Improved resolution in depth imaging through reflection static corrections derived from model-based moveout

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Summary

When seismic data are used to image the subsurface, assumptions and calculations are made about the near-surface to overcome the uncertainty of the velocities in the low velocity layer. A near-surface velocity model is generated to calculate a time shift that is used to correct for velocity anomalies in the near-surface for time migration.
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. The NMO equation based on the assumption that the moveout can be approximated by a hyperbola. However, the accuracy of this assumption is valid when the moveout on data is near-hyperbolic and deviates when the moveout is more complicated. A few scenarios of non-hyperbolic moveout are when the topography isn't flat, strong lateral heterogeneity of velocity is present, and when there are variations in the seismic weathering thickness and velocities.
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. Using the depth migration velocity model, we apply an offset dependent traveltime summation as the moveout correction for reflection static calculations in depth imaging.

Introduction

There are several potential geologic and technology related issues in acquiring seismic data that make it difficult to image the subsurface accurately. Near-surface modelling, seismic weathering corrections, and time delays are areas within seismic data processing that are constantly being tested, updated, and improved to increase the ability to image the subsurface of the earth. The assumptions made when modelling the frequent changes in the near-surface of the Earth are an attempt to quantify variations in weathering thickness and velocity with the intent to improve the quality of the final migrated image.
Reflection statics are calculated because often the lack of detailed near-surface information leads to inaccuracies (Cox, 1999). To pick reflection statics an NMO velocity field is picked and applied to stack the data in preparation for the reflection statics calculations. NMO velocity is approximated by a hyperbola and assumes lateral homogeneity (Figure 1). However, NMO deviates from the hyperbolic assumption when the topography isn't flat, strong lateral heterogeneity of velocity is present, and when there are variations in the seismic weathering thickness and velocities. (Marsden, 1993).

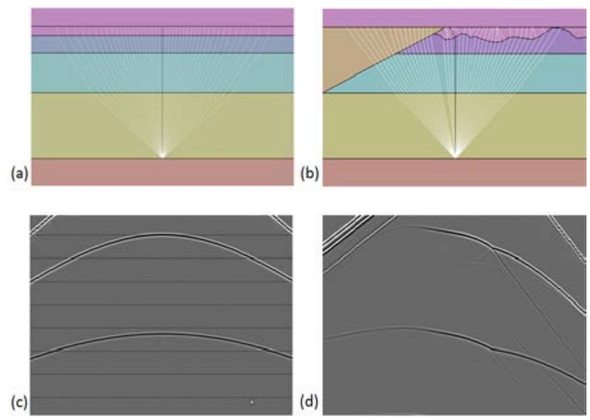


Figure 1: Ray fan showing (a) near-vertical rays at the near-surface when velocities are slower in the near surface and when seismic weathering is flat, and (b) non-vertical rays in the near-surface when velocities are faster than the layer below and when seismic weathering is complicated. (c) is the expected hyperbolic moveout for flat geometries, (d) is moveout that deviates from the hyperbolic assumption.

As we continue to incorporate better technology, and search for newer methodologies to mitigate the risk imposed by older assumptions, we gain greater ability to measure and calculate the subsurface of the Earth. Advances such as grid-based first-arrival tomography has many advantages over layer-based for seismic weathering corrections. First-arrival tomography has a greater potential for estimating strong lateral velocity variations and are calculated in greater detail (Zhu et al., 2000). By improving near-surface modelling methods, others have enhanced the data processing quality to ensure that they have correctly imaged deep structural layers. Particularly in foothills/structured data the weathering corrections can make or break the final image (Gray et al., 2002). As such a lot of effort has been put into conditioning of seismic data before processing to improve the final image (Baufo C. 2008; Zhu T. et al., 2000).

These improvements have focused on corrections specific to the time migration image and relatively little research and resources have been allocated to the development, enhancement, and application of near-surface modelling and weathering corrections specific to the depth migration image. Generally, the static corrections from the time processing flow are applied to the input for depth migration.

