2-D Prestack Wavepath Migration Applied to Single Well Imaging

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ABSTRACT

In earlier reports, wavepath migration (WM) method was developed and tested on 2-D and 3-D surface seismic data sets. It was shown that WM can, in some examples, give rise to fewer migration artifacts and can define complex structure better than Kirchhoff migration (KM). However, the fidelity of a WM image is sensitive to the accuracy in computing incidence angles and so may be less suitable with extremely noisy data. In this report, WM is applied to 2-D prestack synthetic data for single well imaging. The results show that both the KM and the WM can successfully image the salt flank and the salt bottom. Compared to the KM image, the WM image contains fewer migration artifacts and delineates the salt boundary slightly better.

INTRODUCTION

The WM method was developed in earlier reports (Sun and Schuster, 1998 and 1999). In their theory, 3-D WM migrates the trace energy along 1.5-D fat wavepaths rather than a volume of quasi-concentric ellipsoids as in 3-D KM. Strong far-field migration artifacts can then be suppressed in WM as the trace energy is migrated to positions not far away from the actual reflection point. The WM method is a beam-like migration method, also developed by Hill (1990) for Gaussian beams and Sun et al. (1999) for Kirchhoff beams.

The WM algorithm was formerly tested on both 2-D and 3-D prestack data sets (Sun, 1999, 2000a, 2000b), and was shown, in some examples, to suppress migration artifacts and increase the image resolution. It was also shown that WM performs somewhat better than KM in imaging complex salt boundaries. This is because the reflections from the salt boundary are usually very strong and can be successfully picked and migrated in the WM algorithm.

Notice that all of our former results came from surface-recorded data examples, but surface seismic data can not, typically, illuminate near-vertical geological structures. This drawback can be rectified by conducting single-well imaging, where the sources or the geophones are deployed in the well as shown in Figure 1. As an emerging technique in borehole seismic industry, single well imaging has found many applications in recent years. For example, it has been used to image salt flanks (Cameron and Chen, 1995), to detect gas-filled fractures (Majer et al., 1997), and to delineate steeply dipping geological features not far away from the borehole (Takahashi et al., 1999).

In this report, the WM algorithm is applied to 2-D synthetic data for single well imaging. The key objectives of this report are to assess the feasibility of applying WM to a borehole recording geometry, and to determine whether WM can image the salt boundary with comparable or better quality than KM.

2-D SYNTHETIC DATA EXAMPLE

The WM algorithm is tested on a 2-D OYO salt model (courtesy of G. Yu) shown in Figure 2. The
model consists of three layers, the middle of which is the salt layer. The question-marks represent the area of interests. Table 1 shows the parameters of the model.

Table 1. The parameters for the OYO 2-D salt model. Here the model is discretized into a (1801, 1201) grid, with grid intervals of (5 m, 5 m).

<table>
<thead>
<tr>
<th>Sequence of the Layer</th>
<th>P Velocity (m/s)</th>
<th>S Velocity (m/s)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2743.2</td>
<td>1810.5</td>
<td>2.3</td>
</tr>
<tr>
<td>2</td>
<td>4495.8</td>
<td>2967.2</td>
<td>2.2</td>
</tr>
<tr>
<td>3</td>
<td>3048.0</td>
<td>2011.7</td>
<td>2.4</td>
</tr>
</tbody>
</table>

There are 73 shot stations distributed along the well with coordinates ranging from (4000 m, 5100 m) to (5500 m, 1500 m). The source interval is 50 m in the vertical direction. For each source station, there are 12 geophones deployed along the same well, with a geophone interval of 10 m in the vertical direction. The lowest geophone is always 150 m above the source.

Figure 3 shows a common shot gather (CSG) generated by the 2-D elastic forward modeling code. A 25 Hz zero-phase Ricker wavelet is used as the source wavelet. The sample rate is 1.0 msec, and the recording time is 3.0 sec. The seismograms contain direct waves, primary reflections from the salt top, the salt bottom, and the free surface, and also contain different orders of surface-related and interbed multiples.

In single well imaging, only the features close to the borehole can be imaged effectively, it is reasonable to truncate the data such that those events scattered far away from the borehole can be excluded. In this way, some multiples can be removed. Figure 4 shows the same CSG as Figure 3 except with time truncation and removal of the direct wave.

Figure 5 shows the full-aperture prestack KM image. In the migration, all of the traces were used to construct the image at any subsurface point. Compared to the KM image, the WM image in Figure 6 contains fewer migration artifacts and resolves the salt boundary as well as the KM image. In both KM and WM, only the vertical component data are used, which can explain why there are mirror boundaries symmetric to the borehole.

Figures 7a and 7c show the zoom views of the KM image and the WM image, respectively, and Figure 7b shows the zoom view of the associated velocity model. It is shown that both KM and WM resolve the questionable salt boundary well. It seems that the image coverage in the WM image is narrower than in the KM image, but actually, the additional image coverage in the KM image represents the far-field migration artifacts. For example, position A on the salt bottom is the farthest point whose reflection can be observed by the geophones. Thus, in theory, any position on the salt bottom beyond point A can not be imaged. The KM image shows strong migration artifacts from image point A to image point B, but in the WM image, the salt boundary suddenly stops at point A. Similarly, the KM image contains strong artifacts from image point C to image points D and E, all of which severely pollute the real image.

**DISCUSSION**

Applying the 2-D WM algorithm to single well synthetic data shows that WM can image the questionable salt flank and salt bottom similar to the full-aperture KM. The WM image contains fewer migration artifacts and defines the salt boundary slightly better. It is sometimes difficult to discriminate the true salt boundary from the far-field migration artifacts in the KM image, because the recording geometry is too sparse for the KM to effectively stack out the artifacts. In contrast, the WM algorithm does not generate strong far-field migration artifacts by not smearing the trace
energy far away from the true reflection point. The advantage of WM could become more obvious in cases where the model structure is more complicated.

Future work will apply WM to single well field data and synthetic data from complex models.

ACKNOWLEDGEMENTS

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REFERENCES


Sun, H., 2000a, 2-D prestack wavepath migration applied to the Husky data: Univ. of Utah Tomography and Modeling/Migration Development Project, 1999 Annual Report, 75-84.


Figure 1: Schematic diagram of the single well recording geometry. As an important supplement to surface recording, single well imaging can be used to resolve the near-vertical salt flanks from a nearby well.
Figure 2: The synthetic layered salt model, where the source and geophone well is denoted by the white line, and the salt boundary of interest is indicated by white question marks.
Figure 3: A synthetic CSG, where both the direct wave and the free surface reflection are very strong. There are only 12 traces per CSG, with a sampling rate of 1.0 $\text{msec}$. 
Figure 4: The same CSG as Figure 3 except that the direct wave has been removed, and the traces have been truncated for removing primary surface reflection and different kinds of multiples.
Figure 5: Prestack KM image obtained by single well imaging. All of the 876 traces were used to construct this image.

Figure 6: Same as Figure 5 except the WM image, where the imaged structure agrees well with that in the KM image. The zoom views of this image and the previous KM image are shown in Figure 7.
Figure 7: Zoom views for the (a) KM image, (b) associated velocity model, and (c) WM image. Both the KM and the WM images resolve the salt boundary of interests well. Compared to the KM image in (a), the WM image in (c) contains fewer migration artifacts, e.g., the artifacts from point A to point B, and from point C to points D and E.