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Imaging complex structures with near-surface and residual static corrections coupled to depth migration

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Summary

Conventional methods of using refraction and reflection statics limit the imaging ability of depth migration. Refraction statics assume vertical raypaths in the near-surface layer. Reflection statics are derived from data that have a normal moveout (NMO) velocity correction based on the assumption that the moveout can be approximated by a hyperbola. These assumptions are valid when the moveout is near-hyperbolic, symmetric, and deviates when the moveout is more complicated due to complex geology. Scenarios of non-hyperbolic non-symmetric moveout are when high velocities are near the surface and when there are variations in the seismic weathering thickness and velocities.

I will show the results of three methods used on a foothills field dataset. First, was the conventional approach to depth imaging. The input traces to depth imaging had the same refraction and reflections statics that were applied to the input traces for time migration. Second, the input traces to depth imaging had the refraction statics calculated from the tomographic near-surface model but reflection statics that were derived using a model-based moveout correction rather than an NMO. Third, the tomographic near-surface refraction model was merged with the velocity model and reflection statics that were derived after applying a model-based moveout were applied to the input traces for depth imaging.

By merging the near-surface tomographic model with the depth velocity model and calculating reflection statics derived from a model-based moveout correction, depth imaging can be enhanced.

Introduction

In processing land seismic data, the highly variable near-surface layer is difficult to determine. As such a refraction tomographic model is created to approximate the near-surface layer and static corrections are derived and applied to the traces. These vertical trace shifts theoretically correct for what would have been the time the seismic energy would have spent in the near surface layer. While reflections statics are calculated using an NMO correction, it has been recognized in the industry for some time that conventional NMO corrections are not suitable for all geologic settings (Widess, 1952). The hyperbolic assumption of NMO is violated when the topography isn't flat, strong lateral heterogeneity of velocity is present, and when there are variations in thickness and velocity in the low-velocity layer (Marsden, 1993).

Raytracing in depth migration has overcome many of the issues with the assumptions in time migration. Foothills datasets and other geologically complex environments compel us to look for ways to overcome these assumptions as they are violated. Gray (2002) and Newrick (2004) have developed processes to test the advantage of incorporating the tomographic near-surface model into the depth velocity model in place of static corrections on synthetic data. This method uses the near-surface model generated from refraction tomography for static corrections. But instead of applying the vertical time shifts to the traces derived from the tomographic model, they merged the model with the depth migration velocity model. However, if the velocities are inaccurate, the depth image can be severely deteriorated. When applied correctly, this method is beneficial as it does not assume the raypaths to be vertical in the near-surface but applies depth imaging principles by reconstructing the raypath by imaging through the near-surface velocity layers.

Method

The foothills field dataset used, is from the Canadian foothills and was publicly released in 1995 at the SEG AGM Workshop #6 in Houston as a foothills imaging benchmark. This dataset is known as the 'Husky Structural Dataset' and has a lot of geologic complexity and excellent signal quality (Stork et al, 1995). At the workshop, the presenters provided many insights and expertise imaging the foothills dataset.

The velocity model has been converged upon through a conventional interpretive depth imaging process. The velocity model is built interpretatively using the latest image and migration outputs to identify where and how to update the velocity magnitudes and boundaries until the velocity model is optimized.

To fully use the advantages of depth imaging, the assumptions with the static corrections should also be tailored to the depth migration algorithm (Figure 1). Taner et al (1974) discuss assumptions that justify static corrections: the effect of the near-surface is purely a time delay, due to near vertical raypaths; and the time-delay is the same regardless of reflection time. These assumptions justify using a time shift that is constant or 'static' for the entire trace.

Applying static corrections derived from model-base moveout (MMO) is still a constant time shift, but it is a dynamic moveout velocity that allows for asymmetric non-hyperbolic moveout (Ellison and Innanen, 2016). This method is coupled with depth imaging and ensures that the reflections statics are shifts that optimize reflector coherency rather also accommodating for NMO theory error. MMO is employed using the reciprocity assumption for the relative source and receiver positions (Taner and Koehler, 1981), which allows a consistent method in applying the traveltimes to the respective source and receiver traces.

