Seismic-While-Drilling on ODP holes 1107 and 1105A: A Preliminary Report on Correlation Processing

Prepared by Professor James Rector and Zhuping Liu

Department of Materials Science and Mineral Engineering
557 Evans Hall
University of California at Berkeley

Table of Contents

Table of Contents of Figures

Introduction

Seismic-While-Drilling (SWD) , also termed Tomex^{R} is a technique that monitors the seismic signals created during rotary drilling using a pilot sensor located near the top of the drillstring along with 'earth' sensors deployed near the surface of the earth. Cross-correlations between the pilot sensor signal and each of the earth sensors are used to attenuate incoherent noise and to compute traveltime differences between signals received at the earth sensors and signals received at the pilot sensor. By compensating for the delay and multipath filtering created by propagation in the drillstring, the correlated signals can be processed to create a data set equivalent to an inverse VSP, with a point source at the drill bit and a receivers near the earth's surface. Real-time information from the SWD data such as interval and average velocities and reflectivity ahead of the bit are used commonly by the oil industry to position the drill bit on the (time) seismic section, predict overpressure, and steer the bit in the case of deviated wells. In some cases, logging runs cannot be made after the hole is drilled (due to stability problems), and SWD data may be the only borehole geophysical data recorded. The attractive characteristics of SWD make it a natural for ODP cruises, where hole conditions sometimes make it impossible to perform wireline logging.

Data Acquisition

In the summer of 1998, SWD was tested on ODP holes 1107 and 1105A. Figures 1a and 1b show the acquisition geometries for these tests. A 3-component accelerometer was attached to the top of the drillstring and the vertical component was used as the pilot signal in subsequent correlations. Two OBS packages were deployed on the ocean floor for each survey. On hole 1107, one horizontal geophone, a hydrophone and a vertical geophone were used at each location (A4 and A8). On hole 1105A, location A4 also contained a second horizontal geophone. SWD data were successfully collected during a few periods of drilling, and then converted into 40 second SEGY files for subsequent correlation analysis at UC-Berkeley.

Data Processing

Pilot Signal Analysis

In previous studies, spectral analysis of the pilot signal showed differences in the levels of the horizontal and vertical accelerometers that were related to changes in drilling parameters and drilling lithology. Harmonics of the rotary rate were also observed in the spectra. In this study, we evaluated one other QC indicator that is often used is the pilot signal autocorrelation function—the presence of drillstring multiple events. A drilllstring multiple arrival travels up and down the drillstring at least three times before it is recorded at the top of the drillstring. For example, the first drillstring multiple is an arrival that travels from the bit to the top of the drillstring, reflects at the top of the drillstring, travels back down to the bit where it is reflected again and travels back up to the top of the drillstring where it is recorded. If drillstring multiple events are observed in the pilot signal autocorrelation, then correlated data often show high signal-to-noise ratios. Figure 2a and 2b show the pilot signal autocorrelation functions for hole 1107 and hole 1105A. The red line in Figure 2a represents the estimated delay of the 1st drillstring multiple (relative to the drillstring primary arrival) using a drillstring velocity of 4300 m/s. The drillstring velocity can vary by up to 4% depending on the quality of the drillipipe used, and the moveout of the drillstring multiple is often used to estimate the propagation velocity. The first drillstring multiple for hole 1105A is at a much smaller delay, and is somewhat obscured by sidelobes, however, the higher-order multiples are easily identified.

