ACQUIRING AND PROCESSING SEISMIC WITH THE DRILL-BIT SOURCE AND WIRELESS GEOPHONES IN A DESERT ENVIRONMENT

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Summary

Recordings of seismic waves generated by a drill bit while drilling can give information about drilling conditions and current formation properties, and can provide lookahead prediction. As a part of the recently introduced DrillCAM system, aiming to become an integrated solution for imaging and predicting ahead of the drill bit and geosteering, seismic-while-drilling data is acquired by a 3D full-azimuth spread of geophones. We present data acquisition and processing results from the first pilot test in a desert environment, where, for the first time, wireless geophones installed around a rig were used to acquire the drill-bit seismic while drilling. We demonstrate the feasibility of such a system to provide flexible and depth adaptable acquisition geometries without impacting drilling operations. Using special processing steps, we successfully transform the drill-bit noise into meaningful and reliable seismic signals. The real-time capabilities of the system make the data available for continuous data processing and interpretation that will facilitate drilling automation and improve real-time decision-making in future applications.

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Introduction

Recordings of seismic waves generated by a drill-bit while drilling can give information about drilling conditions, current formation properties and can provide look-ahead prediction. Seismic-while-drilling (SWD) technology has evolved over several decades and experienced alternating interest from oil and gas industry and academia (Kostov, 1990; Haldorsen et al., 1995; Poletto and Miranda, 2004; Naville et al., 2004). Recent advances in geophysical instrumentation and processing, availability of high-speed wellbore telemetry and high-performance computing capabilities directly at the drilling rig, facilitate acquiring, processing, and analysis of SWD data on site. With the current trend in drilling operations toward automation and robotization, SWD has a new potential role to play in delivering real-time information that facilitates fast and reliable decision making.

As a part of the recently introduced DrillCAM system, aiming to become an integrated solution for imaging and predicting ahead of the drill bit and geosteering, SWD data is acquired by a 3D full-azimuth spread of geophones. Efficient acquisition with a large number of seismic receivers near the rig requires cableless systems to avoid any interference with drilling operations at the surface. Since the data must be continuously processed to provide ongoing information to a driller, conventional node systems are unsuitable, and instead wireless radio-based stations are capable of transmitting the data in real time are required. The first DrillCAM acquisition with such a system was recently conducted at an onshore well in a desert environment. Bakulin et al. (2019) presented instrumentation details of this field trial. In the current work, we discuss details of the acquisition and processing of the acquired data that provide reliable seismic gathers ready for SWD applications.

Novel data acquisition with adaptable wireless geophones

Around 2500 wireless geophone stations were installed near a drilling rig as shown in Figure 1. The distance between the receivers was 25 m in both inline and crossline directions. To adapt to different drilling depths, two receiver configurations were used during the survey. A condensed square spread of wireless geophones with maximum offset of 500 m was acquired up to the depth of 2,600 ft. This provides good coverage and illumination around the shallower part of the well. While drilling below this depth, larger offsets (up to 2,500 m) were acquired commensurate with depth. Changing from one acquisition pattern to another was efficiently handled during casing and cementing operations occurring between two drilling runs with zero impact on drilling operations due to the usage of wireless geophones. A saw-tooth-like pattern (Poletto and Miranda, 2004) was also acquired around the well to evaluate nonconventional 3D full-azimuth acquisition geometries useful for SWD that provide additional noise-attenuation capabilities in comparison to more conventional receiver layout consisting of orthogonal lines. In addition to the surface geophones, several accelerometers were mounted to the top drive of the rig to measure the pilot signal propagating along the drill string. Downhole memory-based accelerometers directly above the bit were used to provide alternative and complementary measurements of the pilot signal that will be the subject of future publications. The data were acquired in a nearly vertical well over a period time covering a depth interval from the surface to around 10,000 ft.

Processing single-sensor geophone and top-drive data for SWD applications

Continuous raw seismic gathers recorded at the surface during the drilling activity clearly show strong seismic events (Figure 2a) propagating from the rig. To transform these records into conventional impulse-like seismograms, conventional SWD techniques make use of a pilot signal similar to the vibroseis technique. Unlike a vibroseis sweep, the drill-bit source signature is *a priori* unknown, random, complex and highly variable, and not readily extractable from one single trace of the SWD geophone survey. In the current work, we use the vertical component of a top-drive accelerometer sensor as an estimate of the pilot signal (Figure 2b). Autocorrelation of the top-drive traces and stacking over 30 ft (one drill-pipe length) of drilling interval provides evidence of vibrations propagating along the drill string over an extended drilling depth range (Figure 3a). Additional deconvolution removes periodic events, improves the pilot signal and shows strong and reliable signal up to a depth of 6200 ft (Figure 3b). Above this depth, mostly rollercone bits were used with a single occurrence of polycrystalline diamond compact (PDC) bit use. Below 6200 ft only PDC bits were utilized that seem to induce weaker vibrations of the drill-string column that do not propagate over large distances. Dipping events that are observed after the correlation and deconvolution in Figure 3 correspond to multiples bouncing between the borehole assembly and the top drive. They are typically used during data processing to estimate drill-string propagation velocity and time delays required to “redatum” the pilot time from the top drive to the actual source in depth.

