# Shot-profile migration of multiple reflections

*Antoine Guitton*, Stanford University*


## SUMMMARY

A shot-profile migration algorithm is modified to image multiple reflections at their correct location in the subsurface. This method replaces the impulsive source with an areal source made of recorded primaries and multiples. In addition, the extrapolated wavefield at the receivers consists of recorded multiples only which have been previously separated from the primaries. Migration results with 2-D synthetic and field data prove that the migration of multiples can bring valuable structural information of the earth with or without separation.


## INTRODUCTION

Seismic migration aims to move recorded seismic wavefield at the surface back into the earth at the reflector location from which they have originated. Multiple reflections, which are also recorded, are usually not accounted for in the migration process. Therefore, as a prerequisite to any correct imaging of the subsurface, multiples are traditionally attenuated (Guitton et al., 2001).

In this paper, I try to treat the multiples like signal rather than noise. My goal is to show that multiples can be easily imaged with a conventional shot-profile migration algorithm (Jacobs, 1982; Rickett, 2001). This migration is carried out in the ($\omega$,x) domain. I will assess if the migration of multiple reflections adds any type of structural information and if it can increase the signal-noise ratio of the final image.

In the first section, I review theoretical aspects of shot-profile migration and expand its concepts to image multiples. In the second part, I show migration results with 2-D synthetic and field data. In the last section, I discuss practical aspects of multiple migration.

## THEORY OF REFLECTOR MAPPING WITH SHOT-PROFILE MIGRATION

In this section, I review basic principles of earth imaging as pioneered by Claerbout (1971). Then I generalize these principles to reflector mapping with multiple reflections with a shot-profile migration algorithm.

### Imaging of primaries

Shot-profile migration aims to produce an image of the subsurface by extrapolating both the source and receiver wavefields into the interior of the earth. The imaging condition (Claerbout, 1971) consists of crosscorrelating the two wavefields at each depth-step. Reflectors are formed where the two wavefields correlate. Figure 1 illustrates this principle.

In general shot-profile migration is performed in the ($\omega$,x) domain one frequency at a time and one shot at a time. The final image is formed by adding all the different contributions of every shot together.

### Imaging of multiples

A similar machinery can be effectively used to image multiples at their correct location in the subsurface. I keep the same imaging principle as developed by Claerbout. The differences stem from the choice of up- and down-going wavefields I extrapolate.

Figure 2 illustrates the basic idea behind the migration of the multiples. In Figure 2a, a wavefield generated at S is recorded at the receiver $R_n$. The reflector location $r_a$ is imaged by extrapolating both the primary wavefield recorded at $R_n$ and the source wavefield at $S$ simultaneously in the subsurface and by crosscorrelating them

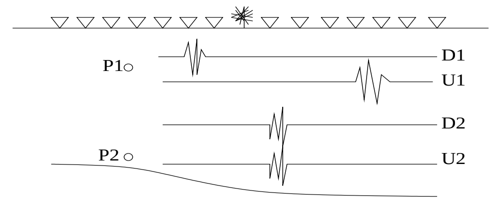


Figure 1: The up-going wavefield is recorded everywhere at the receiver locations (shown as triangles). The down-going wavefield is emitted at the source location in the center of the survey (shown as a star). At earth location P1, the two extrapolated wavefields do not crosscorrelate because the down-going wavefield arrives at a much earlier time than the up-going wavefield. At earth location P2, which is the reflector depth, the two wavefields crosscorrelate and an image is formed. Adapted from Claerbout (1971).

at each depth step.

Similarly in Figure 2b, a multiple recorded at $R_n$ can be used to image the reflector location $r_b$ if we use the primary wavefield recorded at the receiver $R_1$ as a source function. Hence a multiple reflection recorded at any receiver location can be used to image the subsurface if a primary is utilized as a source. The impulsive source becomes an areal-shot record. In theory, any order of multiples can be properly imaged if their corresponding source path exists in the down-going wavefield. Hence first order multiples need primaries as sources, second order multiples need first order multiples, and so on.

Note that the source function needs to be time-reversed before the extrapolation. This is done in the ($\omega$,x) domain by computing the complex conjugate of the source wavefield.

A similar approach has been presented by Berkhout and Verschuur (1994) using the so-called "WRW" model. Notice that so far, this approach works for surface-related multiples only but could be easily extended to internal-multiple migration.

