

# Geologic modeling for seismic inversion

*Impedances inverted from seismic data help generate attributes for reservoir property analysis and estimation.*

## AUTHORS

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Seismic inversion is routinely applied to exploration and development assets to generate spatial models of reservoir (elastic) properties and to create seismic responses that correlate to stratigraphy. In the case of mature fields, seismic inversion procedures can benefit from a wealth of *a priori* data. If this *a priori* data is conveniently synthesized in the form of a geologic model, that model can be used to apply necessary but flexible constraints to control the non-uniqueness of seismic inversion. The flexibility allows us to selectively place more emphasis on the seismic data or on the model. Most importantly, the confidence in the reservoir property models generated by the seismic inversion process is predicated on the confidence in the structural positioning and property distributions of the geologic model. In this regard, a model-driven seismic inversion procedure should be driven by a modeling process that properly honors structural detail (faults) and a modeling procedure that distributes properties in its depositional state.

## Seismic inversion

Modern seismic inversion procedures give consideration to the dimensionality (offset or, preferably, angles) of seismic data and the dimensionality (structure, compressional impedance, shear impedance, density) of the geologic model. Inversion methods that accommodate the dimensionality of

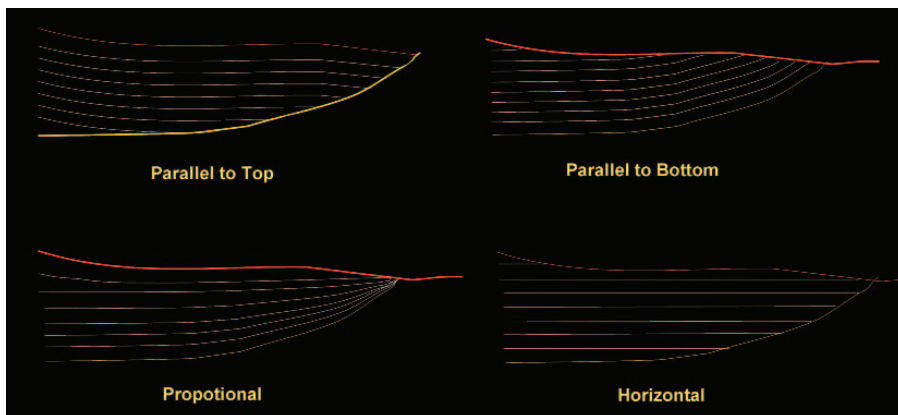


Figure 1. Structural styles used for property modeling. (All images courtesy of Paradigm)

seismic data in a synchronous and global manner are referred to as simultaneous inversions.

The seismic term minimizes the difference between the observed seismic data (angle stacks) and synthetic angle stacks obtained from forward modeling of the geologic property models using a linearized approximation to the Zoeppritz equation. The geologic term incorporates *a priori* impedance and density model(s) with micro-layer geometry descriptions to “steer” the inversion operator. Minimization of this component is based on perturbations to those models.

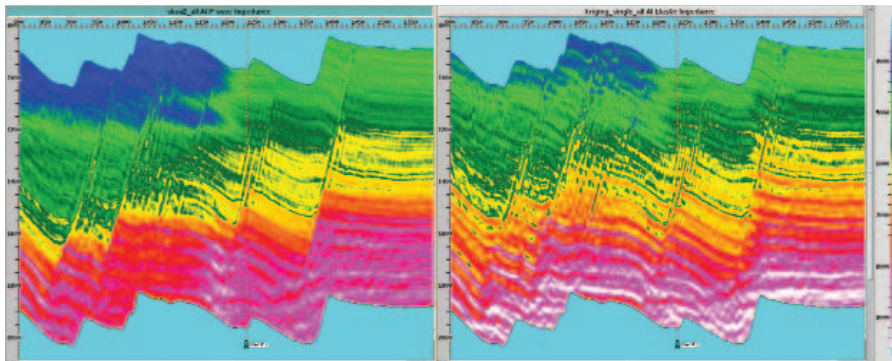
This approach has a number of benefits. First, the inversion is performed simultaneously over all input angle stacks for multiple elastic parameters such as compressional (P) impedance, shear (S) impedance, and density. Second, it is model-based. A multi-channel and geologically oriented filter is incorporated in the inversion process that follows the micro-structure to better constrain the inversion response. Consequently, the inversion results are more accurate than traditional inversion procedures.

