

Improving the low Frequency background model for better seismic inversion: A Case Study

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Keywords

Low frequency model (LFM), Geo-cellular modeling (GCM), Geobody encoding

Summary

The inversion of seismic data often adds valuable information in quantitative interpretations but the value of this information is susceptible to bias depending on the selected low frequency model (LFM) provided to generate absolute instead of relative elastic properties. The seismic data is band limited and hence the inversion output from seismic alone is a relative impedance volume. To obtain the broad spectrum inversion output or the true earth model in terms of its elastic properties, an a-priori low frequency model from recorded well logs has to be provided. This low frequency model also act as a guide for population of impedance properties away from the well. The problem lies in the fact that the low frequency model itself is a statistically populated property. Hence great care must be taken to create a reliable low frequency model (LFM). In-fact seismic inversion can be thought of as the combination of low frequency model and band limited relative inversion derived from the seismic data. In this study four approaches for LFM building was looked into for minimizing spurious artefacts in inversion results.

Introduction

Area chosen for this analysis is from deep water KG block located off the coast of Godavari delta, eastern offshore, India. Hydrocarbons occurs mainly in structurally and stratigraphically controlled traps in Pleistocene to Miocene reservoirs. These reservoirs have been deposited under marine conditions and source rocks is thought to be Eocene to Oligocene marine shale. Seismically these slope channel sands appear as high amplitude anomaly bursts

Our focus is to generate reliable inversion outputs which will later be used for reservoir property prediction. **Figure 1**, shows the seismic data of the area and the location of a successful well drilled into the turbidite. **Fig. 1a**, shows two different Low frequency models (0-6Hz) and **Fig. 1b**, shows their corresponding P-impedance volumes with all other parameters remaining same. **Fig. 1c**, shows the comparison between inverted P-impedance and seismic stack. Basically inversion results has to conform to observed seismic amplitude character. We try to illustrates the point that different LFMs can generate very different

inversion outputs. Please note that both inversions were run with same parameters but different LFMs. Hence, it's apparent that LFM plays a key role in inversion and overall understanding of the area

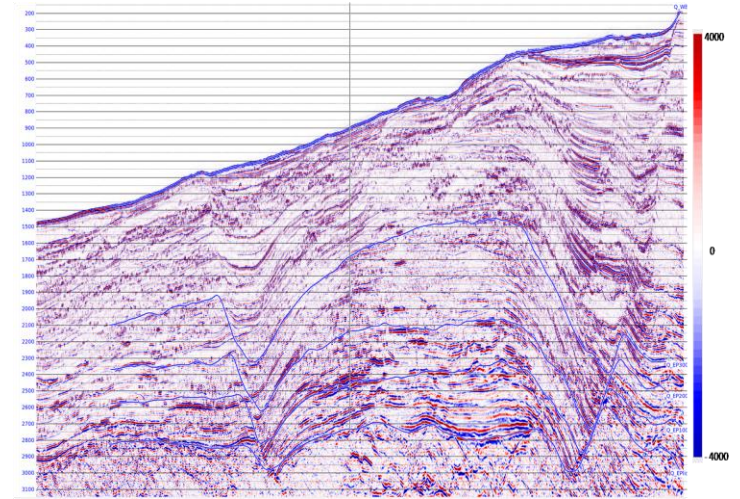


Figure 1: shows the seismic section (Inline) of final migrated stack passing through well#X along with interpreted horizons.

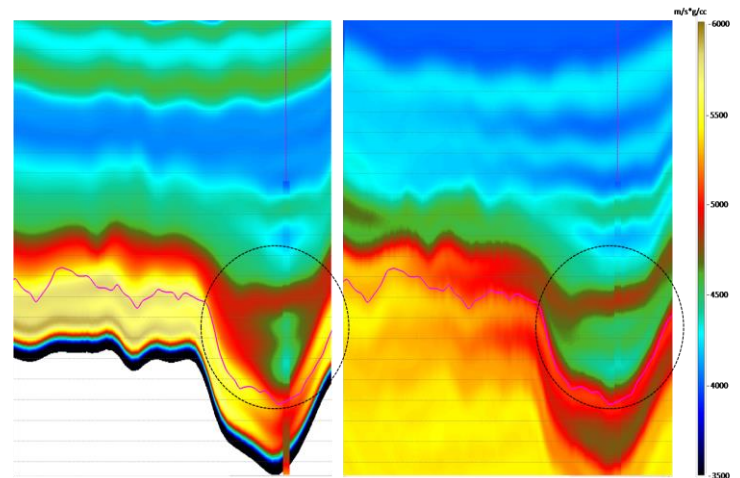


Figure 1a: Different low frequency P-impedance model of 0-10hz populated from well logs with different

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statistical methods. The bottom most horizon of interest is overlaid (pink).

