Depth migration of synthetic surface and VSP data

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ABSTRACT

The purpose of the imaging condition in prestack depth migration is to obtain a reflectivity estimate with high spatial resolution and correct position. This goal can only be reached by perfectly matching an upgoing wavefield with a downgoing wavefield. At each depth of interest, the ratio of the upgoing (reflected) wavefield to the downgoing (incident) wavefield estimates the reflectivity. Usually, the upgoing wavefield is created from downward extrapolated surface data, while the downgoing wavefield is created by downward continuation of the source signature through a velocity model. The upgoing waves were influenced by earth attenuation, anisotropy, multiples, velocity and density of the medium, and etc. All these factors cannot be exactly estimated in the complex geology environment and cannot be fully included in the downgoing wavefield. Thus, the downgoing wavefield is not consistent with the upgoing one at the image position, which reduces the resolution of the final image. An alternative becomes possible if recording is done simultaneously in surface and downhole receivers. Assuming that the downhole receivers have sufficient depth coverage to enable wavefield separation, it then becomes possible to use VSP wavefield separation to estimate the downgoing wave. The estimated downgoing waves are much closer to the real downgoing wavefield than estimated from forward modelling. This work tried to build a downgoing wavefield from synthetic VSP data, and likewise the upgoing wavefield received on the surface, and then created the depth image through the FOCI approach (Margrave et al, 2004). The result shows that the depth image marches the velocity model very well.

INTRODUCTION

To improve the resolution of a migrated section, Miller at al. (1987) derived an approach formalizing the classical diffraction stack by relating it to the generalized Radon transform. This method can handle both complex velocity models and arbitrary configurations of sources and receivers. The synthetic examples illustrated that the spatial resolution in seismic images can be greatly improved by simultaneous migration of VSPs and surface data. However, this method, based on the Born approximation, still is dependent upon a simple model (approximate Green's function) of the incident wavefield. Kirtland and Lawton (2003) investigated combined depth imaging of VSP and surface seismic data and showed that the integration of the VSP migrated section with the surface seismic one yields a better image than can be obtained from VSP migration alone. Although this method uses the same velocity model and algorithm in the migration of the VSP and surface data, it does not take advantage of the VSP downgoing wave in the procedure we propose.

BUILDING A NEW IMAGE CONDITION

VSP data provides downgoing waves for wavefield extrapolation, but they are received in boreholes. These waves can be converted into downgoing waves arrived at different lateral locations on the same depth.

The VSP downgoing waves can be expressed as

$$D_{vsp} = \begin{bmatrix} A(x_{s1}, z_{r1}) & A(x_{s1}, z_{r2}) & \cdots & A(x_{s1}, z_{rn}) \\ A(x_{s2}, z_{r1}) & A(x_{s2}, z_{r2}) & \cdots & A(x_{s2}, z_{rn}) \\ \vdots & \vdots & \vdots & \vdots \\ A(x_{sm}, z_{r1}) & A(x_{sm}, z_{r2}) & \cdots & A(x_{sm}, z_{rn}) \end{bmatrix}, \tag{1}$$

where $A(x_{si}, z_{rj})$ denotes the seismic trace with the source at $(x_{si}, z_{si} = 0)$ and the receiver at $(x_{rj} = x_{well}, z_{rj})$. Here x_{well} is the horizontal location of the borehole.

For the laterally horizontal layers or partly horizontal layers, the downgoing waves at different depth levels can be written as

$$D_{shot} = \begin{bmatrix} A(x_{s1}, z_{r1}) & A(x_{s2}, z_{r1}) & \cdots & A(x_{sm}, z_{r1}) \\ A(x_{s1}, z_{r2}) & A(x_{s2}, z_{r2}) & \cdots & A(x_{sm}, z_{r2}) \\ \vdots & \vdots & \vdots & \vdots \\ A(x_{s1}, z_{rn}) & A(x_{s2}, z_{rn}) & \cdots & A(x_{sm}, z_{rn}) \end{bmatrix}, \tag{2}$$

which is a transfer matrix of original VSP downgoing waves. Then we introduce a deconvolution image condition expressed as

