Report 9

AUTOCORRELOGRAM MIGRATION OF FIELD DATA GENERATED BY A HORIZONTAL DRILL-BIT SOURCE

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ABSTRACT

The goal of Inverse Vertical Seismic Profiling While Drilling (IVSPWD) is to image the subsurface structure below the drill bit with the seismic signal recorded on the surface. This report presents the results of applying an improved autocorrelogram migration method to Union Pacific Resources (UPRC) seismic drill-bit data recorded on the surface with a drill bit. The drill-bit data were recorded when the drill bit was moving along a horizontal trajectory at a depth of 9188 ft in the Austin Chalk formation. Autocorrelogram migration is applied to these data in the time domain with a primary-imaging condition and a ghost-imaging condition. The resulting primary-migration images are compared with a surface-CDP section adjacent to the well rig. The results show that autocorrelogram migration correlates well with the surface stacked section. The ghost migration result suffers from more noise. Our results are further evidence that autocorrelogram migration can be a practical tool in imaging the reflectivity distribution with IVSPWD.
INTRODUCTION

The Inverse Vertical Seismic Profiling While Drilling (IVSPWD) technique uses the drill-bit impacts as a source of seismic energy (Katz, 1990; Rector and Marion, 1991). The drill-bit signal is recorded with a seismic array on the surface so that the IVSPWD method, based on Lew Katz’s patent, is used to construct inverse vertical seismic profiles by computing the autocorrelation of the recorded seismic data. Its theoretical advantage over the TOMEX method is that the source wavelet does not need to be known. This is a significant advantage in deviated holes where the source wavelet’s pilot signal is not observed at the surface (Meehan et al., 1998). Schuster et al. (1997a, 1997b) extended Katz’s IVSPWD method to 2-D and 3-D media by developing new imaging conditions and a set of equations for migrating the IVSPWD autocorrelograms. The equations provide a mathematical procedure for inverting arbitrary reflectivity distributions from IVSPWD autocorrelograms.

In this report we present the processing results for UPRC drill-bit data using the autocorrelogram migration method. The data were acquired using three-component receivers on the surface while a tri-cone drill-bit and down hole motor were used to drill along a horizontal trajectory. The three-component drill-bit data suffer severely from a noisy background. A series of preprocessing steps were required for calculating the autocorrelograms before autocorrelogram migration method could be implemented in the time domain. The resulting migration images correlated well with the nearby surface-CDP section.

AUTOCORRELOGRAM IMAGING OF UPRC DRILLBIT DATA

An overview of the method

The basic scheme of the IVSPWD technique is illustrated in Figure 9.1, where the drill bit is used as source of seismic energy. The acoustic waves propagate through the earth as direct, reflected and surface-related ghost events (see Figure 9.2a and 2b), which are recorded by a seismic array on the surface. According to the reports presented by Schuster et al. (1997a and 1997b), assume that seismic energy emanates from the drill-bit source at depth \( r_s \) and is recorded by geophones at \( r_g \) on the surface, where the observed drill-bit data are denoted by \( s(r_s, r_g, \tau) \); the migrated image \( m(x) \) is approximated by the following formula:

\[
m(x) = \sum_{g,s} \tilde{s}(r_g, r_s, \tau = \tau_{sx} + \tau_{xg} - \tau_{sg}),
\]

(9.1)
where the summation is over all source locations in the well and receiver positions at the surface; \( \tau_{sx}, \tau_{sy} \) and \( \tau_{sg} \) are traveltimes for seismic waves to propagate, respectively, from the source point to the image point at \( x \), from the image point to the receiver position, and from the source to the geophone location (see Figure 9.2a and Figure 9.2b); and \( \varphi \) represents the second-time derivative of the wavelet’s autocorrelation function. Multiplicative factors related to geometrical spreading and inversion have been harmlessly dropped, and we assume that autocorrelograms have been deconvolved.

Similarly, the surface-related ghost image can be obtained with the following equation:

\[
m(x) = \sum_{g,s} \varphi(\xi_g, \xi_s, \tau = \tau_{sx0} + \tau_{xx0} + \tau_{xg} - \tau_{sg}) ,
\]

where the raypaths are depicted in Figure 9.2b and \( x_0 \) defines the ghost-reflection point on the free-surface. The implementation of autocorrelogram migration is performed by autocorrelating the seismic data recorded on the surface and migrating autocorrelograms using either one of the above equations. Using equation 19.1 is referred to as autocorrelogram migration with a primary-imaging condition and using equation 19.3 is referred to as autocorrelogram migration with a ghost-imaging condition.

