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Identifying and Mapping Facies from Petrophysics to Geophysics

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Summary

It has become common to use a Bayesian inference procedure as the key interpretation tool for seismic inversions. The results are facies and their probabilities of occurrence derived from the native outcomes of inversions or their derivatives. The same ideas can be applied to the definition of petrophysical facies from wireline logs. These petrophysical facies are then mapped to elastic space where elastic-based probability density functions are defined to identify elastic facies. The key is to preserve petrophysical meaning throughout this procedure and deliver meaningful results to interpreters and reservoir modelers.

Introduction

Bayesian inference can be used to infer the probabilities of occurrence of geologic facies from seismic reflection data and in particular, from full-stack and AVO inversions (Pendrel et al., 2006). It is observed that facies when displayed in a cross-plot space defined by inversion outcomes, commonly exhibit a clustering behaviour. This clustering can be described by assigning joint probability density functions (PDFs) to each facies. Applying Bayes' rule with optional priors provides the probability of occurrence of each of the facies at every location in 3D space. Volumes of the most-probable facies follow immediately. The design of the PDFs comes initially from well log data but can be augmented by rock physics modeling or any other available information. The cross-plot space need not be restricted to the native outcomes of inversions but can be any derivatives thereof. For example, in unconventional shale plays, Vqtz and Brittleness have been used (Pendrel et al., 2014). Pendrel et al., 2016 showed how seismic and low frequency model uncertainties could be detected and included in the analyses.

We take these ideas and apply them to the problem of identifying petrophysical facies from wireline logs. Facies generally have a geological origin and are important for petrophysicists. In due course, they are also of interest to reservoir modellers. In between these domains are geophysicists who want to interpret seismic inversions in terms of facies with geologic meaning. The requirement is one of mapping facies from the petrophysical to the elastic (geophysical) domain. The challenge is to preserve some petrophysical meaning in the elastic facies which will ultimately be of real use to interpreters and modellers. We will show how petrophysical facies can be identified from wireline logs using a Bayesian method. We will then show how they can be mapped to elastic space and used as templates to determine facies from seismic inversions.

Method

A set of wireline log curves which each contribute unique information to facies definitions are identified. The data points that they represent are then viewed in multi-dimensional cross-plot space. If the set of curves has been judiciously chosen, clusters of points in this cross-plot space will be observed. They are then modelled by multi-dimensional PDFs, one for each individual facies. Next using Bayesian inference in a manner completely analogous to that described above for elastic facies, facies curves can be constructed at each well location. In addition, facies probabilities become available for use as a QC tool and to aid in the recognition of hybrids of particular facies members.

Next, the identified facies are viewed in elastic cross-plot space, typically, P Impedance and Vp/Vs. Wireline logs are still used, the elastic curves being representative of reservoir properties which can deduced from seismic inversions. Now, elastic PDFs are constructed to optimally define the previously defined petrophysical facies. There will generally be more PDF overlap in elastic space than existed in the petrophysical cross-plot, especially when filtered to seismic resolution.

Finally, the elastic PDFs are used as Bayesian templates to determine facies from inversions. The probabilities of occurrence which are outcomes of this method are used in an assessment of risk.

Example

We test the above ideas with a Gulf of Mexico data set. The key horizon is the top of the Green sand which is shown in Figure 1. Below the Green horizon, we recognize both upper and lower Green sandstones. Sharp discontinuities are the results of faulting. Geologically, there is a set of two vertically-stacked deltaic systems of middle Pliocene age. They average about 400 ft. in thickness and are separated by about 500 ft. Within the play area are delta slope deformation, slump-induced turbidites, thin mouth-bed deposits but without the presence of any delta plain facies. Gas can be found in both clean sandstones and shaley sandstones with high water content. The main challenge is to differentiate between these two types.

The available seismic consisted of five partial-angle stacks with the maximum angle in the farthest stack being 50 degrees This was not judged to be sufficient to resolve density with any degree of certainty. A single set of wavelets, one for each partial stack, was obtained by matching elastic synthetics to the seismic at each of the seven available wells. The log sets included full-wave sonic logs over the reservoir interval, facilitating the creation of the AVO wavelets. A simultaneous AVO inversion algorithm (Pendrel et al., 2000) was used to complete the inversions. Low frequency information was supplied to the inversion in the form of facies-based constant trends interactively defined at horizons and hung on structure. The lowest frequencies were further modified using stacking velocity information (Pendrel, 2015).

The results of the relative (no low frequencies) simultaneous inversion are shown in Figure 2 along an arbitrary line passing through all the wells. Band-pass-filtered logs are overlaid. The matches are not perfect since the inversion has no prior knowledge of the high frequency component of the logs. The region of interest is the G sand (between the orange arrows) where there is the possibility of hydrocarbon deposits. The P Impedance agreement to wells is good and the Vp/Vs fair.

