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# Low Frequency Models for Inversions – Is Simple Better?

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## Summary

We discuss the problem of creating low frequency models for inversion and suggest a simple facies trend-based method which reduces reliance on prior laterally-varying assumptions about the heterogeneity of native reservoir properties. In our example, we were able to identify key hydrocarbon-bearing facies from inversions and tie them accurately to the corresponding petrophysical facies derived from logs.

## Introduction

Post-stack seismic inversion is the transformation of seismic reflection data to layer-based impedances. In the pre-stack context, this translates to the transformation of partial angle or offset stacks to native elastic properties of the reservoir, usually P Impedance, Vp/Vs and Density. Density is ill-determined for surveys which do not include PP reflections beyond 55 deg. and where converted wave data is not available. We shall not discuss it further here. Given that our goal is to image absolute reservoir properties, it is required that broadband data are available. Missing high frequencies reduce resolution. Missing low frequencies do the same but more importantly, restrain the explorationist from putting the seismic data into a geologic context. Since there is a finite limit to the lower frequencies in the seismic data (6-12 Hz, typically), this becomes an issue in every inversion project. There are two ready sources of further information. First, in the ultra-low frequency band (0-2 Hz.), stacking velocities converted to interval velocities can provide lateral information if correlatable to the native reservoir properties. Second, P Impedance, Vp/Vs and Density logs can be used to populate a structural model, the low frequency component of which can be used as a low frequency model (LFM) for inversion. Of course, the non-trivial issue is how to interpolate properties between well locations. Various approaches have been attempted but all suffer from the obvious – how can we really know what is happening between wells?

In this paper, we retreat to a simpler approach and develop its complexity by adding available information. Our basic information comes from trends gathered from logs on a facies-by-facies basis. The primary facies identification is petrophysical but we seek elastic proxies to bring the facies into the seismic world. With this basic information, merged with low frequencies from interval velocities from processing, we strive for a clear understanding of the reservoir while making the least assumptions, especially those of a laterally-varying nature.

## Method

We experiment first with trends from logs which are constrained to be constant across the project. They are hung on geologic structure defined by horizons interpreted from a first pass of relative (no low frequencies) inversion. We find quite often that very simple trends will not suffice. While we aim to acquire seismic in a band which contains all the information about our play, such is rarely the case. The hydrocarbon-bearing facies often manifest in the low frequency band below the seismic. Filtered logs can indicate the magnitude of this effect and further, will allow us to encode this response into the trends. We still resist the inclination to do any sort of interpolation. This means that the trends thus obtained, are not ideal at each well location or in between. But perhaps they can be used as templates to highlight pay-prone regions.

Then, with the pay zones and any other relevant facies identified, the model and the LFM derived from it can be upgraded by the replacement of the initial model properties with trend information, again from the logs but now on a facies-specific basis. Still, no actual interpolation of logs is done.

## Example

We test the above ideas on a Gulf of Mexico data set. Geologically, it consists of two vertically-stacked deltaic systems of middle Pliocene age. They average about 400 ft. thick and are separated by about 500 ft. Within the play area we see delta slope deformation, slump-induced turbidites, thin mouth-bed deposits and the absence of any delta plain facies. Our interest for this study is the *G Sand*.

The available seismic consisted of five partial-angle stacks with the maximum angle in the farthest stack being 50 deg. A single set of wavelets (one for each partial stack) was obtained by matching synthetics to the seismic at each of the seven available wells. The logs sets each included full-wave sonics over the reservoir interval. A simultaneous AVO inversion algorithm (Debeye and van Riel, 1990) was used to complete the inversion. Subsequently, facies were identified by a Bayesian method (Pendrel et al., 2006), the inputs to which are probability density functions for each of the facies and the P Impedance and Vp/Vs from inversion. The technique produces as output, the most-probable facies at each point in 3D space and the probabilities of occurrence of each of the facies considered.

From a petrophysical perspective, the definition of facies was by Vshale and Sw and was done in a Bayesian manner. Sandstones were indicted by Vshales values lower than 60%. Pay Sand was defined by sandstone water saturations less than 60%. It was found that elastic proxies for these facies could be found in the inversion domain in P Impedance – Vp/Vs space. An example of an inversion is shown in Figure 1 along an arbitrary line passing through all the wells. The G sand interval is indicated by the orange arrows. High-cut filtered logs are overlain (red arrows) and it can be seen that the matches are decent, if not perfect. This is to be expected of an inversion technique which has no prior knowledge of the high frequency component of the logs. The LFM input to the inversion in the figure contained no lateral log interpolation. This is discussed in more detail below. In the following examples, we show not the result of the inversions but of the subsequent Bayesian classifications. In each case, the petrophysical facies from the wells are overlain. The three critical facies considered are shales, wet sand and pay sand located in the *G sand* test interval. The PDF template for Bayesian facies identification is shown in Figure 2.