$$P(x,z) = \sum_f \frac{U(x,z,f) D_{shot}(x,z,f)^*}{D_{shot}(x,z,f) D_{shot}(x,z,f)^* + stab}, \tag{3}$$

where $U(x,z,f)$ and $D_{shot}(x,z,f)$ represent the frequency spectra of surface upgoing waves and converted downgoing waves. $D_{shot}(x,z,f)^*$ is the conjugate of the converted downgoing waves, and *stab* is the stabilization factor. Unlike the traditional image condition with the downgoing waves from forward modelling, the new one uses a downgoing wavefield from VSP. Thus we don't need to know the velocity model and source signature in downgoing wave extrapolation. In horizontally or nearly horizontally layered media, the recorded downgoing waves should be more accurate than those from forward modelling.

TEST ON SYNTHETIC DATA

To prove the accuracy of our approach, we created both surface data and VSP data using CREWES Matlab finite difference codes (Youzwishen and Margrave, 1999), which simulated the joint surface and VSP data acquisition. Figure 1 shows the velocity model where a structure with low velocity lies in the middle of a horizontal layer. There is a well in the middle of the model. Figure 2 shows the source signature and its amplitude spectrum, which is a minimum phase wavelet. Figure 3 shows the synthetic surface seismic data with one source near the boundary and the other in the centre of the model respectively. Figure 4 shows two synthetic VSP data with sources the same as those shown in Figure 3. Here we should point out that for each source we recorded data simultaneously on the surface and in the borehole to make the source signature the same for both upgoing and downgoing waves.

The next step is to simulate surface downgoing waves from VSP downgoing waves. To do this, we isolated at first the VSP downgoing waves from the whole wavefield by FK filtering. Then the surface downgoing waves were created by common depth sorting to the VSP downgoing waves. Figure 5 shows two shot gathers of surface downgoing waves. The surface downgoing waves in horizontally layered media or mildly dipping layers are more accurate than those in the steeply dipping areas since our approach is based on the horizontal shift of the VSP downgoing waves.

By now, we have both upgoing and downgoing surface waves. Then we applied the FOCI approach (Margrave et al., 2004) to do downward continue both of them. Figure 6 shows the downgoing and upgoing waves at the same depth step. The downgoing waves have the same traveltime as the upgoing waves at the interface. Figure 7 shows the downgoing and upgoing waves from another source to the interface depth of 600 m. Here the downgoing wave is at the same time as the reflection from the bottom interface.

Figure 8 shows the final depth image created by our approach. The original horizontal reflectors are represented by dashed lines. In this figure, the consistency between original reflector and depth image verified that VSP downgoing waves can be converted into the surface downgoing waves that are used in pre-stack depth migration. The vertical resolution can be improved by this method. Figure 8 also shows that even for the mild dip reflections, this procedure can generate quite good images.

CONCLUSIONS AND FUTURE WORK

Our result shows that our migration method is accurate in terms of the position and amplitude of the depth image compared with the velocity model. It is proved that the downgoing waves in depth migration can be replaced by the downgoing waves converted from VSP data in horizontally layered media or mildly dipping layers. By using VSP downgoing waves, the vertical resolution of the depth image can be improved.

Future work will focus on building the downgoing wavefield in more complex media. We will also run the migration on real data from a joint surface and VSP acquisition which will be acquired by the CREWES project.

