[GC]Seismic-While-Drilling: Techniques using the Drill Bit as the Seismic Source*

Bob Hardage[1]

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[1]Bureau of Economic Geology, The University of Texas at Austin (mailto:bob.hardage@beg.utexas.edu)

General Statement

In concept, any type of mechanical vibration that is introduced into the Earth can be used as a seismic wavefield to illuminate and image subsurface geology. Seismic imaging does not always have to be done with controlled, sophisticated sources such as air gun arrays, vibrators or shot hole explosives. One unique mechanical vibration that illustrates the principle of seismic imaging without the use of a conventional seismic source is the repetitive Earth impulses that are created by the teeth of a rotary-cone drill bit as a well is being drilled to reach a geologic target. Drill-bit seismic technology was a topic of rather intense research and development in the 1980s and 1990s, and the application should not be forgotten.

Principal of Drill-bit Seismic

The principle of geologic imaging with a rotary-cone drill bit is illustrated in Figure 1. The key to the imaging procedure is to position a reference sensor at the top of the drill string, near the swivel. This reference sensor records each impact of each tooth of a rotary-cone bit as rock strata are being drilled. As shown in Figure 1, the drill-tooth impulses propagate along direct paths to sensors deployed on the Earth surface (or on the seafloor if the well is offshore) at stations that allow specific target geology to be imaged. An imaging capability is created by the drill-bit wavefields that propagate downward and reflect upward from rock interfaces below the drill bit as depicted by the raypath diagram.

By continuously correlating the reference-sensor response with the responses of the surface sensors, a sequence of seismic traces can be created as the drill bit traverses equally spaced depth intervals during the drilling process. Usually this cross-correlation between reference sensor and far-field sensor responses is done continuously as the drill bit penetrates a depth interval equal to one joint of drill pipe (30 feet, or nine meters). Depending on rock type, bit quality and drilling parameters, the cross-correlation computation during the drilling of this 30-foot interval may span a time period of five minutes to one hour. The resulting output trace is equivalent to that generated by a seismic source having a vertical dimension of 30 feet and positioned across the 30-foot interval that was drilled. Under appropriate conditions, the image created from drill-bit wavefields can be quite good.

Examples

Figure 2 is an example comparing a drill-bit image created as a well was being drilled, and an image made from vertical seismic profile (VSP) data produced by a conventional seismic source after the well reached target depth. In this instance, the drill-bit image has a signal-to-noise character equivalent to that of the conventional VSP data.

A second example, comparing a drill-bit image with surface-recorded seismic data across the drilled well is displayed in Figure 3. At this latter well site, the drill-bit image was a good match to the surface seismic data.

Applications

Using a rotary-cone bit as a seismic source has several proven applications such as:

- Real-drill-time velocity check shot information.
- Guiding the bit to a target seen on surface-acquired seismic data.
- Real-drill-time imaging ahead of the bit.
- Real-drill-time depth-to-time conversion to know when the bit is reaching an important depth interval.
- Positioning the bit at the top of an interval that needs to be cored.

All of these applications, and others, were achieved with drill-bit seismic technology in the 1980s and 1990s. Even with these proven applications, drill-bit seismic technology is not as widely used today as it was 15 and 20 years ago. The principal reason for the technology's demise has been the conversion to poly-diamond-composite (PDC) bits by drilling contractors. PDC bits cut by a scraping action – not by vertical impacts of chisel teeth as occurs with a rotary-cone bit. Effective seismic wavefields are difficult to achieve with PDC bits. However, in current drilling practice, if a significant interval of rock is to be drilled with rotary-cone bits, the technique of drill-bit seismic technology is still on the shelf ready to be used.

PDC Bits

Alternate technology that allows usable seismic data to be acquired when PDC bits are utilized has now come onto the scene. Polydiamond crystalline (PDC) bits are now replacing rotary-cone bits in many drilling programs. PDC bits cut rock by a scraping action – *not* by an axial chiseling action, as does a rotary-cone bit. And because of its rock-cutting style, a PDC bit does not generate a seismic wavefield that is adequate for seismic imaging or for other seismic applications, unlike the robust wavefield produced by a rotary-cone bit.

Technologies are now available that acquire seismic-while-drilling (SWD) data by embedding seismic sensors in the drill string near the drill bit (Figure 4). With this technology, vertical seismic profile (VSP) data can be acquired while drilling with any kind of bit, including PDC bits, by using these downhole sensors together with a surface-based seismic source. At each depth where seismic information needs to be obtained, drilling action must cease for several minutes so that the downhole sensors are in a quiet environment as they record the seismic wavefield produced by the source. The responses of the drill-string sensors are stored in a downhole memory unit included in the drill-string system. The data are retrieved when bit trips are made and the seismic-sensor section is returned to the drill floor. This downhole seismic sensor technology allows numerous seismic applications to be implemented as a well is being drilled, with examples being:

- Predicting overpressure intervals ahead of the bit.
- Imaging below and laterally away from the well bore.
- Defining the relationship between drilling depth and seismic image time in difficult velocity areas in real drilling time.
- Guiding the bit to a target identified on a surface-based seismic image.
- Positioning core barrels at the onset of a seismic reflection interval of interest.