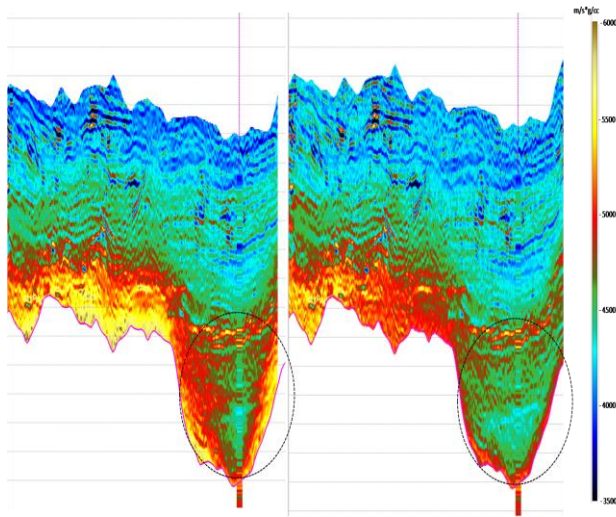


Figure 1b: The pre-stack inversion output using low frequency models shown above. Note the difference in the graben part of 2nd output. This difference in P-impedance is because of different trends provided by the low frequency models (LFMs).

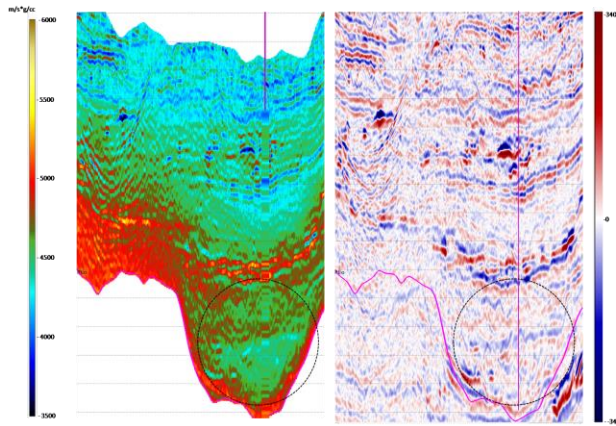


Figure 1c: shows the conformance between inverted P-impedance of 2nd output of Fig 1b. and seismic. The seismic doesn't show a localized body close to the well as opposed to 1st output of Fig 1b.

Methodology

Figure 2, shows the general workflow adopted for Pre-stack inversion. The only change is the various approaches used for low frequency trend modelling. These approaches are described below in detail.

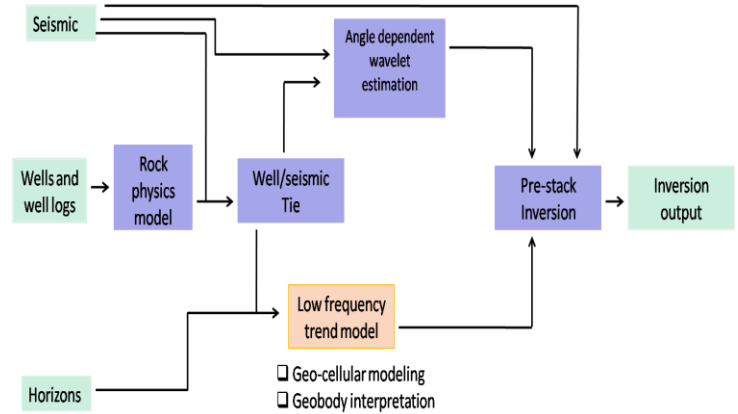


Figure 2: The workflow used for Pre-stack inversion. Various approaches for low frequency trend modelling is shown.

a: Geo-cellular model approach for low frequency trend

One of the latest trend in the oil industry is to create grid / cellular property models of the reservoir. Inadvertently inversion outputs play a major role in modelling exercises. our approach is to populate the low frequency trend of well logs using the capabilities of Geo-cellular modeling (GCM) and use this LFM as input to inversion. The advantages are proper layering of well properties with breaks at faults due to superior structural model of the GCM. Abundant statistical tools for interpolation and extrapolation of properties based on various analysis. Higher vertical resolution of the output, though it may not be very important for creating low frequency models of 10-15Hz.

A 3D geological modeling grid was built, covering the area of interest and incorporating well markers, interpreted horizons and fault information. The grid was constructed in the time domain to honour the reservoir horizons and well markers and the stratigraphic conformance rules in the reservoir zone. It is important to design the 3D geological modeling grid at a scale that captures the geological heterogeneities of the well logs - independent of seismic sample rate. However, it is observed that after filtering the property models of P-impedance, S-impedance, Vp/Vs, Density to 0-10Hz i.e. to a frequency range of low frequency trend for inversion, the vertical resolution obtained with 3D grid of one seismic sample or two seismic sample doesn't have much difference between them. Hence, the vertical grid definition may be restricted to two seismic sample interval for quick processing.

Figure 3, shows the workflow for creation of Geo-cellular model of low frequency trend.

