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Pre-Stack Inversion for Reservoir Characterization of Jambusar Block of Western Onshore Basin of India: A Case Study

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Summary

Rock-property-related attributes are easier to interpret than seismic reflectivity, which is related to interface between zones of contrasting mechanical properties. Inversion of seismic reflection data for various lithological and petrophysical attributes is used broadly to characterize reservoirs and to predict pore fluids. The P-wave acoustic impedance provides the initial basis for constructing such attributes, and its S-wave counterparts and related properties like Poisson impedance reveal AVO properties in pre-stack seismic data. In the present work, pre-stack inversion study was carried out in an area having 22 wells. But elastic logs were available in only 13 wells of which only one well was having shear sonic log. Shear sonic logs were predicted using multi attribute regression for remaining wells. Detailed rock physics analysis and Simultaneous angle dependent inversion were carried out to have an understanding of the likely anomaly for hydrocarbon bearing sediments. Rock physics analysis indicates that histogram of P-impedance doesn't show any discrimination between hydrocarbon and non-hydrocarbon bearing zones, while histogram of Vp/Vs shows some discrimination. Crossplot of P-impedance versus Vp/Vs logs show moderate to high P-Impedance and low Vp/Vs for hydrocarbon bearing zones.

***Keywords**: Pre-Stack Inversion, Reservoir Characterization, Cambay Brain*

Introduction

The study area, of nearly 52 Sq. Km, lies in the south western part of Jambusar field of Cambay basin, Gujarat (Fig. 1). Other producing fields are there adjacent to this area. Sands of Hazad member are the main pays of which GS-6 (JS-I) is the most prominent one. The objective of this study was to characterize the GS-6 and GS-4 pay sands in Hazad formation and to decipher the most probable distribution through pre-stack inversion, if feasible.

Cambay shale, which is widespread, thought to be deposited in brackish to marine environment during Lower Eocene, is acting as kitchen for hydrocarbon generation. Cambay shale is overlain by deltaic sands of Hazad member of Mid Eocene age are main reservoir rocks. Hazad sediments were deposited as distributaries aligning N-S to NE-SW direction with deltaic progradation to the SW direction. The dominant clastic input was from N with variation from NE and E as well. Hazad sands were overlain by the marine transgressive Kanwa Shales of Mid Eocene which is acting as cap rock.

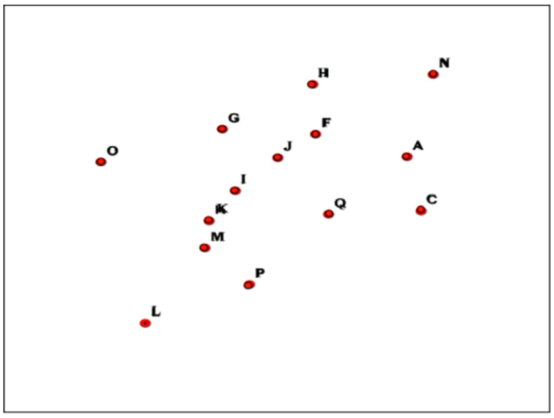

Fig.1 Base Map showing area of interest along with the wells used for studies.

Conventional G&G interpretation of this area have been done several times leading to drilling of number of wells. The accumulation of hydrocarbon is well established in the area. Rock physics analysis shows that only on the basis of P-Impedance, It is difficult to separate hydrocarbon and non-hydrocarbon bearing zones. But histogram of Vp/Vs

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shows most likelihood of occurrence of hydrocarbon bearing zones in low Vp/Vs range. In this situation, post stack inversion will not help in reservoir characterization. Pre-stack inversion studies were carried out to decipher the most probable distribution of aforesaid pay sands.

Methodology

Data QC and Conditioning

Seismic data used for reservoir characterization need to be conditioned to remove as many undesirable effects as possible. These effects that are commonly removed or reduced in pre inversion gather conditioning are random noise, NMO stretch, and non-flat reflections. In the present study, all the gathers were examined at regular interval and minor problems related to multiples and random noise was removed. Residual alignment of events within gather was done by applying trim statics. Depth of interest varies from 2225 to 2550m (Fig: 5) from north-east to south-west in the area with zone thickness of approximately 65-90m (~ 80100ms TWT). For reliable and stable prestack inversion, gather should have long enough offsets. Unfortunately, in this data maximum offset is only 2800 m which may limit the stability of higher order solutions