Correlation Analysis

The data collected by the pilot sensors and the data collected by the OBS sensors were not designed to be easily cross-correlated as would be done in a commercial Tomex survey. Sample rates, data formats, gains, and recording durations were not consistent betweeen the pilot sensors and the OBS sensors. However, after a great deal of effort the data were successfully output into SEGY files and correlated. Figure 3 shows the hole 1107 correlation functions computed between the vertical accelerometer recordings and each of the OBS channels for the two locations, A4 and A8. The pilot signal was advanced by 1000 ms prior to correlation so that negative correlation lags could be computed. A correlated event occurring at correlation lags less than 1000 ms represents an arrival that is recorded by the OBS sensor *before* it is recorded by the pilot sensor. Since the OBS sensor is much closer to the bit than the pilot sensor, arrivals may be recorded by the OBS sensor first, however for this data, no early arrivals were detected. In addition to the time advance, the pilot sensor was deconvolved using a prediction error filter with a 400 ms filter length to remove drillstring multiples recorded by the pilot sensor from the correlation functions. After correlation, the data were binned over 0.5 m depth intervals.

In Figure 3, coherent events (between 1150 and 1250 ms) were only detected when the drill bit was drilling basement. The coherent events appear to be propagating at a very slow group velocity (less than 1000 m/s), but the change in arrival time from A4 to A8 is less than 100 ms. The events also appear to be polarized horizontally. There is no response on the hydrophone sensor (channel 6). These characteristics suggest that the arrival is a direct shear wave from the drill bit.

Figure 4 shows the correlated data for each of the channels from hole 1105A. While there are coherent events at about the expected arrival times, the events are very discontinuous as a function of depth. The discontinuous nature of the events probably indicates some degree of error in the start time of the pilot trace as opposed to the start time of the OBS traces. When the OBS traces are correlated against each other, the events are no longer discontinuous. The start time errors were probably introduced when the data were split into 40s records and output to SEGY.

Although moveout with depth cannot be used as an arrival discriminator in this data, the event delays and polarizations can be used to infer the travelpaths. Figure 5 shows the data of Figure 4 with the square root of the average amplitude computed between 800 and

1200 ms displayed above the traces. Also displayed in Figure 6 is the expected arrival time of an event originating at the drill bit, traveling up the drillstring to the ocean floor, and then traveling horizontally along the ocean floor at the water velocity to the OBS receivers. Since the arrival is polarized horizontally (the amplitude of the horizontal component is roughly 10 times the amplitude of the vertical component) and yet is also recorded by the hydrophone, it is probable that the arrival is a horizontally propagating P-wave. The delay is consistent with a water propagation velocity.

There is another arrival observed on the vertical component at the longer offset that arrives earlier (occurring at a correlation lag of about 910 ms). Assuming a straight raypath and an initiation position at the drill bit, this arrival would propagate with a velocity of 3300 m/s. This arrival is probably a direct shear arrival. It's polarization is primarily vertical at this site as opposed to horizontal at the 1007 site because the offset to bit depth ratio is larger and because there is presumably little vertical velocity gradient.. There appear to be some weaker coherent arrivals at other lags, but due to the problems in acquisition and transcription, travelpath interpretations of these arrivals is questionable.

Conclusions and Recommendations

The SWD collected at holes 1105A and 1107 demonstrated that useful drill-bit-source data can be recorded on ODP vessels. Pilot signal autocorrelation functions exhibited drillstring multiples when drilling in basement materials. These drillstring multiples indicate that the bit is producing seismic energy. The OBS-correlated data showed wideband events that can be interpreted as originating at the drill bit. At 1105, the most energetic of these events is interpreted to radiate from the drillstring as a horizontally propagating compressional wave in the water. The vertical component of hole 1105A appeared to contain a direct shear arrival from the drill bit. Data formatting problems made it difficult to confidently identify many of the weaker coherent events. At 1107, identifyable events were only observed when drilling in basement. The events created when drilling basement appear to be direct shear waves.

In general, the SWD data were identical in character to SWD data collected on offshore platforms, semisubmersibles and drillships by Schlumberger and Baker-Atlas (formerly Western Atlas). For subsequent surveys, it is strongly recommended that the wheel not be reinvented. Survey design, equipment development, and data processing/analysis should more closely involve industry personnel/resources.

Acknowledgements

This work was supported by the National Science Foundation (NSF Grant Number OCE - 9730588).