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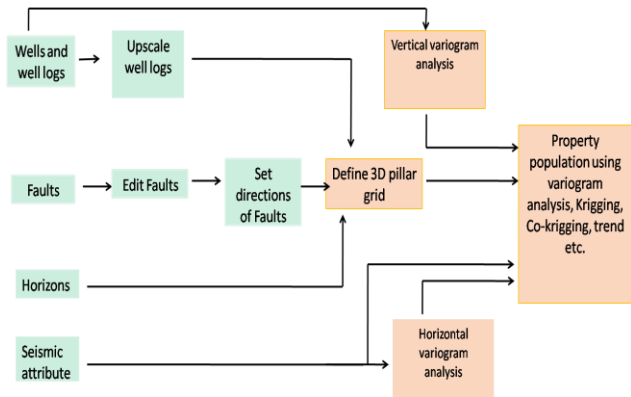


Figure 3: Workflow adopted for creation of low frequency trend from well log using geo-cellular modeling.

At first, the interpreted faults are edited and later upscaled into a 3D grid of 200X200m. Subsequently the horizons are added and layering performed to complete the framework. **Figure 4**, shows the effect of over smoothing faults during upscaling which should be avoided. One key step of fault editing is giving directions (i & j) to them so that the grid cells align properly along them or intersect them so as to avoid any leakage in the grid model.

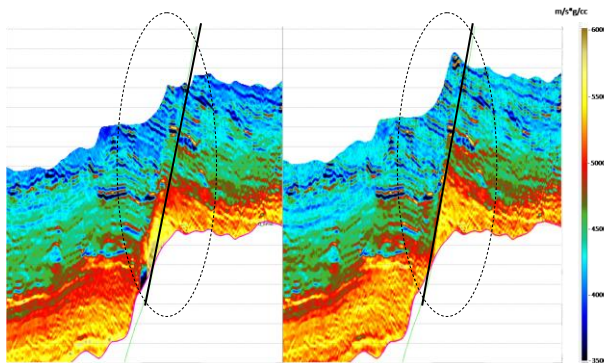


Figure 4: shows the problem that may arise due to over-smoothing of fault sticks during upscaling into the grid model. Output on left shows the fault break in inverted P-impedance volume away from the interpreted fault (black). Whereas, output on right has fault break exactly on the interpreted fault. The improper placement of fault in Low frequency trend model generated using different structural framework has created the difference. This difference may have a huge effect on the subsurface model and reservoir flow model during the later stages of reservoir characterization.

Secondly, the horizons (**Figure 5**) are upscaled into the model. We create a constant top and bottom horizon of

1200ms and 3200ms respectively and define them as top and bottom of the final corner point grid. Then, proportionate layering is done between the interpreted horizons while maintaining a vertical cell size of one seismic sample.

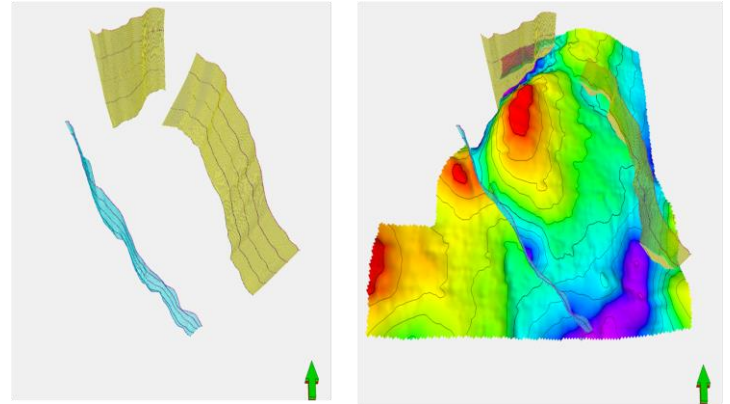


Figure 5: shows the upscaled horizons. The horizons have been edited near the fault-cuts and merged with the faults to avoid any leakage in the model.

Third, is upscaling the desired seismic attributes into the grid model. we have chosen RMS amplitude and Coloured inversion as the desired properties. The RMS amplitude is used for calculating the horizontal variogram and coloured inversion is used as trend for population of well properties in the entire grid.

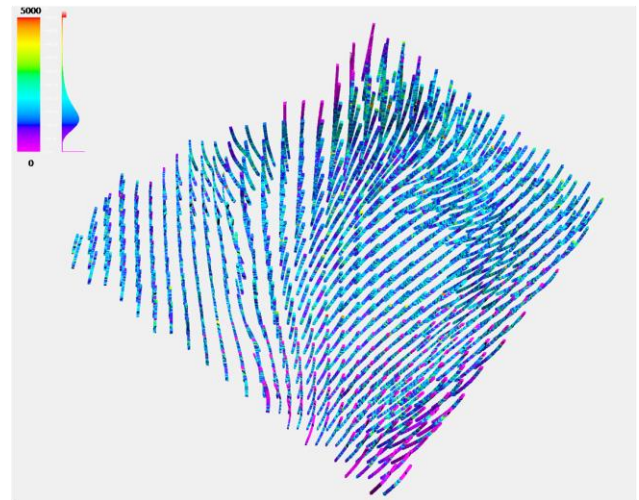


Figure 6: The RMS amplitude is upscaled and resampled at every 5th Inline and 5th Cross-line for quick calculation of horizontal variogram.

