geoconvention
Virtual Event
September 13 - 15
2021

Does Geostatistical Inversion Increase Resolution?

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Summary

We review modern Geostatistical inversion with respect to its potential to add value and in particular, to increase resolution. In doing this, we review the constraints on typical deterministic inversions and assess how the absence of such constraints affects geostatistical realizations. We also examine the key characteristics of geostatistical Inversions that lead to value in exploration and production projects and are distinct and unattainable from deterministic inversions. These include increased resolution, uncertainty estimates and static models suitable for reservoir simulation.

Method

One of the essential requirements for building useful quantitative 3D reservoir models of subsurface properties is to properly integrate disparate data sources with multi-disciplinary prior information into a realistic stratigraphic grid, sufficiently detailed to capture reservoir heterogeneity and flow characteristics. This integration is of particular importance in facies modeling, since facies generally dominate rock properties such as porosity and permeability which in turn, govern the overall static character and dynamic behaviour of reservoir models. Seismic reflection data can contribute meaningful additional information regarding the spatial distribution of facies away from well control but should be interpreted in a geologic context. Optimum estimation of reservoir properties are achieved when

- Seismic, well and geological constraints are applied simultaneously
- Seismic and reservoir properties are related through a predictive rock physics model
- Facies definitions are meaningful and have relevance across all domains: elastic, reservoir and geologic.

Bayesian geostatistics combines known information about the reservoir and updates it given new evidence, usually as sets of seismic angles or offset partial-stacks. All input data is assumed, to be uncertain. This uncertainty is expressed by assigning probability density functions (PDFs) to each. The prior information can be 1D, 2D or 3D and represent elastic properties or facies probabilities. Further, non-linear rock physics constraints can be utilized which describe the relationships between elastic and petrophysical properties. Once these relationships are established the outcomes of geostatistical inversion can be elastic or petrophysical or a combination of both. Additional information in the form of fluid contacts and facies ordering can be provided. These are then combined into a single global PDF using a Bayesian framework which describes the distributions of the desired outcomes. A customized Markov Chain Monte Carlo sampling scheme is subsequently applied to obtain realizations from that PDF. A key feature is the ability to estimate facies and continuous properties simultaneously.

The above procedure is perhaps more modelling than inversion. Nevertheless, the term, *geostatistical inversion* has become commonplace. More important are our perceptions of the meaning of *resolution*. Beyond the simple resolution of thin beds, a collective set of realizations can bring together disparate sources of information to model detail beyond the seismic band and to assess its variability. We review examples in the literature demonstrating increased resolution and added value compared to what could be expected from traditional deterministic processes. We identify three general sources of added value from geostatistics.

1. Deterministic inversions usually include some sort of sparsity constraint. There can be many solutions from which, the derived synthetics match the seismic equally. This non-uniqueness is addressed by invoking sparsity assumptions which limit the detail in the solution. These constraints are not found in geostatistical inversion, leading to the possibility of increased resolution when the additional detail is consistent across realizations and agrees with prior information (e.g. well logs). In these cases, the mean over a set of realizations can show improved resolution of thin beds. For examples, see Chelia et al, 2019, Kneller et al., 2019, Fillipova et al., 2013, McCrank et al., 2012, Ahmad et al, 2008, Pendrel et al., 2006. That aside, we do not generally advocate the mean as a final product. More value can usually be obtained from an analysis of the complete set of realizations. Certainly, if accurate flow simulation is a goal, then using the mean as a model will give a wrong result.

2. Deterministic inversions make use of wells only softly – for wavelet estimation and perhaps for low frequency model generation. In geostatistical inversion they are optionally incorporated into the solution more formally and with a user-specified degree of softness. This additional information when combined with spatial consistency information in the form of variograms, can increase the detail in simulated properties away from wells. The result is a distribution of simulated property volumes. See, for example, Hameed et al., 2019, Jimenez et al, 2013 and Ahmad et al., 2008.

