Leveraging Stochastic Inversion to increase understanding of Drilling and Completion Hazards in the Midland Basin

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Summary

Permian operators face many challenges in the exploration and development of resource plays such as the Wolfcamp and Spraberry Formations in the Midland Basin. Advances in drilling and completions have unlocked enormous amounts of hydrocarbons in the short term, but geology remains the strongest driver of long-term production (Canada Energy Regulator, 2018).

Carbonate debris flows are an example of the significance that geology plays in the Permian Basin. These debris flows may represent drilling hazards, and when they are not avoided, they may increase rig time and costs. They are also stress barriers that may negatively impact hydraulic stimulation efforts, resulting in poor well performance (Petre et al., 2019). Isolating debris flows from resource-rich reservoirs is critical during the target selection process to optimize horizontal well placement and achieve the desired rock failure from hydraulic stimulation, both needed for higher production performance (Othman and Amao, 2019; Iverson et al., 2020)

From a previous deterministic inversion, a carbonate debris flow within the target was identified but needed more information about its thickness and extent. The objective of this study was to provide high-resolution elastic property volume through the Modified Stochastic Inversion (MSI) workflow with careful consideration of the geologic context and availability of the data. This was also an opportunity to propose a repeatable workflow and practice that may be applied to other seismic assets in the Permian Basin.

Theory

Stochastic inversion is a modeling process that generates multiple property realizations at higher resolutions than what is available from deterministic inversion and enables geoscientists and engineers to estimate subsurface uncertainty.

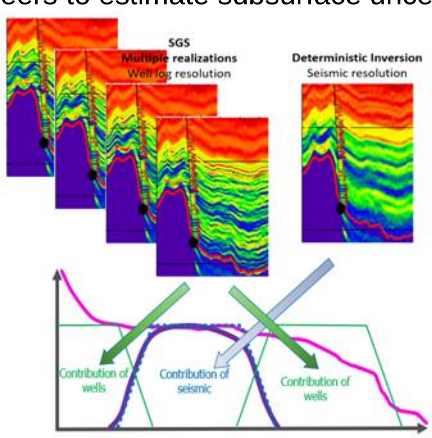

Figure 1. Modified Stochastic Inversion (MSI) schematic implementation in frequency domain.

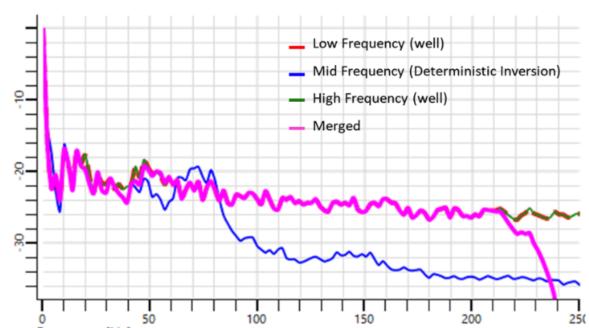

Figure 2. Modified Stochastic Inversion (MSI) output after the spectral merge (pink curve). Notice how more frequency content was added after the process. The blue curve represents the previous inversion volume spectrum.

In practice, classic stochastic inversion is expensive to compute, so only a few realizations are usually calculated. The costly aspect comes from generating several stochastic predictions, from which only those that match the seismic data are selected. This case study is based on a technology known as Modified Stochastic Inversion (MSI) workflow where the deterministic inversion result is spectrally merged with the desired number of simulations to generate several broadband realizations of the reservoir. High and low frequency bands are created from Sequential Gaussian Simulations (SGS) from the well data. The seismic is merged with each SGS realization as the middle frequency band (Figure 1). MSI simplifies the stochastic inversion process through explicit use of the inversion, satisfying the seismic data constraint and significantly reducing the computational time (Canning et al, 2020; Mouliere et al, 2020).

Figure 2 shows the Modified Stochastic Inversion (MSI) output after the spectral merge performed in this project. The pink curve represents the MSI output after the spectral merge. The previous inversion volume (blue curve) went up to about 70 Hz, but with the MSI output more frequency content was added considering the well information (red and green curve).

Results

Using the MSI workflow we were able to create accurate high-resolution models that better constrained the carbonate debris flow. The realization with the best correlation to the blind wells was selected as the high-resolution subsurface model and used to represent the reservoir.

Figure 3 contains a comparison of the deterministic inversion results versus 3 selected realizations of P-impedance. Note the higher frequency content on each of the realizations, compared with the deterministic inversion, but also the variability of the properties.

