Eliminating time statics from depth imaging

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ABSTRACT

Refraction and reflection statics are calculated because often the lack of detailed near-surface information leads to inaccuracies. A normal moveout (NMO) velocity field is picked and applied to stack the data in preparation for the reflection statics calculations. NMO is a correction based on the assumption that the moveout can be approximated by a hyperbola. The accuracy of this assumption is valid when the moveout on data is near-hyperbolic and 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.

This paper is a continuation on the "Improved resolution in depth imaging through reflection static corrections derived from model-based moveout" report done last year at the 2016 CREWES sponsors meeting. That report focused on synthetic data this is about a field dataset from the Canadian foothills. The focus this paper will be about how using reflection static corrections coupled to depth migration and merging the near-surface tomographic model with the depth velocity model will improve the final image.

Three methods are 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 applied that were calculated for the time stack. Second, the input traces to depth imaging had the refraction statics calculated from the tomographic model but reflection statics that were derived from model-based moveout. Third, the input traces to depth imaging had the refraction model merged with the velocity model and reflection statics that were derived from model-based moveout

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

INTRODUCTION

The foothills field dataset 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. Schmid (1995) proposed and applied 'model-based NMO' and had promising results and helped to refine the velocity model for depth migration.

It has been recognized in the industry for some time that conventional NMO corrections are not suitable for all geologic settings (Widess, 1947). 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).

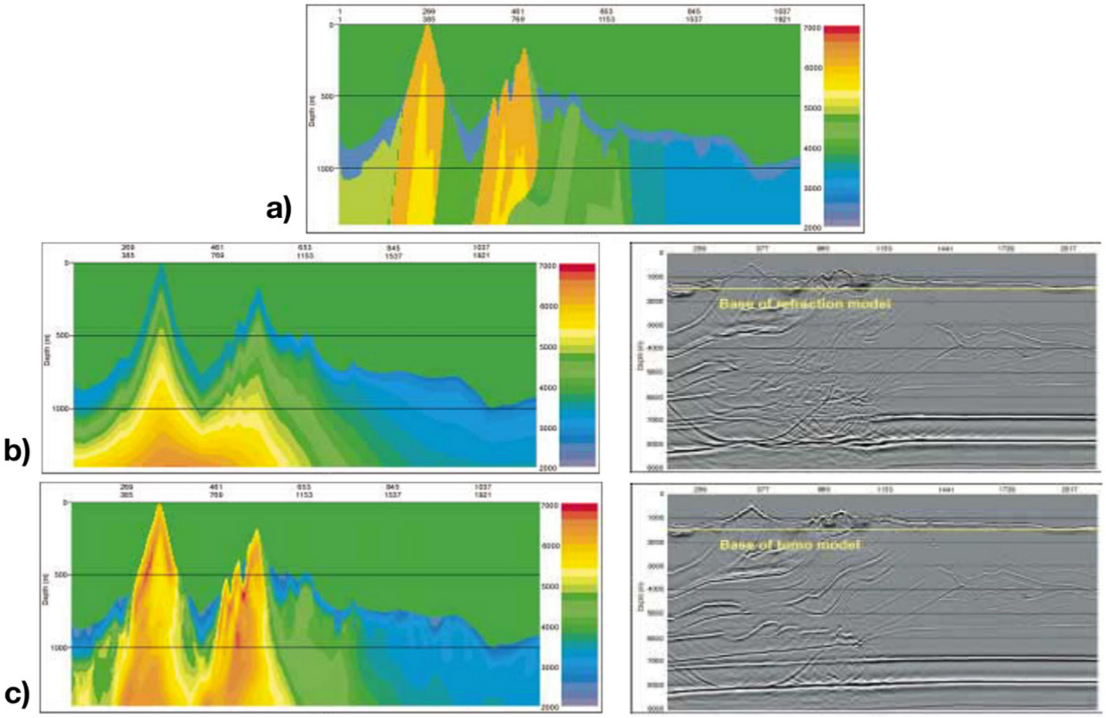

Fig 1. (a) Top 1400 m of model used the generate synthetic data. (b) Near-surface velocity model generated using generalized-linear inversion (GLI) and associated depth image when near-surface is merged with the depth velocity model. (c) Final model from tomographic inversion and associated depth image when near-surface is merged with the depth velocity model.