ACKNOWLEDGEMENTS

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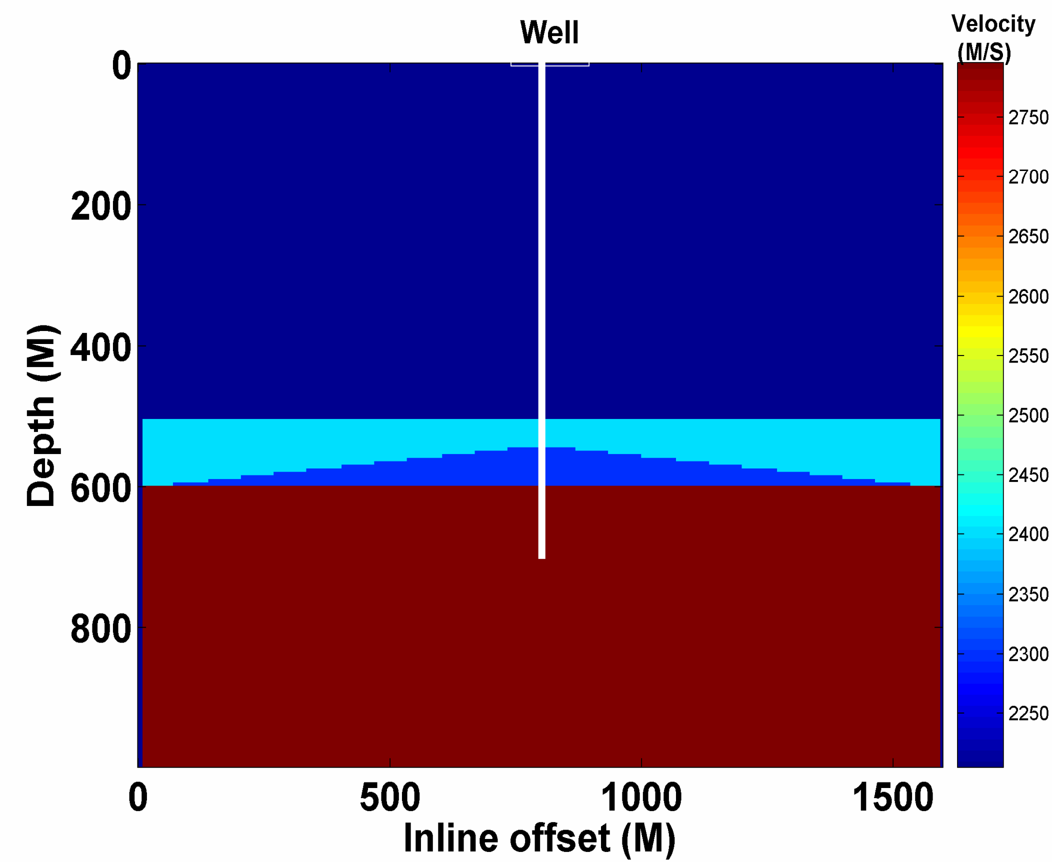

FIG. 1. Velocity field applied to the finite difference modelling.

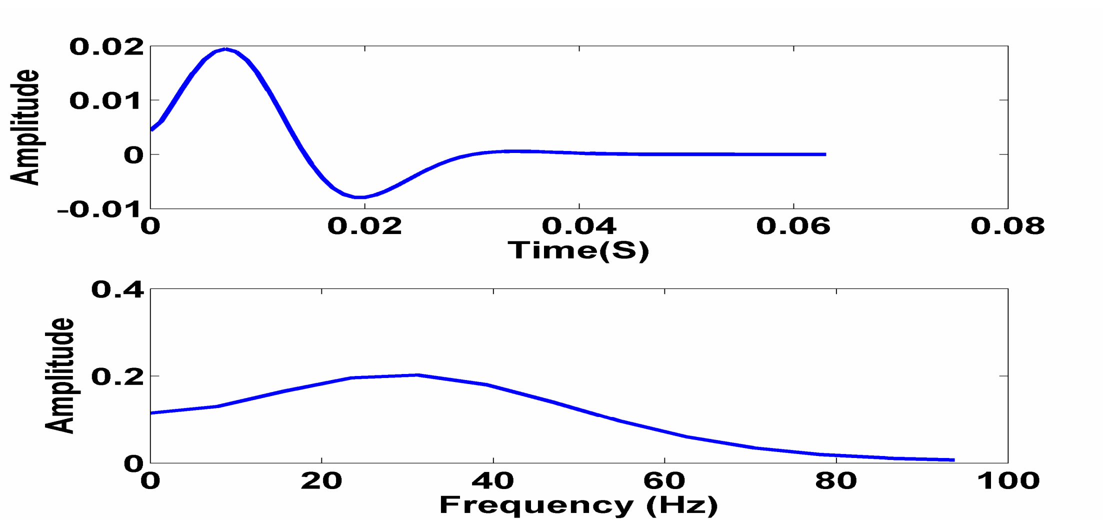

FIG. 2. Source signature and it's amplitude spectrum.

