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While Drilling Checkshots and Prediction Ahead of the Bit Using a Drill Bit as a Source

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Summary

DrillCAM is a fully integrated real-time system for predicting and imaging ahead of and around the drill bit by utilizing seismic-while-drilling data (SWD) as well as assisting with drilling optimization and automation. We present results and analysis of several SWD applications from the first field trial in an onshore well in a desert environment. Data was recorded with an adaptable grid of wireless geophones and top drive sensor using depth range of 0-10,000 ft. DrillCAM delivered robust checkshots while drilling down to a depth of 7300 ft that included a combination of roller cone and PDC bits. The obtained velocity profile was found in good agreement with three nearby offset wells. VSP reflection data were successfully processed and delivered a more accurate estimate of over-pressured formation about 2000 ft ahead of the bit. Finally, a reliable VSP corridor stack was generated and shown to tie the surface-seismic data.

Introduction

Seismic-while-drilling (SWD) has been widely used to assist with drilling decisions and deliver VSP data without consuming rig time (Poletto and Miranda, 2004; Naville et al., 2004). The drill bit in SWD is used as a seismic source that emits a continuous random signal throughout the drilling operation. Therefore, it provides a reverse vertical-seismic-profiling (RVSP) survey with a line/carpet of surface receivers recording the signal from the drill bit traversing the subsurface (Poletto and Miranda, 2004).

A vital condition to a successful SWD technology implementation is the accurate estimation of the drill-bit signature or the so-called pilot signal (Rector and Marion, 1991; Haldorsen et al., 1994; Poletto and Miranda, 2004). The signature could be recorded using a dedicated reference sensor placed at the drilling top drive or another predesigned positions (Poletto et al., 2000). In some cases, a pilot can be estimated directly from the recorded data as shown by Haldorsen et al. (1994).

SWD surveys are usually conducted to reconstruct RVSP dataset (Rector and Marion, 1991; Poletto and Miranda, 2004). Also, Armstrong et al. (2000) and Malusa et al. (2002) demonstrated how drilling noise can be used for imaging ahead of the drill bit similarly to conventional lookahead VSP surveys. SWD experiments can also be used to estimate over-pressured zones, which are required for appropriate adjustment of drilling mud weight (Poletto and Miranda, 2006).

SWD technology has remained a niche technology due to the proliferating usage of the acoustically "quieter" polycrystalline diamond compact (PDC) bits producing signals with lower signal-to-noise ratio (SNR). While the PDC bit may be approximated as mostly shear seismic source producing much weaker compressional waves in the drilled formation, the roller-cone bits crush the rocks using both shear and compressional forces that tend to produce a higher SNR for seismic-while-drilling signals (Malusa et al., 2002).

Recent advances in seismic sensors using wireless high-channel recording systems, signal processing and enhancement of large-scale seismic data, and imaging algorithms have made a large-scale deployment of SWD feasible. DrillCAM was recently introduced targeting both SWD and non-SWD applications with a broad focus to assist drilling optimization and automation (Al-Muhaidib et al., 2018; Bakulin et al., 2019). The first field trial of the DrillCAM system was conducted in an onshore well in a desert environment.

In this paper, we present the initial results of the trial with a focus on SWD applications. We demonstrate the ability of DrillCAM to provide a robust checkshot while drilling (CWD), predict an over-pressured zone ahead of the bit more accurately, and provide a reverse VSP corridor stack that ties with the surface seismic time-migrated image.

DrillCAM dataset from first trial

First trial was conducted on an onshore nearly vertical well. A complete dataset was recorded from surface to 10,000 ft depth with wireless geophones, top drive and near-bit sensors (Bakulin et al., 2019). In this study we use SWD data from wireless surface geophones and a top-drive sensor. Well was drilled using a combination of roller cone and PDC bits.