We gain greater ability to image the subsurface of the Earth as we continue to incorporate current technology, and search for newer methodologies to mitigate the risk imposed by older assumptions. Advances such as grid-based first-arrival tomography has many advantages over layer-based for static corrections where there is strong lateral velocity homogeneity in the near-surface. First-arrival tomography has a greater potential for estimating these strong lateral velocity variations and are calculated in greater detail (Zhu et al., 2000).

Gray (2002) and Newrick (2004) have developed processes to test the advantage of incorporating the near-surface tomographic 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 (Figure 1). When applied correctly, this method is beneficial as it does not assume the raypaths to be vertical but in a specific direction determined by the near-surface tomographic model based on ray-bending through the near-surface velocities.

METHODOLOGY

Velocity Model

The velocity model has been converged upon through the interpretive depth imaging process. This starts with the time stack converted to depth using the replacement velocity. The velocity model is built interpretatively using the latest image to identify where the velocity magnitudes and boundaries should be until the velocity model is optimized (Figure 2).

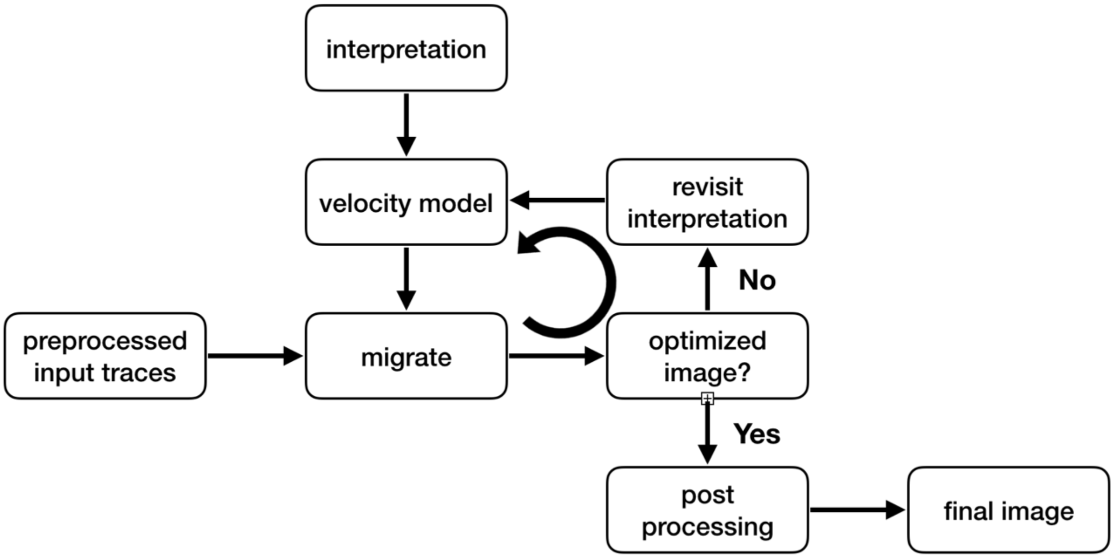

Fig 2. The interpretive velocity model building workflow based on conventional preprocessing of the input traces to depth migration.

