

## Delineation of discrete reservoir sands in Panna formation using Geo-statistical inversion: A case study from western offshore basin, India.

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### Keywords

Broad-Band seismic, Geo-statistical, pdf, Variogram, Random forest method and ML

### Abstract

Geo-statistical inversion technique can be applied to quantitatively relate well and seismic data, analyze quantitatively the resulting map and estimate the probability of success directly from the available data. The aim of the present work is to delineate the extent of discrete reservoir facies of Panna formation in B-157-127 area of Western offshore Basin, India. Panna is mainly dominated with shale sequences with intercalations of sand and coal facies. Reservoir characterization of hydrocarbon bearing sands is a challenging task in this area as sands are not having similar elastic properties in all the drilled wells. To tackle the above issue a geostatistical pre-stack inversion methodology was adopted. Rock physics modelling were carried out in a few wells and in remaining wells, wherever required, S-sonic as well as P-sonic logs were predicted using machine learning. The pre-stack geostatistical inversion outputs helped in mapping of sand dispersal pattern in Panna formation with a good confidence and matching with the well observations.

### Introduction:

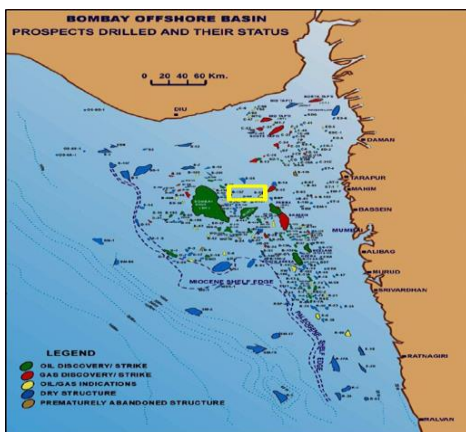


Fig.1 Geographical location of the study area (Yellow polygon)

The study area falls in the western offshore basin of India (Fig.1) with a bathymetry is around 40m. The major reservoirs are Limestone in Bassein and Clastics in Panna formations respectively. Mumbai Offshore Basin is proved to have been endowed with intricate source, reservoir and seal facies assemblage in the Panna Formation of Paleocene-Early Eocene age. The syn-rift sediments comprising lacustrine source rocks are highly potent and capable of generation of hydrocarbon. The recent studies have shown multiple mature source intervals within Panna Formation with organic matter and excellent generation potential. The average TOC (total organic carbon) of Panna Formation ranges from 0.5 – 3.0% and VRo (Vitrinite reflectance) as 0.4 – 3.6% (fair to good maturity). Strati-structural entrapment model is envisaged for the prospects in the Panna formation. The Panna clastics, which have reservoir facies, are derived from Trap/Granite/ Metamorphic Highs and deposited in continental to marginal marine environment. The transgressive marine shale within Panna Formation acts as seal. The black carbonaceous shale, which is deposited in marshy near shore environment also acts as top/lateral/juxtaposition seal locally over individual sand reservoir.

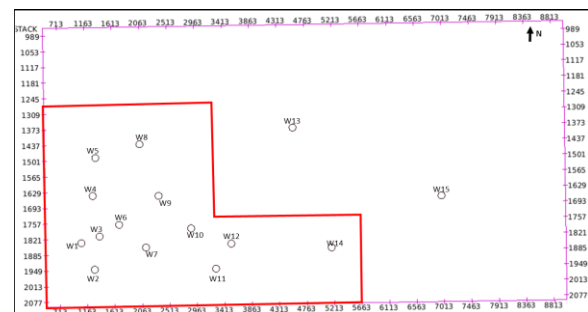


Fig.2 Base map showing study area with drilled wells. Red polygon indicates area of interest for geostatic inversion

Broad band seismic data of bin size 25mx6.25m with low to high impedance as peak in the seismic is available in the area. Base map is showing the drilled

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wells in the area (Fig.2). The net pay of reservoir sand in Panna formation is around 6m. The major challenges in delineation of these reservoirs are to find spatial extent as these sands are having different elastic properties in different wells. Fluid level discrimination on the basis of P-impedance and  $V_p/V_s$  is not possible even at log level as demonstrated in cross plot coloured with facies. Deterministic inversion studies will not help in fluid discrimination in such a scenario but it will have some interpretative value. It was decided to merge reservoir facies as sand, because of elastic properties overlap, and perform pre-stack geostatistical inversion.