3. Geostatistical inversions consist of sets of realizations – enough to represent statistical significance. Inferences about the reservoir are best made from that set collectively rather than from averages over them. For example, all the realizations might support the existence of thin sandstones, although their exact vertical positioning might be slightly different from one realization to the next. Creating a mean of the realizations can smooth this information to the extent that its impact is greatly reduced or eliminated. Ranking and assessment of P10, P50 and P90 cases are good strategies to use. This approach is a valid whether the well logs have been used in either a hard or soft manner. Examples can be found in El-Behiry at al., 2019, Sulistiono et al., 2015, Wang et al., 2015, Fillipova et al., 2013, Torres-Verdin et al., 1999.

Results

We review the results of Pendrel et al. (2006) from the geostatistical inversion of the Blackfoot seismic data (Figure 1) acquired over a Cretaceous three-valley complex. The targets are gas-charged sandstones in the upper and lower valleys. The middle valley is not productive. Figure 2 shows three of the realizations of Vp/Vs. There is no single answer, but a set, each of which is consistent with the input seismic. It was run in a “soft wells” mode, so the agreement to the logs is not perfect. In Figure 3, the left panel is from a deterministic inversion for Vp/Vs while the right is the mean of six geostatistical realizations. The resolution of the valley complex in the realizations is retained in the mean. The variability between the realizations has been used to compute a probability of occurrence for the low Vp/Vs facies representative of the gas-charged sandstones (Figure 4). This demonstrates the capability to gain insight into the underlying uncertainties.

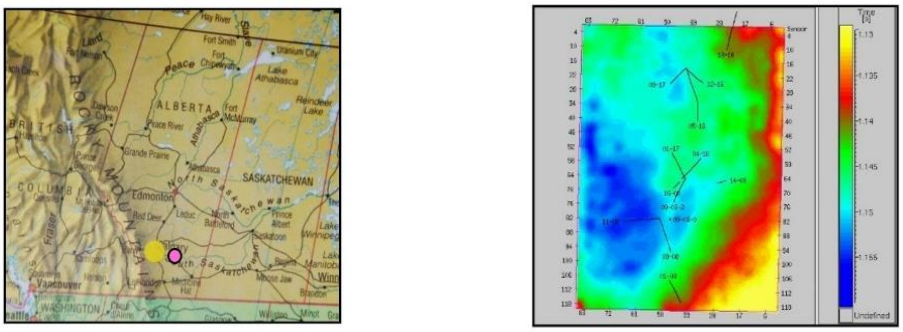

Figure1: The left panel shows the location of the Blackfoot play (pink dot). On the right is the time structure of the top of the reservoir with well locations.

