Joint migration of primary and multiple reflections in RVSP data
Jianhua Yu* and Gerard T. Schuster; University of Utah

Abstract

Seismic imaging for RVSP or drill-bit data recorded for deviated or horizontal wells is a challenging task. Conventional filtering methods such as dip-filtering will fail to separate the primary and multiple (or ghost) reflections because the drill path generates primary and multiple reflections with similar moveout and the same polarity. In this paper, I present a migration method that uses both primary and free-surface related multiple reflections to image the reflectors below the source. The merit of this method is that it does not require the separation of the primary and multiple reflections. This joint imaging is implemented using the autocorrelogram imaging condition because it can produce a subsurface image without knowing the pilot signal. Additionally, it is also capable of suppressing the static errors at the source or/and receiver positions.

Test results on synthetic data and field data show that the joint imaging method is capable of suppressing spurious interferences and also performs robustly when seismic data are distorted by statics shifts at the source and receiver locations. In the field data example, the joint imaging approach produces a better ”look-ahead” image compared with the primary-reflection autocorrelogram images.

Introduction

RVSP from a drill-bit source can produce valuable real-time and on-site information for drilling exploration and engineering. An example is the IVSPWD method of Katz (1990), which uses the drill bit as a source of seismic energy. The drill-bit signal recorded by a seismic array on the surface is used to construct inverse-vertical-seismic images. Later, 2-D and 3-D IVSPWD migration methods were developed and applied to real data (Schuster et al., 2000; Yu et al., 2000a, 2001b). The corresponding imaging conditions and a set of equations for migrating the IVSPWD autocorrelograms were also presented.

Why do we migrate autocorrelograms? For deviated or horizontal wells, the pilot signals are difficult to record accurately (Meehan et al., 1998). In some cases, we have little or inaccurate information about the source location, and we don’t even know if there are statics shift errors at the source or/and receiver positions. One of the theoretical benefits of migrating autocorrelograms is that the source wavelet history does not need to be known. This is particularly important for imaging data obtained from a source located in a deviated or horizontal well. In addition, a drill-bit trajectory in deviated and horizontal wells induces a similar moveout for both the primary and multiple reflections. Thus, it is difficult to separate primary and reflections at only one vertical depth using conventional filtering methods.

To address the above problems, we present a joint imaging approach that uses both primary and multiple reflections with autocorrelogram imaging conditions. The advantage of simultaneously using both primary and multiple imaging conditions is that coherent noise can be suppressed, which makes it possible to avoid the separation of primary and multiple waves before migration. This is beneficial for deviated and horizontal well data where it is impossible to separate the above two kinds of reflections using a standard filtering technique. I also investigated the sensitivity of this imaging method to velocity error and statics shift errors at the source and geophone locations. Tests on synthetic traces show that this imaging approach produces accurate images even though the observed seismic data includes strong static-shift errors. A field data example shows that the joint imaging approach produces better ”look-ahead” images with less interference.

Brief Description of Joint Migration

Autocorrelograms have been migrated for RVSP data (Yu, 2001a, 2001b). The basic equation for autocorrelogram migration using the primary imaging condition is given by

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

(1)

and for the multiple migration equation is given by

\[
m(x) = \sum_{g,s} \varphi(r_g, r_s, \tau = \tau_{sx0} + \tau_{sx} + \tau_{sg} - \tau_{sg}).
\]

(2)

Here we assume that seismic energy emanates from the drill-bit source at the buried location \(r_s\) and is recorded by geophones at \(r_g\) on the surface, where the observed drill-bit data are denoted by \(s(r_s, r_g, \tau)\); \(m(x)\) is the migrated image; the summation is over all source locations in the well and receiver positions at the surface; \(\tau_{sx}, \tau_{sg}\) and \(\tau_{sg}\) are traveltimes for seismic waves to propagate,
Joint migration of primary and multiple reflections

respectively, from the source point to the hypothetical image point at \( x \), from the image point to the receiver position, and from the source to the geophone location as a direct wave; and \( \hat{\tau} \) represents the second-time derivative of the data’s autocorrelation function for a trace with a source at \( S \) and recorded at \( r_g \). We also assume that the autocorrelograms have been deconvolved (Schuster et al., 2000). In equation (2), \( x_0 \) defines the multiple-reflection point on the free-surface.