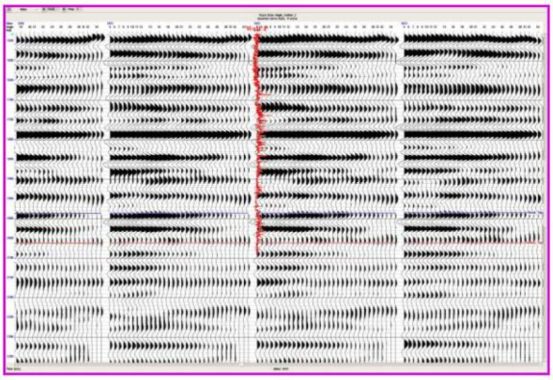

Fig.2 Angle Gather with well P displayed

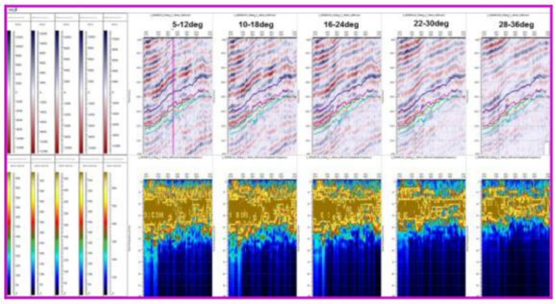

Fig. 3 Data bandwidth is around 10-40 Hz(Far stk) to 8-45 Hz.(near stk)

resulting in uncertainty in Vp/Vs estimation. The horizons provided were interpolated using triangulation method and smoothed over 11 IL X 11 XL for computing an initial model.

After conditioning of seismic gathers in offset domain, angle gathers (Fig.2) were generated using the RMS velocity. Five angle stacks viz., 5-12deg, 10-18deg, 1624deg, 22-30deg & 28-36deg were created from the conditioned gathers.

The seismic bandwidth is approximately 10-40 Hz with dominant frequency ranging between 20-25Hz (Fig.3). The amplitude histogram display of the seismic data indicates Gaussian distribution, no clipping and skewness.

Shear Sonic Prediction & Validation using Multi Attribute regression

Out of 13 wells which were having Sonic and Density logs in zone of interest, only one well, P, was having Shear Sonic log. For remaining 12 wells, shear sonic log was predicted using multi attribute regression in zone of interest i.e. Hazad Top to Hazad Base using other logs. The multi attribute relationship was derived in well P and applied to other wells to generate shear sonic log. Attribute vs. error plot was generated using five attributes (Fig. 4).

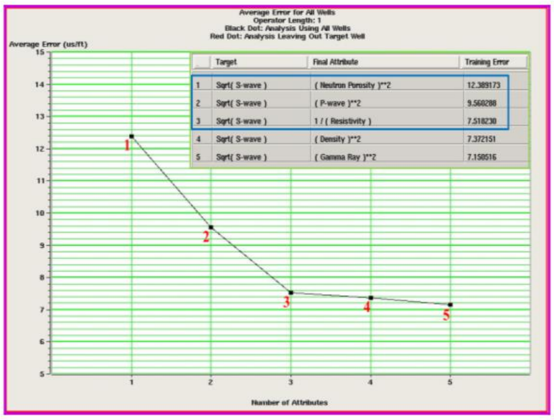

Fig. 4 Multi-attribute analysis for prediction of shear sonic log in well P. Considerable error reduction is evident using first 3 attributes (Neutron Porosity, P-wave and Resistivity)

It was predicted (Fig. 5) using these three attributes. Shear sonic predictability with NPHI, DT and Resistivity are 89.2%, 84.7% and 78.5% respectively. Correlation between predicted and actual shear sonic is 95.97% which is very good (Fig. 6). QC of logs at all the 13 wells in zone of interest were done by cross plotting P-Impedance and Vp/Vs and verification with reference to respective pay and non pay zones are found to be in good agreement (Fig.7) with observations.