Three log curves were used to define the petrophysical facies: water saturation (Sw), shale volume (Vsh) and density porosity minus neutron porosity (ΦND). The target facies were shale, wet sand, gas sand and gassy silt. Figure 3 shows the petrophysical PDF templates used for the Bayesian inference in the upper G sandstone. Figure 4 is an example of the resulting facies at Well 6, one of seven available. The probabilities of occurrence of each of the facies members are also shown.

Figure 5 shows these same facies in P Impedance – Vp/Vs elastic cross-plot space. In this figure, elastic PDFs have been defined. In Figure 6, they have been used to determine facies away from the wells and throughout the seismic volume. The inputs were P Impedance and Vp/Vs from simultaneous AVO inversion. Note that the upper G sandstone can now be viewed as a mainly gassy-silt with discontinuous clean gas-charged sandstones. The petrophysical facies have been overlaid for comparison at the well locations. In addition, those facies identifications which were less than 90% probable have been greyed-out. Many of these were the results of confusion between Wet Sand and Gassy Silt. This would have been reduced had density been available from the inversion. Due to angle limitations, the inversion density was not reliable. The agreement is generally quite good, especially for the prospective facies. Where the agreement is poor, further QC and analysis should be undertaken. We are aware, for example, that pressure differences across fault blocks account for some of these effects in our example.

Conclusions

We have demonstrated that petrophysical facies can be defined from wireline logs using a Bayesian procedure, which, in addition to building facies curves, produces probabilities of occurrence for each member facies, useful in identifying facies hybrids. We have mapped these facies to elastic space and then used the new elastic definitions to map the facies away from wells using a seismic inversion. The result should be a facies volume usable for interpretation and reservoir modeling purposes.

Acknowledgements

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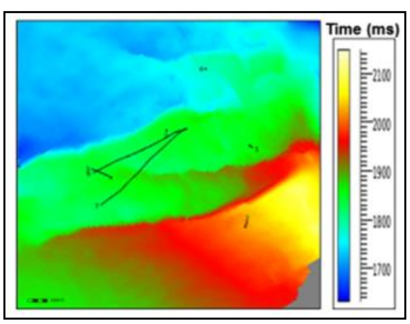


Figure 1: Project map shows the green horizon and the well locations.

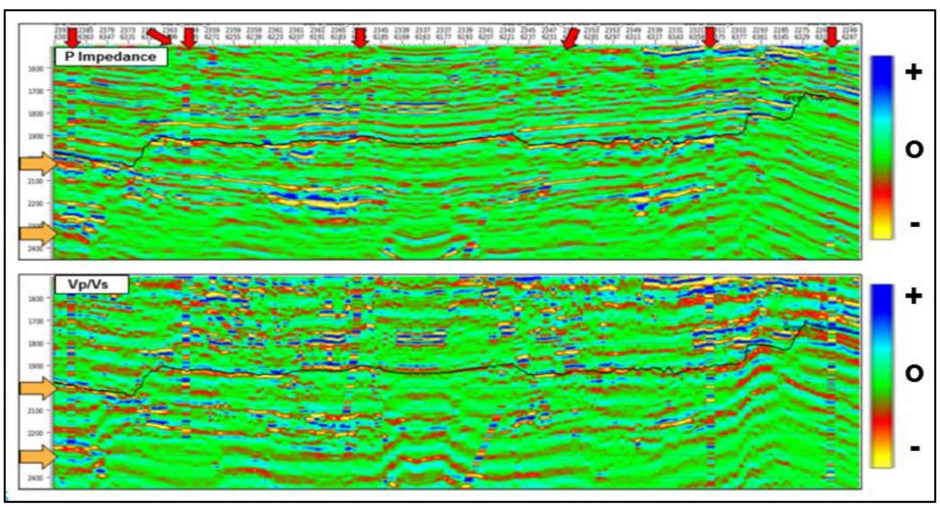
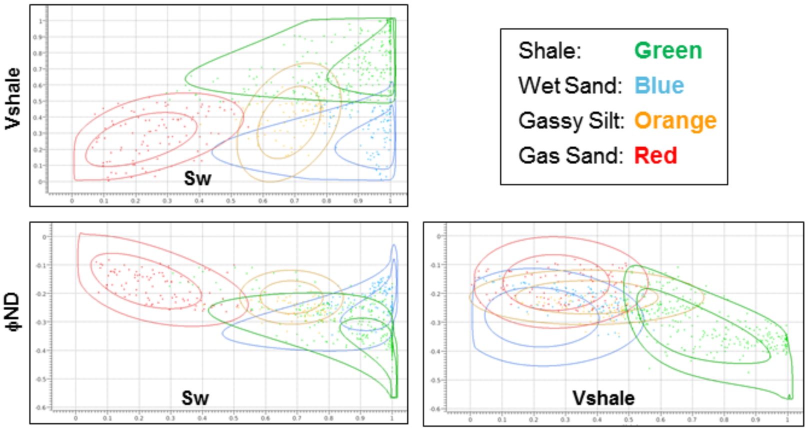


Figure 2: P Impedance and Vp/Vs from a relative inversion (no low freq.) Band-pass-filtered logs are overlain at the well locations (red arrows). The inversion algorithm was blind to the wells in the seismic band.