Numerous other applications are possible, and several encouraging proof-of-concept tests have been done.

An example of the data quality that can be achieved with drill-string seismic sensors is illustrated in Figure 5. Conventional VSP data acquired in the same well with wireline-deployed sensors also are shown to aid in evaluating the quality of the SWD data. VSP data almost always are recorded at regularly spaced depth intervals, as they are in this data display. However, as in this example, SWD data may be recorded at irregularly spaced stations positioned at depth coordinates where well conditions allow drilling to be stopped so a quiet seismic condition can be produced in the borehole. The reflections noted in these particular SWD data are of sufficient quality for the data to be used in seismic imaging applications.

An example of an image produced from drill-string seismic sensors is displayed as Figure 6. These data were acquired as a deviated well was drilled toward the targeted interval marked by the robust seismic reflection events on the seismic profile. The intent was to ensure that the well penetrated the objective at a structurally high position where there was optimal time thickness of the target interval. These data are an example of SWD data being used to guide a drill bit to a seismic-defined point of penetration on a target.

Conclusion

Acquiring seismic data while drilling is good strategy in areas where:

- Precise time-vs-depth relationships are not known.
- There is concern about drilling into an over-pressured interval.
- Where a core needs to be collected starting at the top of a seismic-defined stratigraphic interval.

Contact your well services provider to find out how to implement SWD technology when you are confronted with drilling in any of these challenging situations – plus numerous other applications that have not been illustrated in this short review.

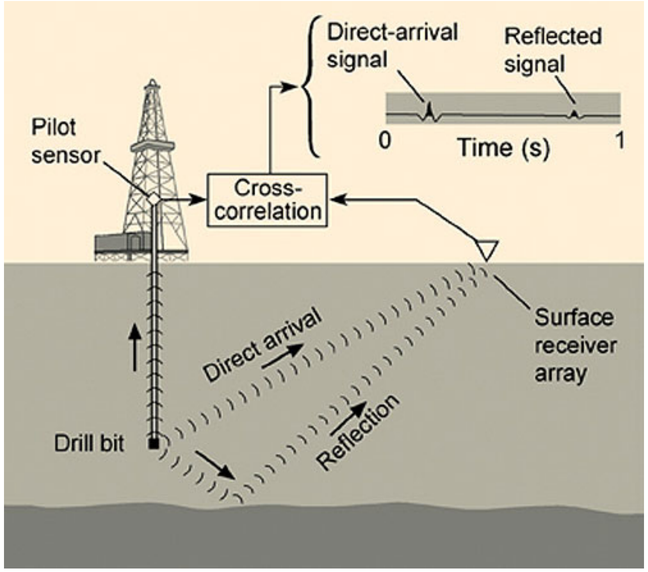

Figure 1. In drill-bit seismic technology, the mechanical energy produced by an active rotary-cone drill bit propagates up the drill string to a reference sensor positioned on the swivel and also radiates into the Earth as a seismic wavefield. Seismic events are created that travel direct and reflected raypaths from the drill bit to surface-positioned sensors. A conventional seismic trace is created by continuously correlating the response of the reference sensor at the top of the drill string with the responses of the surface sensors.

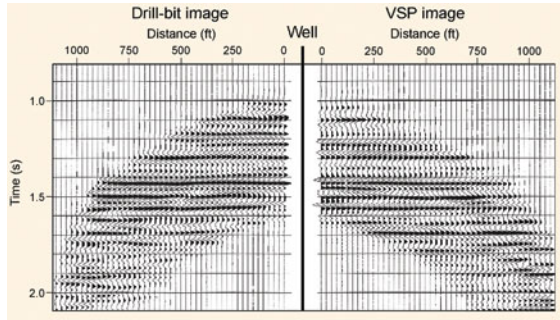

Figure 2. Comparison between an image made with wavefields produced by a rotary-cone drill bit (left) and an image made in the same well with conventional vertical
seismic profiling data (right).

