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Beam Migration of Canadian Foothills Datasets

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Summary

We have developed a beam method for shot-domain prestack depth migration. Based on a complex-ray Maslov formulation, this method overcomes the limitations of Kirchhoff migration in imaging multipathing arrivals, while retaining its flexibility with input geometry and its capability of imaging steep dips and overturned structures with turning waves. It is especially useful for seismic imaging of the Canadian Foothills, where subsurface structures are complex and data-acquisition geometries are often irregular. We demonstrate in this study the application of this method to 2D and 3D datasets from the Foothills. We show that the beam method produces better images than the Kirchhoff method on both shallow and deeper parts of the migrated sections, and when compared with the Kirchhoff images, the beam migration results are often cleaner and have much less migration swinging artifacts.

Introduction

Seismic imaging of Canadian Foothills structures is challenging because of their complex folded and faulted structures and because of their large topographic variations. These difficulties are further compounded by irregular data-acquisition geometries often found in the seismic surveys from these areas. Kirchhoff migration is flexible with input geometry and topography, but has difficulties in handling multipathing arrivals, making it relatively inaccurate in geologically complex areas (Hill, 2001). Wave-equation migration, on the other hand, can image multipathing arrivals properly, but suffers the limitations in imaging steep dips (e.g., Gray et al., 2001; Li et al., 2003). Combining the advantages of both Kirchhoff and wave-equation migrations, ray-based beam migrations such as Gaussian beam (e.g. Hill 2001; Albertin et al., 2001; Gray, 2005; Zhu et al., 2007) provide a powerful tool for seismic imaging of the Canadian Foothills. They overcome the limitations of Kirchhoff migration in imaging multipathing arrivals while retaining its flexibility with input geometries and its capability of imaging steep dips and overturned structures with turning waves. We have developed a complex-ray Maslov algorithm for shot-domain prestack depth beam migration which further enhances the accuracy of Gaussian beam migration in imaging land data. The purpose of this study is to demonstrate the applications of this algorithm in imaging both 2D and 3D datasets from the Canadian Foothills.

Theory

Similar to other beam migration methods (e.g., Hill, 2001; Schleicher et al, 2008), the complex-ray Maslov beam algorithm consists of two main components: local plane-wave decomposition of shot records and beam propagation and imaging of the decomposed plane waves. The local plane-wave decomposition begins by unity partitioning a shot record into Gaussian-windowed traces; slant stack is then used to decompose the windowed traces into local plane waves with a range of initial propagation directions. Figure 1 shows one of these plane waves propagating from a Gaussian window centred on **L**. The centre of the Gaussian window is also referred as the beam centre. Our algorithm for local slant stack is flexible and can deal with both regular and irregular trace spacings.

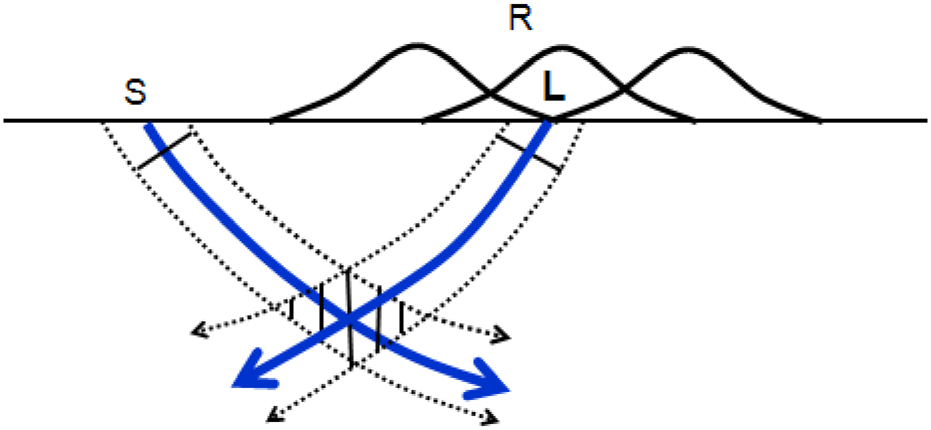

Figure 1: Schematic sketch of the main components of complex-ray Maslov beam migration for a shot record. S indicates the source location and R the receiver locations. L represents a beam centre.

After data decomposition, each local plane wave from a beam centre is back propagated by a Maslov beam constructed around a central ray traced from the beam centre (the blue solid line on right side of Figure 1). One of the differences between the Maslov and Gaussian beam algorithms is that the width of a Gaussian beam is controlled by its initial beam width at the surface. In the cases where the initial width is small, the beam width will increase rapidly along the central ray and become excessively large at deeper parts of the beam, which will in turn lead to inaccuracy in traveltime extrapolation along the beam fronts and produce migration swinging artifacts. This can be a problem for land data where near-surface velocity structures have strong lateral variations, and the initial beam width in such cases must be sufficiently small in order to accurately image the shallow structures. Our Maslov beam method, on the other hand, has no difficulty in handling this near-surface problem, as the width of a Maslov beam is determined by the Fresnel zones along the central ray instead of its initial beam width. Similar to the wavefield at the receivers, the source wavefield at point **S** is also decomposed into local plane waves and propagated by beams with different initial propagation directions (Figure 1). A subsurface image is generated from the overlapping area between a pair of source and receiver beams (shaded area in Figure 1). Accumulating the contributions from all shot-receiver beam pairs for a given beam centre produces a beam-center image, and summing over all beam centers from a shot record gives a common-shot image. The final subsurface image is formed by stacking together all individual common-shot images.