A special workflow has been applied to reconstruct the desired RVSP signal from the drill bit noise records as shown in Figure 1 (top). The time-delayed vertical component pilot traces are used to deconvolve the corresponding noisy CSG records to remove the drill bit signature. This step is followed by a bandpass filtering step with a low cut of about 20 Hz and a high cut of around 70 Hz. The filtering step helps suppress the severe surface noise caused by the drilling operation and the mud pump, which obscures the useful subsurface data emitted by the drill bit. Then, the deconvolved records that span 30 ft depth intervals are stacked to enhance the signal-to-noise ratio of the gathers. Additional seismic processing was applied to further enhance data recorded with single sensors. For further VSP SWD analysis, we selected a single common-receiver gather at an offset of around 475 m away from the well that is shown after preprocessing in Figure 1 (bottom).

First arrival traveltimes were picked on the selected CRG and followed by a verticalization step to compute the zero-offset VSP (ZVSP) traveltimes for this particular receiver gather. A set of dip-median filters are applied to the gather to suppress the downgoing wavefield. The gather is then flattened using the two way traveltimes (TWTs) picks, and the upgoing reflections are further enhanced by median filtering. Lastly, the gather is un-flattened using the TWTs for further analysis and interpretation.

Checkshot while drilling

A key product of the DrillCAM system is the real-time retrieval of a reliable time-depth curve (i.e., the checkshot profile). Typically, a conventional ZVSP experiment is conducted post-drilling to construct checkshot profiles. The deployed system provides a cost-effective solution to reconstruct checkshot profiles without any impact on the drilling operation converting drill-bit noise into ZVSP-type gather.

Due to the strong surface noise in the vicinity of the well during the drilling operation, we select a DrillCAM gather recorded at around 475 m away from the rig to reconstruct the checkshot profile. The gather after verticalization is shown in Figure 2 (left), and the green dots mark the first break picks. Note that the first arrivals are clearly visible from about 1830 ft to about 7290 ft. It is remarkable to note that intervals 4200-5200 and 6200-7300 ft were drilled with PDC bits. We were able to see signals and pick reasonable first breaks.

Checkshot profiles from three nearby wells were used to construct a composite velocity model and simulate a synthetic gather. Figure 2 (left) shows a comparison between the synthetic gather and the DrillCAM field gather. Figure 2 (right) shows the comparison of the synthetic and field synthetic picks on the verticalized gathers. The traveltime picks are mostly within 1-3 sample points (~4-12 ms), and the variation is mainly due to the first-break jittering effect noted on the noisy field gathers.

Ahead of the bit prediction

The verticalized field and synthetic ZVSP gathers are further processed to enhance the upgoing reflection arrivals. Figure 3 (left) shows both gathers after TWT flattening and median filtering to enhance the upgoing wavefield. The figure shows some key reflectors' arrivals associated with already drilled and ahead of bit formations. The field gather is un-flattened and plotted in Figure 3 (right). A key reflector associated with an over-pressured zone is predicted at about 2000 ft ahead of the bit. This has helped the driller update the drilling program and set the casing at the right depth, which was set at the program to be about 127 ft deeper than the actual depth.

As a last step, we generated a narrow corridor stack around the first breaks from the TWT-flattened gather and spliced it into the surface seismic time-migrated section as shown in Figure 4. We observed a good correlation between the surface seismic and the VSP corridor stack, and a notable tie of many key reflection events. This comparison also identifies a depth range on surface seismic with potential multiple contamination (marked with the yellow circles) causing tunings effect that remain unobstructed on VSP corridor stack.

Conclusions

The first DrillCAM field trial was successfully conducted on a land well in a desert environment. DrillCAM data from wireless surface geophones and a top drive sensor were processed using a special workflow deconvolving the source signature, and enhancing the downgoing and upgoing wavefields. We demonstrated that DrillCAM can provide accurate first arrival traveltimes. These first-break traveltimes from a verticalized ZVSP DrillCAM gather match the synthetic ZVSP ones simulated using a composite checkshot profile from adjacent wells. We also showed how the DrillCAM system can be quite efficient to accurately predict formations ahead of the drill bit. It has helped to identify an over-pressured zone more accurately while the drill bit was still 2000 ft away from the formation. A narrow VSP corridor stack, generated from the verticalized DrillCAM ZVSP gather, correlates well with the surface seismic time-migrated image. The VSP corridor stack was useful to identify a zone in the surface seismic section, where primary reflections are contaminated by potential multiple reflections.

