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Geostatistical Inversion of Seismic Data from Thinly Bedded Ardley Coals

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Summary

3D seismic data, acquired to image the Ardley Coals, were deterministically inverted to estimate acoustic impedance. However the band-limited results overestimate both the acoustic impedance of the coals and the thickness of the coal zones. Additionally, the thin sub-zones of the Ardley Coals are not differentiated in the inversion. A geostatistical inversion was conducted in an attempt to improve the inversion resolution and assess model uncertainty. The inversion provides multiple model realizations, each of which honors the seismic data, the well data and the geostatistics. The mean of the realizations gives a highly resolved estimate of the acoustic impedance and the multiple model realizations provide a range of acoustic impedance and net coal-thickness estimates that can be used to quantify uncertainty in the results.

Introduction

A 560 m x 560 m 3D seismic survey was acquired to image the stratigraphy of the Ardley Coal Zone in west-central Alberta. The well correlation cross-section illustrated in Figure 1 shows that the Ardley Coal Zone can be divided into several sub-zones. The Upper Ardley Zone is approximately 10 m in gross thickness while the Lower Ardley Coal Zone is represented by two smaller zones: the Mynheer Coal Zone and the Silkstone Coal Zone. The Mynheer Coals are the deepest sub-zone and represent ~8 m in gross thickness while the shallower Silkstone Coals are ~3 m in gross thickness.

The acoustic impedance of the Ardley Coals was estimated using a constrained sparse spike inversion algorithm which is a deterministic inversion technique. However, when compared to the acoustic impedance well log (Figure 2), the inversion result overestimates the thickness of the coal beds and the acoustic impedance of the coals, and additionally, does not detect the thinly bedded nature of the coal sub-zones.

Geostatistical Inversion

The inversion can be improved by constraining the model estimation with the regional geostatistics as well as the high resolution acoustic impedance data from the well logs. The overall workflow is illustrated in Figure 3. The inversion result produces a number of possible acoustic impedance models, as well as facies models, each of which match the seismic data, the geostatistics and pre-defined petrophysical acoustic impedance cut-offs for the individual facies. The results can be optionally constrained by the well data.

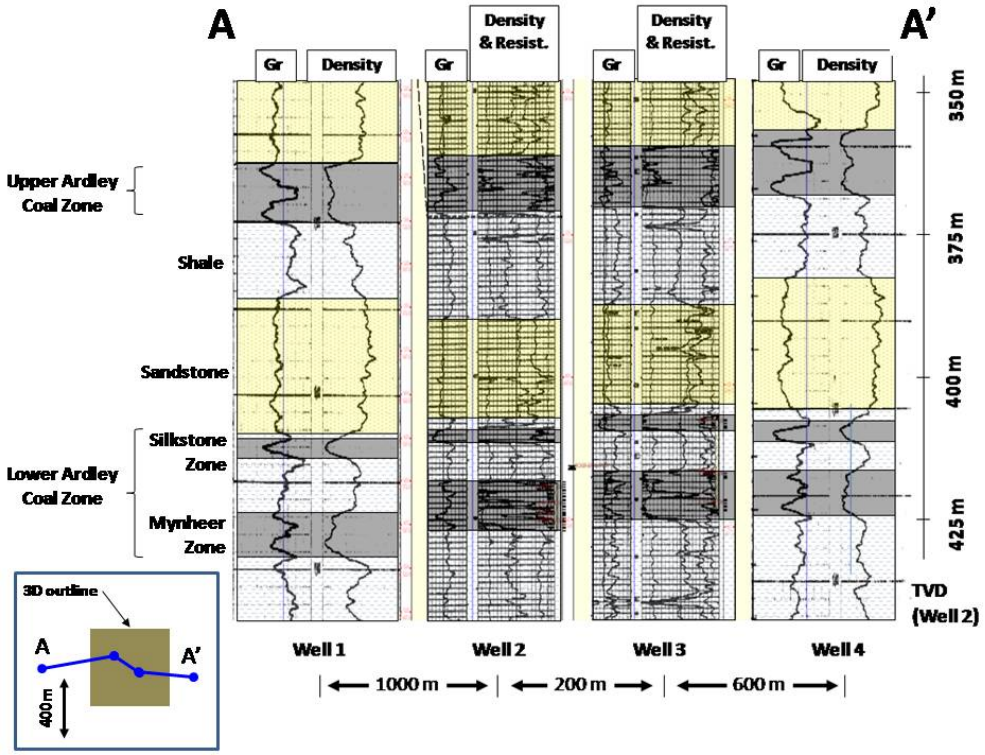

Figure 1: A north-south geological cross-section of the Ardley Coal Zone traversing the 3D seismic volume.