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Figure-6, shows the upscaled RMS amplitude volume. For quick calculation of horizontal variogram the attribute is re-sampled at every 5th Inline and 5th Xline. We have calculated the major/ minor direction and range from RMS attribute using horizontal variogram analysis and sill .nugget, type and vertical range from vertical variogram analysis of P-impedance well logs. **Figure-7**, shows the variance map of RMS amplitude. In a deep water turbidite system like this particular case study, the RMS amplitude is a reliable indicator of depositional agents. Hence, we assume that the direction of deposition and extent is fairly consistent with RMS amplitude. **Figure-8**, shows the spherical variogram fitting in horizontal variogram analysis for finding the major/minor range.

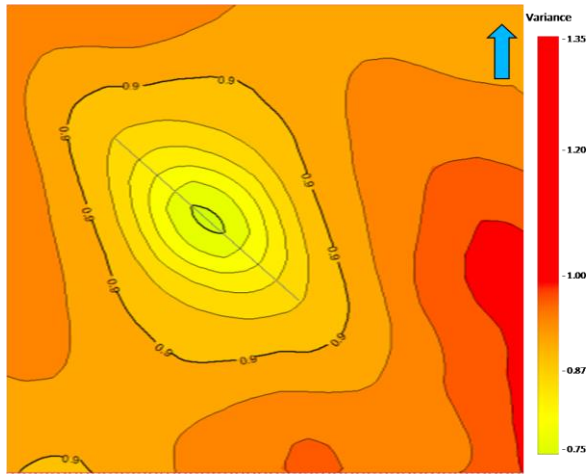


Figure 7: The horizontal variogram analysis gives the major direction as 315 deg and minor as 225 deg.

Figure-9, shows the vertical variogram analysis of P-impedance logs of all the 18 wells. Vertically there appears to be cyclicity of deposition which is fairly consistent with geological understanding of turbidite systems getting re-activated time and again to give rise to amalgamated deposits. We have de-trended the data before continuing with the analysis. The nugget(0.007), which defines the short scale variation in the data is almost zero and sill (+ 0.4) shows a spatial trend in the data and range for the layer (ep300-ep200) is 16.34 ms. Similarly, values are calculated for other layers namely ep200-ep100, ep100-ep10.

Figure-10, shows the upscaled colored inversion attribute into the 3D geo-cellular grid. As can be seen in the figure the turbidite channels are prominent in the colored inversion. This capturing of geological trends for property population is much more meaningful than statistical methods of interpolation and extrapolation.

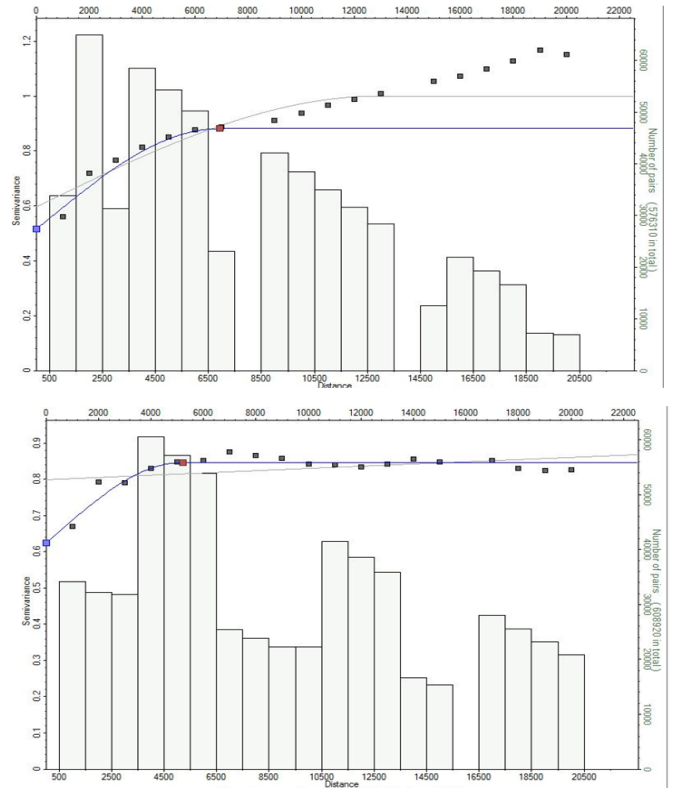


Figure 8: Analysis of major and minor range along the major direction of 315 and minor direction of 225 with a lag distance of 1km and 20 lags search radius i.e. 20km. The major range is 7km and minor range 5km.