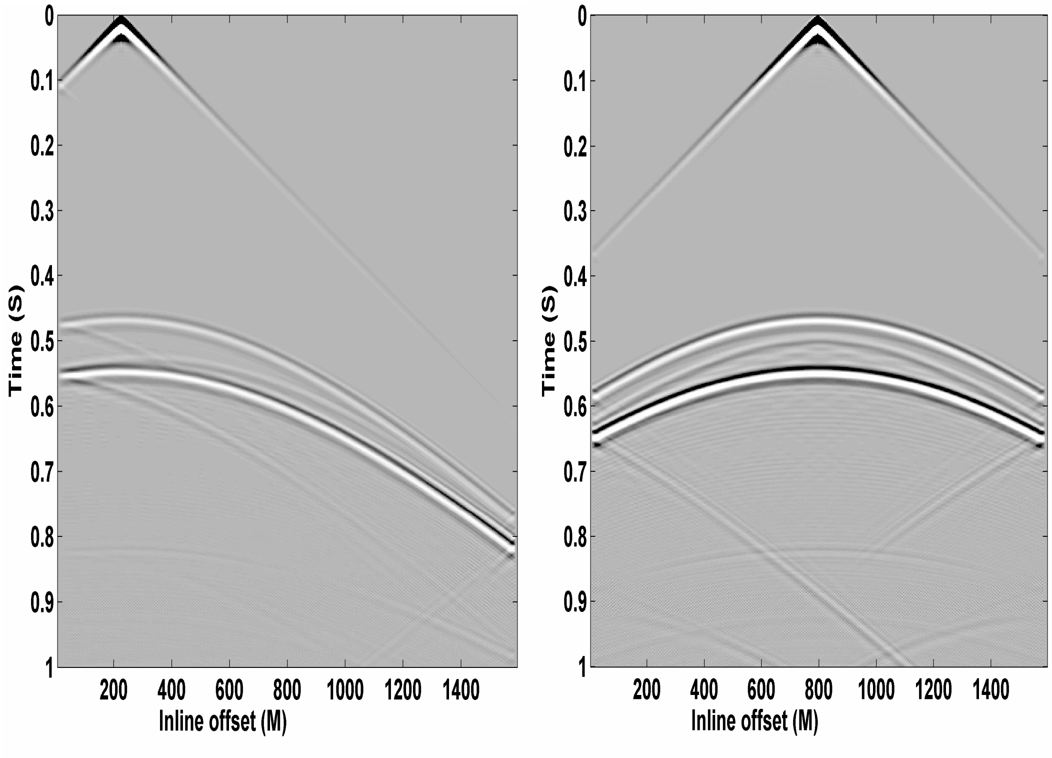

FIG. 3. Two synthetic seismic shot gathers received on the surface.