Data analysis and processing

UPRC drill-bit data were acquired with three-component receivers at the Austin Chalk area in May, 1991. The drilling rig location and the acquisition survey are shown in Figure 9.3. Figure 9.4 shows the zoom-view schematic of the V-shaped acquisition survey, and three-component traces begins with trace number 21, 22, 23; 25, 26, 27, \ldots; 65, 66, 67. Furthermore, \((0E, 0N)\) denotes the location of the drilling rig, and the offset to Trace 21 is at about 2700 ft. The horizontal view of the drill-bit’s trajectory projected on the surface is shown in Figure 9.5, where ”*” denotes the drilling rig location; and symbol ”+” represents the drill-bit position projected at the surface. Figure 9.6 shows the cross-section of the vertical trajectory of the drill bit and symbol ”X” indicates the drill-bit position at \((999.75E, 1205.9S)\) with a depth of about 9188 ft.

The traces have a recording length of 20 seconds with a sample interval of 2 ms. A total recording time of 4 seconds were used to produce each autocorrelogram. Each ”shot” record is recorded by ten receivers on the surface for each component with offsets ranging from about 2700 ft to 6300 ft relative to the drilling rig position. A common-shot gather is shown in Figure 9.7, where we loosely use the word ”shot” to indicate the drill-bit source. After editing and sorting, ten common-receiver gathers
were obtained. Here the drill-bit location is calculated according to the drilling direction in the deviation log. For drill-bit data imaging, the desirable arrivals contain two parts: the primary reflections from the subsurface layers (see Figure 9.2a) and the surface-related ghost reflections (see Figure 9.2b).

For the primary reflector image, autocorrelogram migration can be implemented in the common-shot domain (CSG). In order to better image surface-related ghosts, the autocorrelogram migration has to be implemented in the common-receiver gather (CRG) domain since ghost waves can be more easily separated from primary reflections. For this data, the special drill-bit trajectory induces the moveout of upgoing and downgoing waves to have the same polarity. This may cause some artifacts due to the difficulty in separating up and down going waves at only one vertical depth.

The main processing steps for autocorrelogram migration of drill-bit data are as follows:

- Geometry assignment, orienting and rotating the receivers, data editing, and static shifts. The dataset was acquired with a noisy background and the coupling conditions are different for each receiver station, and some traces in the shot gather are severely polluted by noise. Before doing preprocessing, shot gathers need to be edited. The static shifts, including elevation of receivers, need to be corrected in the shot gathers in order to reduce static problems.

- Frequency panel analysis, bandpass filtering, and noise burst elimination. Through frequency panel analysis, a rational frequency range is selected in order to eliminate strong noise bursts and keep the main signals. Figures 9.8 is a spectrum of the common shot gather shown in Figure 9.7. The corresponding frequency panel analysis is shown in Figures 9.9. A 5-40 Hz bandpass filter was applied to the raw data in the common shot gathers, but some burst noise can’t be effectively eliminated with this band-pass filter. An adaptive noise method and notch filters are used to suppress such noise.

- An adaptive noise filter was used to suppress the pervasive high coherent noise. Some energy, such as noise bursts, is caused by a secondary source, and appears in the form of several sample points with high energy. This noise has a wide frequency range so that bandpass filtering and deconvolution will fail to effectively suppress it. In time domain processing, according to the input data in a common shot gather or common receiver gather, the data are windowed. In each window the average energy is calculated. Combined with a moveout operation and weighted median filtering, the data-driven model trace is obtained. According to this data-driven model trace, we can determine whether the wave energy is reflection or noise energy. If it is noise, we further determine if it needs to be killed or attenuated. For the coherent noise with a constant frequency, a notch filter needs to be used.
Figure 9.1: Two types of waves used in the IVSPWD method.
Figure 9.2: (a). Primary reflections (solid line) and direct wave ray path (dashed line); (b). The ghost reflections from the surface and associated rays denoted by solid lines. The direct wave is depicted by a dashed line; $x_0$ is the ghost reflection point at the free surface.
Figure 9.3: The map of the UPRC data acquisition survey. The geophone stations 1001 to 1020 along the V line were used to record the drill-bit data. The drill rig position is defined by *NICKLOS RIG42*. 
Figure 9.4: Map view of the UPRC data survey.
Figure 9.5: The drill-bit trajectory projected onto the surface. The symbol * denotes the rig position at the surface; the symbol $\oplus$ denotes the drill-bit position with a depth around 9188 ft.
Figure 9.6: The vertical cross-section of the drill-bit trajectory. The rig position is at the surface coordinates (0, 0); the symbol × denotes the drill-bit position with a depth of approximately 9188 ft.
Figure 9.7: Raw common shot gather (CSG 96).
Figure 9.8: Spectrum of common-shot gather 96.
Figure 9.9: The frequency panel analysis for common-shot gather 96.
Figure 9.10: Same as Figure 9.7 except preprocessing was applied to the data.
Figure 9.11: Part of common receiver gather 6.
Amplitude balancing and energy normalization (Yilmaz, 1987). The receivers on the surface have different coupling conditions so that amplitude balancing and energy normalization are applied to the traces. Figure 9.10 shows the result of a processed common shot gather.