## Background geologic model

The background geologic model provides the initial estimate of impedance values and provides constraints for subsequent updates in the internally iterative inversion procedure. One of these critical constraints includes the incorporation of low-frequency components that are missing from the seismic data. Consequently, the background geologic model is used to control both inversion non-uniqueness and accuracy.

The background model is often created from sparse well log data and seismic interpretation data using geostatistical procedures. Through geostatistics, well log information (e.g., P-wave impedance logs) is interpolated following the structure style within the project area to create the impedance volumes. There are different ways to honor the geologic structure during the geostatistical process. Figure 1 shows common structural styles (parallel to top, parallel to bottom, proportional, and horizontal) that can be used to guide the geostatistical process.

Although geostatistical methods are both readily available and generally easy to use, they are also burdened with restrictions, namely the require-



**Figure 2.** Seismic inversion results with proper fault handling (left) and simplified fault handling (right).

ment that distances between grid nodes are the same throughout the model in the current space or paleo space. In the presence of structure, these assumptions will not be met, and differences will exist between distances obtained in the restored and depositional states. This problem is more severe in faulted reservoirs where modeling of data in the pre-faulted state will result in better spatial correlations of data.

### Better modeling and inversion

There are two major challenges in model building. The first challenge is how to build a water-tight structural model that represents the current-day geological structure style. This problem is exacerbated in structurally complex regimes where the geoscientist is often tasked with generating models with tens or hundreds of faults within a short period of time. The process of structure framework building is to make sure that the fault network and fault-horizon intersections are created correctly and seamlessly. This process is often time-consuming and labor-intensive.

The second challenge is how to represent a 3-D property grid within this structural framework that restores the connectivity of properties that existed in the depositional state. Addressing both of these challenges will result in a better background model to drive the seismic inversion procedure.

These challenges are being addressed

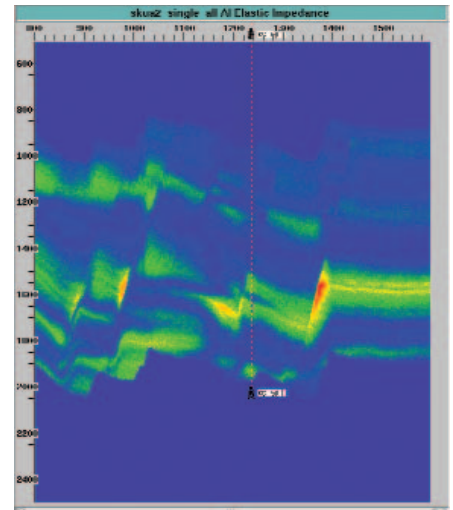
by recent developments in structural framework and reservoir modeling technologies. Through automatic fault network connectivity detection and stratigraphic sequence modeling, the structure framework can be built accurately and in a timely manner.

Another breakthrough in reservoir modeling is geologic grid construction using paleo-geochronological transformation. This transformation (UVT) is carried out such that a unique geochronological time (T) is assigned to a seismic horizon carrying the two dimensions (UV) of paleo-space that define the paleo-geography of each T plane. Using the paleo-geochronological transform, a grid can be constructed inside the present-day XYZ space that will have cells split by faults and offset by fault throws. No cell deformation will be present, so that geobodies, reservoir properties, and other attributes can be correctly modeled in their depositional states.

### Applications

The approach described above is appealing for building accurate geologic models of impedance data to constrain the seismic inversion.

Figure 2 shows the results obtained from seismic inversion with different background geologic models. On the left is the P-wave impedance data obtained from the simultaneous inversion using the more accurate background model. On the right is the P-wave impedance data obtained from the simultaneous



**Figure 3.** Inversion result differences from the two geologic models.

inversion of the simplified geologic model. The difference between the two is shown in Figure 3. The blue color indicates no difference, while the red color indicates a large difference. Green and yellow represent intermediate differences. The presence and distribution of the red color (large difference) is largely associated with the faults.

### Conclusions

Seismic inversion is routinely used in reservoir characterization projects, particularly in mature fields where new reservoir compartments need to be identified or reservoir performance needs to be improved. We use impedances inverted from seismic data to generate other attributes for reservoir property analysis and estimation. Seismic inversion, by definition, is a data bridge or data integrator that relies heavily on the quality of the geologic background model. We prefer a global inversion approach that is performed simultaneously and globally for all angles and all data and an approach that is model-based with geologically oriented filters. Geologic models that incorporate faults without cell deformation and without compromising project times should be given high consideration for all seismic inversion projects. **E&P**