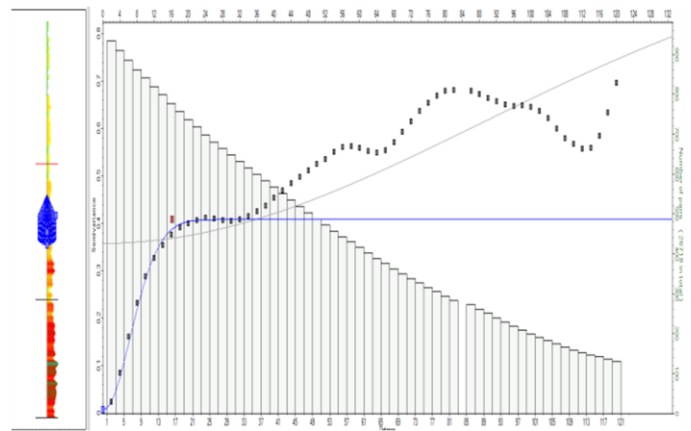


Figure 9: Vertical variogram analysis of ep300-ep200 layer of P-impedance logs with pre-set parameters from previous horizontal variogram analysis and search distance of 120ms. The number of pairs are shown in greyish yellow blocks while semi variance is shown in

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blue dots. Total sill calculated is 0.4064 and nugget is 0.0075 while the vertical range for the layer is 16.34 ms.

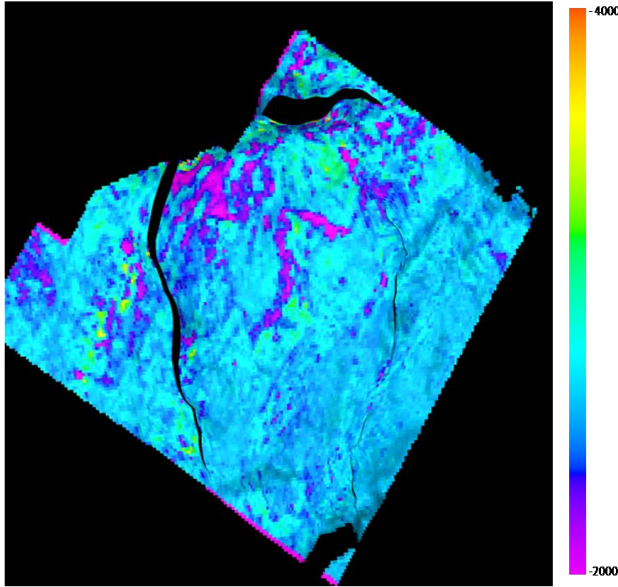


Figure 10: shows the scaled coloured inversion used as 3D trends for property population.

Finally, The upscaled logs of P-impedance, density and Vp/Vs were populated in the entire 3D grid model layer wise using parameters of variogram analysis and trend of colored inversion (Table 2).

Zone	Variogram Azimuth	Variogram dip	Nugget	Type	Major Range	Minor Range	Vertical Range	Sill	Trend
Top-ep300	315 deg	0	0.0079	Gaussian	7000 m	5200 m	16.161 ms	0.4005	Coloured Inversion
Ep300-Ep200	315 deg	0	0.0079	Spherical	7000 m	5200 m	19.174 ms	0.4637	Coloured Inversion
Ep200-Ep100	315 deg	0	0.0079	Gaussian	7000 m	5200 m	13.471 ms	0.2941	Coloured Inversion
Ep100-Bottom	315 deg	0	0.0079	Gaussian	7000 m	5200 m	15.665 ms	0.2309	Coloured Inversion

Table 2: Shows the layer-wise values of variogram and trend used for property population.

Figure-11 and 12 shows the LFM generated using this approach and corresponding inversion outputs.

b: Geo-cellular model for low frequency trend along with geobody interpretation

The term Geobodies is basically used for litho facies boundaries. The boundaries of these geobodies/litho facies like sand/shale or pay/non-pay can be outlined in cross-plots or Bayesian classification of elastic properties like P-impedance, S-impedance, Vp/Vs or lambda-Rho Vs Mu-Rho etc. The benefit is incorporation of detail geological meaning into the LFM and better outputs.