Gray and Newrick have developed processes to test the advantage of a depth specific weathering corrections and have found this method to be beneficial if the model is accurate (Gray et al., 2002; Newrick et al, 2004). This method uses the near-surface model generated for static corrections, but instead of using the vertical time shifts they applied the model to the depth migration velocity model. This method does not assume the ray-paths to be vertical but in a specific direction determined by the near-surface model based on ray-bending through the near-surface velocity model. The process described by Newrick is rudimentary and can be improved because of the enhancement of technology over the past decade.

Typically, reflection statics created in time processing are applied to the input for depth imaging. These corrections are based on NMO velocities pick in time, assuming the moveout is near hyperbolic in shape. The weathering statics previously calculated and applied to force the NMO velocity correction to be more hyperbolic to fit the assumption. However, in depth when the velocity field is not the same, and the vertical static corrections derived from the seismic weathering layer have little meaning to the depth migration process and begins to pull it way from being able to predict geologic features accurately.

This research focusses on the differences of the using the time-dependent reflection statics vs the seismic weathering corrections derived from the depth velocity model. A moveout velocity field is derived from the depth imaging velocity model, thus model- based moveout (MMO) statics.

Method

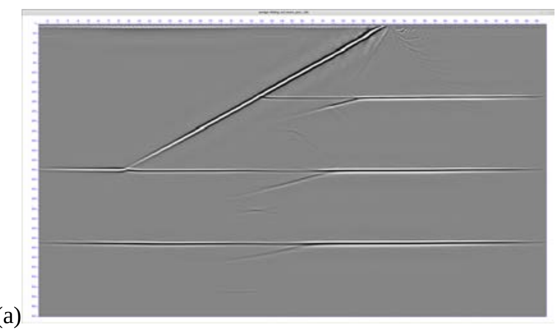
The moveout applied to the pre-stack gathers is derived from the depth migration velocity model, hence model-based moveout. One advantage of depth imaging is the ability to capture the raypath as it moves through the subsurface; this is ignored when using NMO (Equation 1) for reflection static corrections. By using the offset dependent traveltime summation (Equation 2), we can capture a more accurate shift associated with each source and receiver.

$$t_{NMO} = \sqrt{t_0^2 + \frac{x^2}{V_{RMS}^2}} \qquad (1)$$

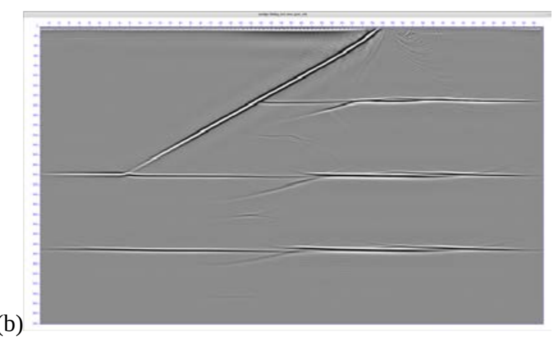
$$t_{MMO} = t_s + t_r \qquad (2)$$

When these traveltimes are applied to the depth input gathers, the gathers are converted to depth. The MMO corrected gathers are then converted back to time to limit variations associated with the correlation window and length and so that the static corrections are in time rather than depth. We used a smoothed version of the depth velocity model, so as not to reintroduce high-frequency velocity pull-up, and push-down structures. Once the reflection statics from the MMO stack were calculated they were applied to the pre-MMO conditioned depth input gathers and migrated with the same velocity field used to derive MMO. The MMO statics derived are unique to each velocity model and should be calculated whenever a new model is created (Newrick, 2005).

Examples



(a)



(b)

Figure 2: Reflection statics comparison (a) MMO statics, (b) reflection NMO statics. Note the decreased coherency caused by the reflection NMO statics.

Conclusions

The assumption that the moveout is near hyperbolic enough in shape to be represented by the NMO equation, breaks down when the topography isn't flat, strong lateral heterogeneity of velocity is present, and when there are variations in the seismic weathering thickness and velocities. It is important to note that the NMO velocity field did increase reflection continuity for the time pre-migration stack. Be that as it may, it did not improve for depth imaging and was more damaging when applied (Figure 2).

Depth migration has a more unique work flow from time migration. Initially with depth imaging the only difference is the migration algorithms. However, is seems that even the conditioning of the data prior to migration could be important step as well.

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