Joint AVO Inversion with Geostatistical Simulation

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Summary

The use of both AVO and Geostatistical Simulation methods in Reservoir Characterization have become widespread over the past few years within the oil industry, with varying degrees of success, for use in Exploration, Appraisal and Development stages. Included within this is the use of Seismic Inversion methods, incorporating not only full-stack seismic data (providing Acoustic Impedance results) but also offset or angle sub-stacks (providing Acoustic Impedance, Vp/Vs and occasionally Density results). Many companies now use some form of Seismic Inversion as a standard part of any interpretation and analysis workflow. This is especially true where some form of quantitative analysis is required to form an input into future field development plans.

Combining Geostatistical Simulation of reservoir properties with seismic data has been successfully achieved through the use of Geostatistical Inversion (for example Pendrel et al., CSEG 2004, [1] and Van der Laan & Pendrel, SEG 2001 [2]). This has been limited to the use of full-stack seismic data (either directly or as secondary data) or using lateral trend information from AVO Seismic Inversion. Although successful, more benefit can be achieved by directly combining AVO information, via seismic angle or offset stacks, with Geostatistical Inversion, using a novel AVO inversion algorithm. This will be demonstrated with field examples.

Geostatistical Inversion Incorporating AVO Information

Incorporating seismic data into Geostatistical methods has been successfully achieved through the use of Geostatistical Inversion. Traditional uses of Geostatistical methods have been limited due to dependence on the availability of a high density of well log information. However, Geostatistical Inversion has allowed the integration of low frequency seismic information with the high frequency log data to provide an improved understanding of the reservoir uncertainty. This method also allows the estimation of lithology or facies volumes between the wells (via Indicator Simulation), complete with uncertainty estimates. The major benefit of this integration is that the asset team involved in developing a field can now have access to a set of data that not only incorporates all well log information, seismic data and geological knowledge, but also one that matches all input data and provides some measure of uncertainty or risk. This has provided a dramatic step forward in the understanding of many oil and gas reservoirs.

The addition of AVO information into Geostatistical Simulation/Inversion methods has previously been limited to the provision of trends from results of an AVO Seismic Inversion project. These trends have been used to constrain the Gaussian Simulation of reservoir properties and lithology.

A new method allows the user to quantitatively integrate seismic sub-stacks (containing rock/fluid information via AVO) and Geostatistical Simulation of reservoir properties. The inversion algorithm is based on the “Markov-Chain Monte Carlo” (MCMC) method (described by Gilks et al., [3]) and combines the Gaussian random field conceptual model than underlies much of geostatistics with the paradigm of iterative local updates familiar to nonlinear optimization. This stochastic inversion process uses a framework defined structurally by horizons combined with stratigraphy to define the micro-layering to be followed and filled by the inversion results.

Inputs to the stochastic process are reservoir property statistics obtained from well log information, multiple offset or angle sub-stacks, with their corresponding wavelets, well log data and trend information if required. The algorithm inverts for all required volumes simultaneously (including lithology) in a robust and meaningful manner. Geological trends present in the seismic data are captured to provide detailed images of reservoir properties. Resolution is enhanced by interpreting the seismic data in the context of geological and petrophysical models. By combining Geostatistical and AVO methods, this process provides multiple scenarios for what the reservoir might be like, showing already what you know but also showing what you may not yet know. Provision of multiple scenarios builds risk awareness into the workflow that may then be incorporated into future field development plans.

Geostatistical AVO Inversion Results

The premise behind the workflow is that we have some form of current evidence (seismic data, well logs) and geological information (analogues, depositional environment, spatial variation and lithology) that, when integrated together in a meaningful manner, will provide some plausible estimate of a reservoir property of interest (Figure 1).