Beamsteering for velocity analysis. The beamsteering technique is used for velocity analysis by scanning the windowed seismic data based on the maximum semblance criterion. This velocity will be used in the migration process.

Calculating autocorrelograms. Figure 9.11 presents part of the CRG data and the corresponding autocorrelograms are shown in Figure 9.12. The autocorrelation window length is obtained by a trial-and-error method aimed at minimizing the generation of virtual multiples. For the horizontal drill-bit data, conventional dip filtering fails to separate primary and ghost waves. For this acquisition geometry, I do a series of tests on the autocorrelation window length for calculating autocorrelograms. It is observed that the correlation window length influences the quality of the autocorrelograms; the deeper ghost events arrive later than the primary events. By properly selecting the window length, the interference from these deeper ghosts can be reduced.

Coherent noise elimination. After correlation, strong coherent noise will appear in some traces which affects the quality of the final migration result. A high energy elimination filter can be applied to the autocorrelograms to attenuate coherent noise for some traces.

Autocorrelogram migration. After all of the above processing, the data were migrated using the equations defined above with primary and surface-related ghost imaging conditions. The migration scheme is implemented in the time domain, and stacking of each gather’s migration images together gives the final image result.

Deconvolution. The virtual multiples (Schuster et al., 1997a) that remain in the autocorrelograms can pollute the quality of the final migration result. Thus a prediction error filter needs to be applied to the post-migration image. The operator length I used was 260 ms, and the prediction distance was 12 ms.

**Autocorrelogram image results**

Time migration is one of most often used imaging tools. It has the merit of collapsing diffractions, enhancing the signal to noise ratio; it is easy to implement, and requires only a smoothed approximation of the velocity field.

In order to avoid aliasing in imaging, an anti-aliasing operator is applied to the time migration operator (Lumley, 1994). With different imaging conditions, the final primary and surface-related ghost autocorrelogram migration results are shown in
Figures 9.13 and 9.14, respectively. The image has a 600 ft lateral shift away from drill bit with 20 ft trace interval. Comparing these two migration images, it is observed that the primary image has better quality and the ghost migration result suffers from greater interference.

The autocorrelogram migration result is compared with the surface-CDP stacked section, Line AC4 which was acquired in 1990. The location of Lines AC4, AC114, and ACX1, and the drilling rig are shown in Figure 9.15. The comparison of the autocorrelogram migration images with the surface-CDP section of Line AC4 is given in Figures 9.16 and 9.17. Drill-bit images are displayed every two traces. These results shows that the primary autocorrelogram image correlates well with the surface-CDP section. Ghost migration, however, gives a poorer correlation with the surface-CDP result compared with the primary image. This is not too unexpected, because the ghost reflection must travel the earth section twice that of the primary reflections.

**SUMMARY**

We obtained the primary wave migration images and surface-related ghost migration images from autocorrelograms calculated from drill-bit data. Tests show that autocorrelogram migration provides reflectivity images that compare well with the surface-CDP section. Compared with the primary migration image, the ghost autocorrelogram image has poorer quality which was caused by the interferences with other events. Our results demonstrate the ability of autocorrelogram migration to provide useful information for reflector characterization and prediction ahead of the drill bit. These results furthermore validate the claim that the autocorrelogram migration method can be used to image subsurface structure with IVSPWD data.

The UPRC drill-bit data were acquired with a drill bit moving along a horizontal well, which requires that more attention be paid to preprocessing the raw data. Processing steps, such as suppressing noise, improving S/N and separating ghost and primary, are crucial in obtaining good image quality.

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**REFERENCES**

Figure 9.12: Some autocorrelograms associated with CRG6.
Figure 9.13: Primary autocorrelogram migration result with a traces interval of 20 ft.
Figure 9.14: Ghost autocorrelogram migration result with a trace interval of 20 ft.
Figure 9.15: Map view of surface line AC4, AC114, and ACX1, and the drilling rig. Symbol "*" defines the drilling rig position; symbol "X" denotes Line ACX1 used for acquiring the drill-bit data; solid line and dashed-dot lines define the surface line AC4 and AC114, respectively.
Figure 9.16: Comparison of primary autocorrelogram image with surface stacked section of Line AC4. The gray solid line denoted as "Drilling hole" indicates an approximate projection of the drill-bit trajectory on Line AC4. Note, no primary reflections should appear above the drill hole trajectory.
Figure 9.17: Comparison of ghost migration image with surface stacked section. The migration image suffers from more noise compared with Figure 9.16. The symbol "Drilling hole" is the approximate projection of the drill-bit trajectory on Line AC4.
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