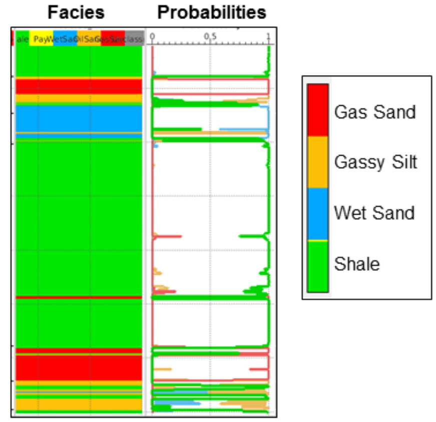


Figure 3: PDF template design in the petrophysical space. The PDFs were input to a Bayesian procedure to determine the facies.

Figure 4: Well 6 facies identification with facies probabilities on the right.

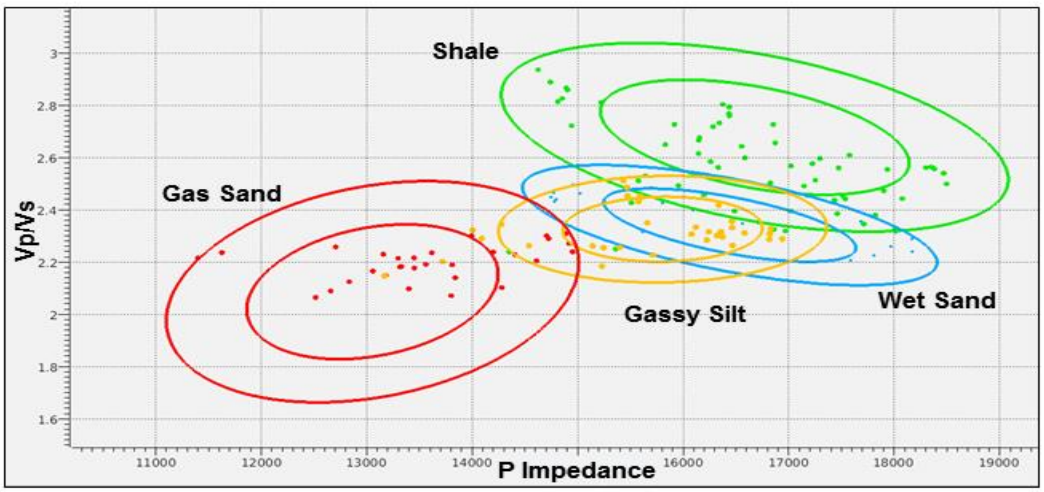


Figure 5: The facies data points have been plotted in elastic space and new elastic PDFs designed. There is considerable overlap between Wet Sand and Gassy Silt. Which would have been reduced by density information had it been available from the inversion.

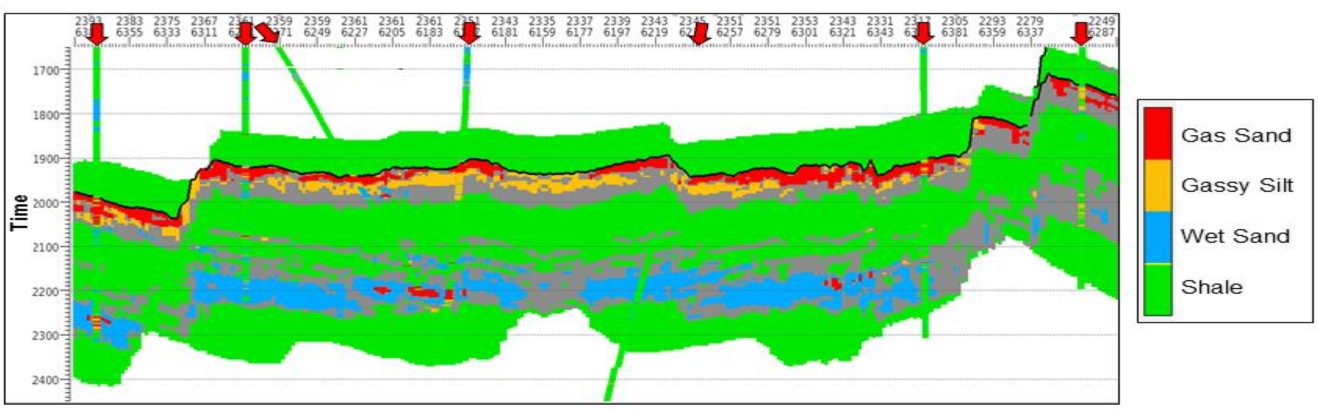


Figure 6: Bayesian inference together with the elastic PDFs and the AVO inversion have been used to identify facies away from the wells. The well petrophysical facies have been overlaid. In addition, facies which were less than 90% probable have been greyed-out.

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