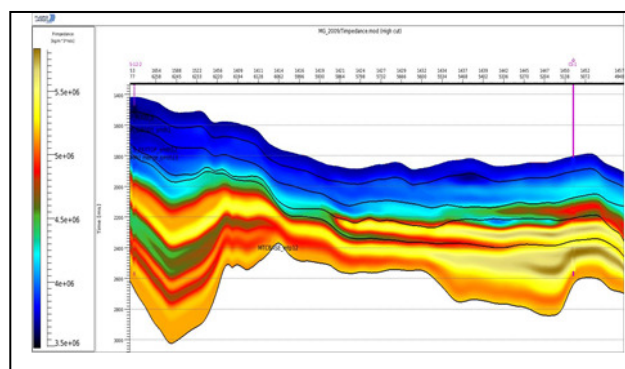


Fig.-7. Low Frequency model as an input to Inversion

6 Inversion

Sparse Spike Simultaneous Inversion (Debye, 1990 & Pendrel 2006) was carried out using three angle stacks. The output volumes of P-impedance and Vp/Vs exhibited good match at the wells substantiating the accuracy of inversion results. Figures 9 & 10 show representative sections of band pass and full band P-impedance and Vp/Vs respectively.

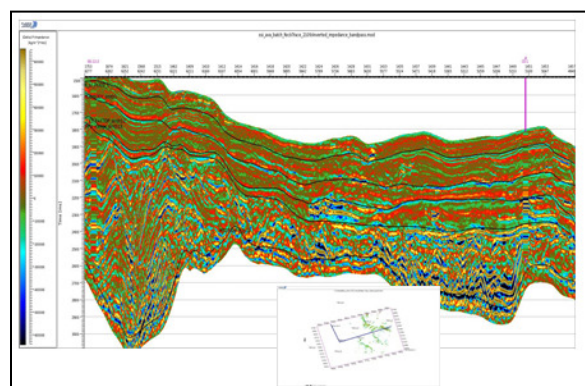


Figure. - 8a: Section View of Band Pass P-Impedance

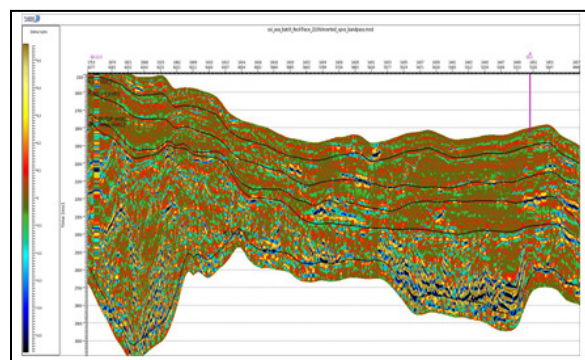


Figure. - 8b: section View of Band Pass Vp/Vs

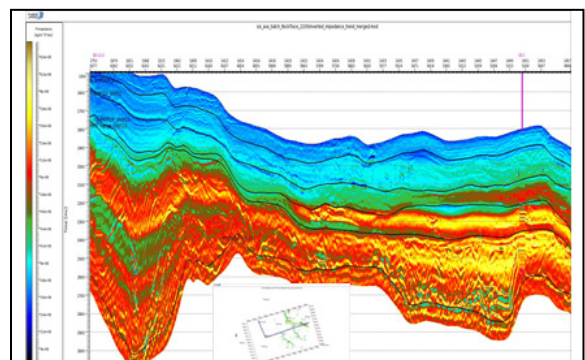


Fig.-9a: Section View Full band P-impedance

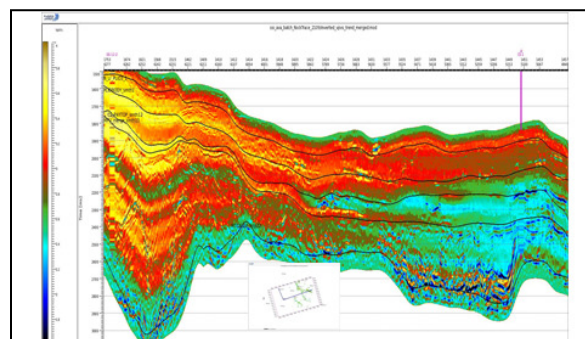


Fig.-9b: Section View of Full Band Vp/Vs

6.1 QC of Inversion Results

Inverted P-impedance and Vp/Vs exhibiting good match at wells (Fig.-9). The correlation between inverted P-impedance & Vp/Vs with that of well logs was found to be 96% and 93% respectively. (Fig.-10).

