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Time-Lapse 3D VSP Processing

Accurate monitoring of reservoir changes caused by injection and production

APPLICATIONS
- Reservoir monitoring
- Onshore oil and gas fields
- Clastic and carbonate reservoirs
- Hydraulic fracturing
- Steam-assisted gravity drainage (SAGD)
- Enhanced recovery operations
- CO_2 sequestration projects

BENEFITS
- More cost-effective than time-lapse surface seismic data
- Deploys more easily around surface obstructions
- Enhances accuracy of velocity models
- Helps optimize oil and gas drainage

FEATURES
- Acquires data with a downhole array of wireline-deployed geophones or permanent in-well sensors (including fiber-optic distributed acoustic sensors)
- Uses the same industry-leading Omega* geophysical data processing platform algorithms as time-lapse surface seismic processing
- Calculates time-lapse seismic attributes to visualize and confirm reservoir changes caused by injection and production
- Provides higher-resolution seismic images
- Directly measures velocity changes in target reservoirs
- Identifies changes in other reservoir properties
- Validates CO_2 sequestration

Measure velocity changes, build better velocity models

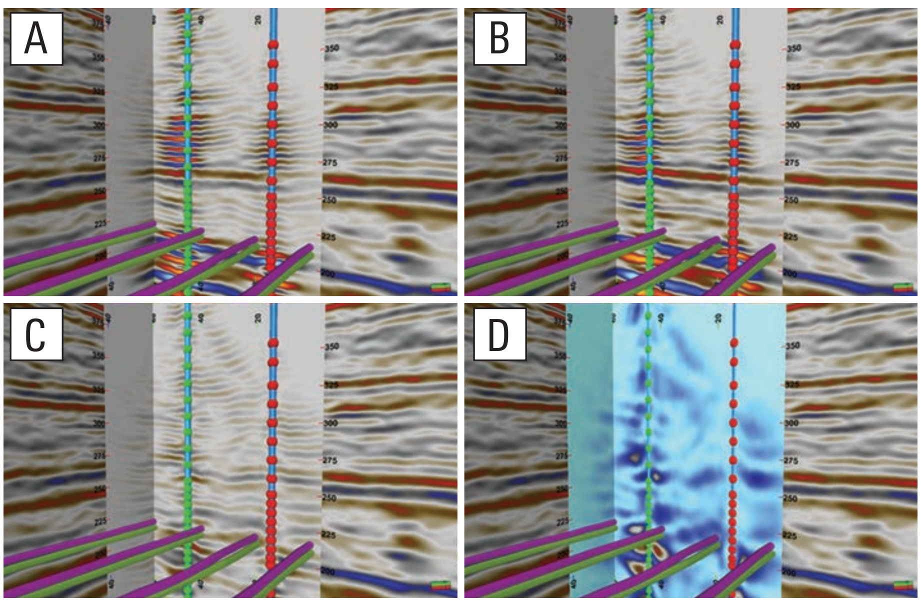
Time-lapse or 4D seismic surveys monitor changes in various reservoir properties over time. These enable operators to track the movement of CO_2, water, and steam floods to optimize either hydrocarbon drainage or CO_2 sequestration. Many E&P companies also use time-lapse 3D vertical seismic profiles (VSPs) for reservoir monitoring.

In 3D VSPs, receiver arrays are placed downhole and seismic sources at various positions on the surface. High-resolution 3D VSPs are routinely used to complement, and in some cases substitute for, surface seismic acquisition both on land and offshore.

When receivers are placed directly in target reservoir zones, time-lapse 3D VSPs can directly measure velocity changes and build velocity models that better explain changes in reservoir properties caused by injection and production.

Reduce expense, achieve higher-resolution data than surface seismic

Schlumberger time-lapse borehole seismic processing workflows use the same industry leading algorithms and Omega platform used for time-lapse surface seismic surveys, carefully matched to maximize repeatability. For QC and interpretation, various time-lapse metrics are also adapted from surface seismic. Time-lapse seismic attribute calculations help visualize subtle property changes, identify barriers to connectivity, and monitor potential leakage.



3D views of a SAGD baseline 3D VSP survey (A), repeat survey (B), difference section (C), and a sweetness attribute (D) showing two observation wells and four horizontal injection and production pairs. Note higher resolution of VSPs than surface seismic (background) and changes in the reservoir (B, yellow) due to steam injection.