Depth Statics

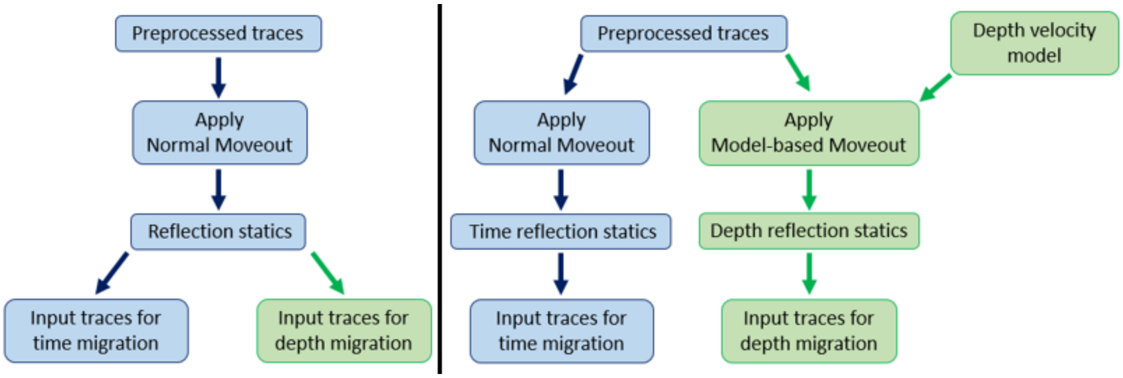

Fig 3. (Left) Conventional reflection statics. (Right) Depth specific reflection statics.

To fully use the advantages of depth imaging, the assumptions with the static corrections should also be tailored to the depth migration algorithm (Figure 3). Taner et al (1974) discuss assumptions that are appropriate for the time-domain but lack application in depth: the effect of the near-surface is purely a time delay; 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 correction created derived from model-base moveout (MMO) is still a constant shift, but it is a dynamic moveout that allows for asymmetric non-hyperbolic moveout (Ellison and Innanen, 2016). 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 trace.

Removing the refraction static corrections derived for time migration can be done through applying the near surface model generated into the depth velocity model. Even though the model may be a low frequency version of the true near-surface would be, if it is accurate enough it can be helpful (Gray et al., 2002). In regions of complex velocity, the tomographic approach of using diving rays generally produce a better near-surface in complex geologic settings as it is more capable of handle lateral velocity variations in the near-surface tomographic modeling process (Zhu et al., 2000).

RESULTS

Figure 4 is the image we converged upon using the velocity model shown in figure 7 and conventional depth imaging techniques for statics for the input traces for depth. Refraction statics and time reflection statics were applied to the input traces for depth imaging. Overall this image seems sufficient and any limitation in the quality of the imaged reflector can be explained as significant geologic complexity that is not able to be resolve using current methods. However, Figures 5 and 6 show that a more coherent stack can still be determined if our assumptions going into static corrections do not limit the potential resolution of the depth velocity model (Figure 8).

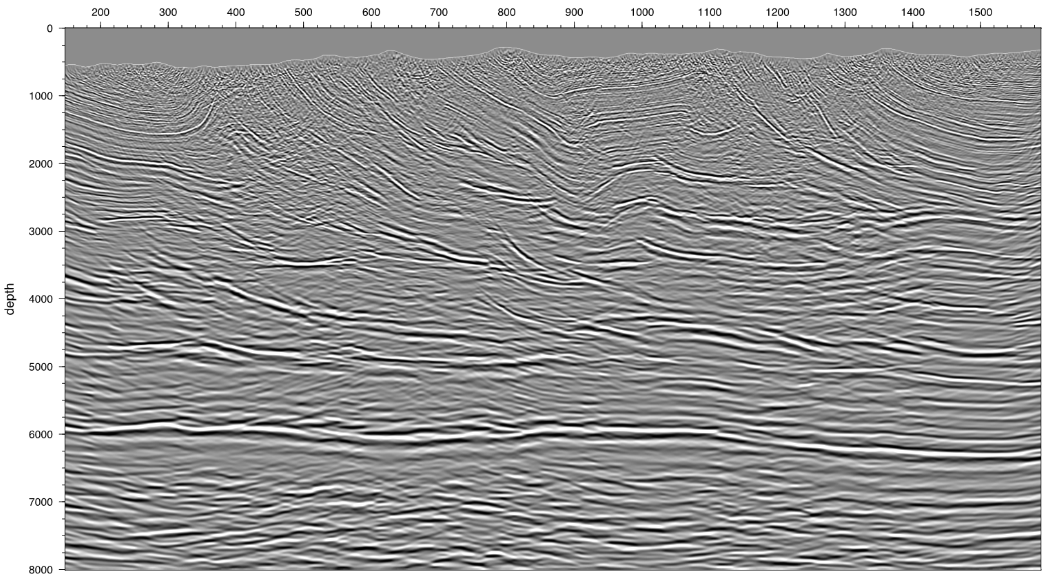

Fig 4. Depth imaging stack with time statics. Refraction statics and time reflections statics derived using an NMO velocity correction were applied to the input traces for depth imaging.