According to the kinematics of primary and multiple reflections, primary and surface-related multiple reflections are simultaneously migrated using the primary imaging condition (equation 1) and the multiple imaging condition (equation 2), respectively. For the subsurface reflectors below the drill bit or source location, both the primary and the multiple reflections should be migrated to the same reflectors as illustrated in Figure 1. In the area where reflectors do not exist, the primary and multiple reflections do not simultaneously focus at the same position as illustrated in Figure 2. Hence the true reflector image will be focused completely while other events will be attenuated due to defocusing with the joint imaging condition. Specifically, we first obtain the primary and multiple migration images by simultaneously applying primary and multiple imaging conditions. Then we used a small window to adaptively estimate the cancellation weight between the primary reflection image and the multiple reflection image. After that, the resulting weight is applied to the primary reflection image and the final joint migration result is obtained (suggested by Yi Luo).

Figure 1: Joint migration using both primary and multiple reflections. (a) primary migration using the primary imaging condition; (b) multiple migration using multiple imaging condition. Both of them migrate the seismic events to the same reflectors. Therefore the joint image enhances the true reflectors below the drill bit.

Synthetic Data Example

In the synthetic data, a five-layer geologic model is used to test the joint migration method using both primary and surface-related multiple reflections. The model data roughly represent that for the real UPRC data used in Yu and Schuster (2001). The drill-bit source moves horizontally at the depth of 1500 m when recording data and the drill bit moves in the horizontal direction from 1650 m to 1940 m. The data are recorded with a source interval of 5 m. The receivers were deployed on the surface over a lateral range of 4000 m, and the receiver interval is 20 m. There are a total of 39 common source gathers (CSG) recorded, each gather having a recording time of 8 s. The synthetic data were generated by computing the solution of the acoustic wave equation with a finite-difference method. The events in the seismograms include primary waves, free-surface related multiple reflections, second-order multiple reflections and some interferences from the side boundaries. Figure 3 compares the images produced by the standard migration (Figure 3a) and joint migration methods (Figure 3b) in the time domain. The joint migration method attenuates the coherent interferences from multiples. Arrows on the right side of the panels show the true reflectors below the drill bit.

Figure 2: Joint migration of both primary and multiple reflections using incorrect imaging conditions. (a). Primary migration using multiple imaging condition; (b). Ghost migration using primary imaging condition. Both of them migrate the seismic events to different false reflector locations. Therefore the combination of them will attenuate false "reflectors" below the drill bit.

A benefit of autocorrelogram migration is that it mitigates the static errors at the source and receiver positions. In this case, the migration imaging condition, \( \tau = \tau_{sx} + \tau_{sg} - \tau_{gy} \) in the above equation eliminates these static-shift errors when the difference between traveltimes is used. For example, let the traveltimes with static errors be defined as \( \hat{\tau}_{sx} = \tau_{sx} + \delta \tau_s \), \( \hat{\tau}_{gy} = \tau_{gy} + \delta \tau_g \), and \( \hat{\tau}_{sg} = \tau_{sg} + \delta \tau_s + \delta \tau_g \). Then the above imaging condition, \( \hat{\tau}_{sx} + \hat{\tau}_{gy} - \hat{\tau}_{sg} = \tau_{sx} + \tau_{gy} - \tau_{sg} \), eliminates the statics errors \( \delta \tau_s \) and \( \delta \tau_g \).

Figure 4 shows the migration images produced by the standard migration and joint autocorrelogram migration methods. Seismic traces were corrupted by a series of random statics shift errors at the source and receiver po-
Joint migration of primary and multiple reflections

positions with a maximum shift of 20 ms and 16 ms, respectively. The arrows on the right side indicate the actual reflectors. Both images produce similar results but there is a depth error in the standard migration result (see Figure 4a) caused by a statics shift. In contrast, reflector depths were correctly imaged in autocorrelogram migration (see Figure 4b) even though there are larger statics shifts at source and receiver locations.

