

# Borehole Geophysics

## Wellbore Seismic

### High Resolution Seismic Imaging—(Near Offset VSP, Fixed Offset VSP, Walkaways, 3D VSP, Salt Proximity Surveys, Microseismic Surveys)

Halliburton provides high-resolution images in the vicinity of the borehole using a number of different techniques depending on the objectives and the geologic environment. The techniques include vertical incidence vertical seismic profiles (VIVSP) in deviated wells, salt proximity surveys, tomographic velocity analysis, fixed offset VSP surveys (FOVSP), 2D walkaway surveys, 3D VSP, and ExactFrac® or microseismic surveys.

Halliburton is an industry leader in providing advanced source and downhole array technologies for borehole seismic. Halliburton's expertise serves to benefit operators with reduced rig time and improved data quality. Advanced source and receiver technology is crucial towards obtaining a more accurate and comprehensive geological picture of your well, field, or reservoir.

Halliburton can offer custom built solutions for client's seismic imaging field needs. For survey planning, we use the most advanced 3D wavefront modeling software available, GeoTomo's VECON software.

Multi-component arrays can be mobilized downhole to more accurately record true amplitude information of both compressional and shear waves.

Compressional and shear images can be used in conjunction for lithology and fluid identification. Surveys can be repeated for time-lapse 4D views of fluid movements.

Downhole seismic tools can also be used to passively listen to the reservoir and to map fluid movements, fault reactivation, or active fracture monitoring.

A full array of tools is available for analyzing high resolution seismic data for reservoir imaging. Halliburton offers advanced pre-processing, including multi-component wavefield separation and final imaging using pre-stack depth migration (PSDM).

### High Resolution Seismic Imaging Features

- Generation of high-resolution multiple free images
- Mapping of steep structures (such as salt flanks)
- Detailed velocity cubes in areas of laterally changing velocity (shallow gas, permafrost, salt, etc.)
- Map structure, stratigraphy, lithology, and fluids with higher resolution and confidence than can be obtained with surface seismic
- Improve a poor data quality area or overcome no-data areas

### High Resolution Seismic Imaging Applications

- Profiling salt dome flanks
- Detecting natural fractures
- Enhanced seismic velocity analysis
- Primary seismic reflector identification
- Porosity and permeability estimation
- Anisotropy determination
- AVO analysis
- Determine height, length, and width of well frac or stimulation process

### Associated Answer Products

- Vertical incidence VSP
- Synthetic seismogram
- FWS™ full wave sonic processing
- ExactFrac® services

## Reservoir Geophysics

### Long Array Multi-Component Acquisition Tools

Halliburton offers survey planning, data acquisition, and data processing using multi-component long seismic arrays. Each tool combines advanced-source technology with industry leading multi-component and anisotropic migration software for a complete package of advanced custom designed reservoir imaging systems. Systems include the GeoChain™ VSP downhole receiver array.

### GeoChain VSP Downhole Receiver Array

The GeoChain vertical seismic profile (VSP) array is designed for large borehole imaging surveys and can be used in open and cased holes with standard seven-conductor cable even in deep and hostile environments.

### GeoChain VSP Receiver Array Features

- Based on the proven ASR-1 downhole geophone
- Can be used in wells up to 25,000 psi and with hole sizes from 3.5-in. to 22-in.
- Unique ACS™ active cooling system allows continuous operation up to 356°F (180°C)
- Up to 42 satellites can be used in the array with a maximum tool spacing of 200 ft
- All satellite locking arms open and close simultaneously, and the entire string can lock into a 9.625-in. well in only 30 seconds
- Can be run in the following configurations:

No. of Tools	Sample Rate
5	1/2 ms
10	1 ms
21	2 ms
26	2.5 ms
32	3 ms
42	4 ms

### Associated Answer Products

- 3D VSP imaging
- 2D VSP imaging
- Interwell imaging
- ExactFrac® (microseismic) services

## Synthetic Seismic and Sonic Log Calibration

The synthetic seismogram obtains an accurate tie between well logs measured in depth and the surface seismic image measured in two-way time. Correlation between logs and seismic is important to verify interpreted horizons and to help determine the true phase of the surface seismic (important for advanced lithologic and fluid interpretations from seismic data).

An accurate synthetic depends on sonic log calibration using data from a vertical seismic profile (VSP) or check shot survey. This calibration is necessary for a number of reasons such as:

- Sonic log and surface seismic are measured at different frequencies (dispersion)
- Sonic log and surface seismic can measure different rock and fluid volumes (fluid differences, invaded zones, damaged borehole, non-vertical ray paths, etc.)

Calibration of the sonic log includes an analysis of the data to determine the cause of the differences (drift) between the sonic and the check shots.