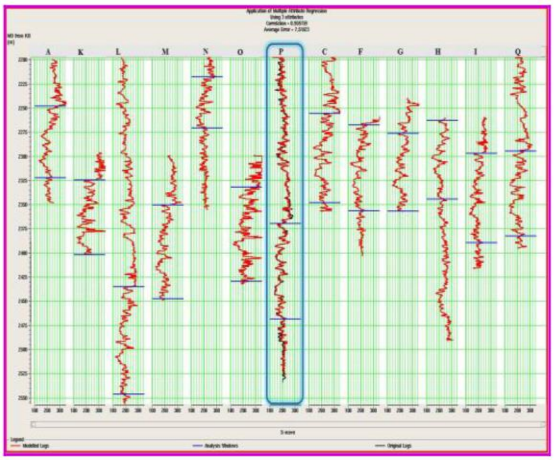

Fig.5 Predicted shear sonic log in all 12 wells

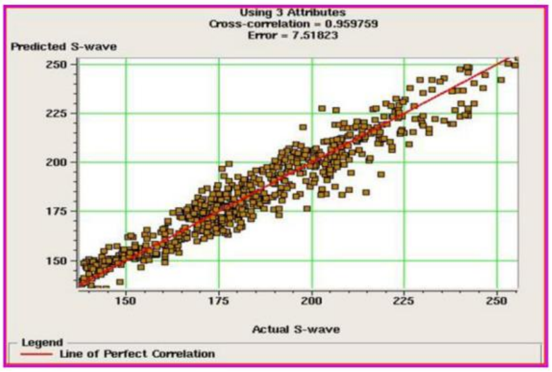

Fig.6 Correlation between predicted and actual Shear Sonic (95.9%)

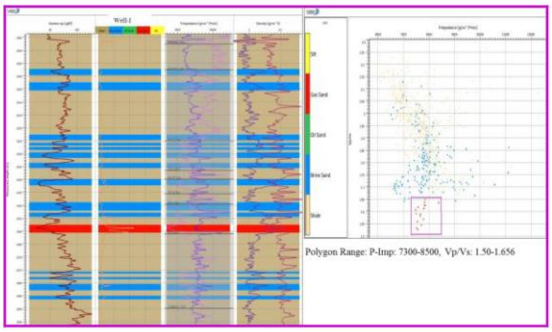

Fig.7 Cross plot of P-Impedance & Vp/Vs (Well I)

Rock physics analysis and feasibility studies

Objective of the rock physics analysis is to determine the pore-fluid sensitivity of different elastic parameters. Analysis through histogram and cross plot of P-impedance and Vp/Vs logs were carried out to find the desired separation for different litho-fluid types. Histogram of Pimpedance and Vp/Vs logs in the zone of interest was generated (Fig. 8). On the basis of only P-Impedance, It is difficult to separate hydrocarbon and non-hydrocarbon bearing zones, while histogram of Vp/Vs shows most likelihood of occurrence of hydrocarbon bearing zones is in low Vp/Vs range. Cross plot of P-impedance and Vp/Vs logs for zone of interest shows moderate to slightly high Pimpedance and low Vp/Vs for hydrocarbon producing wells except well F (gas bearing) which is having both P-impedance and Vp/Vs in low range.

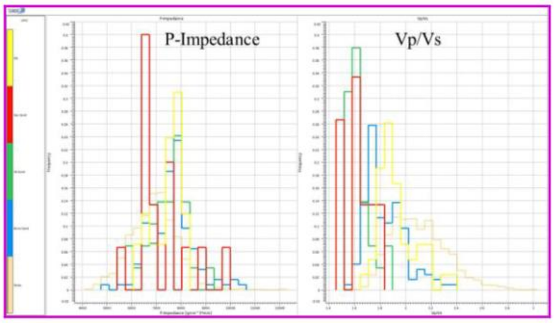

Fig.8 Histogram of P-Impedance and Vp/Vs colored with lito-fluid type

Well to Seismic Tie & Wavelet Extraction

All the 13 wells penetrated the zone of interest i.e., Hazad Top to Hazad Base. In some wells log intervals were not sufficient and zone of interest was partially covered by elastic logs. Correlations were attempted for full log interval where larger log interval was available apart from zone of interest. The correlation between well and near angle stack (5_12deg) is very good which is around 70 to 90% (Fig.9), which decreases at higher angle stacks (2230deg & 28-36deg). The extracted wavelet for all the angle stacks at each well indicates more or less similar character at each well and for far angle stacks the character changes slightly with a few milliseconds shift. Considering the quality of seismic and wavelet characters, multi-well wavelet was estimated excluding the outlier wavelets. This multi-well wavelet (Fig.10) was used for constrained sparse spike inversion.

