Elastic Full-Waveform Inversion

Elastic rock properties from borehole seismic data

APPLICATIONS
- Deepwater and shallow-water offshore exploration
- Clastic and carbonate reservoirs
- Unconventional resource plays
- Enhanced oil recovery operations
- CO₂ sequestration projects

BENEFITS
- Enables higher-resolution vertical transverse isotropy (VTI) velocity models and associated images
- Generates a shallow velocity structure for use in multiple-suppression algorithms
- Maps changes in stratigraphy to improve planning of offset wells and laterals
- Optimizes placement of production and injection wells
- Improves fluid detection in carbonate reservoirs

FEATURES
- Extends full-waveform inversion from surface to borehole seismic data
- Directly estimates five elastic rock properties from vertical seismic profile (VSP) data
- Requires no advanced processing, imaging, or inversion workflows
- Complements traditional 3D VSP and walkaway VSP processing
- Provides a new tool for estimating VTI anisotropy parameters
- Delineates sand stringers with low compressional impedance contrast
- Models changes in velocity directly related to CO₂, steam, or water injection
- Assists with borehole calibration of surface seismic data

Apply elastic full-waveform inversion to borehole seismic data
Schlumberger integrates proprietary advanced workflows for 3D borehole seismic survey design, acquisition, processing, and interpretation to provide operators with high-resolution subsurface images and critical formation properties. The result is improved oil and gas reservoir characterization, modeling, targeting, monitoring, and, ultimately, production.

Elastic full-waveform inversion (FWI) is a new borehole seismic application that provides direct estimates of elastic rock parameters—compressional- and shear-wave velocities ($V_p$ and $V_s$, respectively), density, and Thomsen’s epsilon and delta—from minimally processed 3D VSP and walkaway VSP recordings.

Although acoustic FWI algorithms have been applied successfully to surface seismic data to obtain more accurate formation properties, now Schlumberger can apply elastic FWI to borehole seismic data.

Obtain accurate parameters with complex processing
Typically, obtaining accurate estimates of elastic rock properties from surface or VSP data requires long, complicated processing, imaging, and inversion workflows involving wave separation, deconvolution, model building, and migration. Traditional approaches include various trace inversions, simultaneous inversions, or joint inversions of prestack and poststack seismic data.

Advanced elastic FWI simplifies the process by extracting formation parameters directly from VSP data. The only processing involved is noise reduction and rotation of the 3D data to the

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Synthetic traces (right) generated during elastic FWI match with the real data (left). This is an excellent QC of the inversion. The synthetic data should replicate all the wave modes seen on the real data.
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Elastic FWI \(V_p\) and \(V_s\) profiles from a well in the Horn River basin in British Columbia, Canada. The white circles are the VSP receivers, the black curves are the sonic \(V_p\) and \(V_s\) responses, and the blue curves are the inverted \(V_p\) and \(V_s\) responses at the well location. The inversion produces an excellent tie at the wellhead. Fine details seen in the logs are captured in the property profiles.

Elastic FWI uses elastic wave equations in anisotropic VTI media to model wave propagation, minimizing the misfit between modeled and real data by repeatedly updating model parameters. The technique requires two inputs: a 2D source line from land or marine VSP data, and a smoothed version of the borehole-calibrated VTI model generated from well data. The 2D source line may come from a walkaway VSP, or can be extracted from a 3D VSP.

First, forward-modeled data are saved as synthetic seismograms. Then, the elastic FWI algorithm performs a simultaneous inversion for the source wavelet and five elastic rock properties—\(V_p\), \(V_s\), density, epsilon, and delta. The model is continuously updated until synthetics match the real data. In this manner, elastic FWI generates high-resolution 2D profiles. It is possible to invert for the source wavelet, an important consideration in land work.

Resolve finer geologic details, improve field operations
Elastic FWI is more accurate than the acoustic inversion schemes commonly used on surface seismic data. It produces profiles of formation properties with much higher resolution than conventional imaging. The technique can recover geologic features not resolved on standard VSP images. By extracting anisotropy profiles around the well, it provides calibration points for surface seismic imaging and supports other methods of estimating anisotropy.

In unconventional resource plays, more accurate elastic parameters can enable operators to map high-resolution changes in rock heterogeneity to improve offset and horizontal well planning.

In EOR and CO\(_2\) sequestration projects, elastic FWI can provide a direct, more quantifiable look at changes in \(V_p\) and \(V_s\) due to CO\(_2\) steam, or water injection. In carbonate reservoirs, elastic FWI can identify subtle changes in stratigraphy and improve fluid detection. Reservoirs that are difficult to detect, such as thin channel sands with low compressional impedance contrast, may be detected using another elastic property.

In deepwater exploration, many operators depend on complicated processing schemes to estimate \(V_p\) and \(V_s\) to calibrate pore pressure predictions.