AAPG EXPLORER

GEOPHYSICAL CORNER

Borehole Data: Closer to the Rocks

The Geophysical Corner is a regular column in the EXPLORER, edited by R. Randy Ray. This month's column is titled "New 3-D/3-C High Resolution VSP Technology.")

By BJÖRN PAULSSON
BRIAN FULLER
MARTIN KARRENBACH
PAUL HEUERMANN

Borehole seismic methods have been used since the beginning of exploration seismology. Check shot surveys were used to obtain travel times and interval velocities, and 2-D VSPs (Vertical Seismic Profiles) and 2-D high-resolution crosswell data also have been recorded.

Until recently however, borehole seismology has be relegated to a secondary role in seismology because it generated only 1-D or 2-D images – and they were obtained at a high cost relative to the amount of information they provided.

The limiting factor in borehole seismic methods was that the fundamental designs of borehole seismic systems only allowed a small number of geophones to be deployed in the borehole. Until about two years ago the maximum number of three-component (3-C) clamped geophones that could be deployed in a borehole was around 12. Thus it was expensive to record enough data to make large surveys economically feasible.

A few experimental 3-D VSPs were recorded with a small number of geophones in the borehole. The surveys were expensive and the seismic images were of limited quality because of the small amount of data recorded per shot.

Leaps in Data Acquisition Technology

In the past 18 months a new type of borehole seismic receiver array has been introduced that currently has 80 3-C geophone levels in a single borehole. The design can be modified to allow as many as 400 to1,000 three-component geophone levels when fully deployed.

The fundamental difference between the new and the old borehole arrays is that the new array is deployed on production tubing wherre the old style of receiver arrays are deployed using wireline technology.

The newly developed borehole array currently has a geophone spacing of 50 feet, but can be tailored to any desired spacing. Using a geophone spacing of 50 feet, the length of the 80-level array is 4,000 feet and the length of a 400-level array is 20,000 feet.

Thus, most boreholes can now be filled from top to bottom with clamped three-component geophones. Geophones can easily be deployed in horizontal wells because they are conveyed on standard production tubing using the same method used to deploy electric submersible pumps.

3-D Borehole Seismic Coverage

The advantage of deploying a large number of borehole seismic receivers is that a large amount of reflection coverage can be obtained per seismic shot, thus making borehole seismic method commercially feasible.

Figure 1 compares the amount of data recorded with a small borehole seismic array as compared to a large 80 level borehole seismic array. The large increase in reflection coverage per shot that is gained with large borehole receiver arrays quickly translates to an improved image quality, because rig time and shot effort are reduced to a minimum and datasets large enough for a 3-D image can be economically recorded.

The size and shape of the seismic image provided by 3-D VSP data is controlled by the source locations and path of the borehole.

In a vertical well with shots around the borehole the image is usually cone-shaped and the diameter of the cone in map view is roughly equal to the depth of the image (Figure 2).

By combining data from several wells extensive 3-D images can be generated.

3-D VSP Examples

Using an 80-level 3-C array, our company has recorded the four largest 3-D VSPs in the

continued on next page

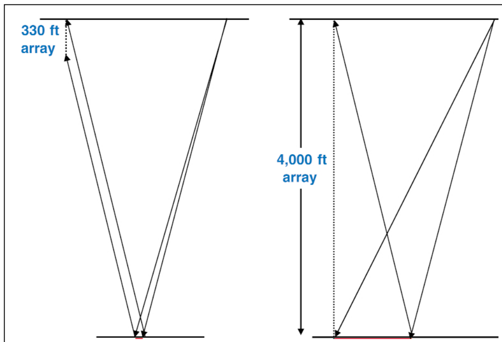

Figure 1. The diagram on the left shows the reflection coverage (red line) obtained from a single shot location using an older style wireline based receiver array that is 330 ft long. The diagram on the right shows that a much larger reflection coverage area is obtained with a single source point when a tubing deployed long receiver array is used to record data in the borehole. The increasing reflection coverage per shot provided by an 80 level 3C receiver array allows 3D/3C VSP imaging to be an economically feasible approach to high resolution reservoir imaging.

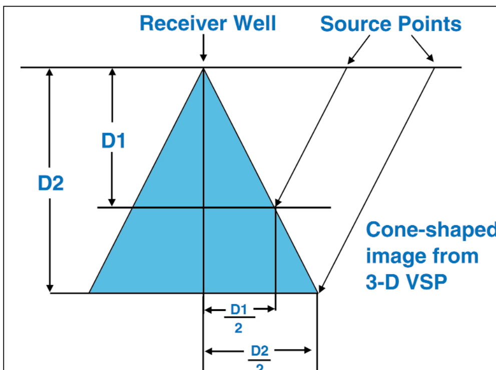

Figure 2. The image volume generated from a 3D VSP is approximately cone shaped. The diameter of the image for a vertical well is approximately equal to the depth of the image. By using several wells the data from several image cones can be combined into one 3D volume as shown in Figure 3.

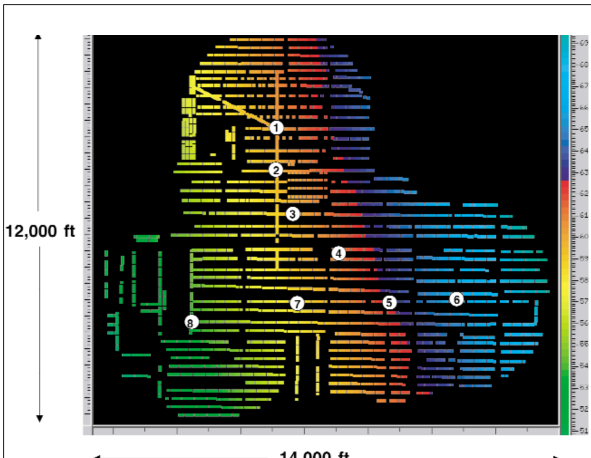

Figure 3. This source point map shows the location of over 5,000 vibrator points that were used to record over 1,040,000 traces in eight receiver wells. Color indicates the source point elevations. This 3D/3C VSP recorded near Bakersfield, California in September, 2000 is the largest 3D VSP ever recorded.