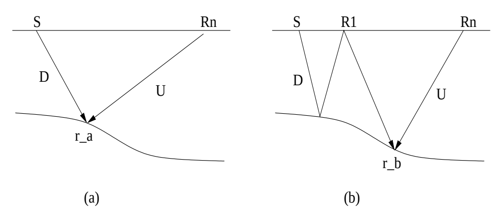


Figure 2: Illustration of the basic idea of reflector mapping with (a) primaries and (b) multiples. In (a) the primary images the reflector location $r_a$ and the source is impulsive. In (b) the multiple helps to image the reflector location $r_b$ and the source is a primary recorded at $R_1$.

## A SYNTHETIC DATA EXAMPLE

In this section I use a modified version of the 2.5-D BP dataset (Etgen and Regone, 1998; Dellinger et al., 2000) to illustrate the migration of multiples. This data example proves that multiples can provide structural information on the earth.

## Imaging of multiples

### The 2.5-D BP dataset

The synthetic dataset I use consists of a modified version of the 2.5-D BP velocity model. Figure 3 displays the velocity model. The data were recorded with a split-spread geometry.

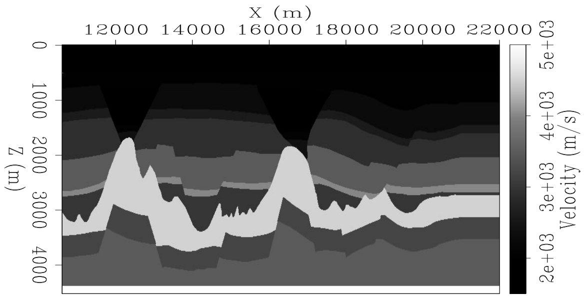


Figure 3: The velocity model used to generate the synthetic data.

### Migration of one shot record

I illustrate the migration of multiples with one shot. The recorded wavefield is the superposition of primaries and multiples. The migration result for this shot location is shown in Figure 5a.

Figure 4 displays the source function and the up-going wavefield for the migration of multiples. As proposed in the preceding section, the source function is not impulsive but areal. The recorded wavefield contains the surface-related multiples only. The migration result is shown in Figure 5b and compares favorably with the output of the migration of primaries.

It is interesting to note that the water-bottom is illuminated with a wider aperture when multiples are used. As illustrated in Figure 2, for a given receiver $R_n$, the primary illuminates the reflector in $r_a$ at a closer location to the source in $S$ than does the multiple in $r_b$. Therefore, for one given shot, the multiples migrate with a wider aperture but with smaller angles.

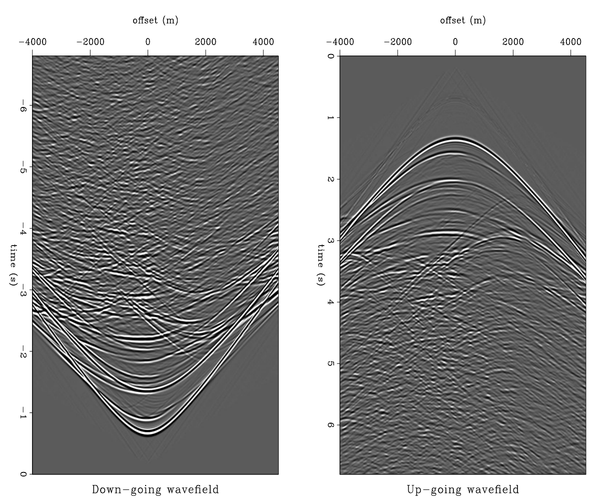


Figure 4: Shot-profile migration of the multiples. Left: Areal source function. Right: Recorded multiples only. The source function is plotted upside-down to represent the computation involved by the time-reversed process.

### Migration of the survey

I now proceed to the final imaging steps of migrating every shot record and summing them. Figures 6a and 6b show the final migration result for both primaries and multiples. The two final images are quite similar although the migration of the primaries with the impulsive source is crispier and less noisy than with multiples. Nevertheless the migration of multiples yields an accurate image of the earth. After closer inspection, it seems that the flanks of the canyon in the middle above the salt dome is better defined with the multiples. This first result is rather encouraging and shows that multiples can be used to image the earth.

### A possible shortcut for the migration of multiples

I see two fundamental problems with the migration of the multiples. First, the final image is noisy, blurring precious information in some areas. Second, multiples need to be extracted from the data.