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Figure 1a: Cross-section of Deploy 2 (Hole 1105A)

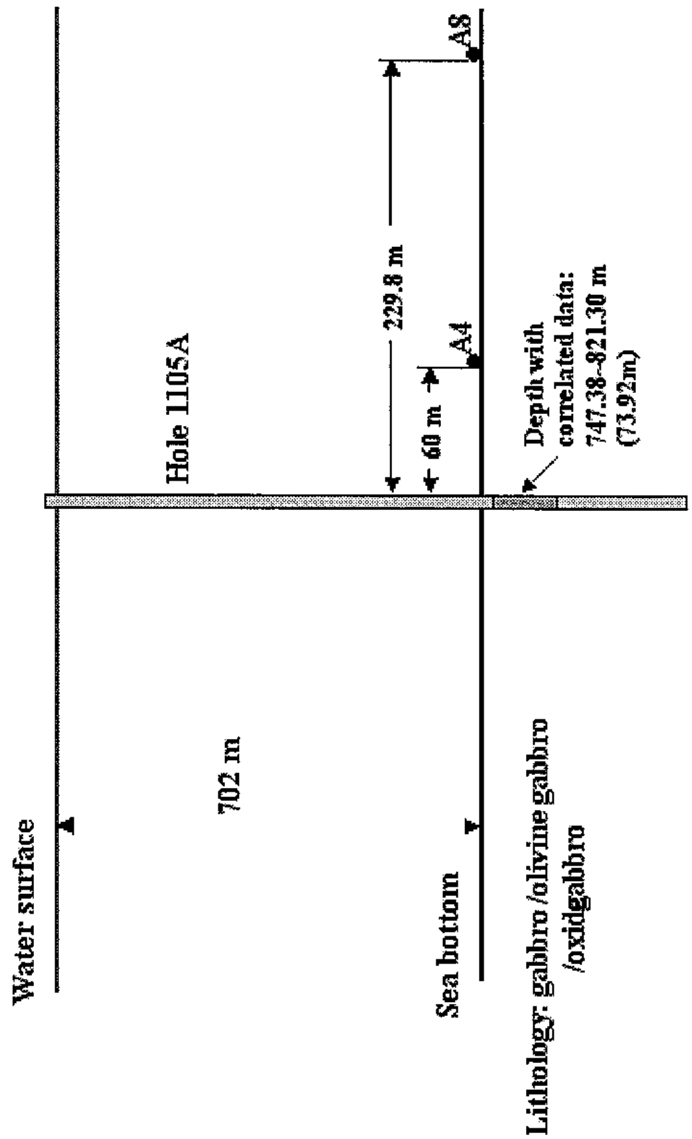
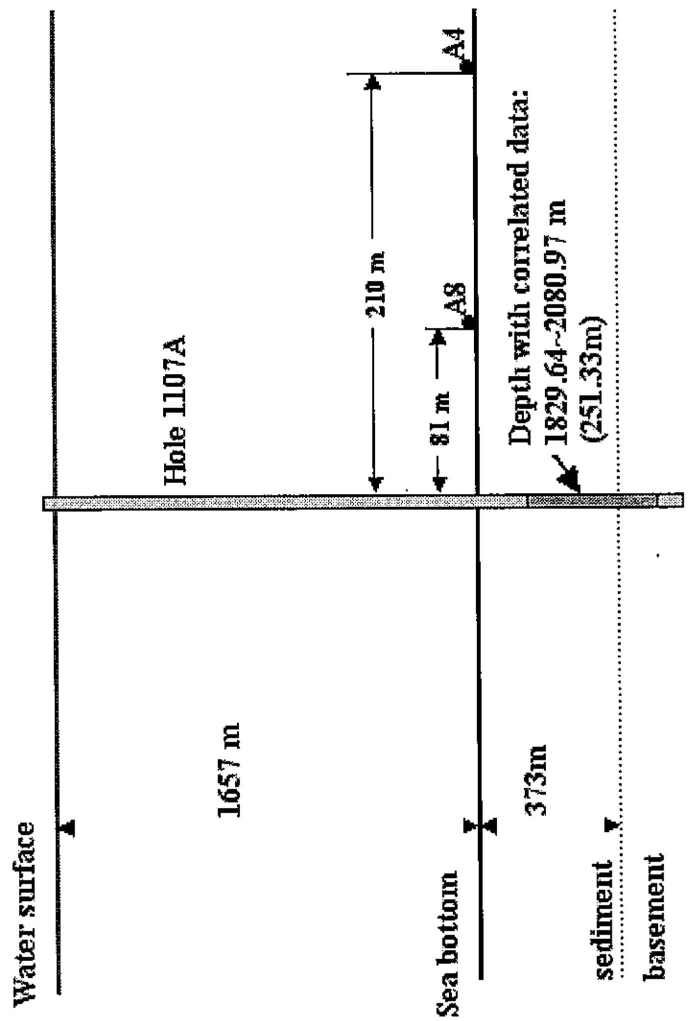