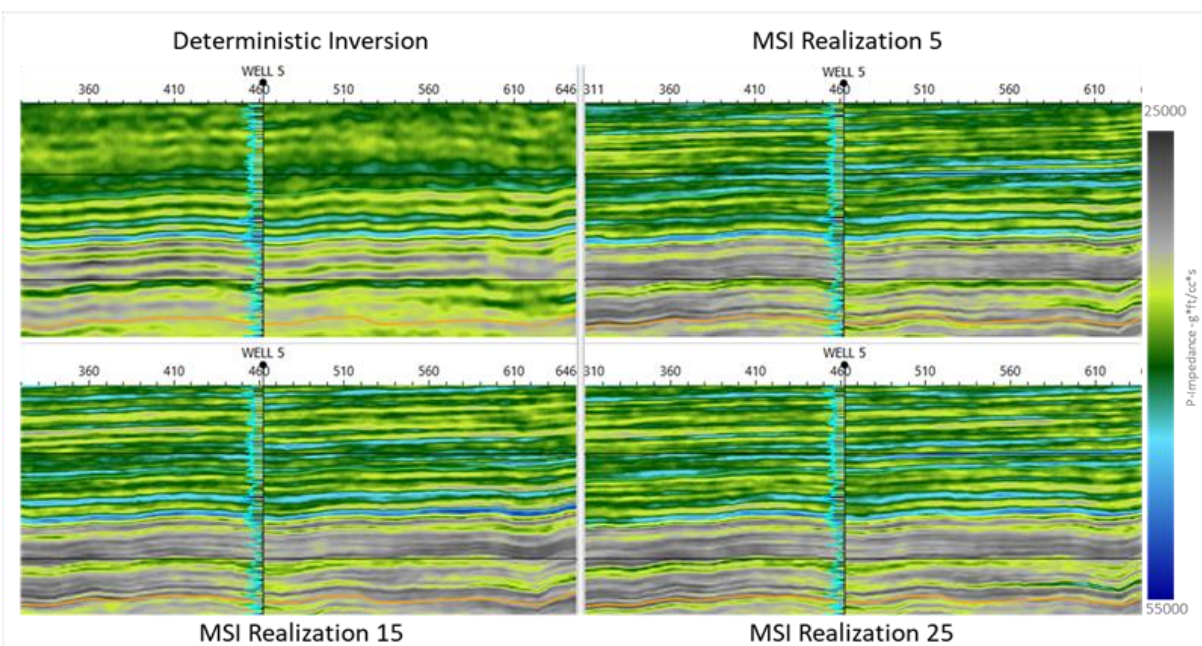

Figure 3. Comparison between Deterministic Inversion vs Realizations 5, 15 and 25 from Modified Stochastic Inversion (MSI) for P-Impedance. Notice the increase in detail in the reservoir and the variability between the realizations

As part of the study, the P-Impedance generated from MSI was extracted along the well trajectory and compared with the real log (upscaled) and the one extracted from the deterministic inversion volume. Figure 4 displays the 3 curves, in the interval of interest MSI (red) provides higher vertical resolution and adjusts better to the original well log (blue) than the deterministic inversion (green) that has a lower frequency content.

To validate the results quantitatively, the correlation factor between the MSI results and the upscaled logs in the interval of interest was estimated, obtaining a 0.75 value compared with the correlation factor from deterministic inversion of 0.65.

Observations

Any stochastic seismic inversion, including MSI, produces multiple, equally likely realizations, consistent with the available well and seismic data, at the fine-scale vertical resolution required for such reservoirs. Many different approaches may be implemented to decide which volume(s) to use. But as the output of stochastic inversion is an ensemble of equiprobable realizations, decisions are best made collectively (Pendrel, 2021). One approach is to rank the realizations based on a criterion that is geologically meaningful and relevant to the problem at hand. Then models corresponding, for example, to the P10, P50, and P90 percentiles are easily identified.

This method can be done by isolating which values are meaningful to constrain the extent of the debris-flow in the zone of interest. In this analysis, a cutoff of P-Impedance values above 40,000 g*ft/cc*s was determined from well logs. From the ranking performed, the P10, P50 and P90 volumes were chosen to assess subsurface uncertainty and determine the geobodies' extension.

Figure 5 displays the debris-flow geobodies extracted from the deterministic inversion and the MSI realization that corresponds to the p90 volume. A better definition of the geobody can be seen in the MSI realization due to the higher frequency information added, providing a better understanding of its thickness and extension.

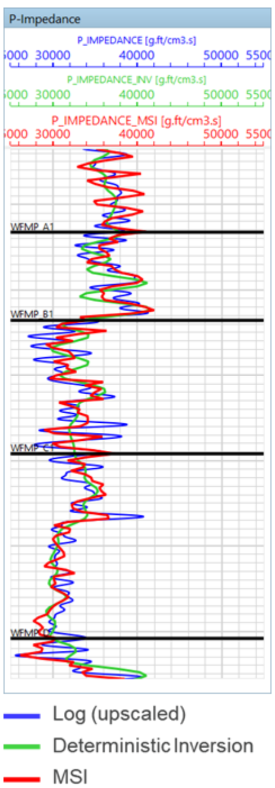

Figure 4. Comparison between MSI curve extracted along well trajectory (red), original well log upscaled (blue) and deterministic inversion volume (green). Notice how in the interval of interest, MSI has a higher frequency content and matches better with the well log than the log extracted from the deterministic inversion.

