Prestack depth migration from topography in foothills using a hybrid reverse-time migration

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Summary

Rugged surface topography for land seismic data presents a challenge in imaging near-surface and subsurface complex geologic structures in foothills. Conventional static correction process that simply shifts the data to a flat or floating datum distorts the wavefield and thus produces the inaccurate image. Migration from topography without static correction is apparently an ideal solution to the imaging of complex structures with a rugged topographic surface. The image result obtained from the migration directly from topography is significantly improved for near-surface and subsurface structures on a synthetic overthrust dataset in the foothills of Canadian Rockies. A hybrid reverse-time migration also produces clearer image for near-surface structures around the topographic surface than the conventional reverse-time migration.

Introduction

More and more land seismic data have being acquired on an irregular surface over the past years. The rugged topography and complex overthrust structure present significant challenges in routine data processing as well as prestack depth imaging especially in the mountainous areas such as the foothills of Canadian Rockies. Static correction is one of the most commonly used routine processing steps. However, a simple static shift of the data could distort the wavefield and eventually degrade the image quality with complex geologic structures. Wave-equation datuming (Berryhill, 1979) is an alternative approach to move the data to a reference datum through upward or downward continuation of the seismic data from topography. Such method favours the wave propagation and naturally removes the distortions caused by topography. A separate dataset, however, needs to be created for the further processing. Migration from topography is apparently an ideal solution. Wiggins (1984) uses a Kirchhoff formulation to incorporate topography directly in prestack migration from an irregular topographic surface. Reshef (1991) uses a phase-shift migration method to migrate the data directly from topography. Although the phase-shift propagator is not accurate for the imaging of complex structures with lateral velocity variations, his concept of adding the data to the extrapolated wavefield each time that the topographic surface is intersected is useful for the more advanced wave-equation based migrations including one-way wave equation migration (WEM) and reverse-time migration (RTM). Gray and Marfurt (1995) applied a Kirchhoff migration directly from an irregular surface to a Canadian overthrust synthetic datasets and demonstrated that migration from topography improves the near-surface image.

In this work, we apply a hybrid reverse-time migration directly from topography to a Canadian overthrust synthetic dataset. Image for both near-surface and subsurface complex structures are clearly imaged.

Hybrid reverse-time migration from topography

Reverse-time migration (RTM) propagates source wavefield forward in time and receiver wavefield backward in time to image the subsurface reflector (Baysal et al., 1983). By using the two-way wave equation, RTM has no dip limitation and is also able to image the overturned waves and prism waves. However, the interferences around the rugged topographic surface by the conventional full-way RTM could degrade the image quality for near-surface structures. A hybrid RTM (Luo and Jin, 2008) performs the downward extrapolation to certain depth level in the near-surface area using the one-way wave-equation propagator followed by the conventional RTM starting from that depth level. Interferences caused by the topography are largely reduced by the downward extrapolation with the one-way propagator. Hybrid RTM basically takes advantages of both one-way WEM and full-way RTM especially for land data with rugged topography and marine data with deep water layer.
**Example on a Canadian overthrust synthetic dataset**

Figure 1 shows a velocity model representing an overthrust structure of the foothills in Canadian Rockies. It consists of a number of faulted and folded layers. Strong lateral variations of the velocity and considerable topography exist at the near-surface. Topography variation is roughly 1,600 m along the line. A synthetic datasets was generated by a finite-difference code of the 2-D acoustic wave equation (Gray and Marfurt, 1995). There are 277 shots with 480 receivers per shot by a split-spread acquisition geometry. The offset ranges from 15 m to 3600 m on both sides of the shot points. The shot interval is 90 m.

Figure 2 shows a comparison of a single shot gather between the original data recorded on the topographic surface and the one vertically shifted to a flat datum at elevation of 2,000 m after elevation static correction. Distortions by topography and complex structures are evident on both datasets. We use a hybrid RTM method for migration of those two data sets. Figure 3a is an image migrated directly from topography using the original data as shown in Figure 2a. Figure 3b is an image migrated from the flat datum after elevation static correction as shown in Figure 2b. Strong migration swings appear at the near-surface area on Figure 3b as the wavefield was distorted by the simple vertical static shift. Figure 4 shows a comparison of the stacked depth image using all 277 shots between the migration from topography as shown in Figure 4a and the one from a flat datum after elevation static correction as shown in Figure 4b. The image quality of Figure 4a is far superior to Figure 4b for both near-surface and subsurface complex structures.

Figure 5 shows a comparison of the image between hybrid RTM and conventional RTM. Both images are migrated directly from topography. For hybrid RTM in this particular example, a downward extrapolation using one-way wave equation propagator is performed at the near-surface area down to the sea level followed by a conventional RTM starting from that level. The image quality is generally comparable. At the near-surface especially around the topographic surface, hybrid RTM produces a clearer and higher resolution image with much less low frequency artefacts.

**Conclusions**

In the presence of strong lateral velocity variation at the rugged topographic surface, even an advanced hybrid reverse-time migration (RTM) fails to produce a nice image for near-surface and subsurface complex structures using the data vertically shifted to a flat datum with simple elevation static correction. Either conventional RTM or hybrid RTM from topography migrates data directly from the topographic surface produces superior image. For the near-surface structures along topography, hybrid RTM produces clearer and higher resolution image with much less low frequency artefacts than conventional RTM. Finally, we suggest to migrate the data directly from topography whenever possible.

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**References**


Figure 1: Velocity model representing an overthrust structure of the foothills in Canadian Rockies. The velocity ranges from 3,500 m/s to 5,900 m/s. The fill-in velocity is 4,000 m/s above the topographic surface.

Figure 2: Comparison of a single shot gather located at a check point “A” on Figure 1. (a) is the original data recorded on the topographic surface; (b) is the data vertically shifted to a flat datum at elevation of 2,000 m after static correction.

Figure 3: Hybrid reverse-time migration on a single shot gather. (a) Migration from topography using the data as shown in Figure 2a; (b) Migration from a flat datum after static correction using the data as shown in Figure 2b.
Figure 4: Comparison of the stacked depth image. (a) Migration from topography. (b) Migration from a flat datum after static correction.

Figure 5: Comparison of the stacked depth image between hybrid RTM and conventional RTM. (a) Hybrid RTM image; (b) Conventional RTM image.