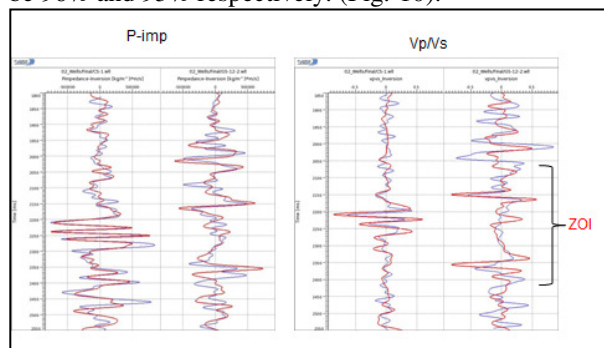


Fig.-9: Inverted Pseudo log (Red) overlain on wire line log (blue) in seismic bandwidth.

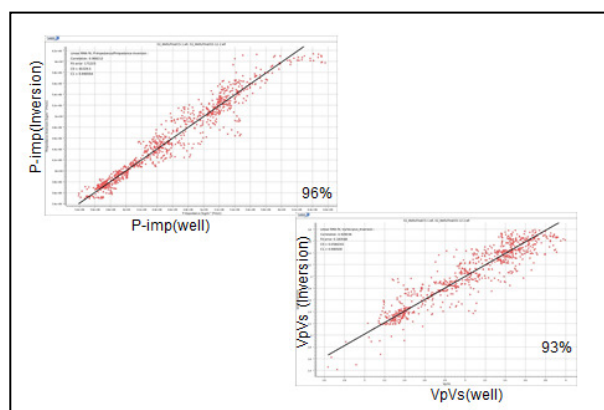


Fig.-10.: Cross plot of pseudo logs from full band Inversion results and wire line logs in seismic bandwidth.

7 Analysis of the Results

The results of the inversion study has been analysed through horizon attributes, cross plots and body capture. The RMS attribute extracted from inverted P-impedance volume and body capture has manifested channel and Fan system as that of seismic attributes (Fig.-13). The attribute extraction from inverted P-impedance has brought out two channel systems of which one of the channels is fanning out in the block while other one continued into basal part. Nevertheless, the entire channel and fan system is not charged with gas but partly. The cross plot between inverted P-impedance and Vp/Vs has clearly indicated separation between gas sand and brine sand in inversion rock properties.

Further, probability of occurrence of identified gas charged zones within Pliocene sequence were calculated. Based on the same, gas sand thickness and mean gas sand probability maps were generated. (Fig.-15 and 16). Using these inputs inplace volumes was estimated.

8 Evaluation of the proposed locations in the block

The results of the studies were useful in validating the proposed locations in the block. It was found that a few locations are located outside the gas sand reservoirs and facilitated to position at a right location (Fig.-15).