Figure 5 is the depth image created using the same velocity that created figure 4, but it has reflection statics derived from MMO (Ellison and Innanen, 2016). The improvements can be seen primarily in the basement reflector where there is an increase in coherency and sharpness. Other improvements can be seen in the fault imaging at CDP 900 and depth of 3500 m, reflectors near CDP 250 and 2000 m depth, and the continuity of the reflectors at CDP 1300 and 2800 m depth. By using a MMO for reflection static corrections that is coupled to the current depth velocity model, we are no longer constrained by a predetermined statics solution that is irrespective to the model we are using to image the data.

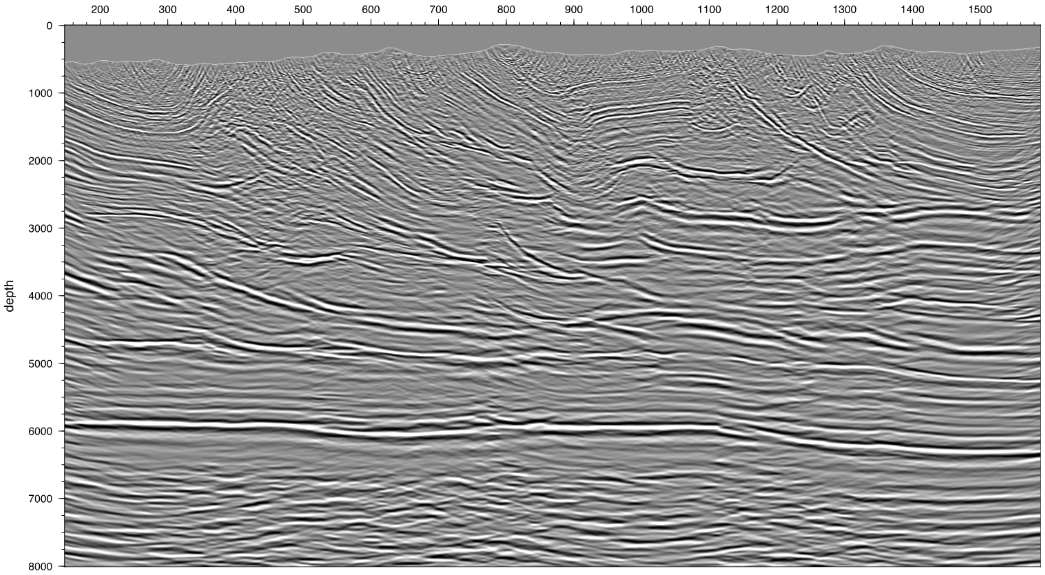

Fig 5. Depth imaging stack partial time statics. Refraction statics and depth reflections statics derived using a MMO velocity correction were applied to the input traces for depth imaging.