### Methodology Adopted:

#### Data QC:

Seismic offset gathers were analyzed and QC was done for multiple attenuation and flattening of the events at far offsets. There was a significant improvement in the data after conditioning making amenable for pre-stack geostatistical inversion (Fig.3).

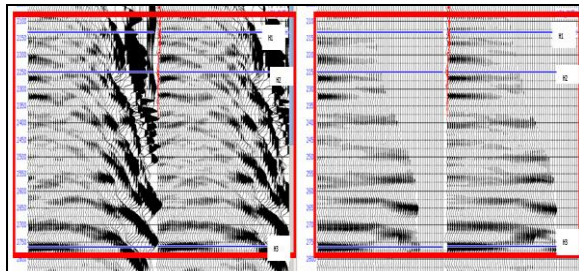


Fig.3 Data enhancement within Panna section.

Offset gathers were converted to angle gathers considering angle up to 42 degree. Six partial angle stacks were generated viz, 4-12deg, 10-18deg, 16-24deg, 22-30deg, 28-36deg, 34-42deg for inversion process. Amplitude spectrum shows 4-50 Hz @12db level. The zone of interest for project was Bassein and Panna formations with main focus on Panna. Three horizons were used which represents H1 (Bassein top), H2 (Panna top) and H3 (Deepest markable reflector, DMR). An interpreted seismic section along with interpreted horizons are shown in Fig.4. Out of 15 drilled wells, only 10 wells were having shear recorded but there was quality issue. Rock physics modelling was carried out in 5 out of 10 wells with recorded shear sonic to address the quality issue.

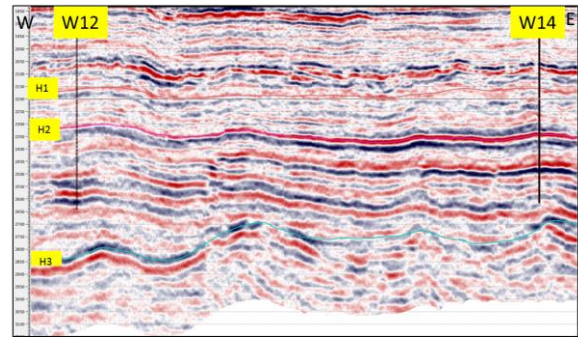


Fig.4 RC seismic section showing interpreted horizons

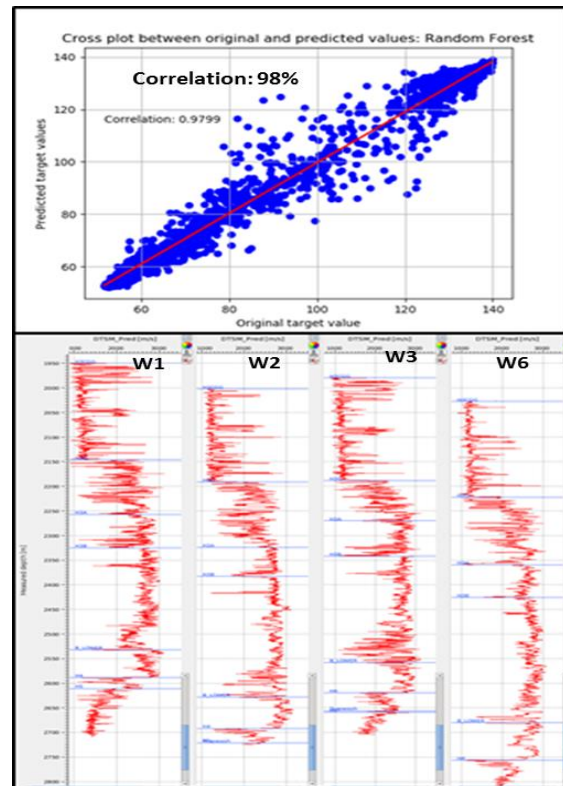


Fig.5: Shear log prediction in wells W1, W2, W3 and W6

Rock physics modeled logs along with good quality available recorded logs in some wells were used as input to predict shear sonic data in other wells. Prior to that missing P-sonic logs in some of the wells in zone of interest were also predicted using machine learning. Shear sonic predictions were made using DT Rhob, NPHI, GR as input and rock physics modeled shear logs as target. Random forest machine learning

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model was found to be good for shear prediction (Fig.5). Rock physics modeled as well as good quality recorded shear sonic logs were spliced with the predicted shear sonic, wherever it was available, to honor the original data within the zone of interest.