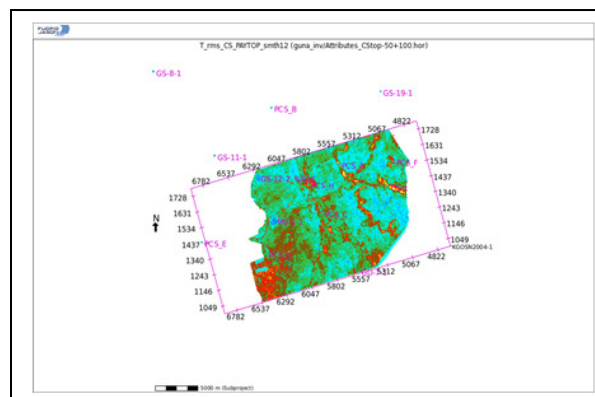


Fig.-11: Channel configuration from RMS attribute of Seismic

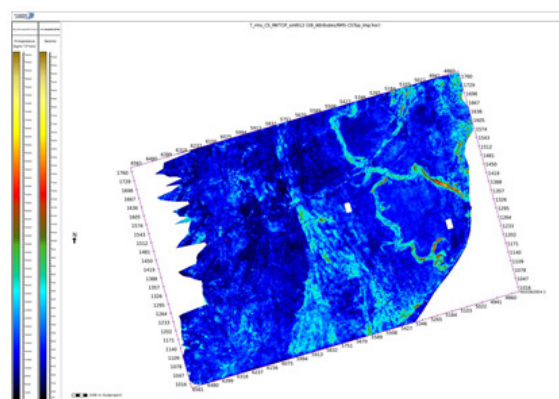


Fig.-12: Channel configuration from RMS attribute of P-impedance

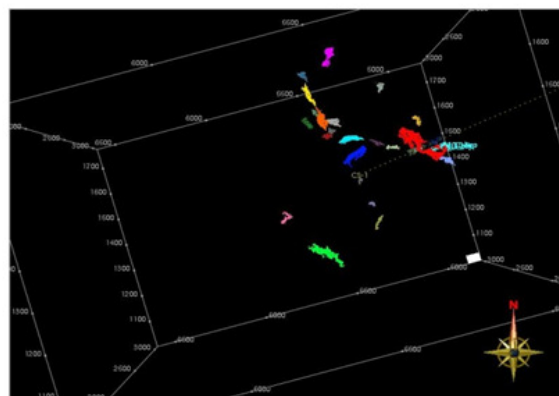


Fig.-13: Body capturing of Well A pay sand

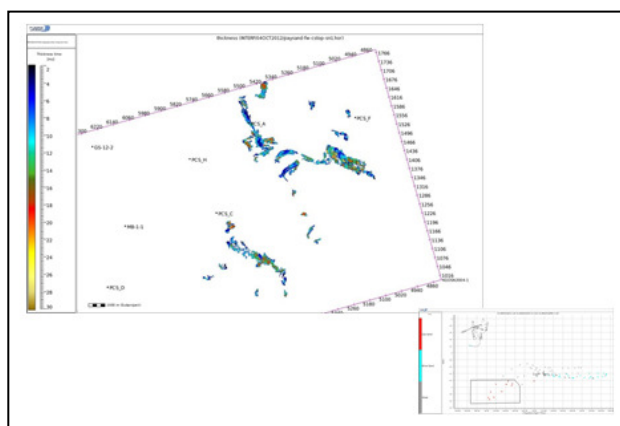


Fig.-14: Gas Sand thickness map of CS pay

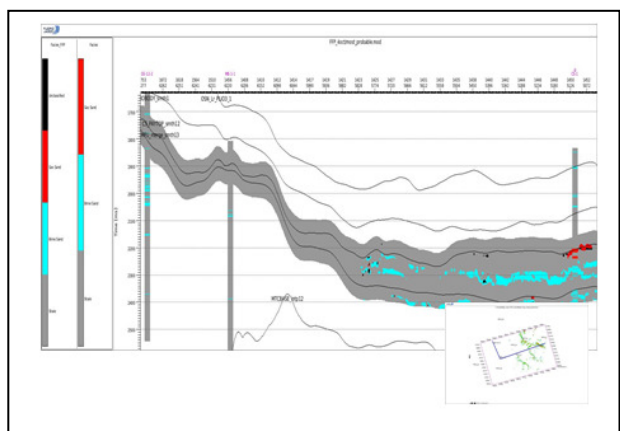


Fig.-15: Most probable facies along a section through well in CS pay layer

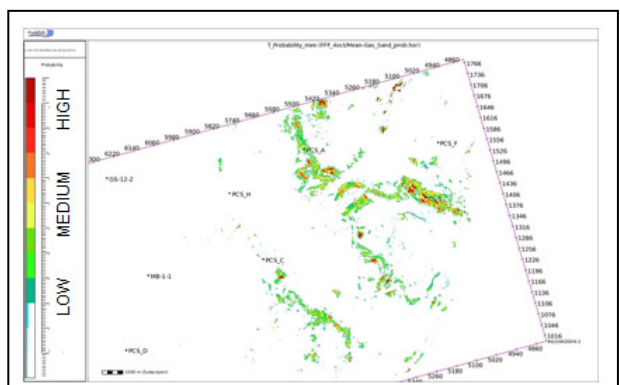


Fig.-16: Mean gas sand probability map in CS pay zone

9 Conclusion:

1. Well log correlations along dip & strike indicates that the channel pay sand of well A is not developed extensively. (Fig.-4).
2. Separation of Gas sand from brine sand is amply defined through P-imp & VpVs which is not possible from P-imp & Gamma ray(Fig.-6)

3. Channel configuration from RMS attribute of P- impedance is distinct as that of RMS attribute of seismic(Fig.-12)
4. Identified gas charged reservoirs within Pliocene sequence through Bayesian inference.(Fig.-15)
5. Based on identified gas charged reservoirs, prepared gas sand thickness and mean gas sand probability maps were generated.(Fig.-14 and Fig.-16)
6. The inversion results enabled to evaluate the proposed locations in the block and indicate that a few proposed locations are falling outside the gas sand area
7. The result of the Seismic Reservoir characterization would be useful in mitigating the risk in the exploratory efforts

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