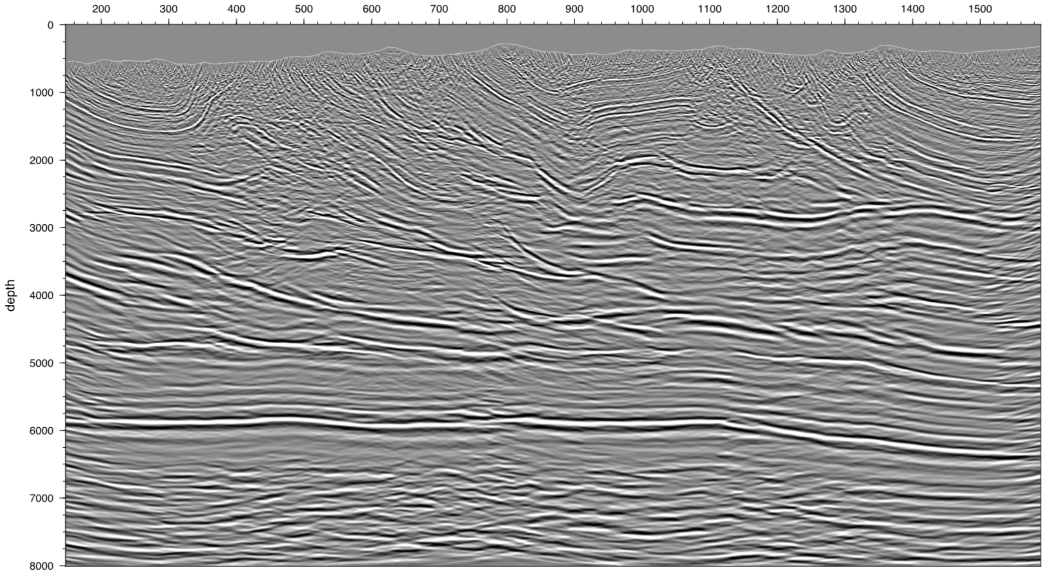

Fig 6. Depth imaging stack with no time statics. No refraction statics applied but depth reflections statics derived using a MMO velocity correction were applied to the input traces for depth imaging.

Figure 6 is the depth image that was migrated with the velocity model in figure 8. What is different about this model is that the tomographic near-surface solution generated to calculate refraction static corrections for time processing is merged with the near-surface in the depth velocity model instead. This is done in lieu of applying the refraction static correction to the input traces for depth. By merging the tomographic near-surface with the depth velocity, MMO will be different and needs to be recalculated for the new 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. The comparison of the near-surface of the depth velocity models are in figure 9.

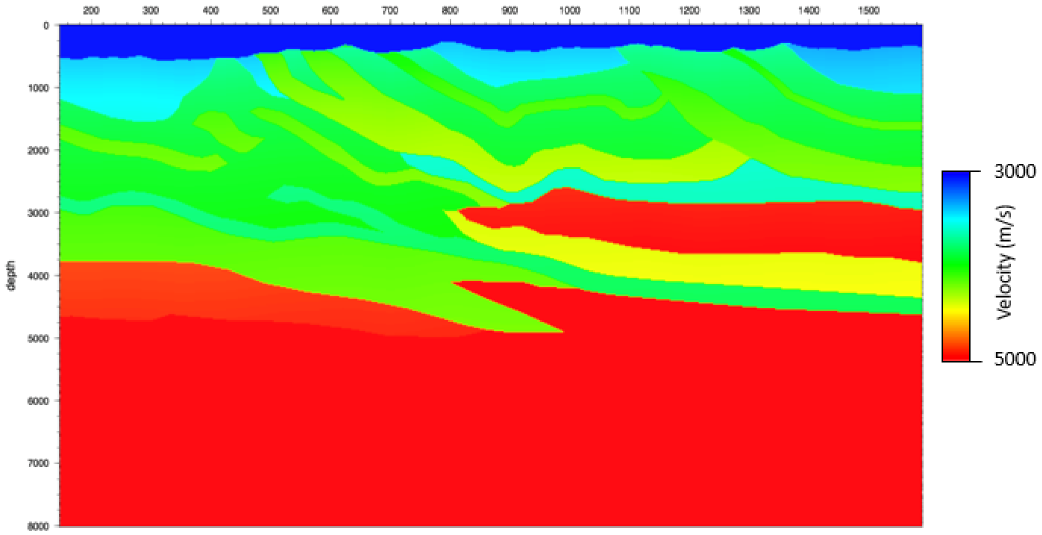

Fig 7. Depth imaging model. This model was used to derive the figure 4 and 5 depth images.