### Cross Plot Analysis & Feasibility Study:

Cross plot of P-Impedance and  $V_p/V_s$  with lithofacies as third axis for all 15 wells together within Panna formation shows nearly complete overlap of hydrocarbon and brine facies, indicating that fluid level discrimination is not possible even at log scale as shown in Fig 6(a). It was decided to merge all the reservoir facies as sand. In this case the separation of the sand from the rest is better as depicted in cross plot in Fig 6 (b).

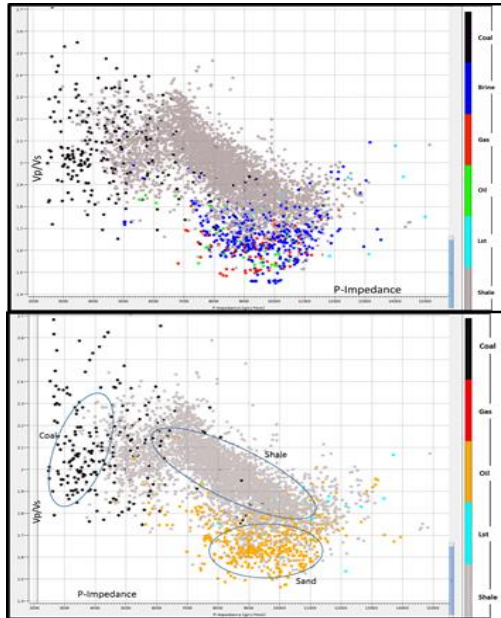


Fig.6: Cross plot analysis showing significant overlap between brine and Hydrocarbon bearing sands (top). Separation between Coal, Shale and Sand is clear after merging of facies (bottom).

In seismic bandwidth, the discrimination will deteriorate because of thin sand reservoirs. Same crossplot of P-impedance and  $V_p/V_s$  when upscaled to 1 ms without frequency restriction indicates separation of sands from the rest although overlap is still considerable with shale. This is the motivation for geostatistical inversion. Although some sand facies are having overlap of elastic properties with shale as

highlighted in Fig. 6b, will introduce uncertainty in detection of sands. Finally three facies (coal, shale and sand) were considered for pre-stack geostatistical inversion.

### Pre-stack Deterministic Inversion:

Well based wavelets extraction was done using all 15 wells and six partial angle stacks, show consistent phase in seismic bandwidth. Well to seismic tie at gather level using multiwell wavelets were done with a good confidence within the zone of interest. Inverted P-impedance and  $V_p/V_s$  sections are shown in Fig. 7.

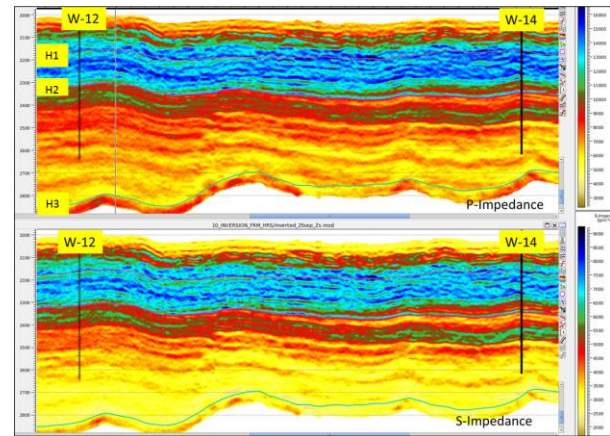


Fig.7 Inverted section passing through well W12 and W14 (from west to east) showing deterministic inversion results.

Corresponding logs are overlaid on the inverted sections. A good match between inverted and log filtered in seismic bandwidth, confirms the good quality inversion. Cross plot between extracted inverted trace and logs filtered in seismic bandwidth show a very good correlation both for P-impedance as well as S-impedance (Fig. 8). But geobodies captured from the deterministic result are not representative of the sands exclusively as there is a lot of overlap in shale and sand facies as shown in the cross plot. In such a scenario, pay sands should be mapped in terms of probability of occurrences. But this result gave some idea of lateral extent and orientation of geobodies of interest. These information about shape, size and orientation of the geobodies was used in geostatistical inversion as prior information. It is also used to QC the results of geostatistical inversion as mean of a large number of realization of geostatistical

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inversion compares well with the deterministic inversion results.

