ABSTRACT

To reduce computational costs and correlation artifacts in seismic interferometry we image the free-surface multiples by applying specular interferometric imaging to field data from a VSP land experiment. Results show that the ghost migration of VSP land data gives a wider subsurface coverage of reflectors which are ambiguous in the primary migration results. However, the primary reflections generally provide a better signal-to-noise (S/N) ratio than the multiple image in the zone imaged with primary reflections. This suggests that more than six geophones should be used in this VSP land experiment to boost the S/N ratio of the multiples.

INTRODUCTION

Migration of primary reflections is the main strategy for VSP imaging of subsurface structures. However, migration of VSP primary reflections have narrower subsurface coverage, lower-fold, and less balanced illumination of the subsurface structures compared to migration of multiples (Jiang and Yu, 2003; Jiang et al., 2004). Furthermore, properly migrating multiples can provide more information about the subsurface structures which cannot be obtained by using migration of primaries (Jiang and Yu, 2003; Jiang et al., 2004). Recently, various methods for migration of multiples have been proposed (Schuster, 2002; Yu and Schuster, 2002; Jiang and Yu, 2003; Schuster, 2003; Jiang et al., 2004). To validate the method of specular interferometry, we apply Kirchhoff prestack depth migration and specular interferometric depth
migration to VSP land data. The primary and ghost VSP images are compared to one another, as well with CDP data.

**DATA PROCESSING**

The land VSP survey has the following acquisition geometry: there are 313 shots with a shot spacing of about 25 meters along the surface and 6 geophones in the well starting at a depth of 1000 meters. The geophone interval is 25 meters in the well. A common receiver gather of the VSP field data after applying an AGC filter is shown in Figure 1 which contains both P and S waves and their multiples. Figure 2 shows the data improvement after applying residual statics correction.

To test the hypothesis that the VSP land data contain very strong primary reflections compared to P-wave and S-wave multiples, we computed synthetic seismograms by finite-difference (FD) modeling of the acoustic and elastic wave equation. The results from FD forward modeling are shown in Figures 3 and 4 where Figure 3 only contains primary reflection events and Figure 4 contains both primary and ghost reflection events. Comparing Figure 3 to 4, we can see that ghosts are not as strong as primaries as we predicted. From these results we might expect that migration of primary reflections will give a better signal-to-noise ratio in the primary imaging zone compared to migration of multiple reflections. However, the multiple image will cover a much larger area than the primary imaging zone.

Kirchhoff prestack migration was utilized for migrating primary reflections and migration with a semi-natural Green’s function (Schuster, 2003) was used for migrating ghost reflections. The semi-natural Green’s function method is the same as specular interferometric migration, and is based on the fact that ghost reflection energy mostly follows along a specular reflection path. The specular reflection time can be found by searching over all possible surface points $s'$ such that

$$
\min_{s'} (\tilde{\tau}_{s'g} + \tau_{s'x} + \tau_{xs}) = \tilde{\tau}_{s'g} + \tau_{s'x} + \tau_{xs}
$$

where $\tilde{\tau}_{s'g}$ and $\tau_{s'g}$ are picked first-arrival traveltimes, and the other terms are computed traveltimes. Note, the picked arrival times are denoted by a tilde and the calculated traveltimes are without the tilde.

The specular interferometric migration kernel for the first-order multiple reflection is a product of a model-based Green’s function and a natural Green’s function:

$$
G^1(s|g) = -G(s|s^*)G(s^*|g) = e^{i\omega (\tau_{xs} + \tau_{xs^*} + \tau_{s^*g})}
$$

where $G(s|s^*) = G(s|x)G(x|s^*) = e^{i\omega (\tau_{sx} + \tau_{sxs^*})}$ is the model-based Green’s function, and $G(s^*|g) = e^{i\omega \tau_{s^*g}}$ is the natural Green’s function. The inner product of this migration kernel with the shot gather $d(s, g)$ yields the diffraction-stack migration image of ghost reflections at $x$:

$$
m(x) = \sum_{s, g} G^1(s|g)d(s, g) = \sum_{s, g} d(s, g)e^{i\omega (\tau_{xs} + \tau_{xs^*} + \tau_{s^*g})}.
$$
Figure 1: A common receiver gather of the VSP field data after AGC filtering.
Figure 2: (Left) A zoom view of the common receiver gather. (Right) The common receiver gather after applying residual statics correction.

Figure 3: A synthetic data only contains primary reflection events.
Figure 4: A synthetic data contains both primary and multiple reflection events.

Figure 5: Specular interferometric condition for ghost migration.
MIGRATION RESULTS

The Kirchhoff migration image of primary reflections without AGC filtering is shown at the top of Figure 6. To boost up the amplitude we applied an AGC filter to the result (the bottom of Figure 6), which has more uniform illumination and clearer structures. Figure 7 shows the specular interferometric migration (Schuster, 2003; Schuster and Zhou, 2005) of ghost reflections before and after AGC filtering. Comparing the primary and ghost images, we can see that the ghost image shows flatter layers than the primary image and also has wider subsurface coverage. However, the primary image has more contrast. This is because the primary reflections are stronger than the ghost reflections. Figure 8 shows the comparison between the CDP migration image and the Kirchhoff VSP migration image of primary reflections. This result shows that the VSP migration image correlates well with the CDP migration image. Figure 9 shows the comparison between the CDP migration image and the specular interferometric VSP migration of ghost reflections. It also shows a good correlation between the two images except the ghost image has a wider subsurface illumination.

CONCLUSIONS

VSP land data usually contain strong primary reflections compared to P-wave and S-wave multiple reflections. Our FD forward modeling validated this statement for the current VSP land data. Comparing the primary and ghost migration images, we can see that specular interferometric migration image of ghosts has a wider subsurface coverage and flatter migrated layers, but the Kirchhoff migration image of primaries has a better S/N ratio in the P-wave image zone. Both the Kirchhoff and specular interferometric images correlate well with the CDP image. Even though the ghost reflections are weak, the specular interferometric migration method still gives comparable results to the Kirchhoff migration method. However, there is an insufficient number of receivers, so the multiples might act as coherent noise.

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REFERENCES

Figure 6: (Top) Kirchhoff migration image of primary reflections using a 5 degree dipping angle constraint and without AGC filtering. (Bottom) Kirchhoff migration image of primary reflections using a 5 degree dipping angle constraint and with AGC filtering. The dotted line shows the strong reflector at the depth of 3.5 kilometers.
Figure 7: (Top) Specular interferometric migration image of ghost reflections using a 5 degree dipping angle constraint and without AGC filtering. (Bottom) Specular interferometric migration image of ghost reflections using a 5 degree dipping angle constraint and with AGC filtering.
Figure 8: Comparison between the CDP migration (Left) and the Kirchhoff VSP migration of primary reflections (Right).

Figure 9: Comparison between the CDP migration (Left) and the specular interferometric migration of ghost reflections (Right).


Schuster, G. T., 2003, Imaging the most bounce out of multiples: Extended Abstracts of Annual EAGE Meeting.