Figure 3 shows the results of facies analysis using a simple trend from logs, defined only at four major geologic horizons. Nothing of use has been identified in the reservoir interval. This is because the imprint of the reservoir sands in the LFM is completely missing. When we improve the LFM trend with a little more detail to encode in it, the low frequency imprint of the sandstones, the situation improves. This is shown in Figure 4 where again no lateral-variation has been assumed except that the facies-independent trends have been hung on structure. Agreement with the logs is good although the extent of the Pay facies seems to be overdone.

We can improve the LFM again in two ways. First, we replace the 0-2 Hz. band information with that from processing interval velocities. Second, we replace property information at the identified facies by facies-dependent trend values from the logs. The result is shown in Figure 5. Agreement with the logs is still good and the result seems to be more geologic. In addition one gets the impression of the development of a pay-water contact. There are also indications of missed pay and opportunities for further drilling. The inversion in Figure 1 employed this last LFM. The two wells on the right hand side of the figure appear to be outliers, at least in a low frequency sense. Log normalization QC tests demonstrated that this was in fact the case.

## Conclusions

We have created elastic proxies for petrophysical facies which can be applied to the outcomes of AVO inversion to good effect. We have shown that sensible geophysical and geological scenarios can be deduced from inversions with a minimum of low frequency assumptions and certainly without detailed model building. The results show good agreement to the wells and are indicative of future drilling locations. A corollary to the method discussed here is the creation of probablistic Sw and Vshale maps should these be of use to the explorationist.

## Acknowledgements

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#### References

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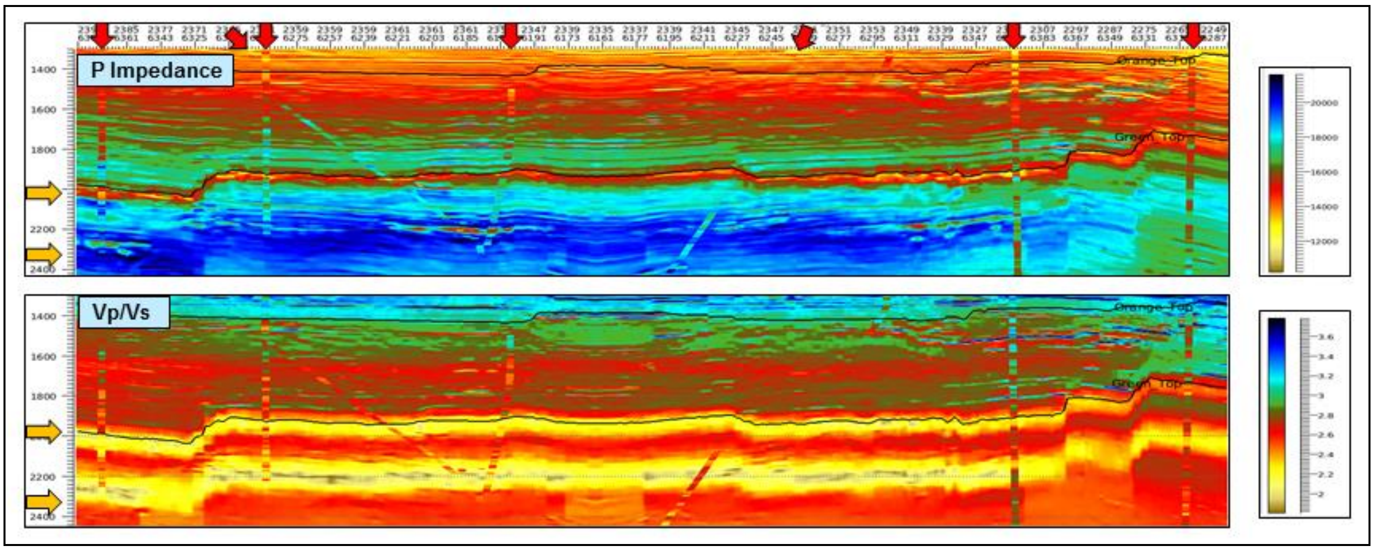


Figure 1: Typical inversion of the Gulf of Mexico data. P Impedance and Vp/Vs are shown overlain by high-cut filtered logs. The constant trend model hung on structure, modified by interval velocities and augmented by facies-based trend values (see text) was used. The two wells on the right side of the figure disagree with the inversion in a low frequency sense. Testing demonstrated that they were indeed outliers in this respect.