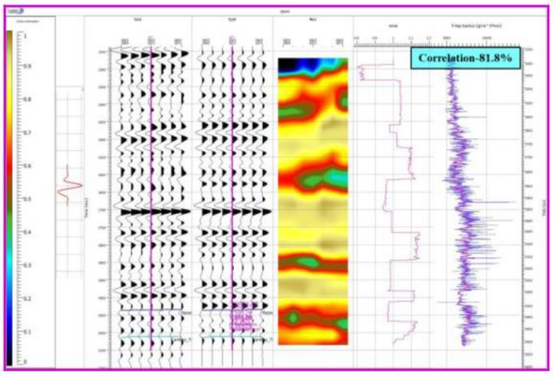

Fig.9 Well to Seismic Correlation (well P)

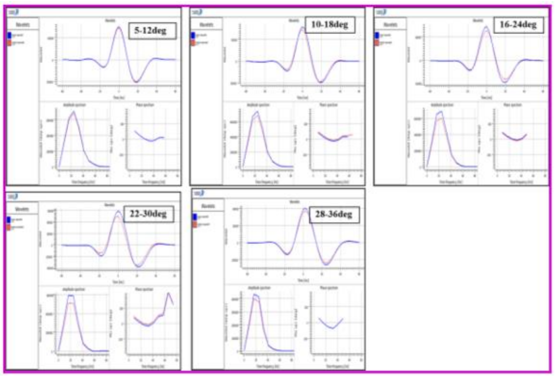

Fig.10 Multi well wavelet from angle stacks

Initial Model and Constrained Sparse Spike Pre -Stack Inversion

Initial model of P-impedance and Vp/Vs were generated by interpolation of well logs by triangulation method (Fig.11). Constrained sparse spike inversion algorithm was applied for inverting the available angle stacks using the multi-well wavelet for all angle stacks and initial model in zone of interest as inputs. Comparison of inverted results with actual well logs (filtered to seismic band) show reasonably good match in zone of interest at most of well locations which confirms the validity of the inversion outputs. An arbitrary line display of the Inversion results passing through all the well location are shown in Fig.12.

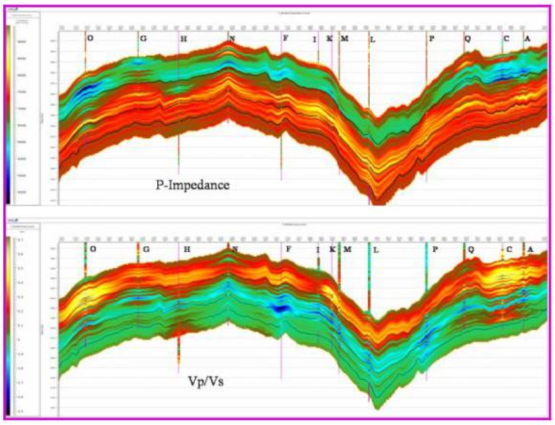

Fig.11 P-Impedance & Vp/Vs Model along arbitrary line passing though all wells

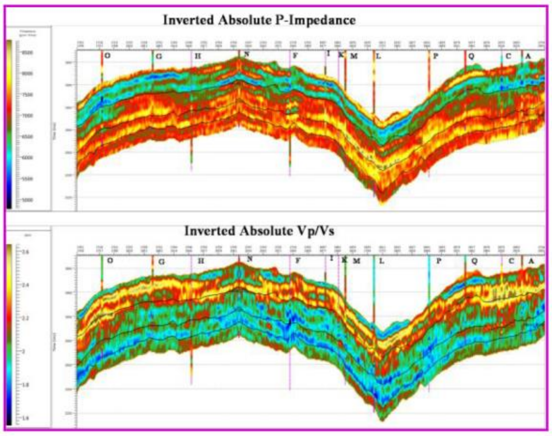

Fig.12 Inverted Impedance & Vp/Vs along arbitrary line passing though all wells

QC of inversion results

To ensure the validity of inversion results, several QCs were done. Pseudo logs were extracted from inverted PImpedance and Vp/Vs volume at each well location and compared with corresponding original logs filtered in seismic bandwidth and found to be having good match. Cross plot of extracted inverted impedance and impedance derived from logs filtered in seismic bandwidth shows a correlation of 78%. Similarly cross plot of extracted inverted Vp/Vs and Vp/Vs derived from logs filtered in seismic bandwidth shows a correlation of 75.5% (Fig.13). Synthetic to seismic correlation map for all the angle stacks show a very good correlation for angle stacks (Fig.14). Correlation is low in north east part of the study area where seismic data quality is also not so good and it is also reflected in inverted S/N ratio for all the angle stacks.