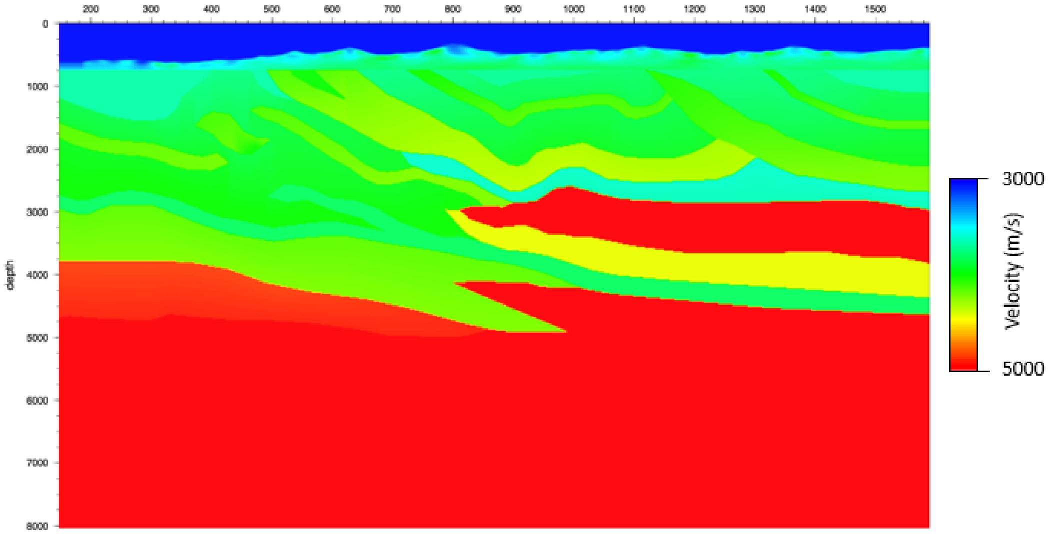

Fig 8. Depth imaging model. This model was used to derive the figure 6 depth image.

By replacing the near-surface tomographic model for refraction static corrections and the deriving reflections static corrections with MMO corrected gathers instead NMO corrected. We have removed the assumptions couple 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. Some post-migration processing methods could enhance this structures clarity but depth imaging itself using time static corrections was limited.

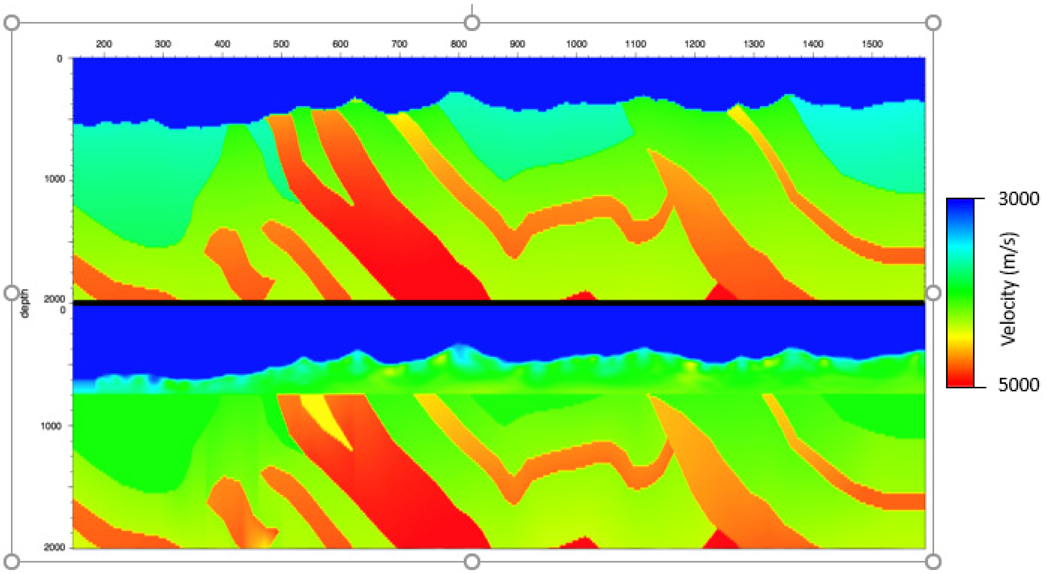

Fig 9. Near surface comparison of the velocity models in figures 7 (top) and 8 (bottom).

Our current method of applying the near-surface tomographic model cause sharp contrasts where the two models merge (Figure 9). Initially there were sharp velocity inversions and increases but the inversions were removed to restore image quality underneath the inversions at the edge of the seismic line. The sharp velocity increases are still present from the tomographic merge. As this is still a working model, improving the velocity model merged with the near-surface tomographic model will take further consideration.

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 derived for 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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