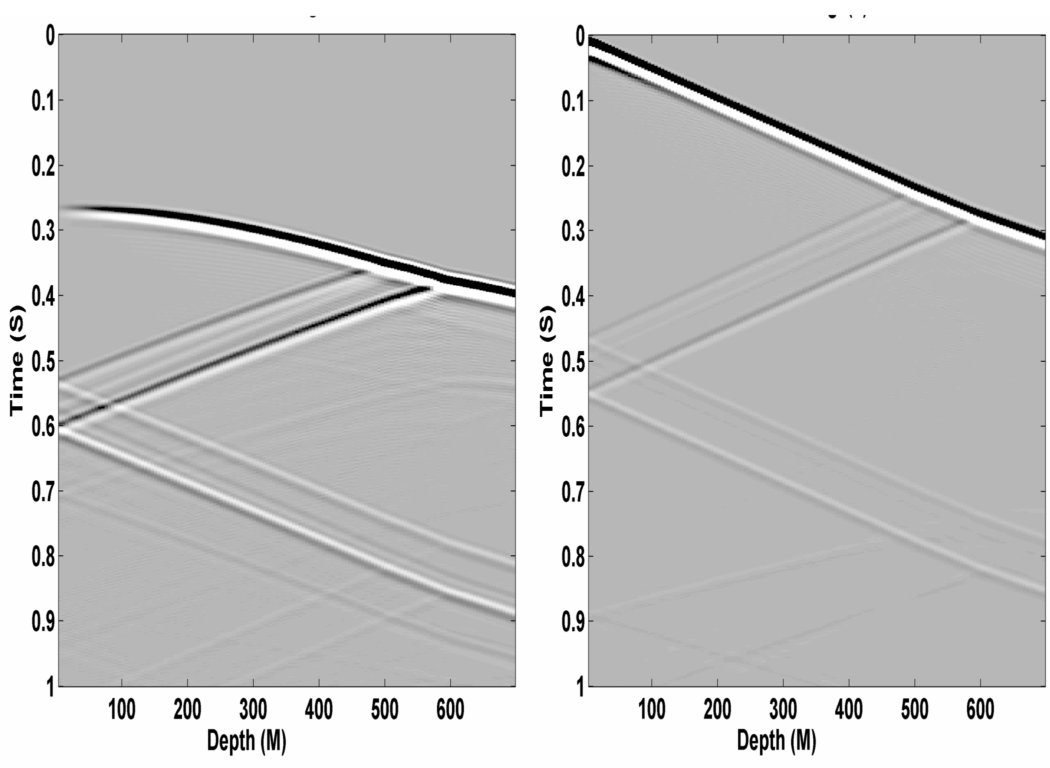

FIG. 4. Two synthetic VSP gathers with the same sources as the data in Figure 3.

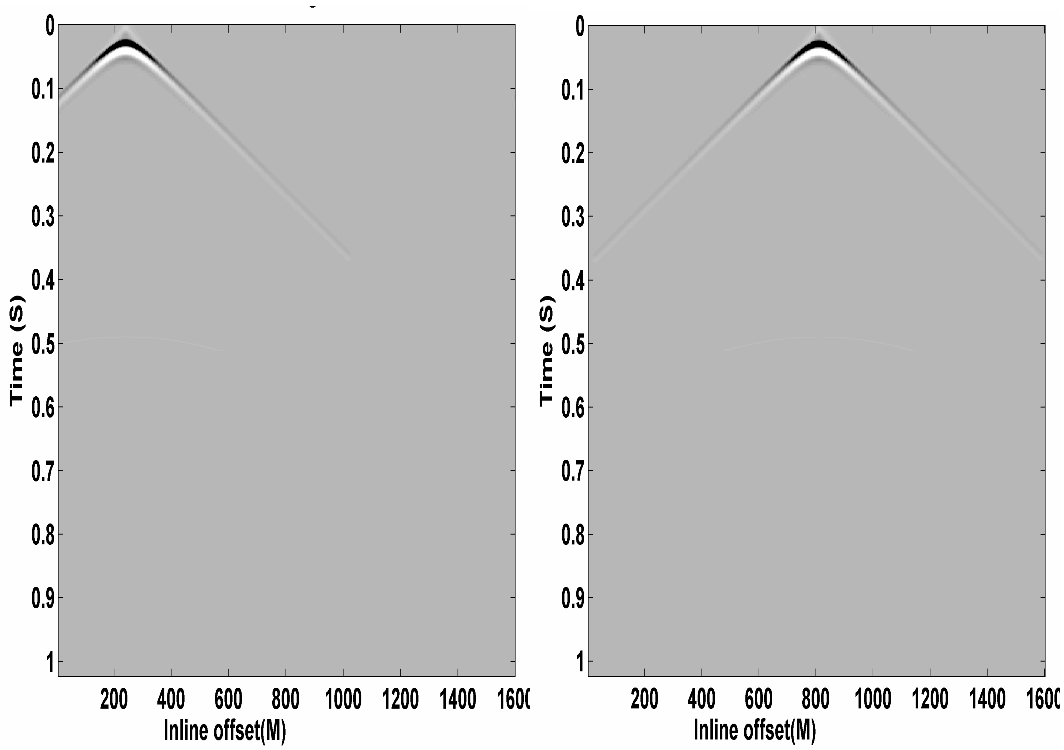

FIG. 5. Simulated downgoing waves at same depth level from two sources .