Depending on the cause of the drift, different methods of correction are used. The corrected sonic log is converted to interval velocity. Acoustic impedance is calculated using the corrected velocity log and the bulk density. Changes in acoustic impedance are used to create a reflection coefficient log, which is subsequently convolved with a desired wavelet to create a synthetic seismic trace.

Recording of a shear sonic log or calculation of a synthetic shear log allows calculation of a 2D synthetic to analyze or predict AVO effects on the surface seismic. Perturbation of the rock parameters also allows study of the effects of fluid and lithology changes on the seismic character.

### Synthetic Seismic Features

- Helps promote accurate tie between well logs and surface seismic including phase determination
- Allows identification of multiples on the surface seismic
- Allows study of fluid and lithology effects on the seismic character

### Associated Answer Products

- Vertical incidence VSP
- High resolution seismic imaging (walkaway, fixed offset, 3D VSP, salt proximity, AVO Studies)
- FWS™ full wave sonic processing

## **Vertical Incidence Vertical Seismic Profiling (VIVSP) Analysis**

The VIVSP analysis is a downhole seismic survey with the surface source positioned vertically above the geophones anchored in the well. In a vertical well, it is known as a zero offset VSP (ZOVSP) with the source positioned in a single location near the wellhead. In highly deviated wells, the source is moved along with the downhole geophone tool to keep the source vertically positioned above the geophone tool at each level.

VIVSP analysis is useful for facilitating more accurate time-depth correlation between your well logs and your surface seismic. It is also useful for determining the phase of your surface seismic and for identifying multiples.

VIVSP data provides an indispensable bridge between sonic log data and surface seismic data. In areas where it is difficult to obtain a good tie between the synthetic and the surface seismic, the VIVSP can be helpful to identify and resolve the differences.

VIVSP is also very useful for predicting lithology, fluids, and pore pressure ahead of the bit. Velocity trends that are useful for predicting pore pressure are calibrated at the well.

VIVSP data is typically higher frequency than the surface seismic and can be used to better understand the reflectivity seen in the surface seismic.

VIVSP data can be useful for computing the dip of the reflecting horizons in the vicinity of the borehole.

This can be used to confirm dips seen on dipmeter tools and help project these dips away from the well.

In deviated wells, the VIVSP also delivers a high resolution 2D image beneath the wellbore. This image is typically higher frequency than the surface seismic, multiple free, and tied directly to the wellbore in depth.

Halliburton uses advanced proprietary software to handle VSPs in the most demanding geologic environments (advanced editing, multi-component wavefield separation, interpolation, deconvolution, and migration tools).

VSP software and processing can be used in the field, in a computing center linked to the wellsite, or in the client offices for special projects.

VSP acquisition teams utilize customized energy sources and the most advanced seismic tools available to record high-

quality seismic data. The rugged, computerized logging systems precisely position the geophone tool in the well, properly synchronize the energy sources, and accurately transfer the measured data to the surface. The data obtained from VSPs provide extremely important information for enhancing and supplementing surface seismic data.

### **VIVSP Features**

- Allows detailed analysis of the downgoing and upgoing wavefield
- Real seismic trace rather than synthetic for log seismic correlation
- Provides detailed velocity analysis

### **VSP Applications**

- Direct correlation between surface seismic data and logs recorded in depth
- Calibrate wireline sonic data for correlating synthetic seismograms with conventional seismograms
- Mapping geologic structure in the vicinity of the wellbore
- Predict stratigraphy, lithology, and structure ahead of the drill bit to help save drilling time and costs
- Improve poor data-quality area or overcome no-data area
- Helps profile salt dome flanks
- Helps detect natural fractures
- Aids seismic identification of lithology
- Prospect delineation
- Enhanced seismic velocity analysis
- Primary seismic reflector identification
- Analyze multiple patterns
- Deconvolution operator for surface seismic data processing
- Porosity and permeability estimation
- 2D and 3D stratigraphic and structural imaging
- Helps locate overthrust granite/sediment interface
- AVO analysis

### **Associated Answer Products**

- Synthetic seismogram
- High resolution seismic imaging (walkaway, fixed offset, ocean bottom cable, salt proximity, AVO studies)
- FWS™ full wave sonic processing

### **ExactFrac® Services**

Halliburton eases frac modeling concerns by taking a full-service approach to logging, offering both dipole sonic and borehole seismic services. To give engineers the answers they require, our microseismic techniques provide real-time assessments of fracturing processes using two wells:

- A stimulation well where actual frac jobs are under way
- A monitor well equipped with a downhole geophone tool array with multiple sensors

These microseismic techniques provide accurate information on the length, height, and distance of the frac being generated in the formation and can dramatically optimize the placement of future wells.

### **ExactFrac Services Features**

- Allows operators to optimize drilling program in field
- Improves later frac jobs (only zone you need to frac)
- Minimizes uncertainty in your fracturing program