Figure 1b: Cross-Section of Deploy 3 (Hole 1107A)



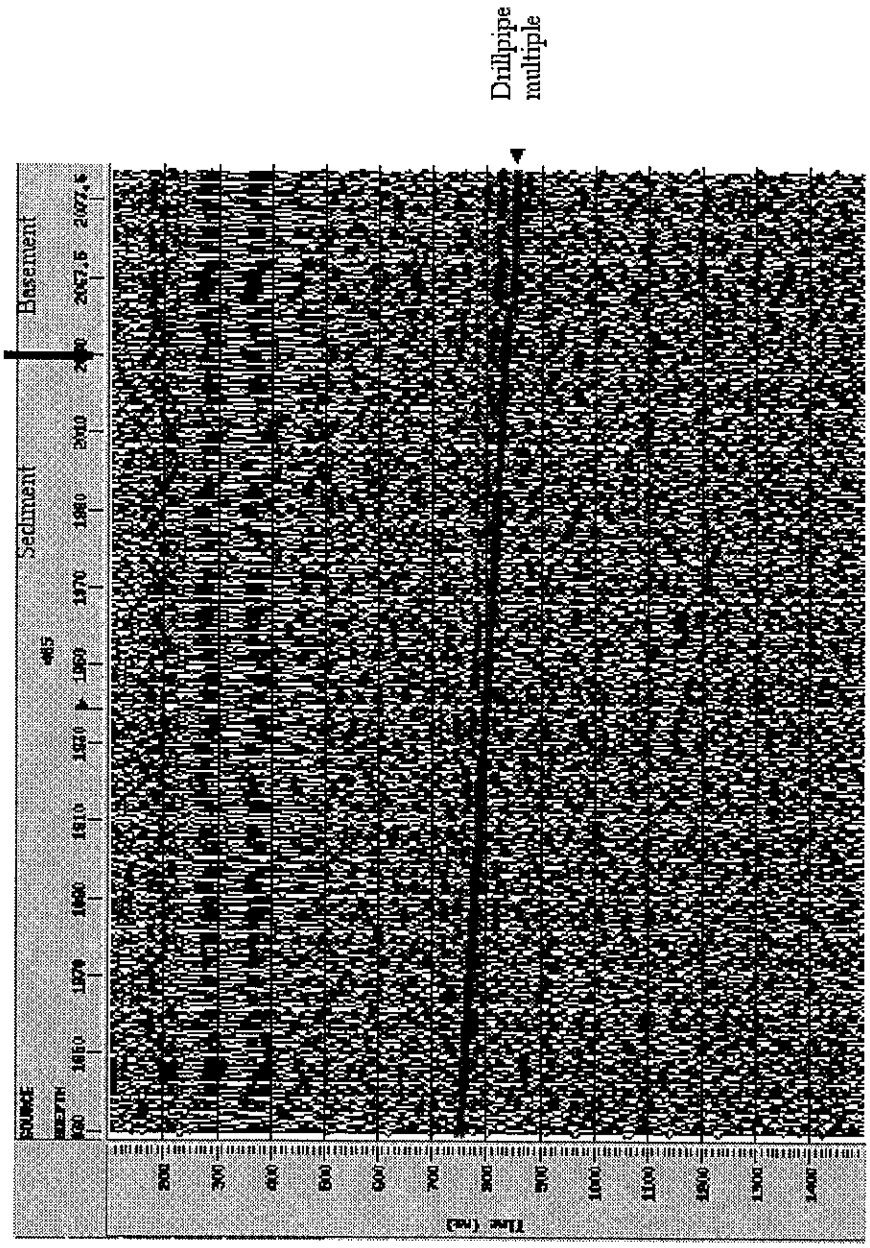


Figure 2a: Vertical Accelerometer autocorrelation functions for hole 1107. The red line represents the expected delay of the 1st order drillpipe multiple.