Figure-13, shows the workflow adopted for this approach

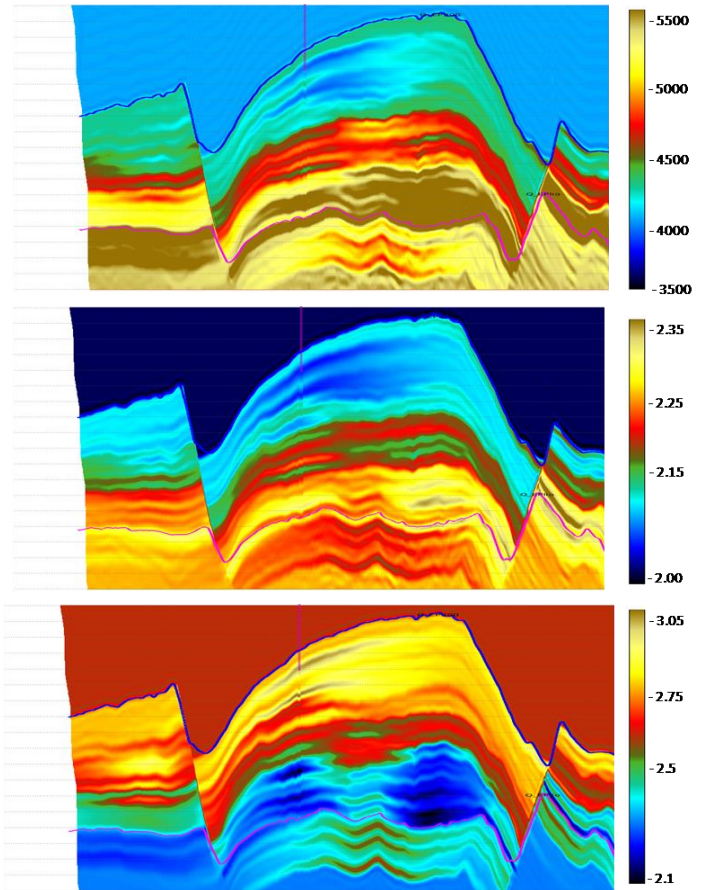


Figure 11: The low frequency trends (0-15Hz) of P-impedance(top), Density (middle) and Vp/Vs ratio (bottom) overlaid by well#X. The top (ep 300) and bottom horizon (eplio) of interest are shown in blue and pink. The use of geo-cellular 3D grid, variogram analysis of attributes and wells and use of trend of coloured inversion has ensured a robust low frequency model generation.

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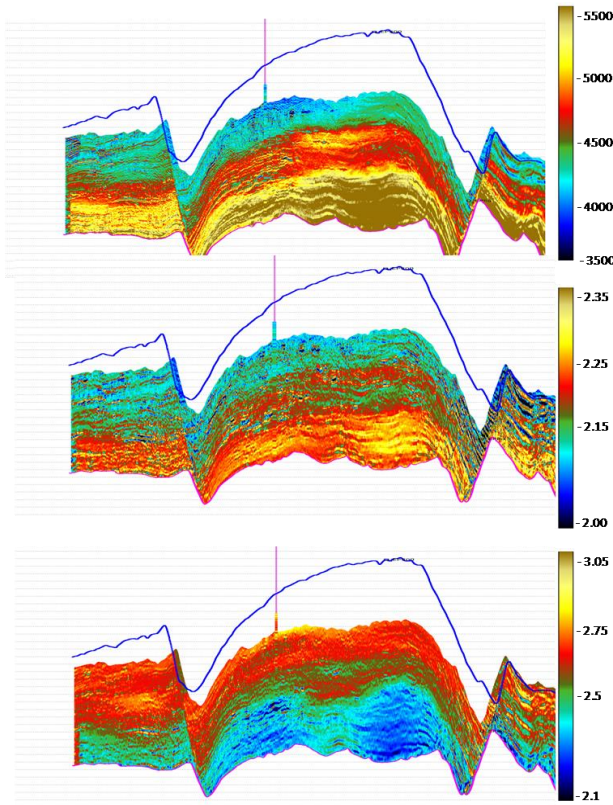


Figure 12: Inversion output of P-impedance (top), Density (Middle) and Vp/Vs (bottom) using the low frequency trends of Fig 15. We call these outputs as 1st pass inversion. Any other legacy inversion output can also be considered as 1st pass inversion.

The pre-requisite for this approach is the initial 1st pass inversion outputs using the low frequency trends of previous approach (already shown in Figure-12). We generate a geobody filter based on cross-plot of petrophysical logs of available wells. **Figure-14**, shows the cross-plot of P-impedance and Vp/Vs and colour coded with effective porosity. We identify the sands with low P-impedance, low Vp/Vs and High effective porosity and cross validate with known sand markers at wells. We then input the 1st pass inversion outputs of P-impedance and Vp/Vs into Bayesian classification and employ the same geobody filter from previous analysis of well logs with slight modifications. The PDFs of various zones and also the entire interval is shown in **Figure-15**. We observe that best separation of geobodies (sand) and non-geobodies (shale) is in Ep200-Ep100 zone. All other zones has considerable overlap. Next, we interactively choose the cut-off (40 %) of Geobody (sand) Probability density functions (PDFs) to select only the sands with high effective porosity and low P-impedance and Vp/Vs and also avoid overlap with non-geobodies (shale).