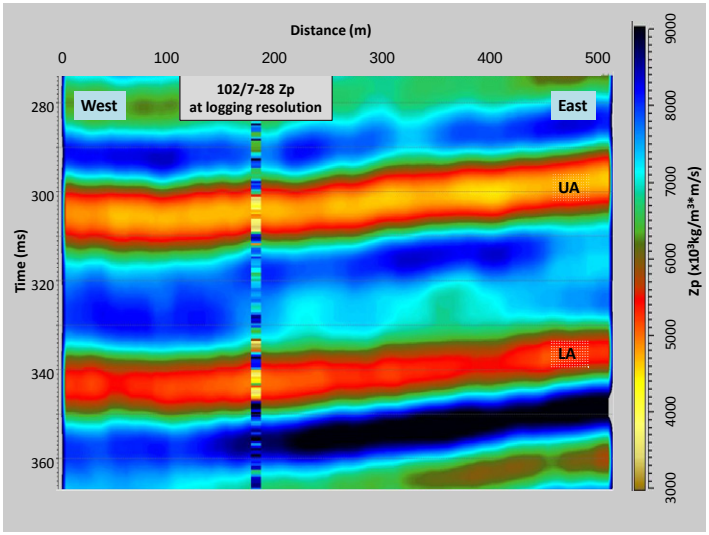

Figure 2: The deterministic acoustic impedance (Zp) seismic inversion result with the acoustic impedance well log superimposed at "logging" resolution. UA=Upper Ardley LA=Lower Ardley

Figure 4 shows the results of an acoustic impedance estimation that was generated (in this case without using the well control constraint). The figure shows five individual realizations as well as the mean of the full set of 10 realizations. The mean is the "most likely" acoustic impedance estimate. However, because each individual realization matches all available data and is an equally probable model, together the set of individual realizations can be used to analyze the probabilistic distribution of model possibilities.

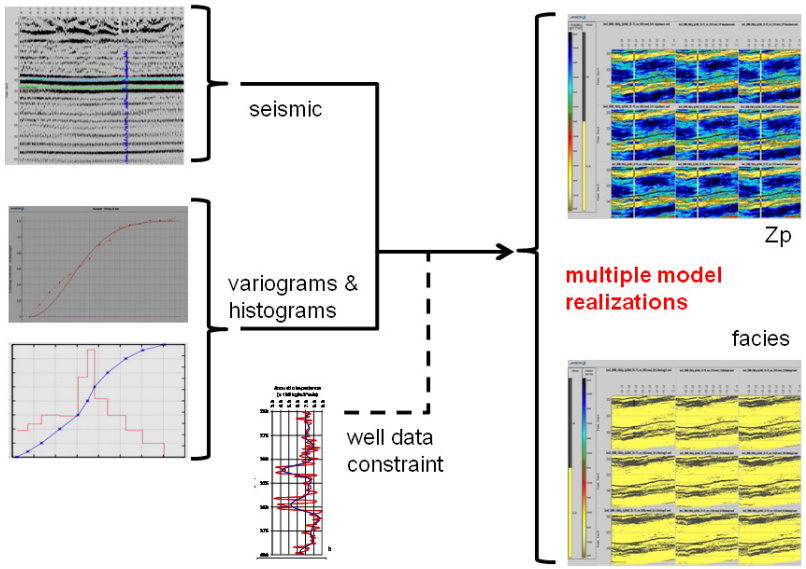

Figure 3: The workflow for performing a geostatistical inversion showing the input data and the outputted model realizations.

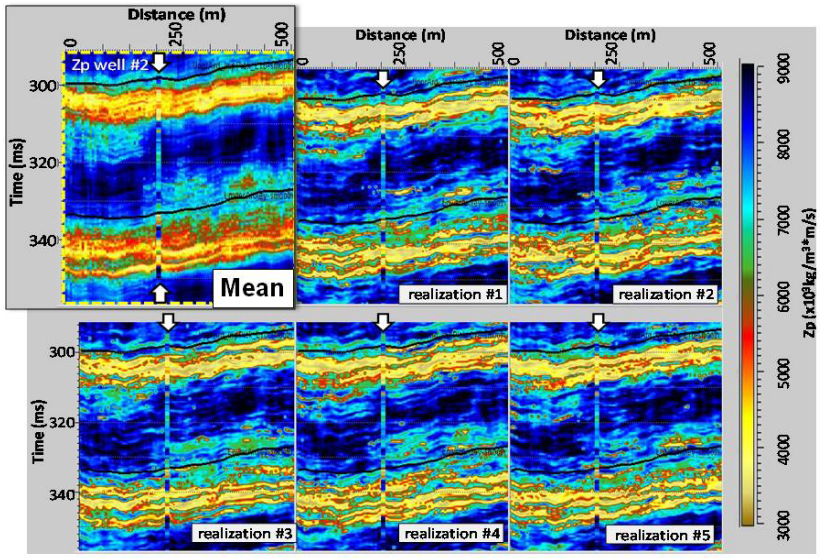

Figure 4: The acoustic impedance inversion results. The cross-section in the upper left is the mean acoustic impedance of multiple inversion realizations. The other cross-sections are some of the multiple realizations.