The need for separating multiples might be quite dissuasive when field data are imaged because it might involve heavy computations and/or an earth model that might not be known in advance. Let us consider for a moment that we do not want to do the multiple attenuation but still want to do some imaging with multiples. This goal requires that the recorded data with primaries and multiples are used for both up- and down-going wavefields. Now I compare in Figure 7 the migration results when only multiples (Figure 7a) and multiples plus primaries (Figure 7b) are extrapolated in the up-going wavefield. The migration of primaries and multiples yields a noisy image but never-the-less structurally interpretable.

In the next section I migrate multiples for one 2-D line from the Gulf of Mexico. It demonstrates potential strengths and weaknesses of the proposed method for multiple migration.

## A 2-D FIELD DATA EXAMPLE

I illustrate the multiple migration with field data. The dataset is a deep-water survey with a shallow salt body. It has been intensively used for testing multiple attenuation techniques (The Leading Edge, January 1999). Figure 8 shows the velocity model that is used for the migration (Gratwick, 2001).

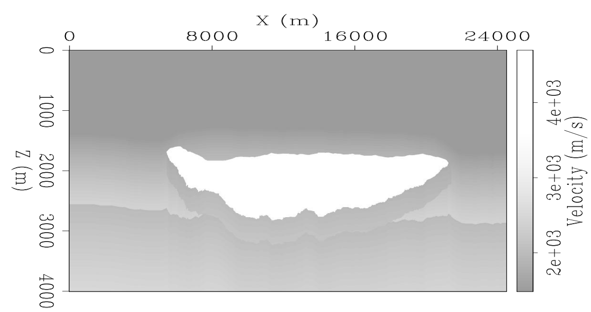


Figure 8: Velocity field for the Gulf of Mexico 2-D line.

For this data set I did not separate primaries from multiples as required by the theory. As an approximate solution, I decided to mute everything above the first surface-related multiple for the up-going wavefield. Therefore the down-going wavefield is made of the complete shot and the up-going wavefield is made of the complete shot minus the primaries above the first surface-related multiple.

The migration results are displayed in Figure 9. Figures 9a and 9b show the migration results for primaries and multiples respectively. The two migrations produce similar results. Despite the approximations made, the multiple migration gives a very accurate image of the salt body and of the sediments.

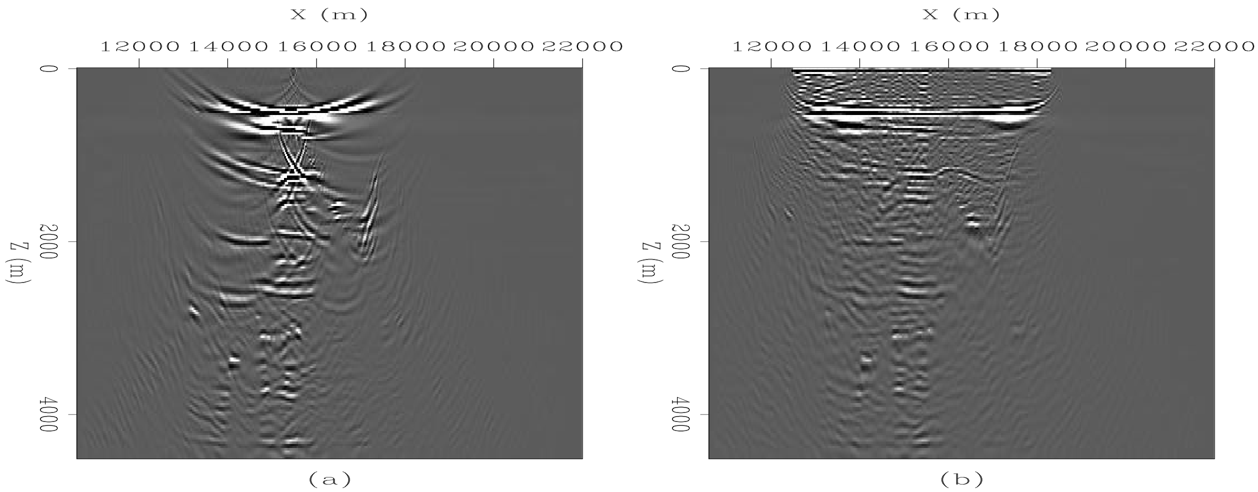


Figure 5: Migration results for the multiples and primaries. (a) Migration of the primaries. (b) Migration of the multiples.