We also investigate the sensitivity of the autocorrelogram migration and standard migration methods to velocity errors in the depth domain. The test results will be shown in the presentation at the meeting but they are consistent with the results in Sheley and Schuster (2000). That is, autocorrelogram migration is less sensitive to velocity errors compared with Kirchhoff migration.

UPRC Drill-bit Data Example

Field drill-bit data were acquired with three-component receivers in May, 1991 by Union Pacific Resources Co. (UPRC). The data are recorded on the earth’s free surface while a tri-cone drill-bit and down-hole motor were used to drill along a horizontal trajectory at a depth of 2800 m in the Austin Chalk formation. There are about 609 "shot gathers". The traces have a recording length of 20 seconds with a sample interval of 2 ms. It is assumed that (0E, 0N) denotes the location of the drilling rig, and the distance of the drill rig to the first trace is at about 822 m.

Because the seismic data were distorted by strong noise, the data were preprocessed as described by Yu and Schuster (2001b). Figure 5 shows the comparison of the joint autocorrelogram migration result (insert) and a surface-CDP section adjacent to the well rig. It is noted that the reflector images below the drill bit in these two images are in a good agreement with one another. Figure 6 shows a primary autocorrelogram migration result we obtained last year (Yu and Schuster, 2001a). Comparing Figures 5 and 6, it can be seen that joint autocorrelogram migration generates a "look-ahead" image with less interference.

Conclusions

We presented a joint imaging method which uses both primary reflections and multiple reflections in the autocorrelogram migration and investigated its performance compared with that of standard Kirchhoff migration.

One motivation for using autocorrelograms of seismic data is that it can reduce the static-shift errors at source and receiver locations. Tests on synthetic results show that, when seismic data are distorted by statics shift errors, autocorrelogram migration is still capable of yielding accurate results with correct reflector depths.

The motivation for developing this joint migration method is that it is capable of producing the primary migration image without requiring separation of primary and surface-related ghost reflections for sources in a horizontal well. This is very important for processing seismic data from deviated and horizontal wells in which conventional filtering methods like F-K filtering, median filtering do not work well because primary and surface-related ghost reflection events have similar moveout. Application to UPRC field data shows that joint primary+multiple imaging can effectively attenuate interferences in the migration image and produces much better quality images below the drill bit with less noise interference.

Our tests on both synthetic and field data sets demonstrate that joint migration can be used to image the reflectivity distribution as an alternative method for processing RVSP or drill-bit data, especially in the situation where the source and receiver locations have errors, the pilot signal is not available or there is difficulty in separating primary and free-surface related multiple reflections such as in deviated and horizontal drilling well data.

Acknowledgments

The data used in this report was a generous donation by Union Pacific Resources and Mr. Dale Clinton. We greatly appreciate the support of UTAM sponsors and DOE support. Lew Katz and Fred Followill are crucial to the success of this project.

References


Joint migration of primary and multiple reflections

Figure 3: Comparison of (left) primary migration and (right) joint imaging sections using both primary and multiple reflections in the time domain. Joint migration yields a better quality image with less coherent noise. The arrows indicate the true reflectors.

Figure 4: (a) Standard migration result; (b) joint autocorrelogram migration. Here data were corrupted by statics errors at receivers and sources. Joint autocorrelogram migration image was less affected by statics shifts than the result obtained by standard Kirchhoff migration. Note, no primary reflections should appear above the drill hole trajectory (at about 1500 m).


Figure 5: Field data result using joint imaging condition. There is good agreement between drill-bit imaging (inserted) and CDP stacked section. Compared with Figure 6, the migration image has less interference. Note, arrow indicates the drill hole trajectory.

Figure 6: Field drill-bit data result using primary imaging condition (inserted). Main reflectors are well matched with CDP stacked section but some unwanted interferences still exist.