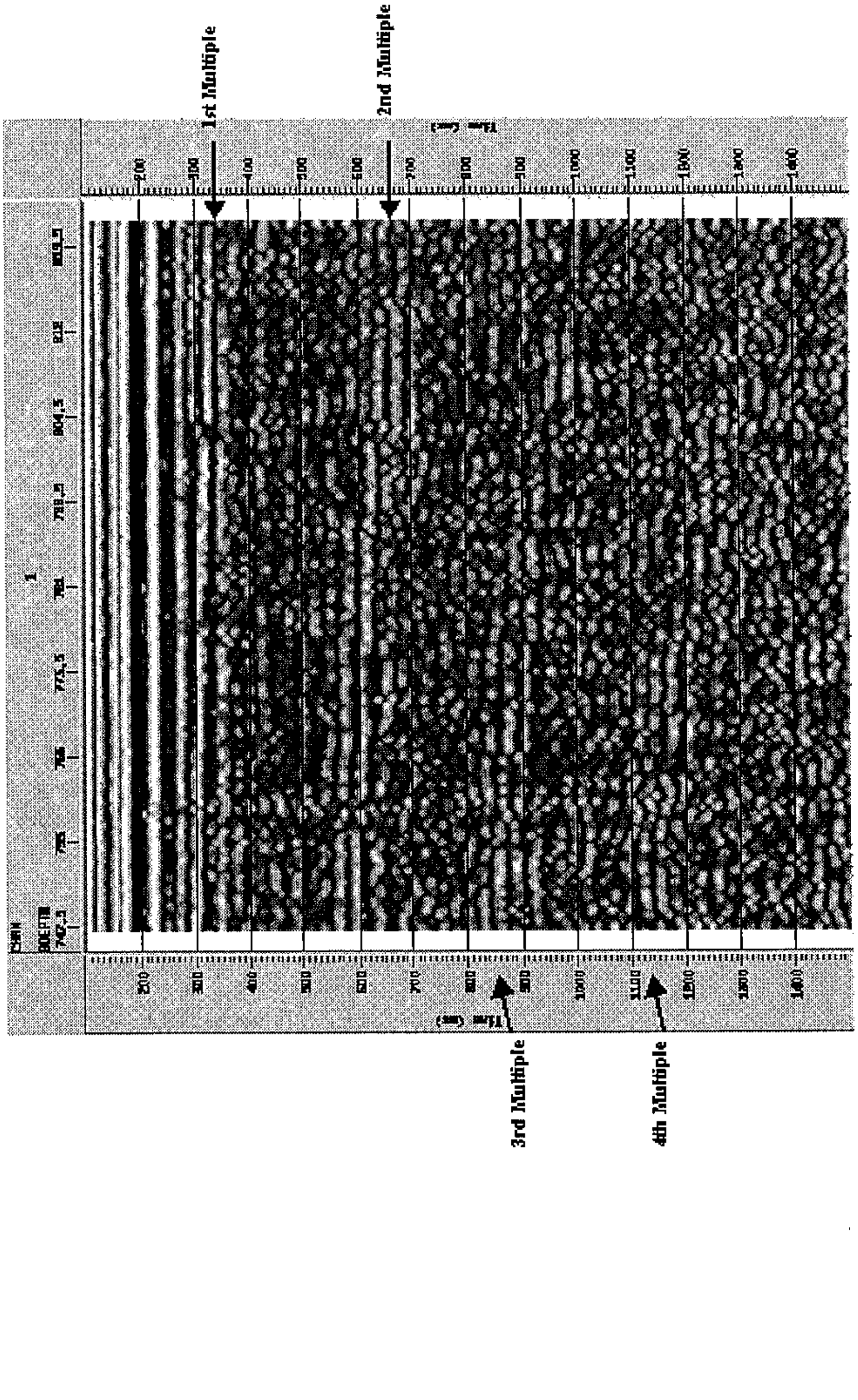


Figure 2b: Vertical Accelerometer autocorrelation functions for Hole 1105A. The drillstring multiples can be