Reservoir-Scale Volumetric Interpretation: A New Approach to Building a Low-Frequency Background Model

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Abstract

As the inversion of seismic data has become a routine part of most seismic-driven reservoir characterization workflows, quantitative interpretation teams are facing a series of challenges when using a model-based seismic inversion. Because seismic data are bandlimited, low frequencies for the seismic inversion process can be obtained from the use of a geologic model with the corresponding objective function of the seismic inversion. The geologic model is typically built from seismic interpretation data, well logs, and spatial interpolation technicques like geostatistics. Time and technology constraints often result in simplified structural and stratigraphic representations of the earth model.

In order to secure a colocation of seismic data and geologic model, high resolution models are required. This paper considers an advanced reservoir modeling approach, paired with a volumetric reservoir-scale interpretation workflow, to build a background model that better fits what is observed in the seismic data.

Introduction

Better acquisition techniques, such as broadband and improved seismic processing algorithms, have led to significantly higher seismic image quality with higher frequency contents and a corresponding greater amount of embedded stratigraphic details. This creates a challenge for geoscientists who need to interpret and derive elastic properties from more detailed seismic features.

In a complex structural and stratigraphic environment, geoscientists must spend considerable time trying to propagate and correlate seismic reflectors, before undertaking any quantitative interpretation workflow. This usually results in a seismic interpretation that tends to be associated with clear impedance contrasts and some partially interpreted seismic events that are not of sufficient quality to be considered for reservoir modeling. This is especially critical in areas where the seismic data is noisy, the structure complex, or in specific geologic environments such as subsalt or unconventional plays, where rock types are very heterogeneous and seismic is characterized by low impedance contrasts. In these cases, the seismic stratigraphic information will be lost between the seismic interpretation and geologic modeling stages; and what is more likely, it will lead to an inconsistent 3D geologic model. This concept is not new; seismic interpretation and modeling technologies need to honor the complex information embedded in the seismic data. A solution to this issue requires a multi-domain approach (G&G interpretation and modeling) and the integration of technologies associated with each domain. Past modeling limitations (horizon and pillar-based technologies) made maintaining synchronization between the model and the respective interpretation difficult; plus, users lacked the time and expertise to perform these workflows efficiently.

Method

A solution may be found in the form of a new workflow that introduces the concept of Reservoir-scale Volumetric Interpretation. This workflow seamlessly combines automatic, waveform-based seismic event extraction with a volume-based modeler that can accept any fault network configuration and any number of partially interpreted reflectors as input, and use them to produce a geologically consistent model honoring all the seismic stratigraphic details.

The objective of using an automatic interpretation technique is to extract as many partial horizons or patch information as possible, using a waveform-based seismic propagator. In order to account for the variability of the seismic signature and automate the extraction process, seeds (or the selection of initial seismic traces to be propagated) are automatically positioned in the volume as a function of both inline and crossline (independently) directions and vertical sampling rate. The seeds are preferentially placed within formations (reservoir-scale approach) of interest, defined by an initial sealed structural model.

As the goal is to track a consistent seismic event (pick or trough) throughout the entire volume within the formation of interest, the vertical distance between two seeds will be chosen and adjusted in order to capture consecutive seismic events.

Typical parameters associated with the 3D seismic propagator, and editing operations like patch merging and areal filtering, allow control over the extraction and finalization of the automated seismic interpretation stage. The objective is to obtain a set of non-overlapping patches. Each patch will have a different size and shape in accordance with the characteristics of the seismic data and the 3D seismic propagator parameters. Figure 1 represents an example of automatically extracted patches within the formation considered as the target. We observe that in some areas the extracted events do not appear to conform to the top and base of the formation of interest (bending close to the faults) and the discontinuity of the propagated patches, based on the parameters used in the event propagation.

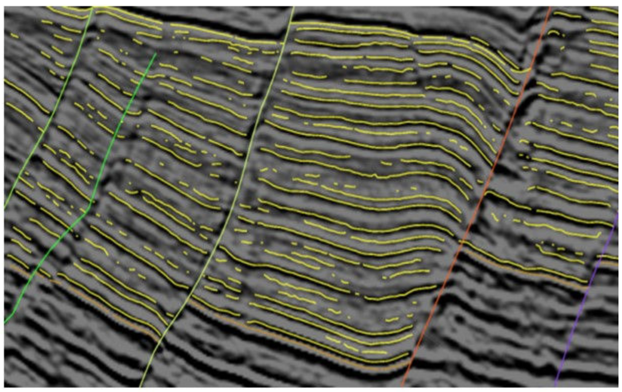

Figure 1 - Automatically extracted seismic events

If we assume that the seismic reflections are consistent with the chronostratigraphy, the extracted patches are a representation of the relative geological time and can be used in a modeling workflow to constrain the stratigraphic model (Figure 2).