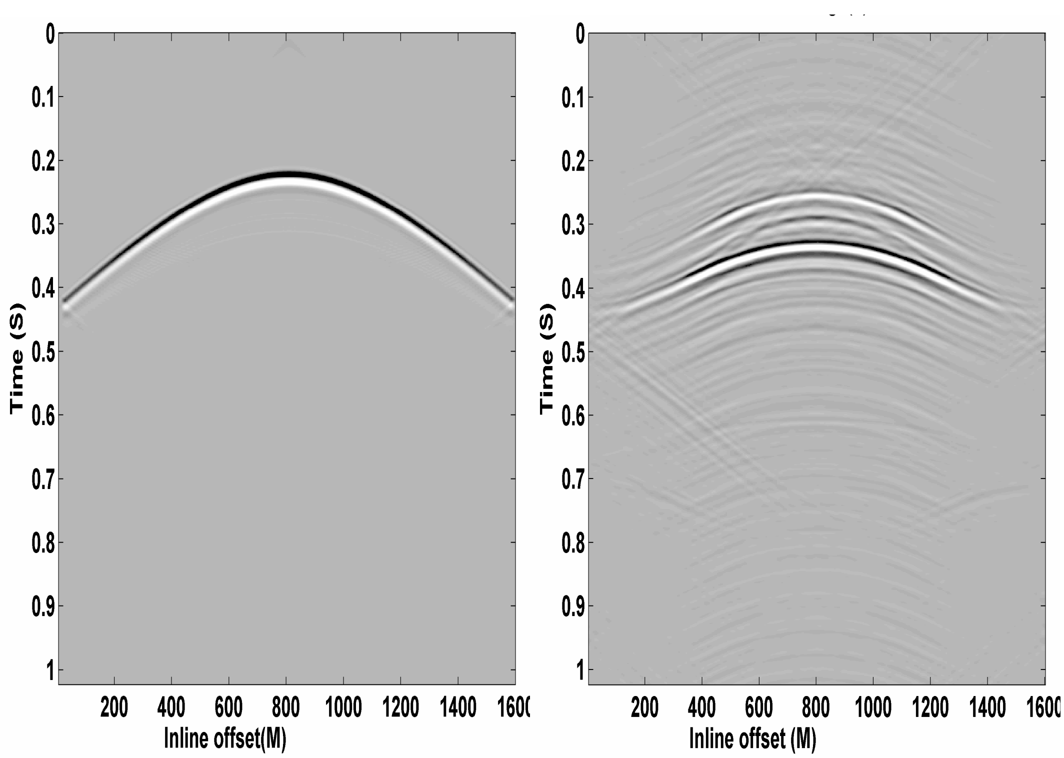

FIG. 6. Upgoing and downgoing shot gathers extrapolated to the depth of 500 m with shot point in the middle of the model.