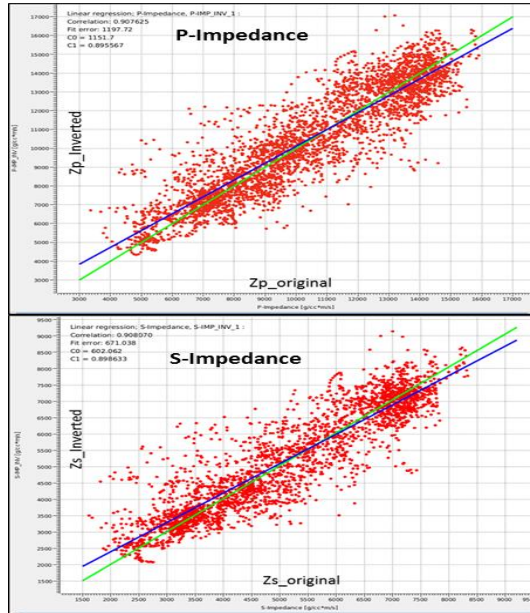


Fig.8: Cross plot between Original and inverted elastic properties

### Geo-Statistical Inversion:

A geostatic inversion was conducted to improve the inversion details and access model uncertainty. The uncertainty becomes even more important where sand thickness is beyond seismic resolution. The main objective of GI studies is to delineate the most probable distribution of reservoir facies. This process involves geostatistical modelling and deterministic inversion simultaneously in a statistically rigorous way. It assumes that subsurface is a realization from a given geostatistical model of rock and reservoir properties (e.g. Elastic parameters like P-Impedance, S-Impedance, Lithology). Pre-stack GI was carried out using Markov Chain Monte Carlo technique for geostatistical modeling and model based pre-stack inversion algorithm. Pre-stack geostatistical inversion was carried out in a specified area where well W13 and W15 were not included. The benefits of geostatistical inversion are:

1. Joint inversion of elastic properties (P&S impedances) and lithology
2. Uncertainty estimation for risk assessment.

The work flow of pre-stack geostatistical inversion is shown below:

- a. Geostatistical modelling and simulation
- b. Optimization for S/N and other parameters for modelling
- c. Pre-stack geostatistical inversion (Unconstrained & Constrained)

Geostatistical modelling process involves the determination of the probability distribution function (pdf) associated with each facies and associated uncertainty. Zone of interest was divided into three layers to capture the vertical heterogeneity. Fig. 9 is showing the probability distribution function (pdfs) estimation using well data for all the three facies, coal, shale and sand and their elastic properties for Panna.

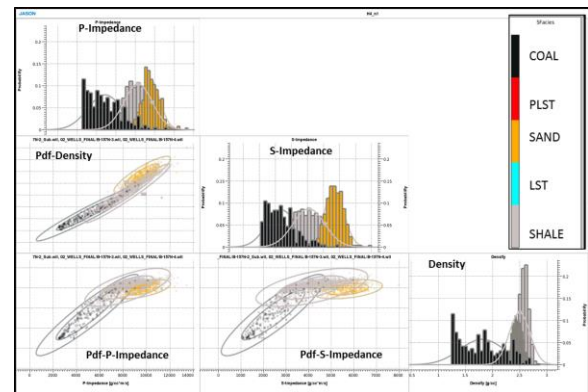


Fig.9: pdf fitting on elastic properties for sand facies in Panna

A variogram is a geostatistical tool that quantifies and models the spatial continuity of the property. Vertical variogram were estimated using facies and elastic logs of all the considered wells. The lateral variogram for these properties are inferred from the geobodies extracted from pre-stack deterministic inversion. The tested ranges of vertical and horizontal variogram for discrete and continuous properties within Panna formation is given in Fig.10. Using all the modelling parameters, several simulations were run. After QC of simulation results, optimal model parameters were decided (Table. 1). Since all the realizations are validated by seismic, signal to noise ratio of seismic data play an important role. The objective of estimating S/N ratio is to have estimation of level of noise present in the data so that model can be constrained to the seismic.