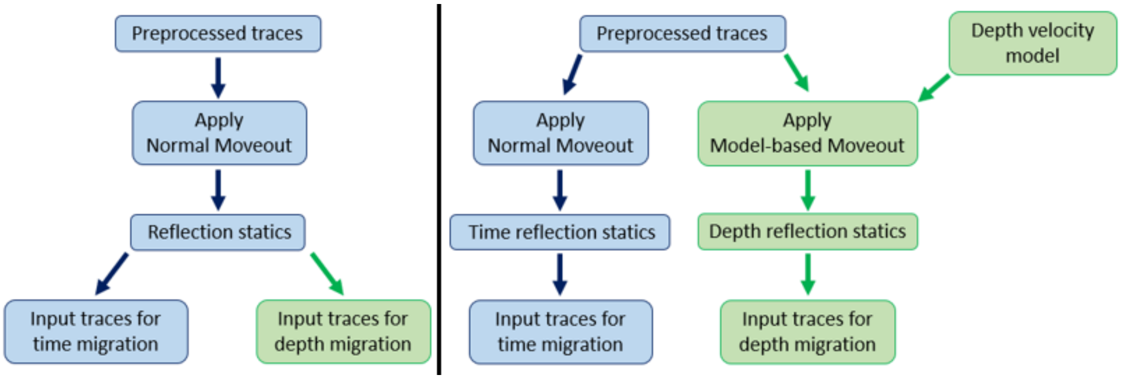

Fig 1. (Left) Conventional reflection statics. (Right) Depth specific reflection statics.

Our current methods of removing refraction statics and using the tomographic near-surface model is relatively simple. The near-surface model is cutoff at a flat datum and merged with the near-surface of the depth velocity model. We choose the top 750 m from the seismic datum of the tomographic near-surface model as ray density in the tomographic inversion severely decayed after this depth. Even though applying the tomographic near-surface model may be a low frequency version of the true near-surface, it can be helpful if it is accurate enough (Gray et al., 2002). In regions of complex velocity, the tomographic approach of using diving rays generally produce a better near-surface model in complex geologic settings as it is more capable of handle lateral velocity variations in the tomographic near-surface modelling process (Zhu et al., 2000).

Results

Figure 2 is the image we converged upon using the velocity model derived from conventional depth imaging techniques applying static corrections coupled to time migration on the input traces for depth imaging. Overall this image is of good quality and any limitations in the imaged reflectors would have been explained as significant geologic complexity or poor illumination. Figure 3 has the tomographic near-surface solution generated to calculate refraction static corrections for time migration is merged with the near-surface in the depth velocity model instead.

By replacing the near-surface tomographic model for refraction static corrections and the deriving reflections static corrections using MMO corrected gathers instead NMO corrected. We have removed the assumptions coupled to time migration from depth imaging. An improvement that can be seen from this update are at CDP 1350 and a depth of 2500 m where the reflectors are now more convincingly connected from the image with MMO and especially the image with time statics. Another improvement is the leading edge of a thrust at CDP 400 and 1500 m depth. The coherency of this structure is visible, but it was difficult to image.

