Seismic measurements while drilling reduce uncertainty in the deepwater Gulf of Mexico
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Summary
Seismic uncertainty in the deepwater Gulf of Mexico impacts the efficiency of well construction and thus has a direct effect on the overall cost of a project. Any advances in technology that can reduce uncertainties and reduce risk have a significant impact on the ability to drill these wells safely and effectively.

A new tool that acquires seismic checkshots while drilling now makes it possible to place the bit on the surface time section, enabling depth-based decisions, such as casing point selection, to be made with increased certainty. Furthermore, the interval velocities derived from successive checkshots can be used to calibrate logging-while-drilling (LWD) sonic data and generate synthetic seismograms. At the end of the run memory data are recovered from the tool and the 4C waveform data are used for transit time quality control and to generate vertical seismic profile (VSP) images that can be tied to the surface seismic and sonic-derived seismograms.

In this paper we present a case study describing the use of this technology in the ultra-deepwater Gulf of Mexico, where checkshots acquired while drilling, transparently to normal drilling operations, were used to provide real-time depth predictions to the drillers. Analysis of the recorded data showed a good match to the surface seismic and significant look-ahead capability.

Introduction
The water depth at the location of the vertical well used for data acquisition was greater than 9,000 ft and the depth uncertainties for the target reflectors, situated between 15,000 and 21,000 ft true vertical depth (TVD) were in excess of 1,000 ft. This level of uncertainty made optimal setting of casing points very difficult and was the driving force that led to the use of the seismic-while-drilling technology. The aim was to achieve an accurate time to depth transform that would enable the driller to be constantly aware of the drill-bit position on the surface seismic section, thereby enabling accurate setting of casing points relative to the geology. Before acquisition commenced, a predrill model from a distant offset well was used to define the initial time-depth relationship.

Method
The seismic-while-drilling method uses a conventional airgun array as the source. The 4C data acquired downhole are automatically stacked and picked, and the checkshot data are transmitted from the tool to the surface in real time via mud-pulse telemetry (Esmersoy et. al., 2001). The

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Figure 1. Process flow

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source is fired during pipe connections so that no rig time is lost.

At the end of a bit run the recorded waveform data are dumped from the tool at the surface, enabling further processing and quality control. The process flow used for this type of job is illustrated in figure 1. During the first bit run checkshot data are used to situate the bit on the surface seismic, calculate interval velocities, and make initial depth predictions. Following the first bit run, the recorded data are processed to provide quality control for the traveltime data, obtain final interval velocities, and produce a fast turnaround VSP corridor stack for comparison with the surface seismic. Obtaining a good seismic tie removes any residual depth uncertainty caused by small static shifts or phase differences between the two datasets. If there is a mismatch between the VSP and surface seismic data, the surface seismic data can be shifted and phase-corrected to match the VSP corridor stack.

Following these steps, both the corrected surface seismic and the VSP should predict the same depth for a given target. The velocity used to predict ahead of the current bit position is based on the predrill model after applying a bulk slowness shift to make it consistent with the latest checkshot data. This velocity can be continuously updated in real time during the second bit run using the new while-drilling checkshot data as it is acquired. The same approach can be used for subsequent runs, enabling accurate depth prediction for additional deeper targets. The velocity data can also be used for other applications, such as calibration of pore pressure models and local re-imaging of the surface seismic data with an updated model.

Results

The seismic-while-drilling tool was used during three bit runs and both while-drilling checkshots and recorded 4C data were acquired on each run. Stacked downhole hydrophone data from the first run are shown in figure 2. The hydrophone data were selected for processing because in a large-diameter vertical borehole the geophone coupling may be unreliable. In deviated wells the geophone coupling is much improved and the geophone data are generally of higher quality than that from the downhole hydrophone. Note that the shallow hydrophone data, acquired inside casing while tripping out of the hole, are affected by strong tubewave arrivals, which are reflected at the casing shoe. Nevertheless it is possible to pick reliable compressional arrival times all the way up to the seabed. Below the casing shoe the data quality is much improved and is suitable for VSP processing. The VSP data were good enough to provide considerable look-ahead capability, and coherence matching (White, 1980) showed a statistically significant reflectivity match with the surface seismic data at the well location, giving confidence in the validity of the checkshot data.

The hydrophone data from the second bit run in the well were also of good quality and this run ended about 800 ft above a key target horizon. The intention was to set casing just above this reflector. Processing of the recorded data from this second run was combined with that of the VSP data from the first run and gave an excellent seismic tie after wavelet processing (figure 3). This tie gives confidence in the time-depth relationship provided by the
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Because of the ability to employ waveshaping deconvolution using the downgoing wavefield in the VSP processing sequence, the control of the VSP wavelet phase is superior to that in the surface seismic data. In this case the wavelet phase difference between the VSP and the surface seismic data was approximately 70º, meaning that the accurate time location of seismic events was significantly improved by the wavelet processing, which corrected the embedded wavelet to zero phase. Note that in this case, due mainly to time limitations and the need to have results before the next bit run, no attempt was made to whiten the spectrum of the surface seismic data and the VSP data have been filtered to match the surface seismic. The VSP corridor stack does in fact contain significantly higher frequencies than the surface seismic.

From the available VSP data, a depth prediction for the target reflector was generated by simply extrapolating the time-depth curve to meet the zero-phase reflector (figure 4). This depth prediction was updated during the third bit run with additional while-drilling checkshot data and the target depth was successfully predicted to within less than 50 ft of its true location.

Deeper targets were also predicted successfully using the same approach. The target depth predictions were more than 1,000 ft deeper than those indicated by the predrill velocity model and led to significant changes to the casing plan. The recorded data from bit run 3 were used to produce a final combined VSP image and a vertical P-wave velocity profile that covered the entire drilled interval from the seabed to the final total depth (TD) (figure 5). The shallow checkshot data were obtained by shooting levels while tripping out of the hole after completion of the first bit run, and the final velocity field was calculated from all the time-depth data using the smooth velocity inversion of Lizarralde and Swift (1999). This final data can be used for the usual geophysical applications associated with VSP data, including sonic log calibration (figure 6) and synthetic seismogram generation (figure 7). In this case both the real-time LWD sonic and subsequent wireline sonic log data were calibrated using the final checkshot times and synthetic seismograms produced. Figure 7 shows the final comparison of the surface seismic, VSP corridor stack from all three runs combined, and the two synthetics. Overall the quality of the tie is impressive, suggesting that integrating LWD sonic and seismic data in real-time can give detailed velocity data with an accurate tie into the seismic time section. Other possible uses of the data include multiple identification and surface seismic reprocessing. However, it is the real-time application to address drilling concerns that is the primary benefit of this technique.

Conclusions

In this paper we have demonstrated a method for providing accurate vertical velocity and target depth prediction while drilling in the ultra-deepwater Gulf of Mexico without any associated loss of rig time. The combination of checkshot data acquired while drilling with fast processing of recorded VSP waveform data and surface seismic matching gives confidence in placing the drill bit on the surface seismic time section. This in turn enables the driller to determine casing points with confidence and avoid potential drilling hazards.
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Figure 6. LWD sonic log before (red) and after (orange) correcting for the significant drift shown on the right.

References


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Figure 7. Final seismic tie with MWD VSP, synthetic based on wireline sonic, and synthetic based on real-time LWD sonic.