Correlation and deconvolution of pilot traces applied to the surface geophone data, following by vertical stacking over 30 ft depth interval, provide conventional common-shot seismograms with a short position corresponding to the current drill-bit depth. An example of such a gather shows a direct arrival event overlain by very strong and coherent low-frequency noise (Figure 4a). This coherent noise is typical of SWD surveys and is interpreted as refracted waves and ground-roll propagating from the rig along the free surface (Figure 4b). After resorting the gathers into the common-receiver domain, we extract a reverse VSP gather as shown in Figure 5a, where additional bandpass filtering (20 to 70 Hz) was applied to attenuate low-frequency rig noise. The signal level in the data is still small due to the single-sensor measurements in the presence of complex near surface, and additional enhancement is required to bring up the signal. This is a significant difference with respect to conventional SWD surveys typically using receiver arrays of several tens of meters (Poletto and Miranda, 2004), which do not have the flexibility of large wireless acquisition spreads. Application of supergrouping (Bakulin et al., 2018) with a group size of 100 x 100 m provides adequate signal enhancement. The final reverse VSP gather at a distance of 475 m from the well (Figure 5b) looks like a conventional VSP gather containing major seismic events such as direct wave, reflected, and converted arrivals. Since wireless geophones stream data from the entire seismic spread to central rig recorder close to real time (Bakulin et al., 2019), automating this land processing flow on a rig computer delivers gathers ready for various SWD applications such as real-time checkshot, predictions ahead-of-the-bit and locating the bit on seismic.

Conclusions

We presented data acquisition and processing results from the first DrillCAM pilot in desert environment, where wireless geophones installed around a rig were used to acquire seismic while drilling in real time. We demonstrate the feasibility of such a system to provide flexible and adaptable with depth acquisition geometries without impacting drilling operations. Using special processing steps, we successfully transform the drill-bit recordings into meaningful and reliable seismic signals that can be used in different SWD applications including imaging and prediction ahead-of-the-bit and geosteering. Challenging near-surface conditions require the use of supergrouping for effective pre-processing and enhancement of weak signals. The real-time capabilities of the system allow for continuous data processing and interpretation that will facilitate drilling automation and improve real-time decision-making in future applications.

Acknowledgments

We are grateful to Hussein Rashad Abdelghani, Bilal Tariq and Peter Ezi (Saudi Aramco) for strong support of this trial. We would like to thank Andrea Scleifer, Fabio Meneghini, Massimo Giorgi and the OGS team for their help and support during the trial.

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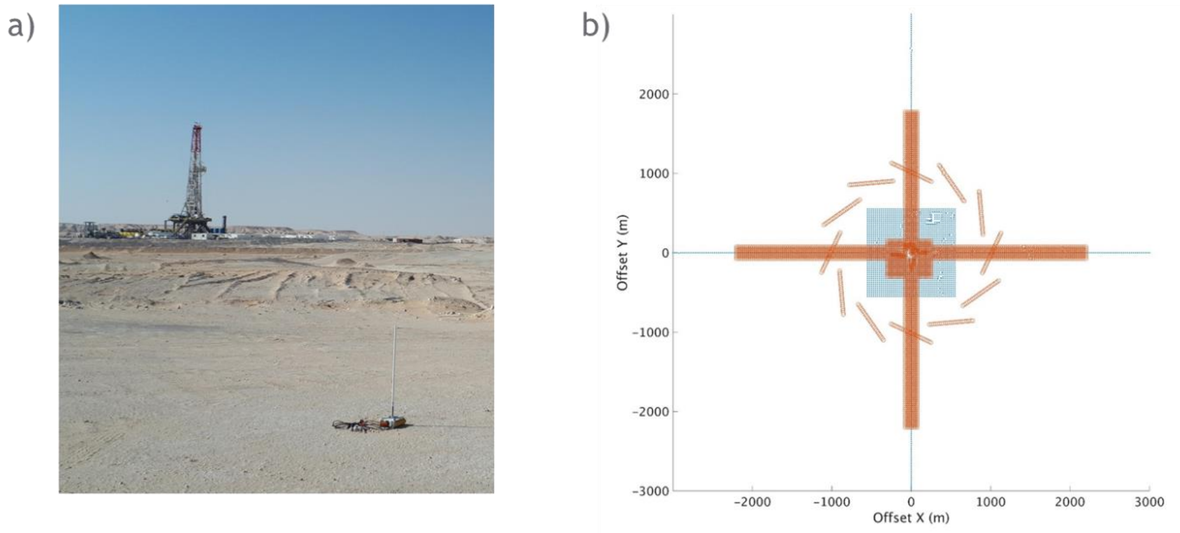