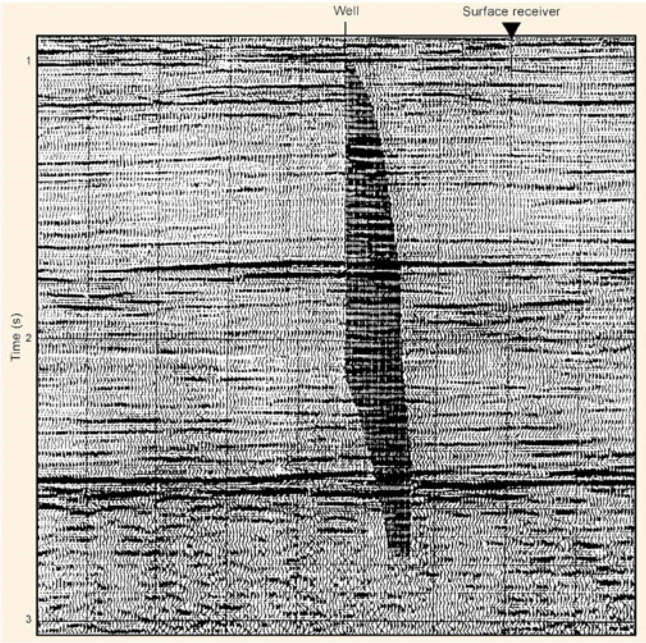

Figure 3. Comparison between images made with wavefields produced by an active rotary-cone drill bit and by a conventional vibrator that made a 2-D profile across the
drilled well.

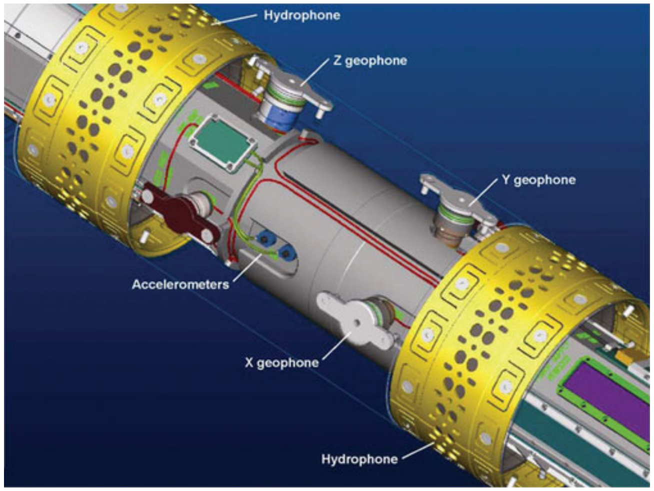

Figure 4. One drill-string seismic sensor package used to acquire seismic data while drilling. This module is positioned in the bottom-hole assembly near the drill bit.

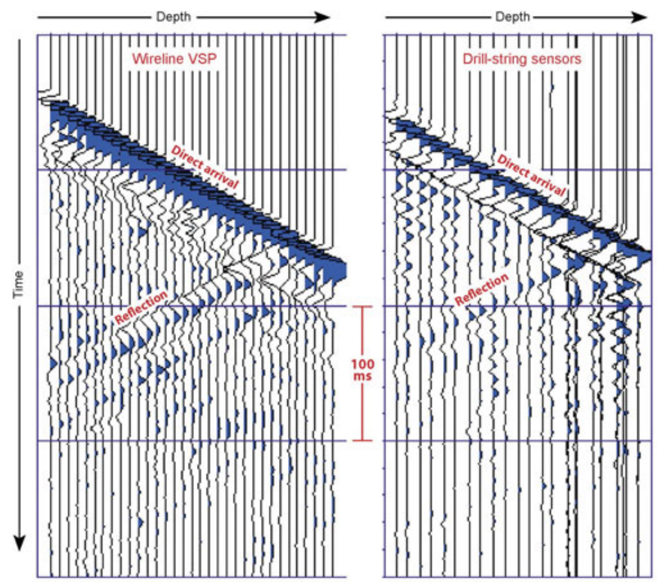

Figure 5. Comparison between seismic data acquired with drill-string sensors (right) and with conventional wireline-deployed sensors in the same well (left).

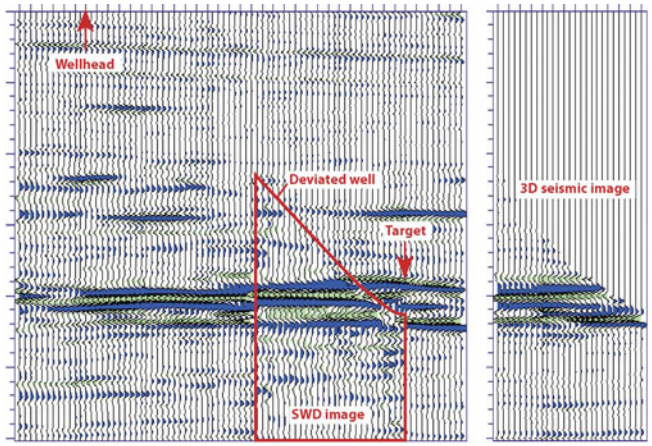

Figure 6. Imaging with drill-string sensor data acquired in a deviated well. The image made with SWD data is spliced into a surface-based 3-D seismic image on the left. The surface-based image that has been replaced by the SWD data is shown on the right for comparison (Figures 4, 5 and 6 illustration and data courtesy of Schlumberger).