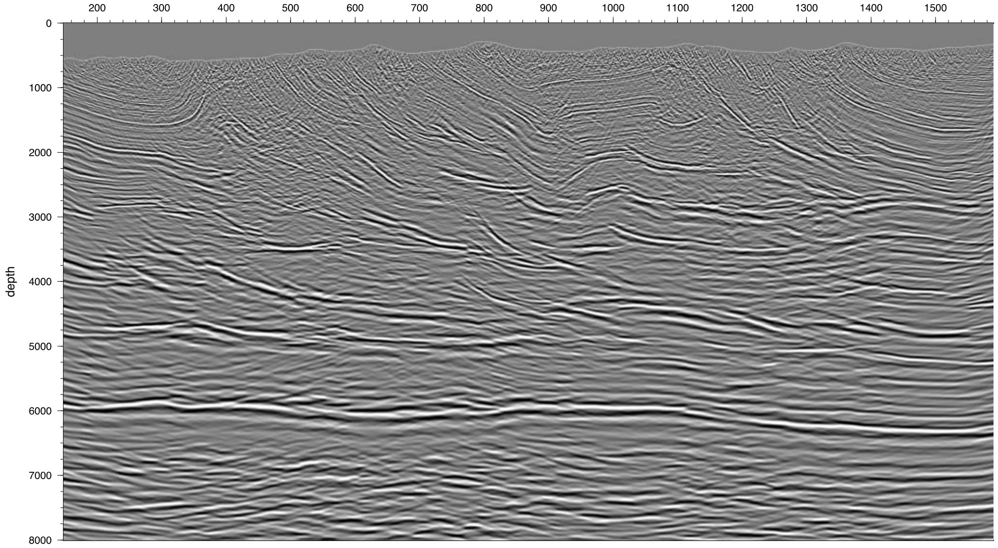

Fig 2. Depth imaging stack with time statics. Refraction statics and time reflections statics derived using an NMO velocity correction were applied to the input traces for depth imaging.

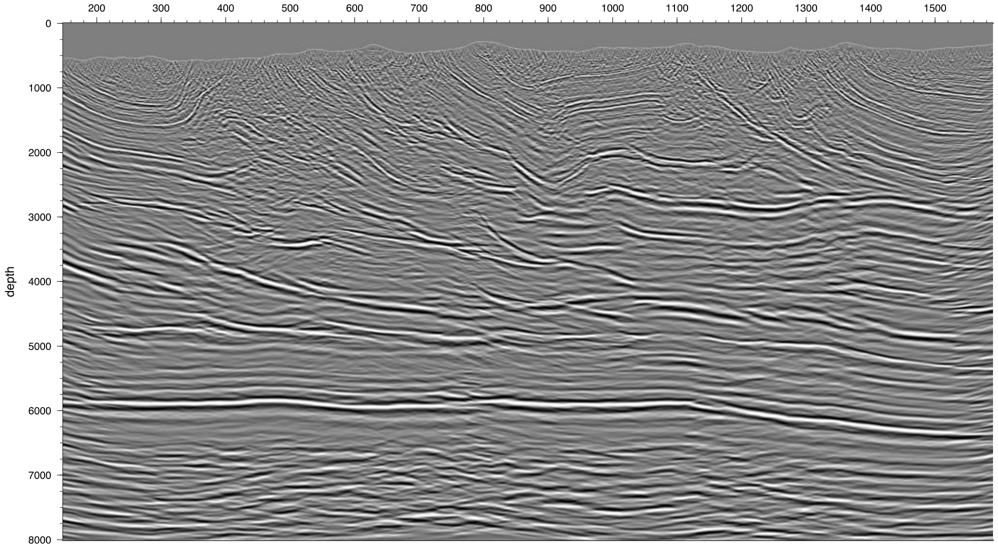

Fig 3. Depth imaging stack with no time statics. No refraction statics applied but depth reflections statics derived using a MMO velocity correction were applied to the input traces for depth imaging.

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Conclusions

The Husky Structural Dataset is a good quality foothills dataset from the Canadian foothills. The assumption that the moveout is near hyperbolic enough in shape to be represented by the two-term NMO equation for reflection static corrections is inappropriate for foothills data and when there are variations in the seismic weathering thickness and velocities. Applying a model-based moveout for reflection static corrections is coupled with the depth migration algorithm and provides better static solutions for depth imaging the Husky Structural Dataset.

Removing the refraction static corrections and merging the near-surface tomographic model with the depth velocity model also enhanced the coherency of the depth image. The assumption that near-surface layer has a much lower-velocity than the next layer is not suitable for the geologic complexity of foothills seismic data. Through replacing static corrections coupled to time migration with MMO reflection static corrections and merging the near-surface tomographic model with the depth velocity model the depth image is improved.

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