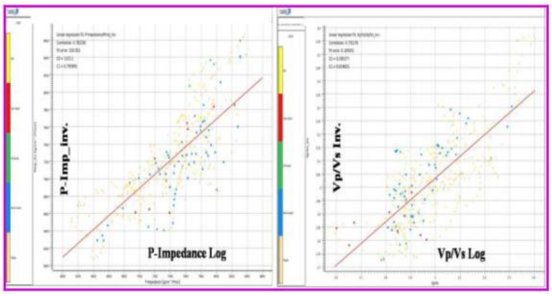

Fig.13 Correlation between Inverted vs. Log (filtered in seismic bandwidth)

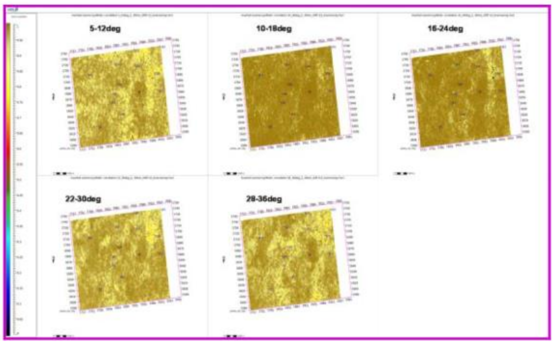

Fig.14 Synthetic to seismic correlation map(inversion QC)

Results and Conclusions

Hydrocarbon sand polygon is identified from crossplot of inverted P-impedance and inverted Vp/Vs in zone of interest (Fig.15). Crossplot ranges of inverted results were verified at each well location (Fig.16& 17).

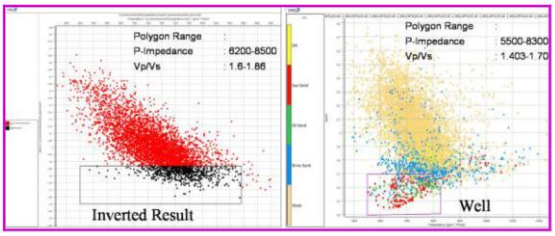

Fig.15 Comparison of cross plot of Inverted vs. Log PImpedance & Vp/Vs (in interval Hazad Top- Hazad Base or Cambay Top)

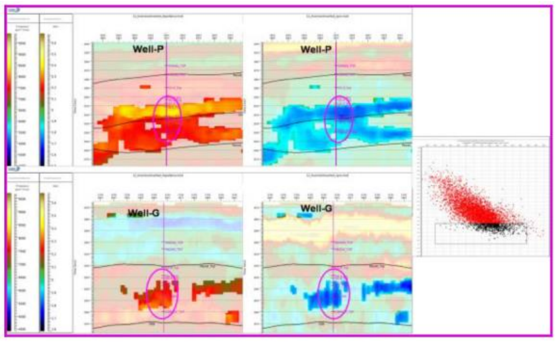

Fig.16 Sections highlighted with pay polygon at hydrocarbon well P&G. Pay zone having moderately high P-Imp and Low Vp/Vs

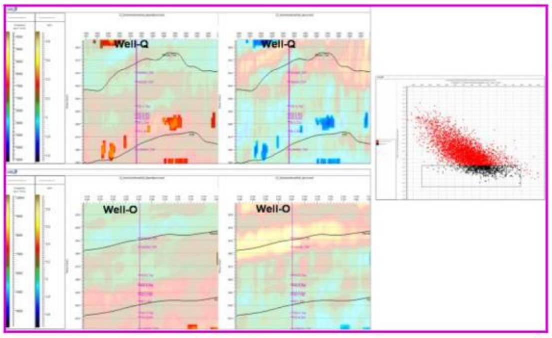

Fig.17 Section highlighted with pay polygon near dry well Q& O.

This result shows that all pay levels are having moderate to high P-impedance and low Vp/Vs except at the well which is a gas producer having low Impedance and Vp/Vs. Inversion attribute maps like mean P-impedance and Vp/Vs, stratal slices at pay levels show probable channel geometry close to GS-6 level (Fig.18) and it shows the most likely distribution of hydrocarbon pay sands close to GS6 pay captured by the pay polygon. All hydrocarbon bearing wells (G, J, I, K, M and P) are falling in moderate to high P-impedance and low Vp/Vs except F where both are low. Some more area is interesting from Vp/Vs ratio point of view at GS6 & GS4 level. Wells A & C falls in poor seismic data quality area where zone of interest is either having a very few events or transparent seismically which resulted in inversion results having low reliability.Pay polygon was used for extracting the geo bodies. Fig.19 & 20 show the 3D and Map view of the most probable distribution of Geobodies close to GS6 & GS4 level respectively.