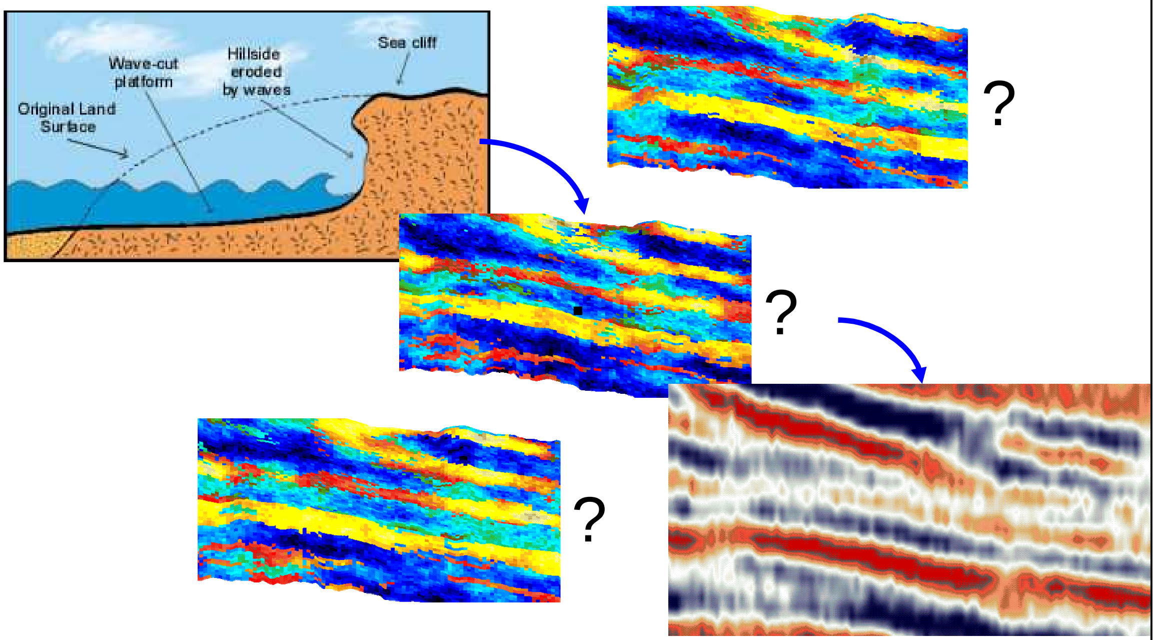
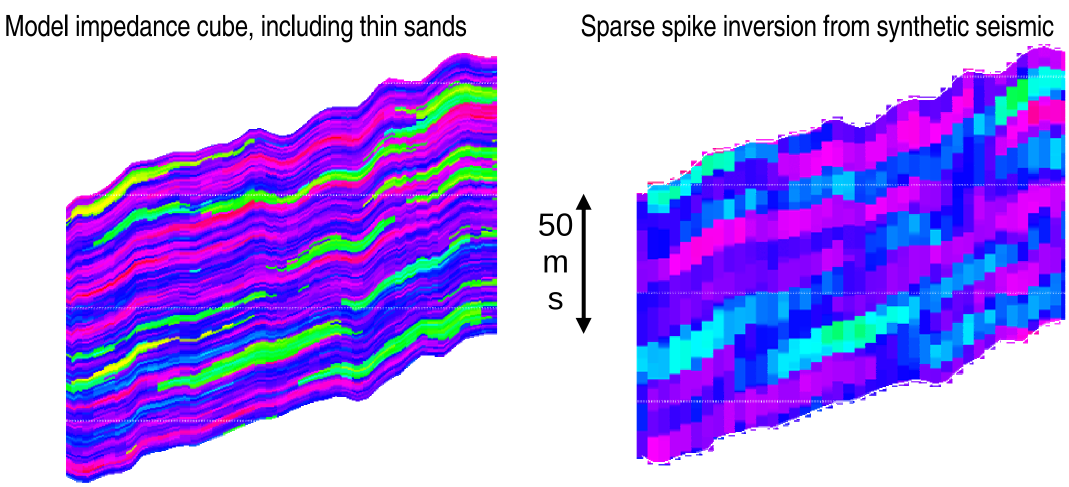


Figure 1. Geological knowledge and seismic evidence with multiple plausible estimates.

The gain in information content over traditional seismic inversion methods can be illustrated by the use of an example. A sequence containing thin sands contained within shale is modelled and inverted using a constrained sparse-spike algorithm (Figure 2). The seismic inversion captures trends within the model but cannot resolve the separate sand bodies.