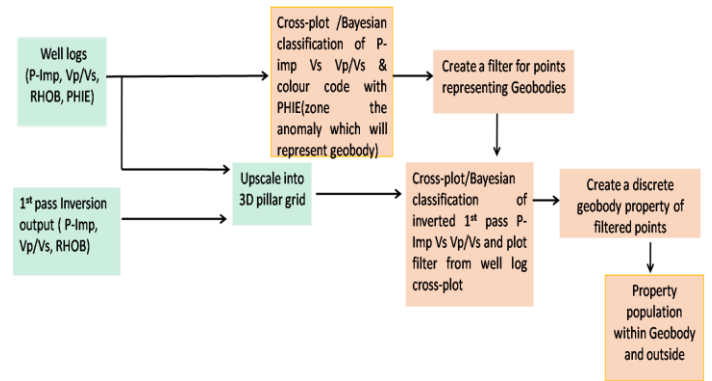


Figure 13: Workflow of geobody interpretation which is integrated with the workflow of Geocellular modeling of low frequency trend.

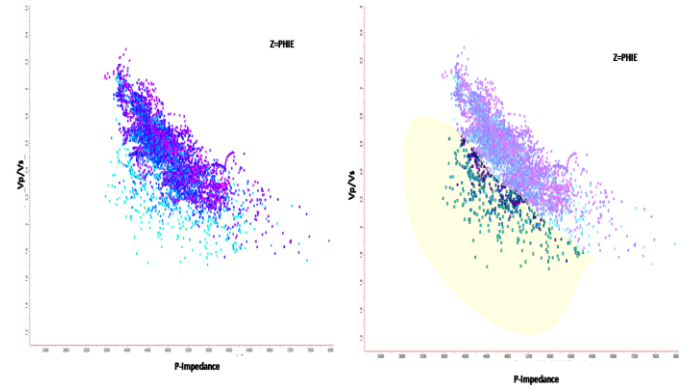


Figure 14: shows the cross-plot of well logs and zoning the anomaly of low Pimp, low Vp/Vs and high PHIE (light blue).

The effect of interactive cut-off of Geobody PDF is shown in **Figure-16**. With a low cut-off (20%), we have almost all available sands in the volume with the associated risk of including some shale. The geometry of these geobodies closely resemble the deep water turbidite typical of the area. However, we are more interested in sands with better reservoir properties which are more likely to be pay-sands and thus a cut-off of 40% was chosen.

Figure-17, shows the final geobodies in a vertical section through some wells and the corresponding seismic. We have validated these geobodies to be pay sand markers at wells. Also the location of the geobodies (sand) in high amplitudes of seismic section implies that they are confined to turbidite deposits as expected.

Figure-18, shows the comparison of P-impedance output using various approach. The two wells shown are producing wells and the pay sands of low impedances

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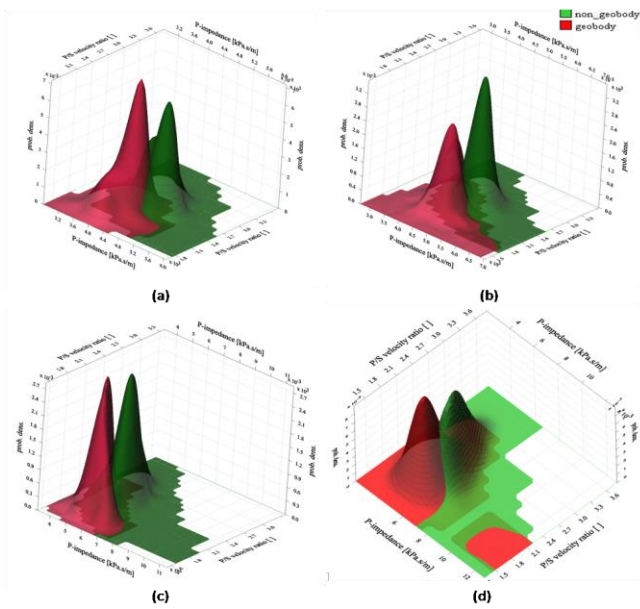


Figure 15: shows the PDFs of Geobodies (red) and non-geobodies (green) of inverted P-impedance and Inverted Vp/Vs (1st pass inversion). (a) PDF of Ep300-Ep200 zone (b) PDF of Ep200-Ep100 zone (c) PDF of Ep100-Ep10 zone (d) PDF of entire inverted interval from Ep300-Ep10.