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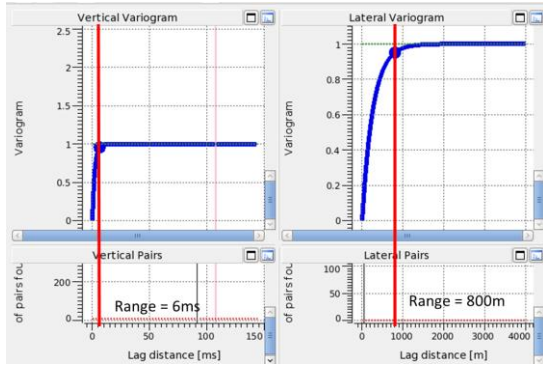


Fig.10: variogram incorporated in the geostatic pre-tack inversion

S/N maps of deterministic inversion as well as wavelet estimation process show optimum S/N of around 11 dB.

variogram		S/N
Vertical	Horizontal	
From wells	From geobodies	
Type	Discrete ( Gaussian) Continuous (Exp.)	
Range	6-10ms / 600-1000m	

Table. 1: Final GI parameters after several iteration of testing

Pre-stack geostatistical inversion results can be generated in two ways, namely a) Unconstrained and b) Constrained. In unconstrained process, no well is used to constrain the results. Rather all the information comes from seismic alone through modelling and inversion process. It is an iterative process. Modeling and inversion parameters are revisited unless the major feature compares well with observed ones from hard data. In constrained inversion process, all wells are directly involved along with seismic information to optimize the modelling parameters. 15 wells were used in constraining both facies as well as elastic properties. Comparison of prior and posterior proportion as well as pdfs of elastic properties of facies for one of representative realization is shown in Fig. 11 & 12. It shows reasonably good match between prior and posterior facies proportion as well as pdfs.

After all optimized parameters finally, constrained geostatistical inversion was run for 50 realizations. Output consists of sand, shale and coal probability volumes (frequency volume) along with the mean of elastic property volumes. Geostatistical realizations show highly detail picture in zone of interest as

compared to P-impedance and S-Impedance volume from deterministic inversion.

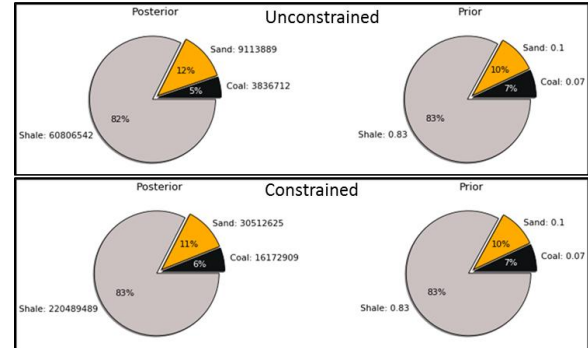


Fig.11: Comparison of prior and posterior facies proportion for both unconstrained and constrained geostatistical inversion.

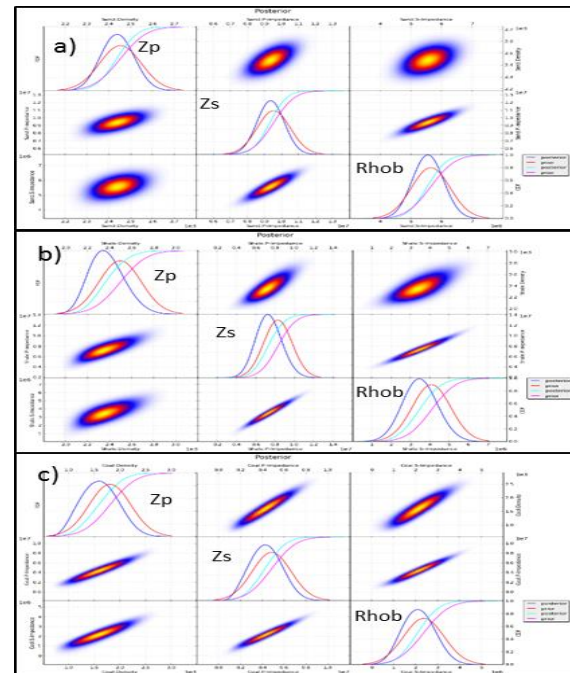


Fig.12: Prior and Posterior distribution of facies within Panna

A representative Sand probability between W12 and W14 wells is given in Fig.13. Arbitrary line of coal probability section (Fig.14) shows the Coal probability is increasing towards eastern side of the study area which is well calibrated with drilled wells. Sand bodies in Panna brought out through GI are discrete in nature as shown in the sand probability section. Well observations also reveal the same fact