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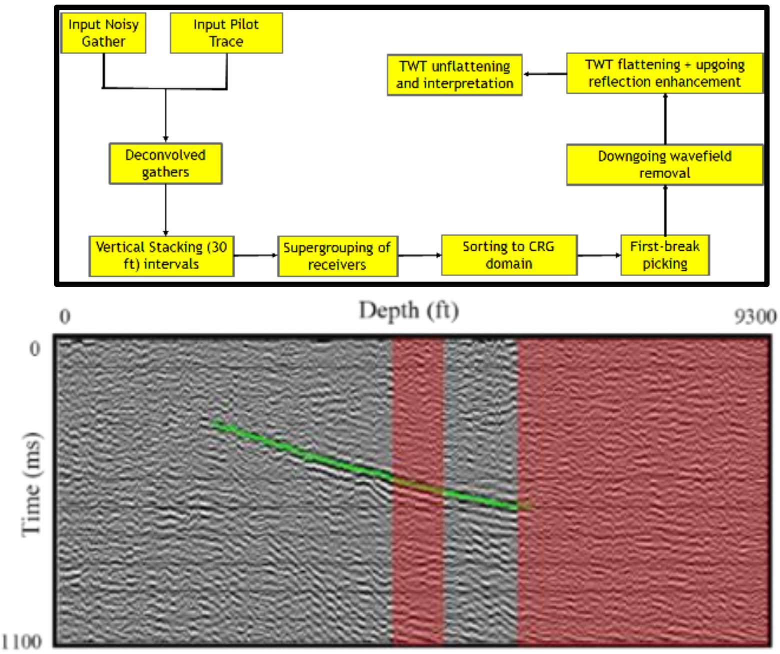

Figure 1 *DrillCAM SWD processing workflow (top). The SWD gather (bottom) is recorded with a fixed receiver position at an offset of 475 m. The first break picks (green dots) are used to derive a time-depth curve (i.e., checkshot profile). The red rectangles denote the section drilled with the PDC bit.*

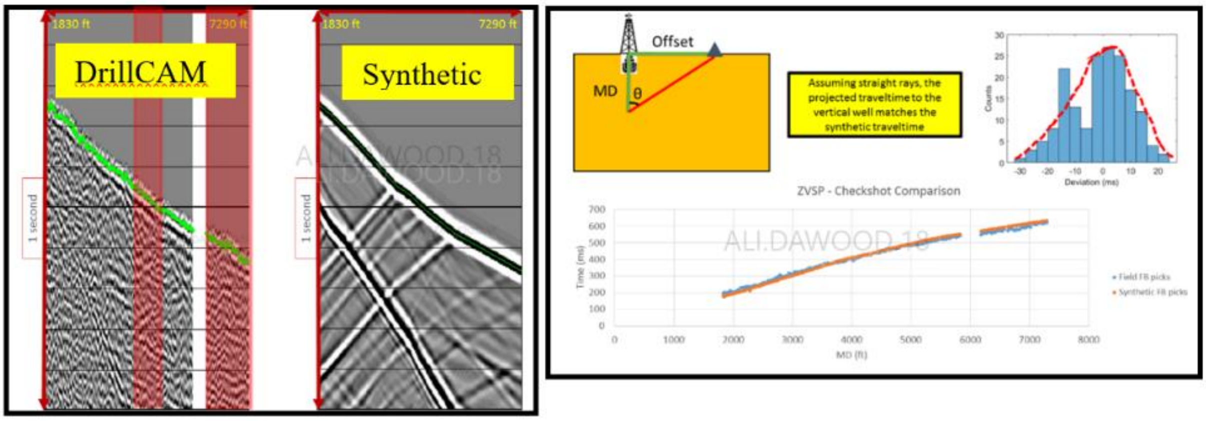

Figure 2 *A comparison between a DrillCAM SWD receiver gather and a synthetic one recorded at an offset of 475 m away from the well (left). The red rectangles denote drilling with a PDC bit. The verticalized traveltime picks of the synthetic and DrillCAM data are compared with each other (right). The verticalization assumes straight rays and the graph shows an average deviation of about 1-3 sample points between the two curves.*