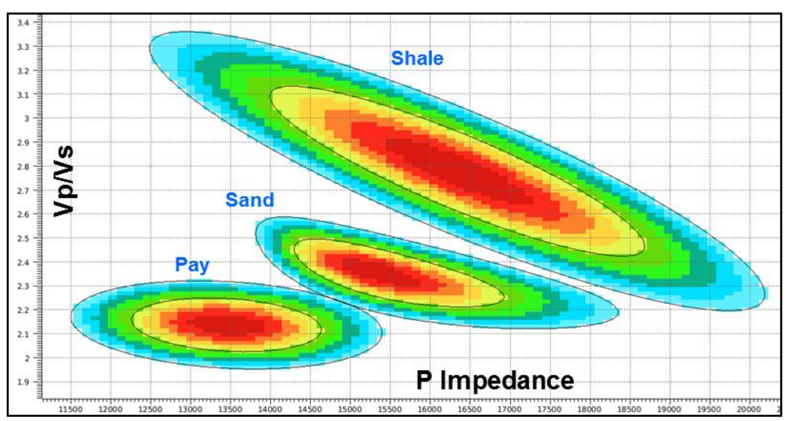


Figure 2: Template for Bayesian facies Analysis showing the PDFs corresponding to each of the key facies in P Impedance – Vp/Vs space. For each PDF, two standard deviations are shown.

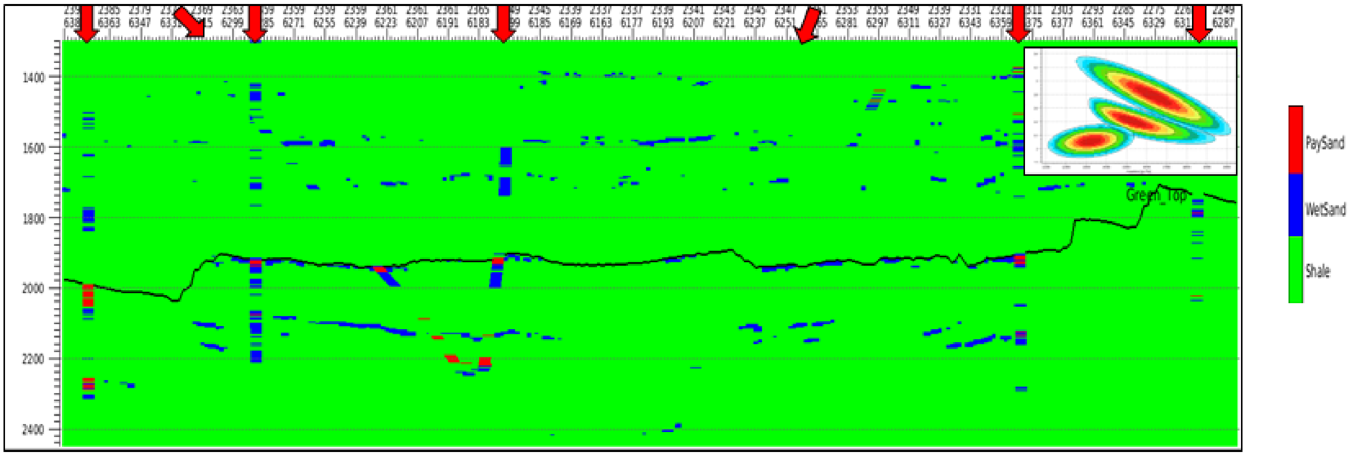


Figure 3: Bayesian classification from an inversion which used very simple non-facies based trends as an input low frequency model. The imprint information of the pay sands in the low frequency band is missing and the result shows no sand fairway and no pay.