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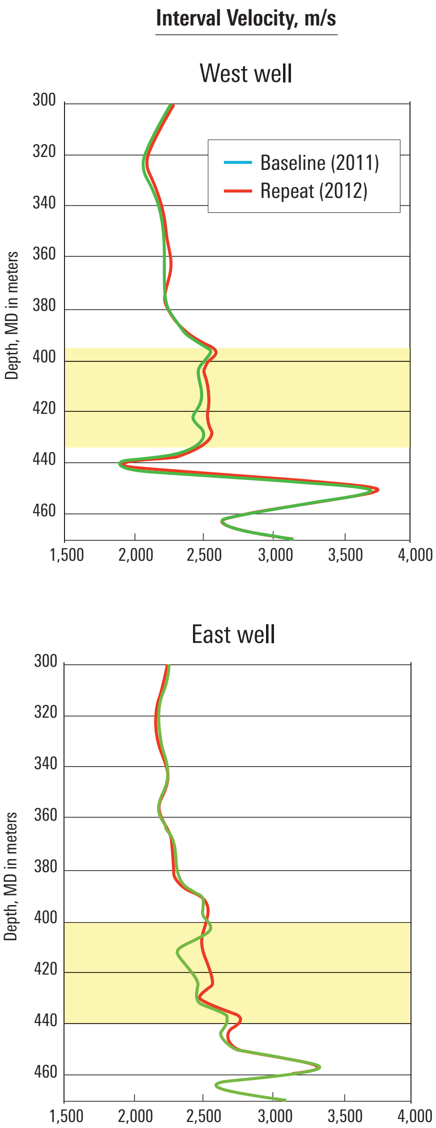


Comparison of near-offset checkshots from a baseline 3D VSP survey (blue) and repeat survey one year later (red) in two SAGD observation wells. Note the velocity decrease within the target reservoir zone (yellow).

Compared with surface seismic acquisition and processing, 3D borehole seismic surveys are more economical, easier to deploy in the presence of surface infrastructure, and provide higher resolution images around the wellbore. They can effectively fill in areas not imaged effectively by surface seismic because of difficult subsurface conditions such as shallow gas, which disrupts P-wave propagation.

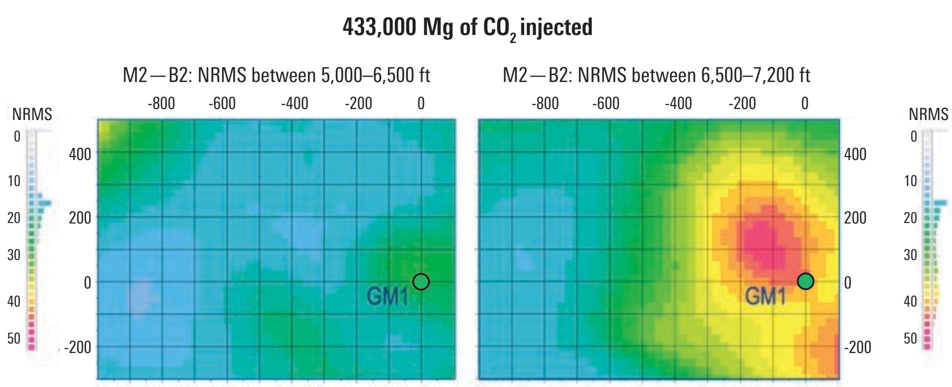
Installing permanent downhole geophone arrays can improve survey repeatability over time, without incurring the costs and complexities of surface seismic acquisition. Some operators are beginning to experiment with distributed acoustic sensing technology, using in-well fiber-optic cables as permanent sensors for time-lapse 3D VSPs.

Accurately monitor reservoirs under injection and production

Time-lapse borehole seismic surveys are optimal for monitoring reservoirs under stimulation, such as heavy oil and CO_2 sequestration.

For example, in a SAGD project, permanent geophones can be installed and 3D VSP surveys acquired in vertical wells, before and after injection of steam in horizontal wells. Time-lapse processing often reveals clear differences between the two vantages. The effects on injection and production might include a velocity decrease within the reservoir zone, or amplitude brightening and lower frequencies just above the horizontal injection and production pairs.

To track the CO_2 plume and to verify containment within a designated storage formation for CO_2 sequestration, 3D VSPs can be acquired—a baseline and subsequent monitor surveys—at different stages of injection. Permanent geophones would improve repeatability and lower survey costs. To detect the presence of CO_2, Schlumberger can calculate the normalized root mean square (NRMS) of the difference image values for various depth ranges. After sufficient CO_2 injection, if time-lapse effects are clearly visible in the NRMS map of the storage interval, but not in the formation above it, the project can meet both of its primary objectives.



NRMS map from time-lapse 3D VSPs, visualizing the spread of CO_2 within the target storage formation (right), but not in the formation just above it (left). This effectively confirms CO_2 containment.

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