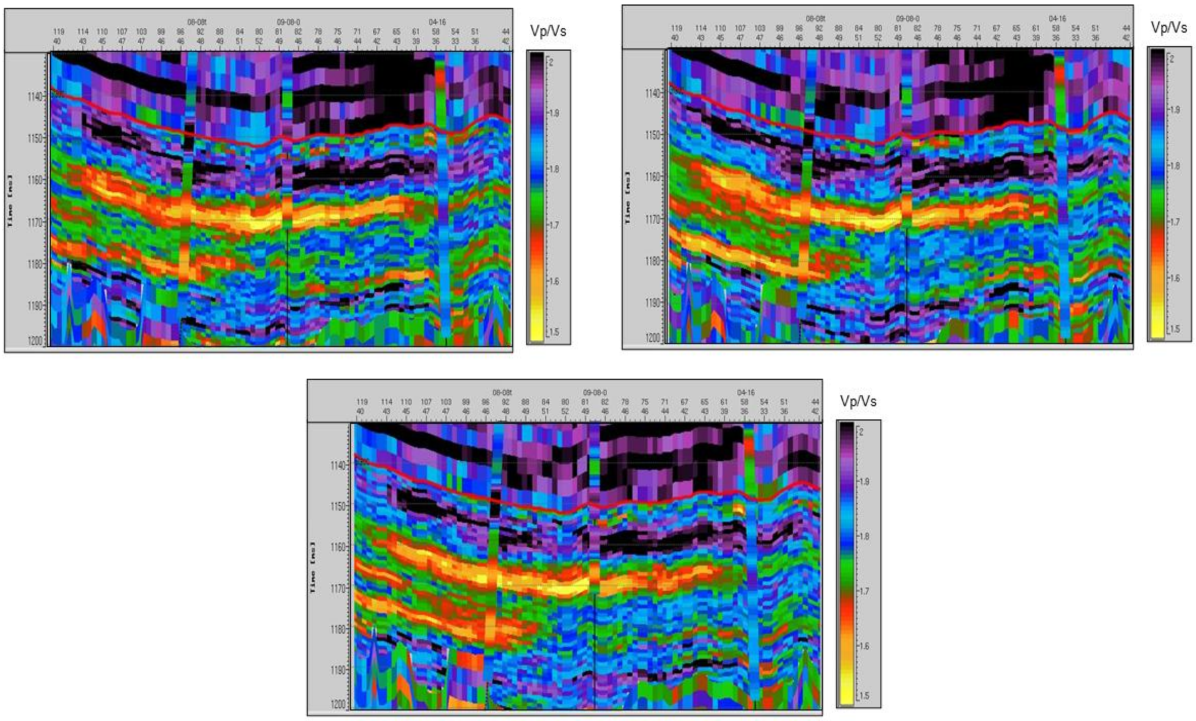

Figure 2: The figure shows three realizations of Vp/Vs from geostatistical inversion along an arbitrary line. The channel system is well resolved in each although the details differ between them.

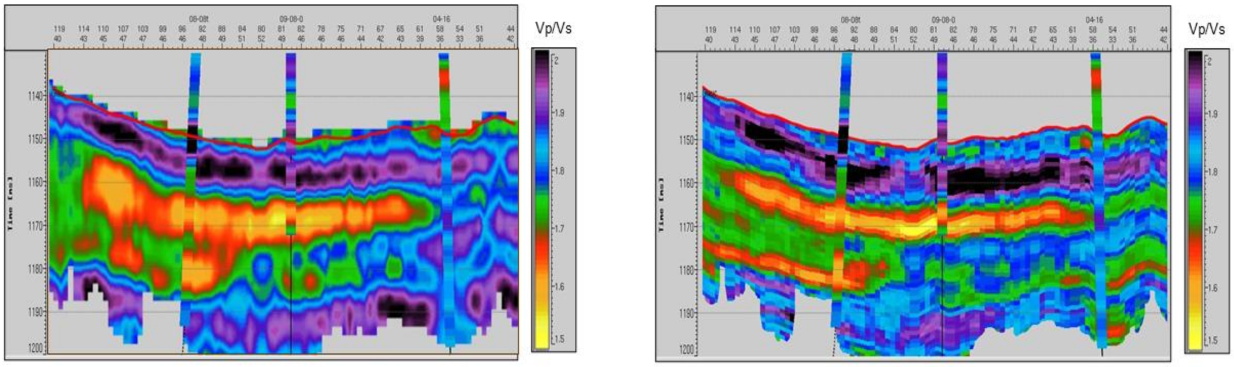

Figure 3: The left panel is Vp/Vs from a deterministic Inversion. The right panel is Vp/Vs from the average of six realizations from geostatistical Inversion. The geostatistical result shows much more detail.

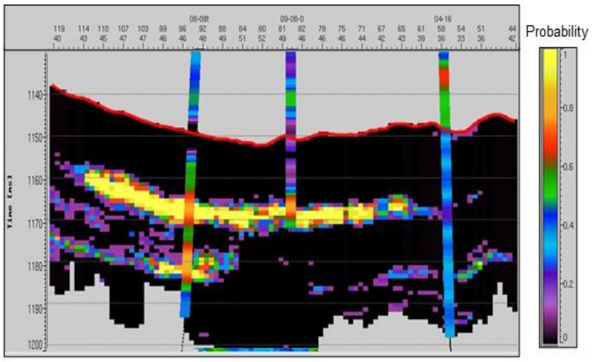

Figure 4: The figure shows the probability of gas-charged sandstones from an analysis of the facies from all the realizations.

Conclusions

The key to building highly detailed, realistic and useful 3D reservoir models of facies and petrophysical properties lies in the integration of disparate data sources such as seismic data, well logs, rock physics models and prior geological expectations. Geostatistical inversion is not restricted by assumptions of sparsity and can include a variety of additional information. This can often lead to an effective increase in the resolution of key reservoir properties.

Acknowledgements

We gratefully acknowledge the CREWES consortium at The University of Calgary for permission to use the Blackfoot data. Thanks also to our CGG GeoSoftware colleagues for their challenging questions and insights which have significantly improved our work and understanding.

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