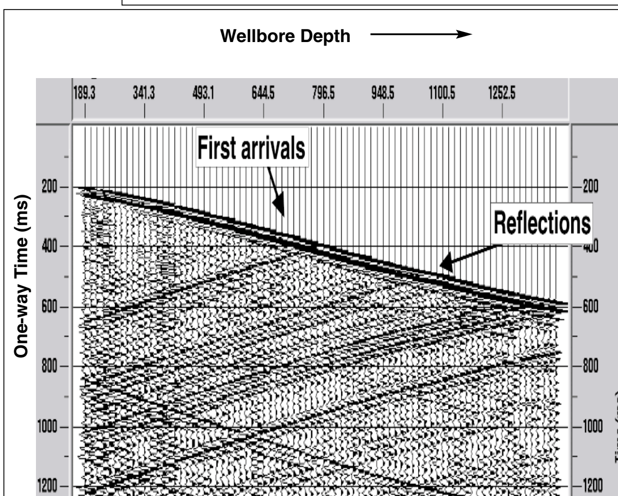

Figure 4. Raw data recorded with a 4,000 ft long 80 level 3C down hole receiver array. The data is not filtered or muted and is displayed with trace-by-trace scaling. The scale across the top is depth in m.

continued from previous page

oil and gas industry. The most recent examples include:

❒ A 372,000 trace 3-D VSP survey recorded in four days in West Texas in February 2001.

❒ A 1,040,000 trace, eight-well 3-D VSP recorded south of Bakersfield, Calif., in September 2000 (Figure 3).

❒ A 350,000 trace 3-D VSP in Alberta, Canada in October 2000.

❒ A 152,000 trace 3-D VSP recorded for PanCanadian Petroleum in the Weyburn Field in Saskatchewan, Canada, in December 1999.

An example shot record from the Weyburn Survey is shown in Figure 4. It illustrates the strong, high frequency reflections that can be recovered in the quiet, downhole environment.

In these surveys much smaller scale reservoir features, including faults and pinch outs, were mapped with higher resolution than had been possible to map using surface seismic methods.

Using the recorded bandwidth of 10-220 Hz in the Weyburn 3-D VSP survey a resolution of better than five meters (15 feet) was evident in the final images (Figure 5). In the Edison field survey in California, 150 Hz 3-D VSP data was recorded in the same area in which surface seismic data did not exceed 25 Hz, and the borehole seismic image contained much higher signal to noise ratio features corresponding to a maximum image frequency well over 100 Hz.

It has been demonstrated that 3-D VSP data recorded with the 80 level array can be used to image the entire drainage volume around the well at more than twice the resolution that can be obtained from a surface seismic survey.

In order to maximize the use of subsurface 3-D imaging using borehole seismic measurements for development and production application, the data can be processed in the field – and an initial image delivered within one to two days.

The improved borehole seismic instrumentation is now driving the development of new, innovative and high resolution processing technologies for borehole seismic data.

Advantages

The principle advantage of borehole seismic data is that the frequency content is consistently much higher than surface seismic data recorded over the same location.

A good rule of thumb is that a borehole seismic image has twice the frequency content of the surface seismic data. Higher frequency means higher resolution and less uncertainty in drilling decisions.

The frequency content of borehole seismic data is higher than surface seismic data because the wave field only passes through the attenuating near-surface layer one time rather than twice when both the sources and receivers are at the surface of the earth.

Additionally, the geophones are strongly coupled to the earth via the geophone clamping mechanism.

Images from 3-D borehole surveys are typically generated directly in depth through prestack depth migration. This allows for an exact tie to depth since the time-depth relationship is precisely known at the receiver boreholes. Interpreters can directly tie seismic data to log properties since logs are always in depth.

A perfect tie to depth minimizes uncertainty in extrapolating reservoir properties derived from well logs into the seismic volume.

Conclusions

Borehole seismic methods now provide commercially feasible 3-D/3-C high-resolution images for reservoir characterization.

New designs in borehole geophone deployment equipment allows hundreds of three-component clamped geophones to be deployed in boreholes instead of the old five and 20 three-component phones that were deployed using older conventional wire line technology.

(Editor's note: The authors are with Paulsson Geophysical Services Inc., La Habra, Calif. The Web site is www.paulsson.com.) ❑

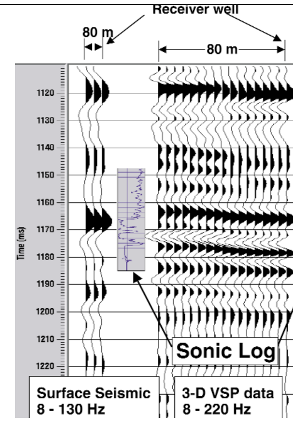

Figure 5. This is a comparison of the image obtained from surface seismic data and borehole seismic data. The surface data was recorded simultaneously with the borehole data using the same dynamite shots. The image on the left is from the surface seismic data at the receiver well. The data has a 40 m CDP spacing. The image on the right was generated from the borehole seismic data and covers exactly the same time range and location as the surface seismic image. The frequency content of the borehole seismic is about twice that of the surface seismic and the spatial sampling of the borehole seismic is 5 times greater than the surface seismic which allows for detailed imaging of lateral changes in the reservoir properties.