Figure 1 *DrillCAM field trial layout in a desert environment showing (a) a wireless geophone station in the foreground and (b) a schematic of changing acquisition geometries between drilling runs allowing to expand the aperture with increasing bit depth. Blue dots show receiver positions used up to 2600 ft bit depth, while red dots show the receiver pattern for deeper levels.*

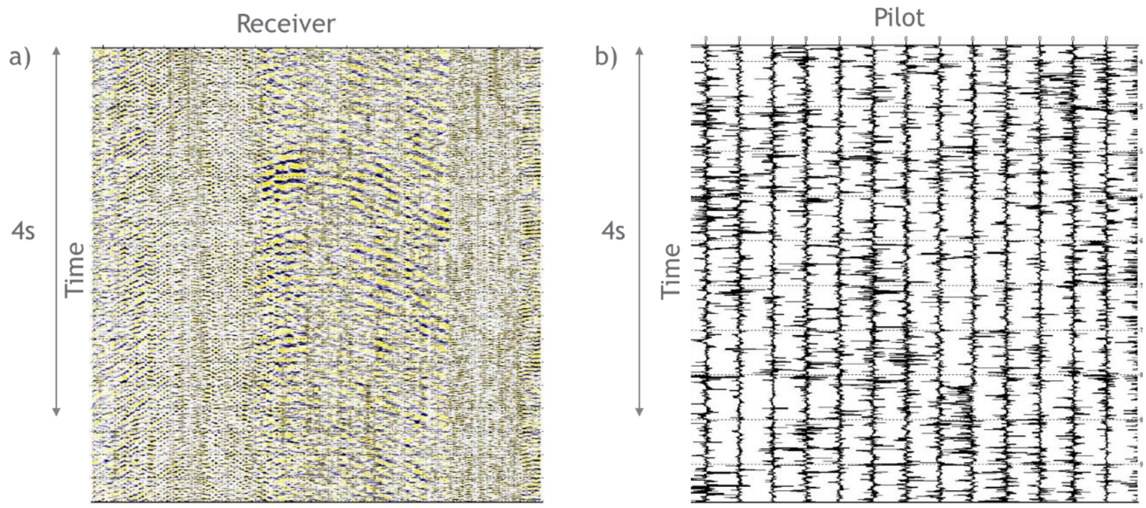

Figure 2 *Uncorrelated geophone data recorded at the earth surface shows (a) continuous seismic signal induced by a drill bit while drilling and (b) drill-string vibrations recorded by vertical accelerometer mounted at a top drive.*

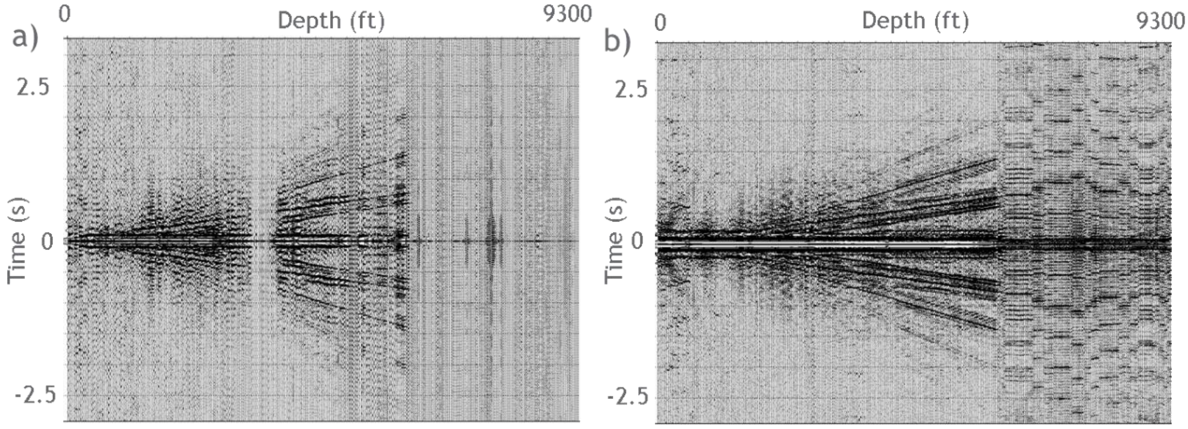

Figure 3 *Pilot traces recorded from the top drive (a) after autocorrelation and (b) deconvolution. Pilot traces recorded by the top-drive sensor show reliable signal up to around 6200 ft depth.*