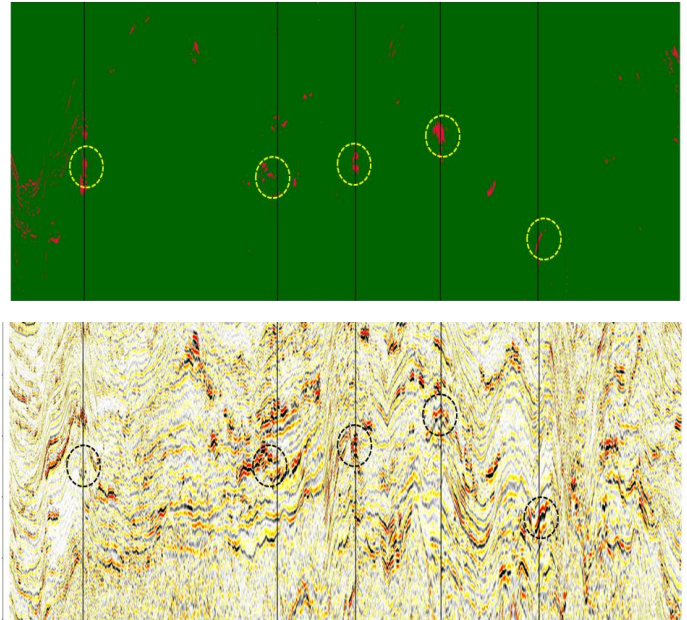


Figure 17: Random line through wells showing the geobodies extracted using 40% cut off PDF. Good sand facies is observed mostly in the high amplitude turbidite channels. These geobodies separated using elastic properties may prove to be good pay sands.

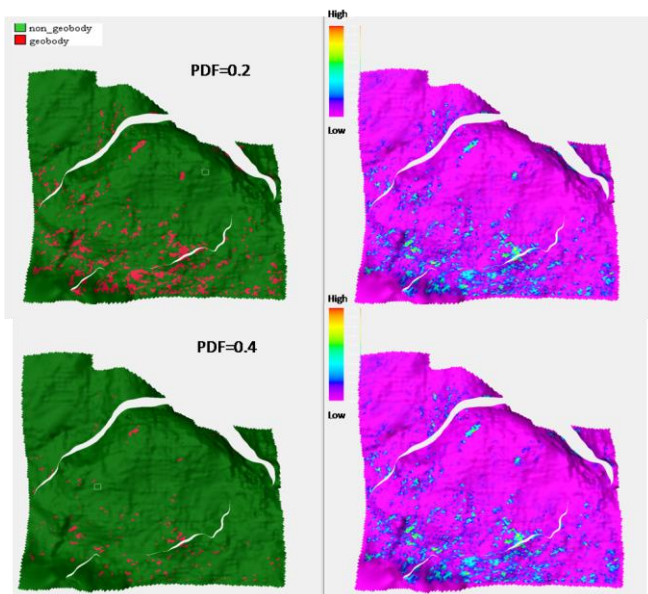


Figure 16: shows the geobodies at 20 % cut off (top left) and 40% cut-off (bottom left) of Geobody PDF and total probability of geobody (top & bottom right) plotted over Ep-200 horizon.

appear to be connected. However, in the output using conventional LFM (top) the sands in the left well is centered around the well. Extension beyond the well is limited. However, with the LFM using geo-cellular and geobody approach the connectivity between the sands and their extension beyond the wells are clearly demarcated.

Conclusion

It has been demonstrated with examples that the "uncertainty" in low frequency trend is propagated as uncertainty into inversion result. Hence, the choice of LFM is extremely crucial in determining the inversion outputs. One of the best structural framework for inversion can be generated using geo-cellular model building. Any industry standard software's modeling modules will enable the interpreter to create better LFM s.

Isotropic propagation of well properties is not sufficient since geology is inherently anisotropic. So statistical tools like variogram analysis, Krigging, co-Krigging or trending using soft/hard constraints could be preferred option for LFM. To mitigate with the limitations of conventional

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methods, it appears better to introduce facies classes in the form of geobodies into the LFM.

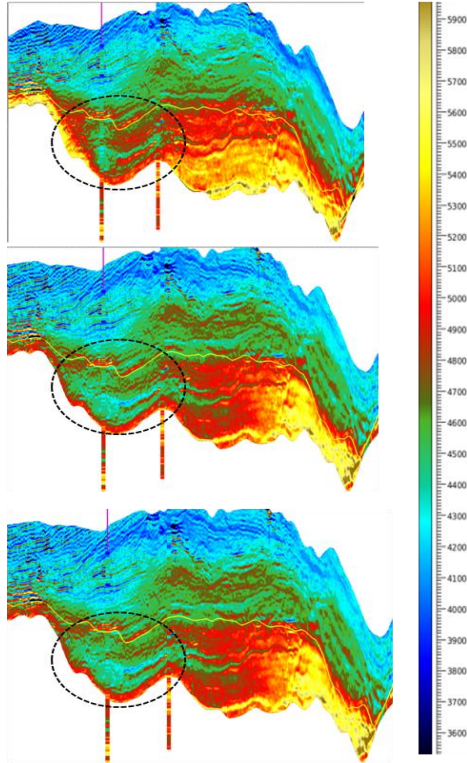


Figure 18: Better extension of well impedances away from the well in the synclinal part due to better guidance of LFM, (top) LFM using the conventional inverse distance criteria (mid) LFM using the geo-cellular approach (Bot) LFM using the geo-cellular and geobody encoding algorithm

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