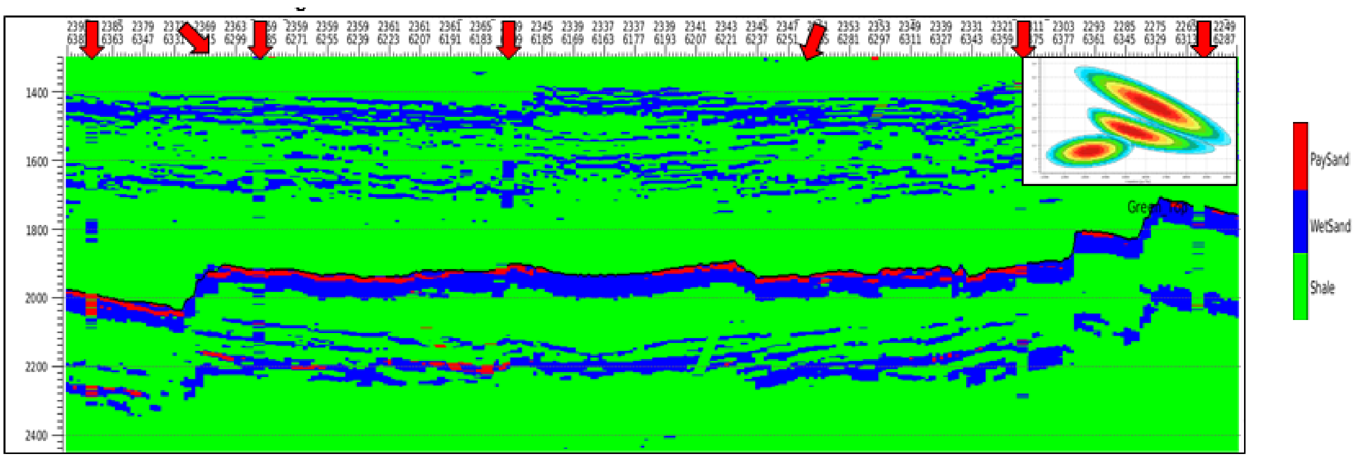


Figure 4: Here frequencies describing the imprint of the sandstones in the low frequency band have been added to the low frequency model for the inversion. These are laterally-invariant and hung on structure. They are best-fit to all the logs. Sand facies have now been identified which correlate to the petrophysical facies in the logs.

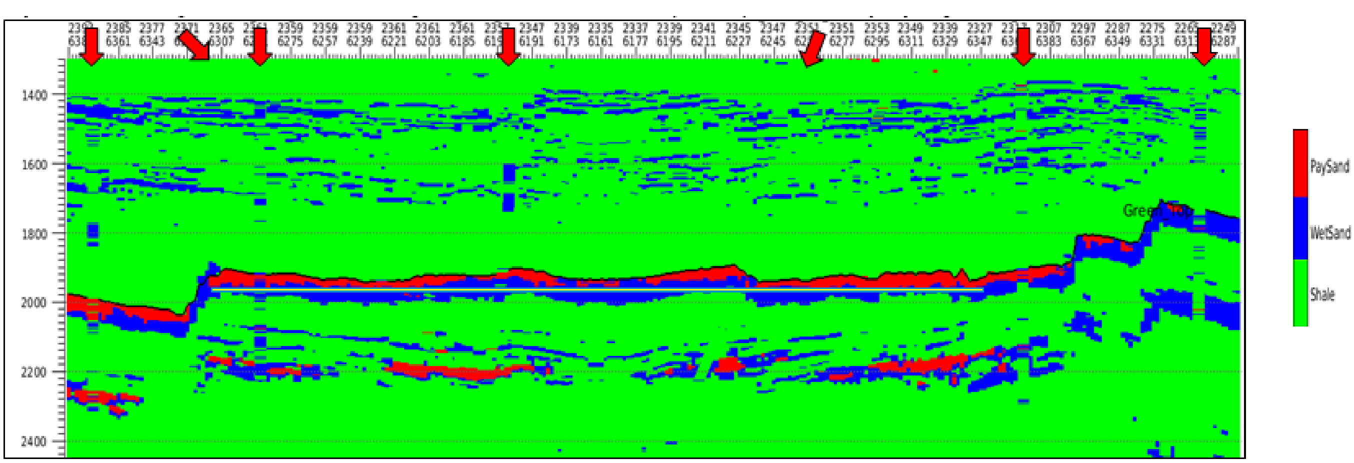


Figure 5: Information from processing interval velocities and facies trends have been added as described in the text. Agreement with the wells has improved and there is an indication of an oil-water contact.