In addition to acoustic impedance realizations, the inversion produces facies realizations. Figure 5 demonstrates five individual realizations as well as the most likely facies model based on multiple realizations. Facies estimations can be used to estimate coal bed thickness. Again, the multiple model realizations can be used to quantify model uncertainty, and significantly, the uncertainty in the bed thickness estimation.

Figure 6 shows a comparison of the result from the deterministic inversion and the mean acoustic impedance estimate from the geostatistical inversion. The figure shows that the geostatistical inversion (in this case constrained by the wells) results in an estimate that more accurately estimates the coal bed thickness, more accurately estimates the very low acoustic impedance of the coals and honors the known statistical nature of the thinly bedded coal sub-zones.

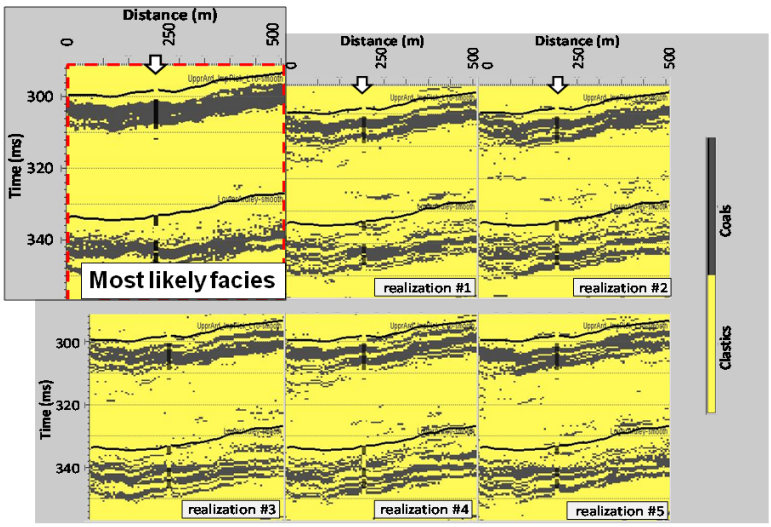

Figure 5: Facies results from the inversion. The cross-section in the upper left is the most likely facies based on multiple inversion realizations. The other cross-sections are some of the multiple realizations.

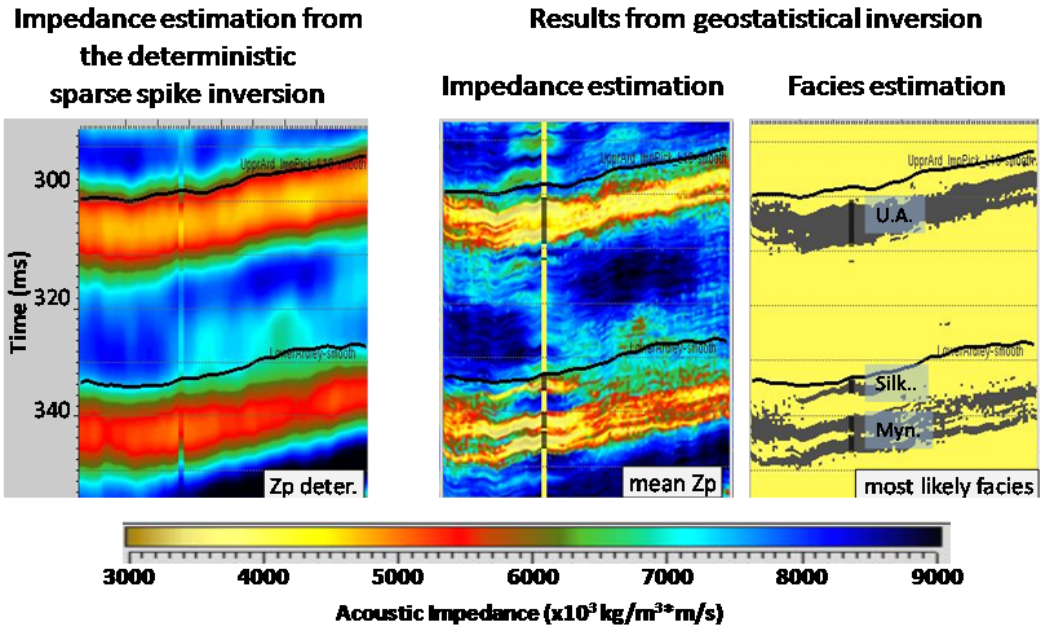

Figure 6: A comparison of the inversion results from the deterministic acoustic impedance (Zp) estimate and the geostatistical inversion estimates. The geostatistical inversion results are the mean of multiple model realizations.

Conclusions

An inversion of seismic data that is constrained by the local geostatistics can yield a high resolution inversion that accurately models the thinly bedded nature of coal zones and models the very low acoustic impedance values of coals. Additionally, the multiple model realizations provide a means of quantifying the non-uniqueness and uncertainty in the inversion result.

Acknowledgements

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