observed at most depths.

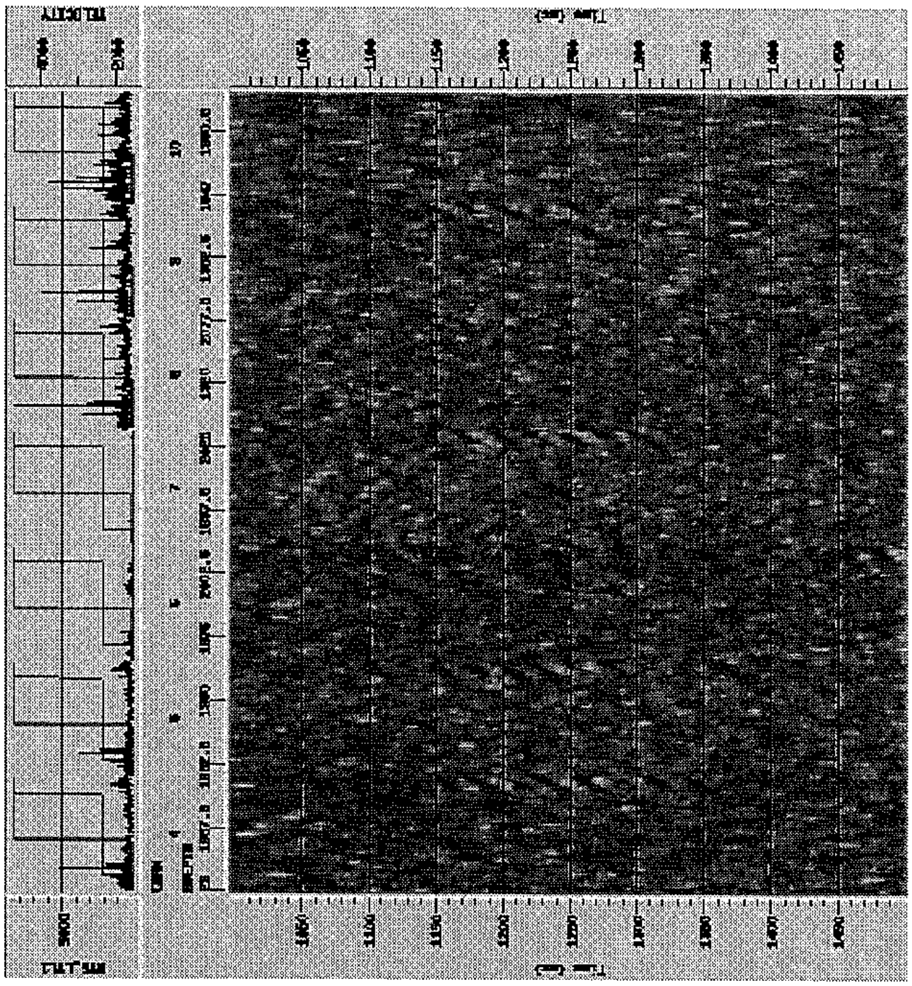


Figure 3: Cross-correlations between pilot sensor and OBS channels for hole 11107.