An example

We have applied the complex-ray Maslov beam migration to both 2D and 3D data sets from the Canadian Foothills. As an example, we present here the results from a 2D Canadian Foothills survey which covers a geologically complex area with steep topographic variations towards the end of the survey. The velocity model determined from the data is transversely isotropic with tilted symmetric axes (TTI) and has strong lateral variations near the surface. The data were migrated using both Kirchhoff and Maslov beam algorithms with the same velocity model and similar processing and migration parameters. The results are displayed in Figures 2a and 2b. Compared to the Kirchhoff section, the beam image is in general cleaner and has much less migration swinging artifacts. The solid ellipse in Figure 2a, for example, highlights an area where migration swinging artifacts are relatively strong, and because of the interference from these artifacts, the seismic events are discontinuous and poorly defined. The corresponding area in Figure 2b, on the other hand, has no visible migration swinging artifacts, and the events are more continuous and better defined. A comparison of the deeper parts of the sections shows that the deep structures are also in general better imaged by the beam method. For example, the flat reflectors beneath the tip of the thrust sheet, as indicated by the dashed ellipses in Figure 2, appear stronger and more traceable on the beam section than those on the Kirchhoff section.

Conclusions

We have developed a complex-ray Maslov beam method for shot-domain prestack depth migration. This method combines the advantages of both Kirchhoff and wave-equation migrations, and is especially useful for seismic imaging in areas where geological structures are complex and data-acquisition geometries irregular. Applications of this method on data sets from the Canadian Foothills show that the beam images are in general superior to those produced by the Kirchhoff method. They are cleaner and have much less migration swinging artifacts, and both shallow and deeper structures are better imaged on the beam sections than those on the Kirchhoff sections.

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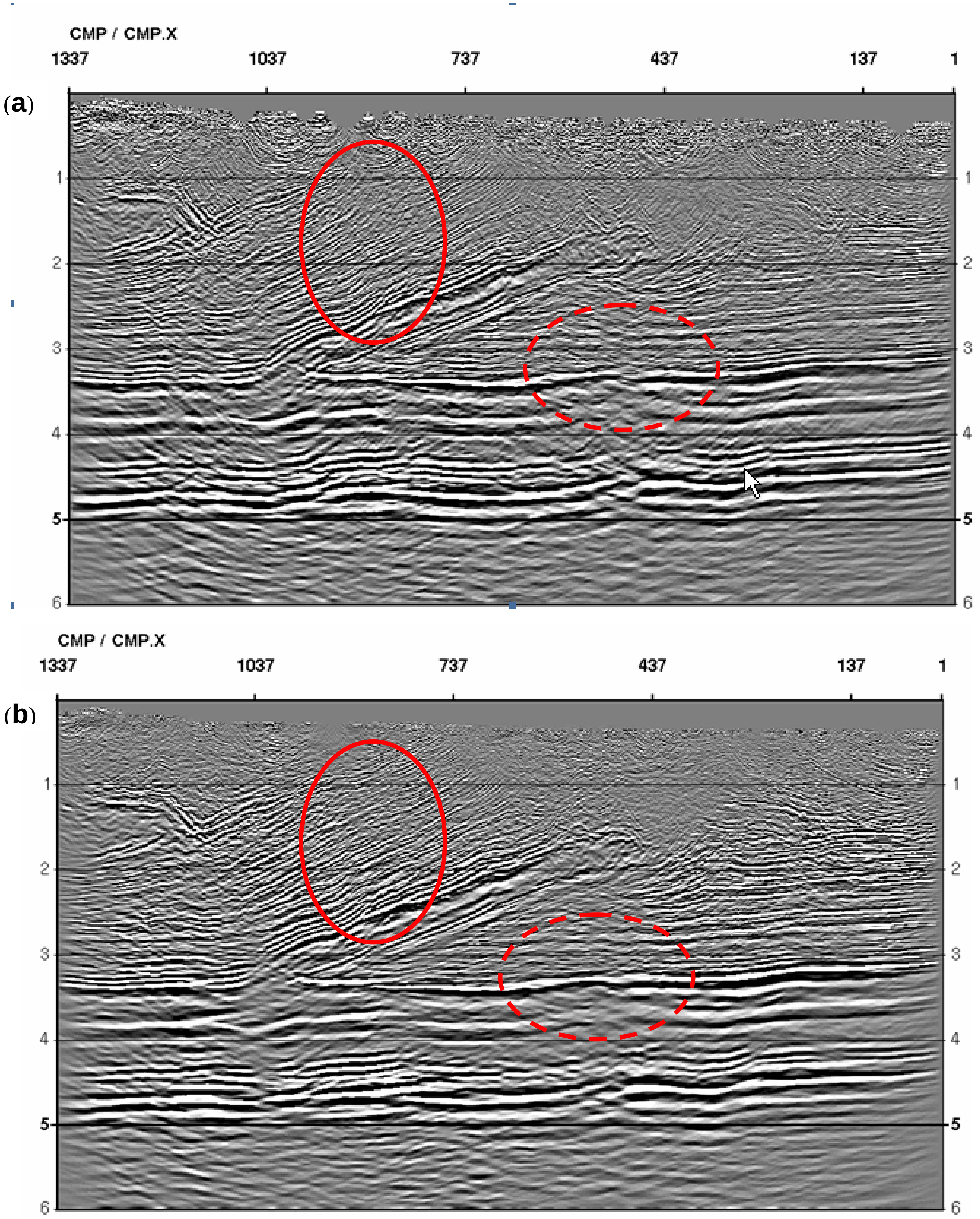

Figure 2: Depth images from the 2D Canadian Foothills survey produced by (a) Kirchhoff migration and (b) by complex-ray Maslov beam migration.