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that the sands are discrete. Well W4 is oil bearing while W5 is gas bearing in Panna formation but W-4 is structurally shallower than the well W-5. This is only possible when these two reservoirs are discrete. Sand probability section also supports the same assumption (Fig.15).

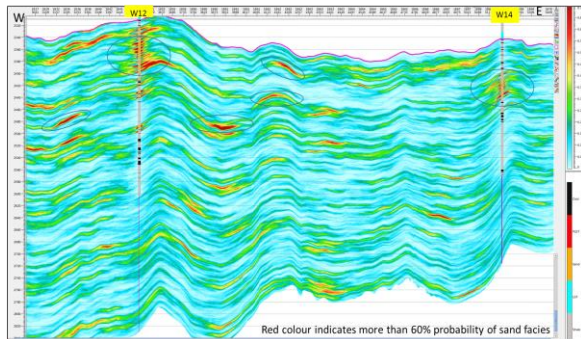


Fig.13 showing most probable distribution of sand facies. Sand distribution is in discrete in nature (in ellipse) within Panna formation

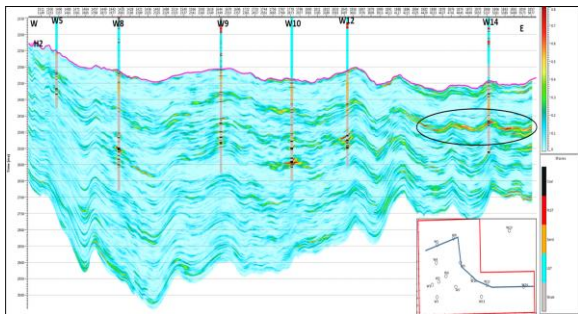


Fig. 14 Coal Probability Section showing probable occurrences of coal is increasing towards eastern side (black polygon)

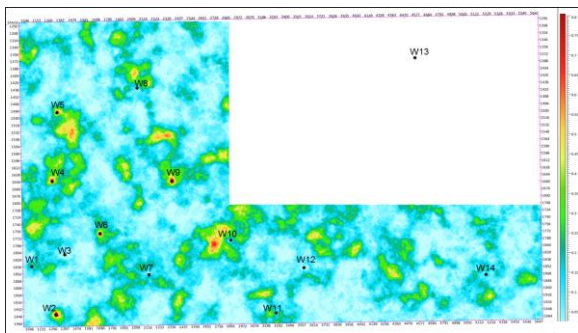


Fig.15 sand probability map close to H2 top (9th layer) showing distribution of most probable (up to 80%) occurrence of sand.

Geobody extraction close to Panna pay reveals the sand dispersal is discrete in nature which is shown in Fig.16.

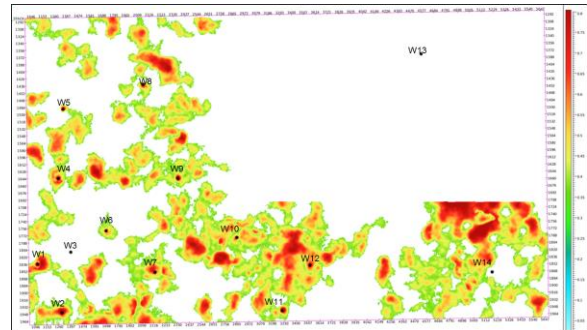


Fig.16: Geo bodies map showing mean sand distribution close to H2 within Panna.

**Conclusions:**

Probability volumes from pre-stack geostatistical inversion broadly explain the well observations and are good in quality. Geobodies extracted from the sand probability volume depicts the sand dispersal pattern and in agreement with the geological understanding of the area. Thin sands at different levels could be deciphered keeping in view the associated uncertainties. Interpreting sand geobodies by considering higher probability range will reduce risk and uncertainty.

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