Pre-stack inversion result was validated with the wells in the area in zone of interest and found to be matching. Absolute values of inverted P-Impedance and Vp/Vs are slightly higher than the absolute value that from well logs. Consequently, crossplot ranges of inverted results for pay zones were chosen slightly higher compared to the ranges from well crossplot. Some more areas which appear to be interesting from hydrocarbon point of view at GS6 & GS4 Levels have come up from this analysis that needs to be studied along with other available G&G data.

P-Impedance - Vp/Vs polygon used for capturing the geobodies does not uniquely represent the pay sand as it contains some contribution from non-reservoir as well. A zone captured through this indicates locales where occurrence of pay sand is more likely. Predicted shear sonic logs in all the wells except one, can not be as accurate as original recorded one. In view of these constraints and uncertainties involved, this inversion results should be used along with other G&G data available in the area before zeroing in the prospective area.

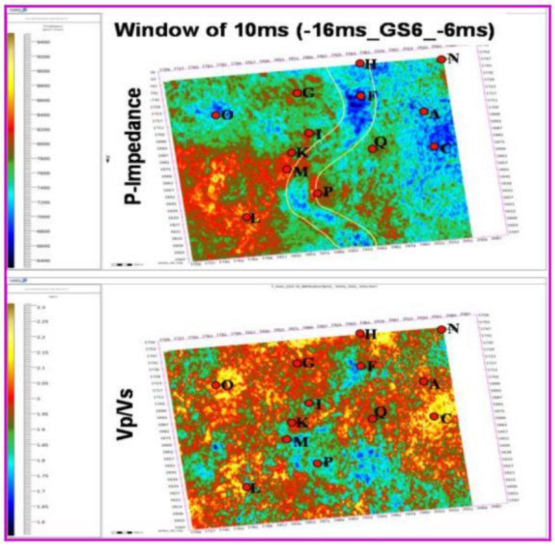

Fig.18 Mean impedance & Vp/Vs close to GS6 level shows channel pattern

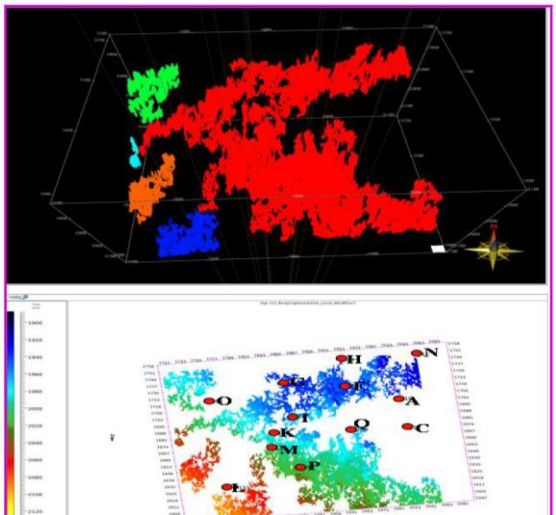

Fig.19 Most probable distribution of Geobodies close to GS6 Level (3D view & Map View)

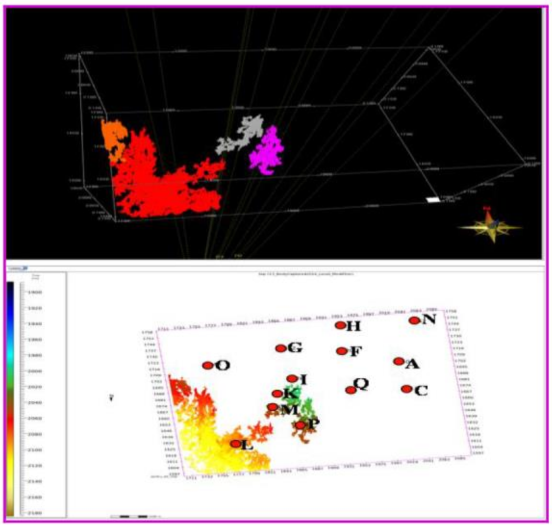

Fig. 20 Most probable distribution of Geobodies close to GS4 Level (3D View & Map View)

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Hampson Russell knowledge base

Fugro-Jason training manual.