- Sand bodies are smeared out (below 10ms: lost)
- Connectivity information is lost
- Absolute property values are lost

Figure 2. Impedance model (left) with sparse-spike inversion result (right).

Absolute values of acoustic impedance (and consequently any reservoir property being modelled) are lost; information that is essential for use in reservoir modelling (for example connectivity) is poorly resolved and inadequate. These results are useful for interpretation and analysis workflow before input to a Geostatistical Inversion workflow (in most cases this is a required step).

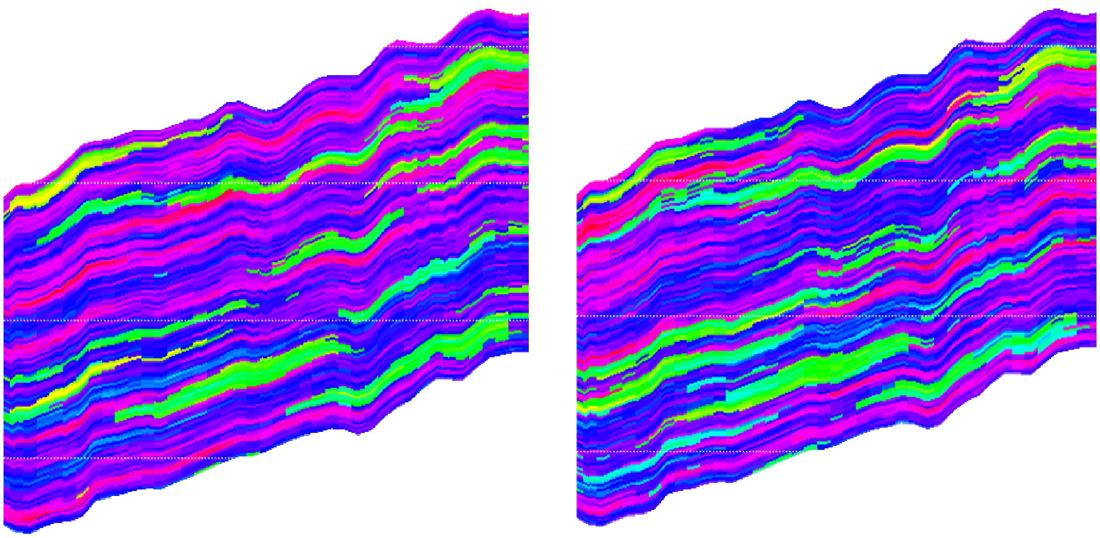


Figure 3. Impedance model (i.e. "truth") with single realization (i.e. one plausible estimate).

There is a dramatic gain in resolution from the AVO Geostatistical Inversion step. In Figure 3 is shown the input model on the left and one realization of acoustic impedance on the right. The thin sands have been captured with the correct geometry and thickness; it is also clear that the absolute values of acoustic impedance and information about connectivity of the sand units have also been imaged correctly. Generation of multiple such realizations will provide good knowledge of the range of plausible estimates, via sand probability or additional information about other reservoir properties that may be used as input to flow simulation and reservoir modelling processes.

Conclusions

High-resolution petrophysical models of reservoir properties are ideal inputs to upscaling and flow simulation and Geostatistical Inversion has long been used as a vehicle to provide such data. Integrating pre-stack seismic data and well log information in an innovative manner provides enhanced high-resolution models, which will enable an asset team to make informed decisions about field development. Incorporating AVO Inversion with Geostatistical Simulation provides a powerful tool to do this. Field examples of the application of this algorithm will be shown, together with ideas of how to analyze the collection of multiple scenarios that can be generated in order to reduce risk in exploration and production.

References

[1] Pendrel, J., Leggett, M., and Mesdag, P. "Geostatistical Simulation for Reservoir Characterization", CSEG 2004

[2] Van der Laan, J. and Pendrel, J., 2001, "Geostatistical simulation of porosity and risk in a Swan Hills reef", 71st Ann. Internat. Mtg: Soc. of Expl. Geophys., 1588-1591.

[3] Gilks, W., S. Richardson, and D. Spiegelhalter, "Markov Chain Monte Carlo in Practice", 1st ed., 1996