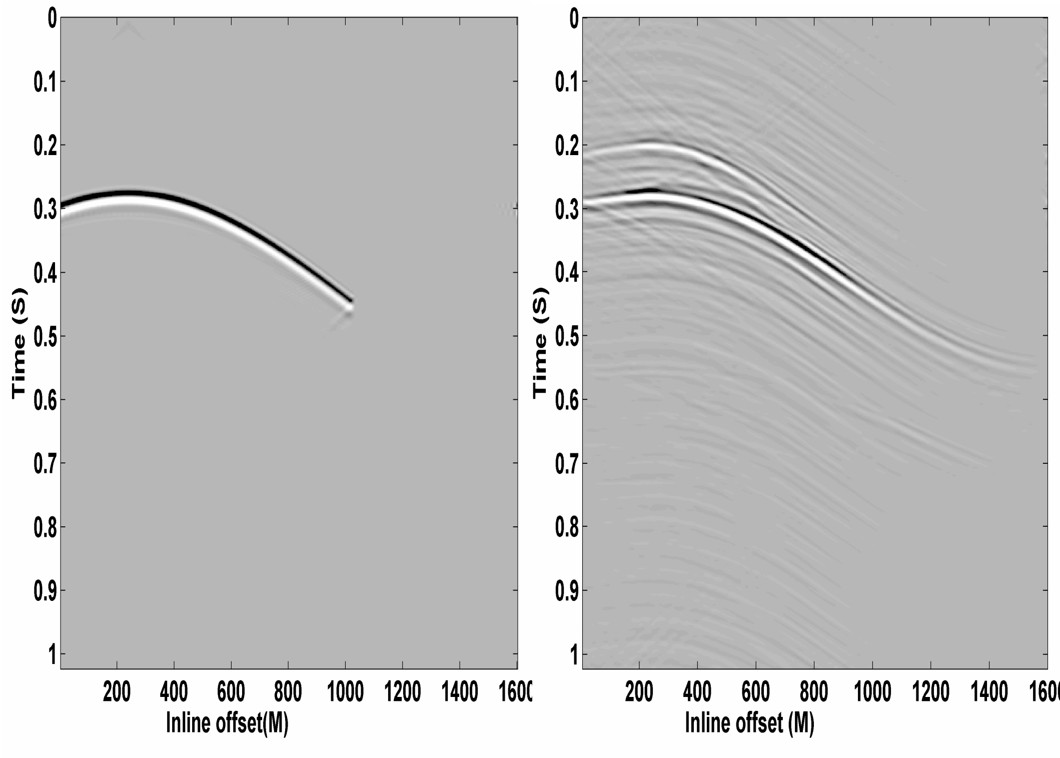

FIG. 7. Upgoing and downgoing shot gathers extrapolated to the depth of 600 m with shot point on the left side.

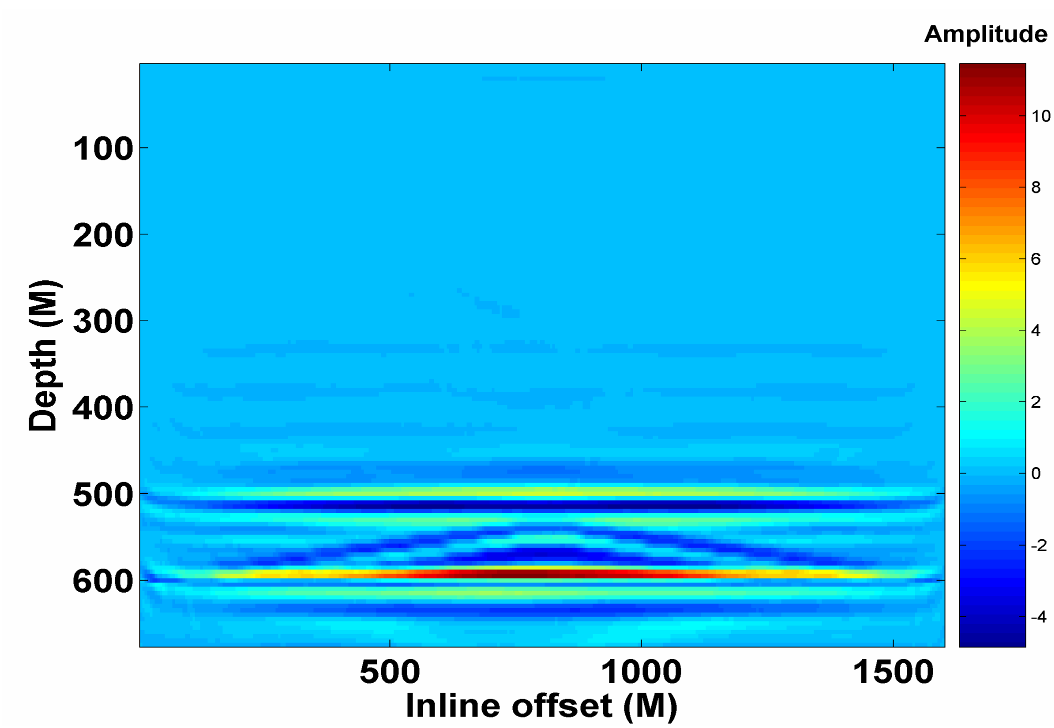

FIG. 8. Migrated depth image.

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