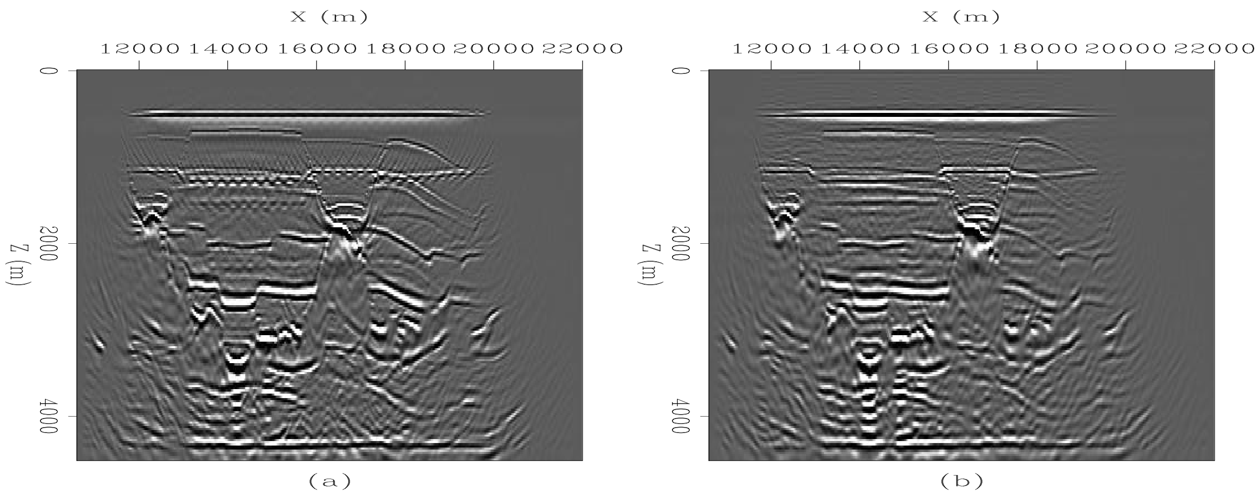


Figure 6: Final migration results. (a) Migration of the primaries. (b) Migration of the multiples.

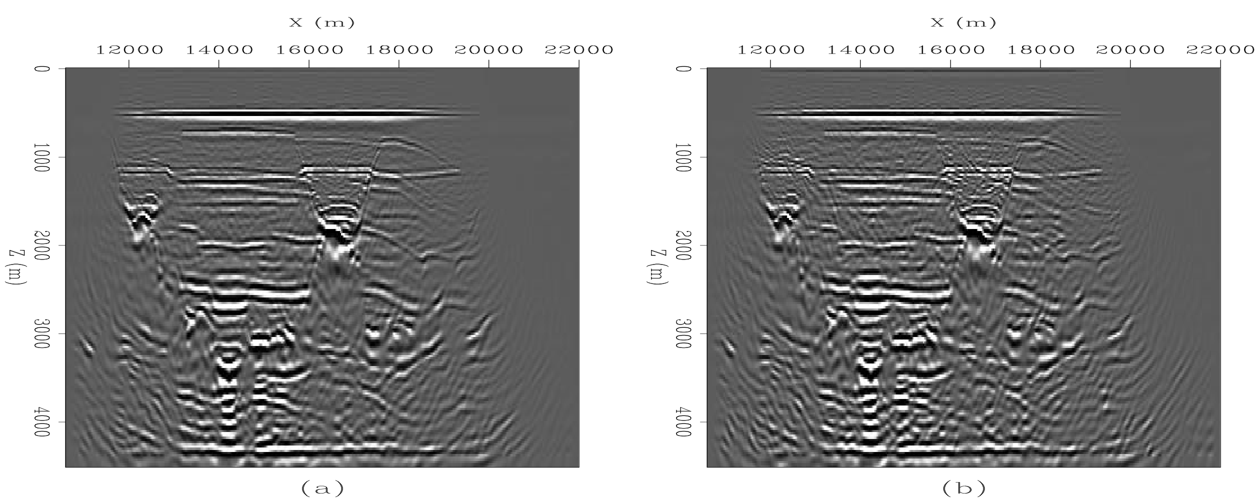


Figure 7: Migration results. (a) Same as Figure 6b. (b) Imaging of multiples with primaries and multiples in the up-going wavefield.