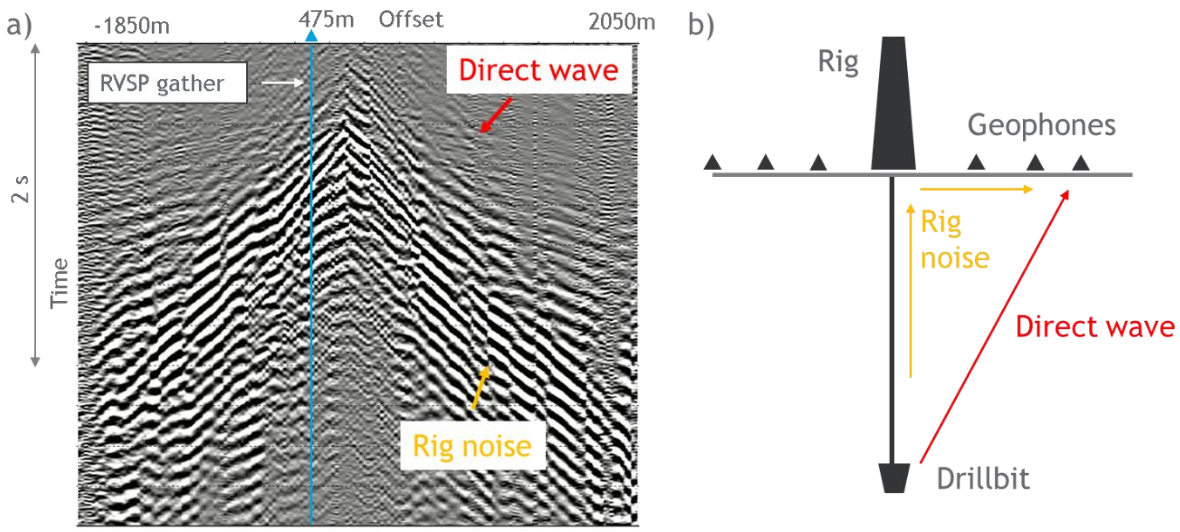

Figure 4 *Common-shot gather at a depth of 4000 ft (a) after deconvolution showing direct arrivals as well as rig noise induced by the bit as well as (b) a schematic of the propagation paths.*

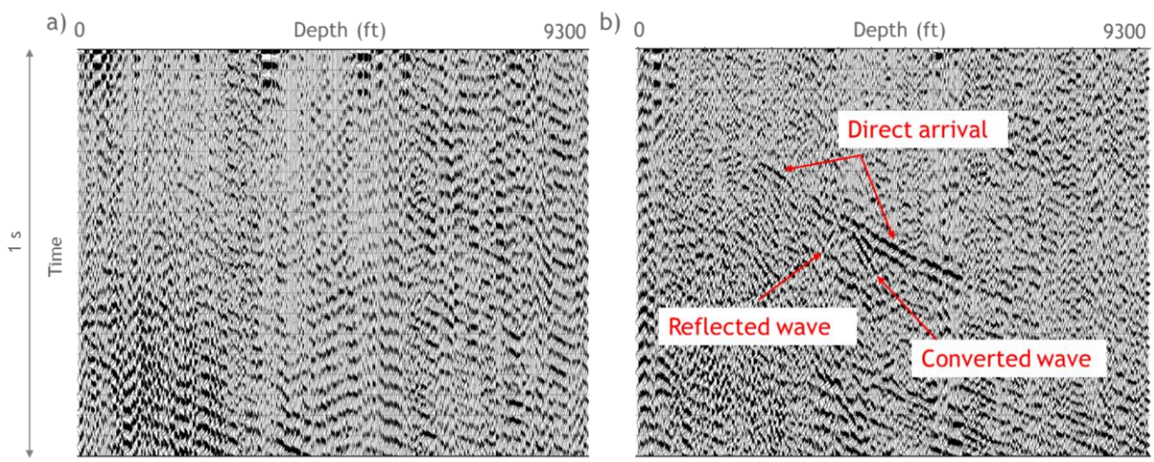

Figure 5 *Single-sensor reverse VSP gather at an offset of 475m from the rig is (a) dominated by noise prior to pre-processing and (b) the same gather after supergrouping of 25 adjacent traces.*