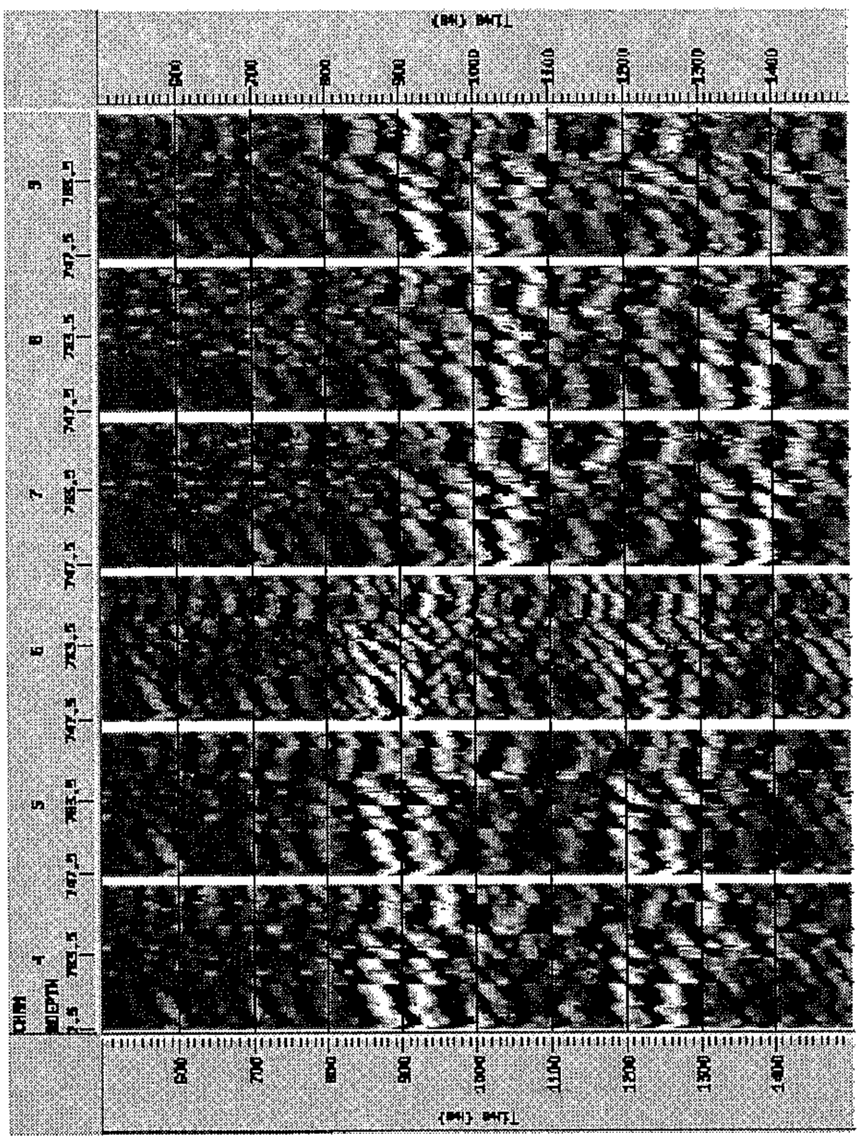


Figure 4: Cross-correlation functions for hole 1105A. Channels 4-6 represent H1, HY, and V for location A4, while Channels 7-9 represent H1, HY, and V for location A8.