The patented UVT Transform® algorithm (Mallet, 2004, 2014) is a mathematically derived 3D methodology that generates a volume description of the subsurface, including the structure, stratigraphy, geological grid, and flow simulation grid. It uses ALL of the data, without simplification. U and V define the paleogeographic coordinates, while T is analogous to the relative geologic time. UVT Transform removes the constraints of traditional, pillar-based technology. Without pillars, users are able to create more accurate models of the subsurface. The algorithm delivers a consistent representation without "dumbing down" the data, so that there is no need to simplify the interpretation.

The relative geologic time T is based on the simple concept that an interpreted horizon (or seismic reflector) corresponds to the same choronostratigraphic event, relative to the definition of a stratigraphic column. If we consider each extracted patch as part of a single horizon, then each patch is associated with a single relative geological time and will contribute to constraining the geological time in the full volume

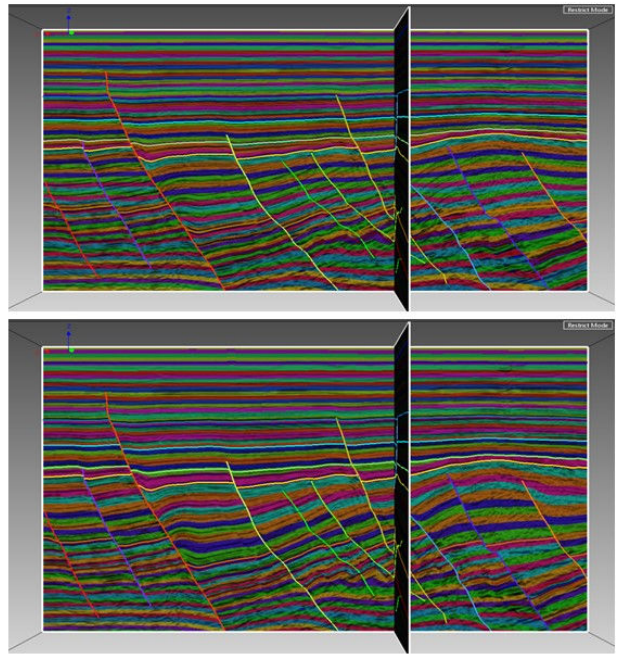

Figure 2 - Relative geologic time (T) before automatic propagation (top) and after update of the structural model following propagation (bottom)

To validate the wealth of interpretation data and the model, this approach offers another innovation: paleo-flattening space, based on the UVT Transform. Once the structural and stratigrapic model is built, the process places the seismic data and the entire interpretation in a Wheeler space, where all fault displacements are removed, deformations minimized and all horizons are flat. Unconformities are represented by void volumes. The user will look for non-flat seismic events in a flattened volume, where each slice is a true stratigraphic slice, making quality control easier in the real depositional and control framework. Figure 3 illustrates the final geologic grid on which low-frequency information can be propagated, before being transferred onto the seismic grid for use in a model-based seismic inversion.

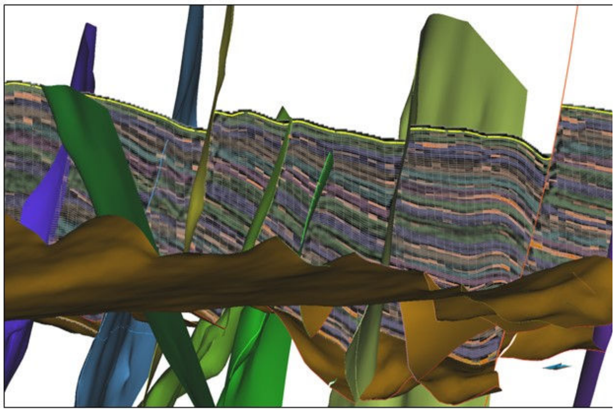

Figure 3- Merge of a simulated reservoir property and seismic data onto the geologic grid to illustrate the correlation between property behavior and seismic events

Conclusions

This approach – high-definition, reservoir-scale volume interpretation - constrains the 3D geologic model to honor the seismic reflections observed in the seismic data, and therefore transfers an accurate image of the subsurface into a reservoir modeling workflow. We can consider the application of this advanced interpretation-modeling workflow to other domains, such as quantitative interpretation, where most of our seismic elastic inversion workflows are based on an initial guess represented by the low-frequency model (background model). In such cases, the stratigraphic geological model supporting the low-frequency impedance property will fit the lateral and vertical seismic response variability.

References

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