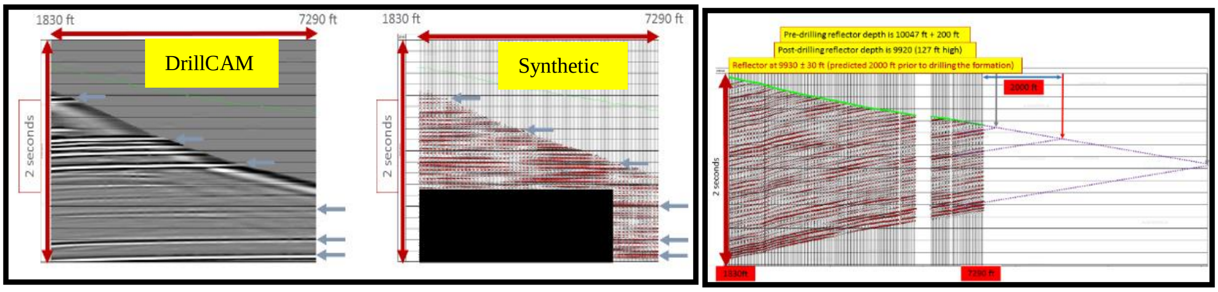

Figure 3 *ZVSP synthetic and DrillCAM CRGs after enhancing upgoing reflections and TWT flattening (left). The blue arrows mark key reflectors that correlate well above and below the bit. The un-flattened field gather is interpreted to predict accurately an over-pressured formation, which is around 2000 ft ahead of the drill bit (right).*

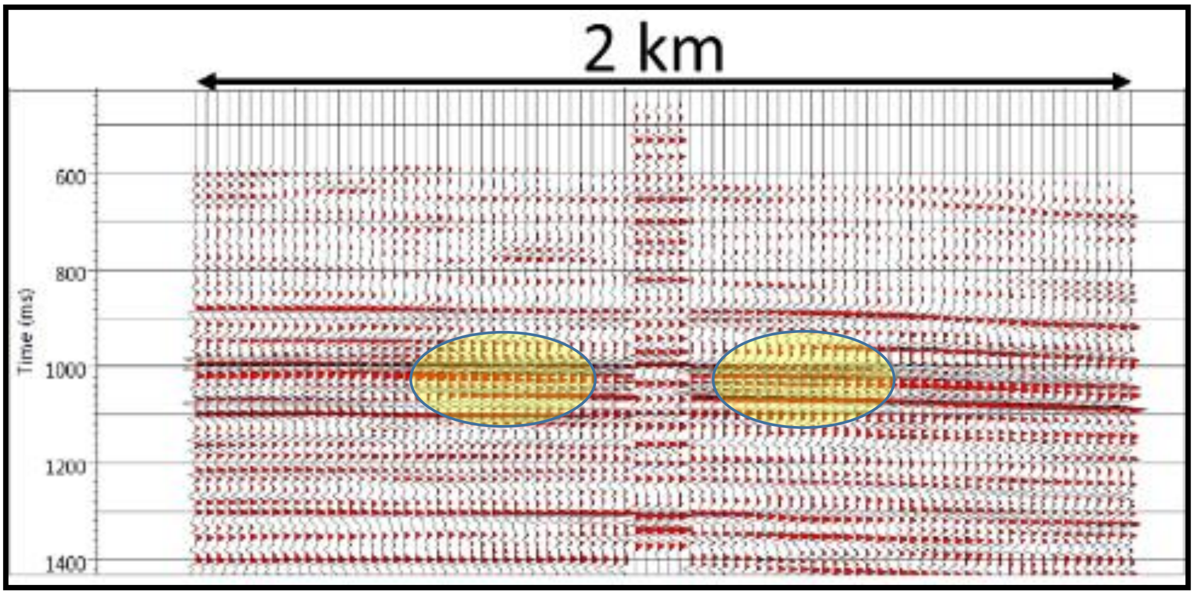

Figure 4 *A ZVSP corridor stack is spliced into a surface seismic section. The corridor stack ties well with the time-migrated image and helps identify potential multiple contaminations at about 1 s (yellow circles).*