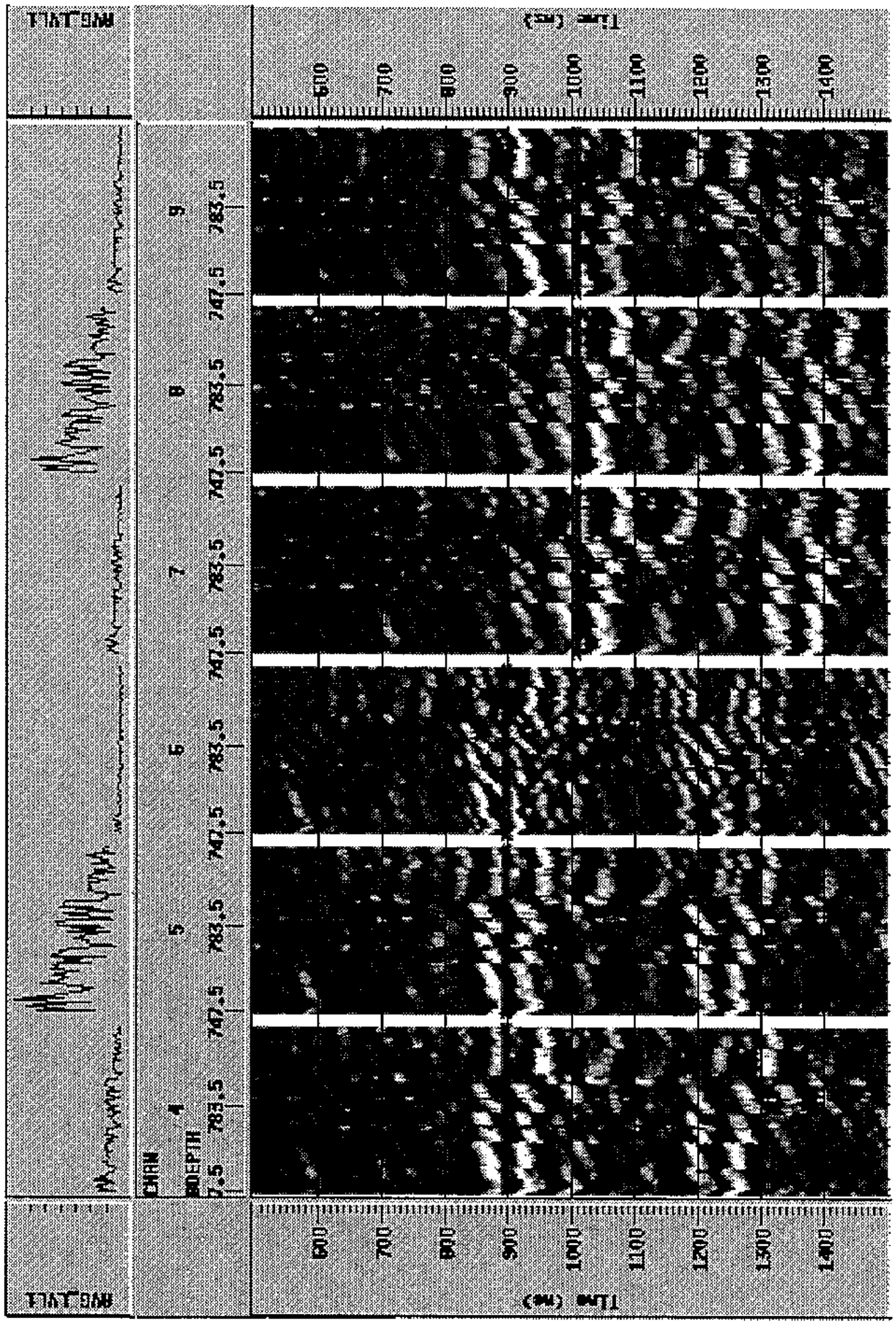


Figure 5: Correlated data with average amplitude (window from 800 to 1200 ms) plotted above. The red line is the expected time of an arrival traveling to the OBS sensors from the drillstring horizontally at water velocity.