Another aspect that stands out from the MSI results is when looking at a thickness map of the target zone (Figure 6). In the deterministic inversion thin layers cannot really be detected; however, the MSI realizations we could see that on average the reservoir is thinner and we are able to detect thinner layers. In other words, geological features as thin as 8 feet could now be modeled with confidence, rather than the original 40 ft resolution from seismic data alone. This will allow the operator to incorporate the uncertainty of the debris flow/drilling hazard into the digital subsurface model.

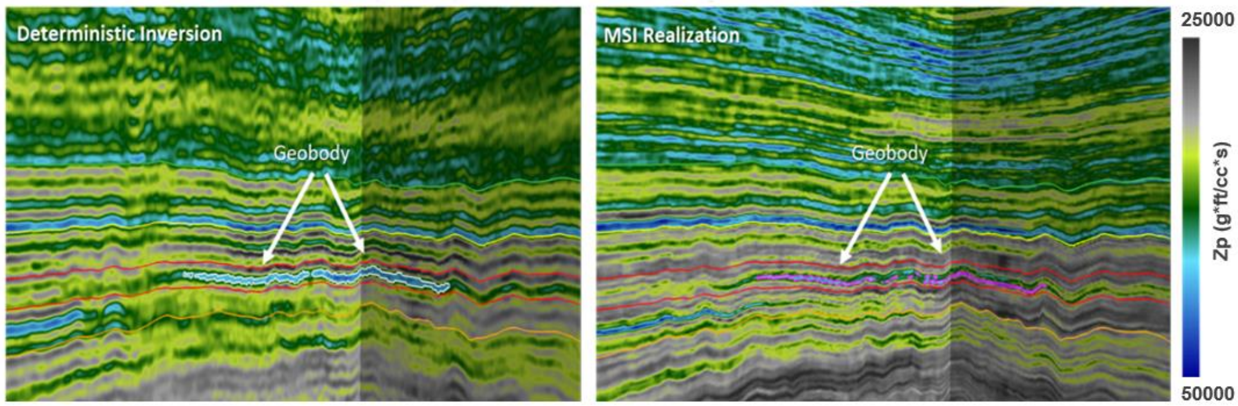

Figure 5. Crossection through debris flow with geobodies extracted based on P-Impedance values above 40000 g*ft/cc*s, from the deterministic inversion volume (left) vs MSI realization P90 (right).

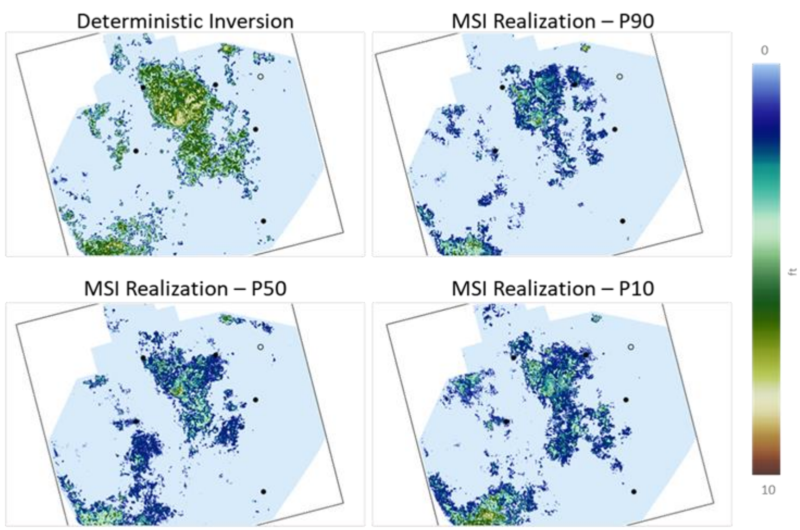

Figure 6. Comparison of thickness map of areas, with P-Impedance values above 40000 g*ft/cc*s in the target zone, generated from Deterministic inversion and p90, p50, p10 from MSI realizations. Thinner layers (as 8 feet, 2ms) can be detected and resolved in the MSI realizations volumes.

Conclusions

The operator built upon its knowledge of the likely position of the debris flow by gaining a better understanding of its thickness and extent at the reservoir. Reservoir specific accommodations could also be made to calibrate hydraulic stimulation parameters to optimize rock failure in the presence of this stress barrier, thus improving performance of the wells.

MSI decreased the time required for the stochastic simulations decreasing computational costs and project timelines. The enhanced detail about the reservoir geology aided in reliably assessing risk for landing target selection and field development. More robust decisions regarding drilling may be made earlier using high-resolution reservoir models that are constrained by all the available data (interpretation, logs, seismic, etc.).

This technology can also serve as a step toward the direct use of high-resolution geomechanical properties derived from seismic to build 3D wellbore stability models in developing fields, characterizing the lateral variation of mechanical properties and providing better prediction throughout the full field.

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