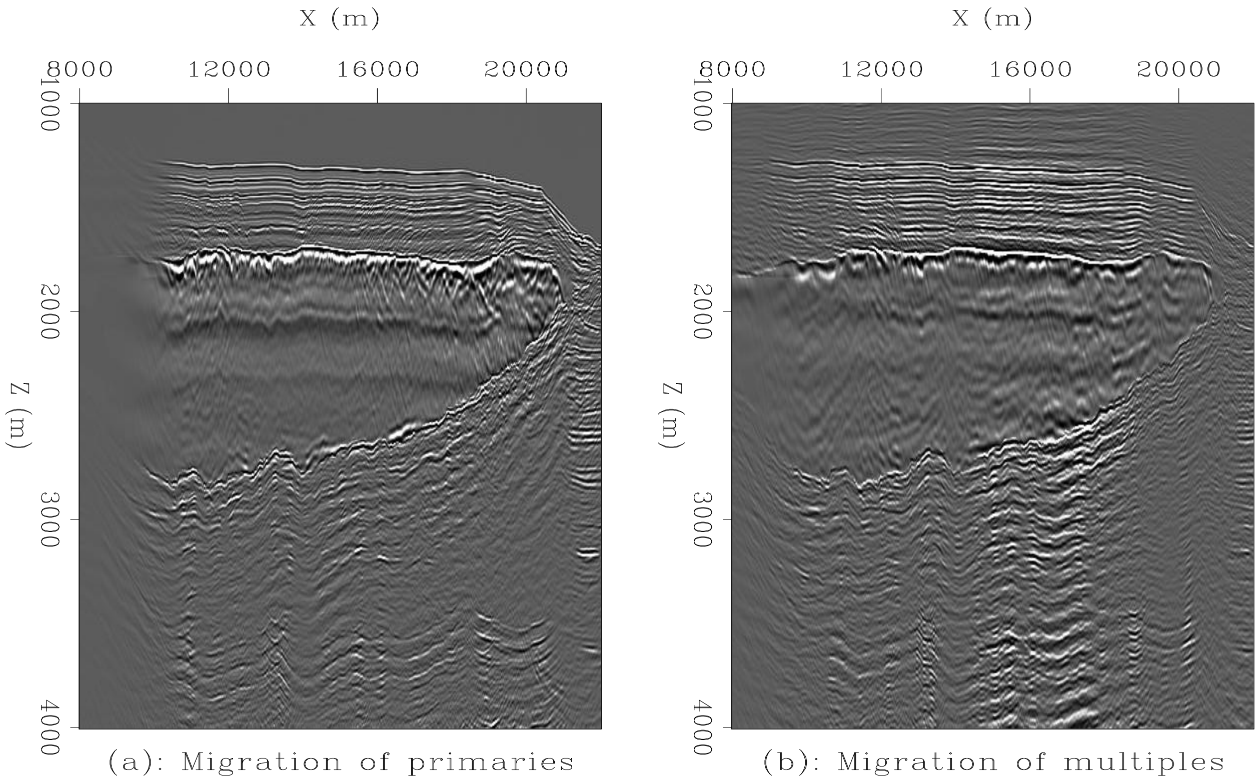


Figure 9: (a) Migration of the primaries. (b) Migration of the multiples. The two images are comparable. The salt body is clearly visible in the multiple migration result.

## DISCUSSION AND CONCLUSION

I have shown that migrating multiples at their correct location is possible. Results with a complex 2-D synthetic model and field data examples prove that multiples can bring valuable structural information. Although very encouraging, multiple migration has some limitations.

First, we need to generate a multiple model with correct kinematics and amplitudes. This can be quite a computation burden. Nonetheless, multiple attenuation is a prerequisite to any imaging step. Thus, instead of trashing these multiples, we might simply use them for migration. As an intermediate solution, I propose to use both primaries and multiples in the up-going wavefield. This is a cheap alternative to the full multiple attenuation that yields an interpretable image of the subsurface.

Second, the final image after migration of multiples is more noisy than the migration of primaries. We might be able to decrease the noise level by keeping strong multiple generators only in the down-going wavefield, like the water-bottom.

Last, we might not be able to simply add the different images in order to increase the signal-noise ratio. When primaries are migrated, we use a synthetic source that is not the true seismic source. When multiples are migrated, the source is perfectly taking into account because we use the recorded wavefield as a source. Hence a direct addition of the migration results of primaries and multiples must be done with care.

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