Overcoming thrust-belt imaging problems in South America from illumination to anisotropy

Jon Gittins[1], Rob Vestrum[1], and Ralph Gillcrist[2]

[1]Veritas GeoServices, [2]Compañía Española de Petróleos, S.A. (CEPSA)

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Summary

Imaging complex geologic structures requires accurate velocity analysis and migration that will image steeply dipping strata and faults. Combine these requirements with hundreds of metres of topographic relief, strong lateral-velocity variation at surface, and steeply dipping anisotropic strata in the overburden and you have the Canadian Foothills imaging problem. Compound these issues with lava flows at the surface, limited penetration and illumination of seismic energy, and a more dramatic tectonic history and you are imaging geologic structures in the South American Foothills. This 2D processing case history outlines our struggles with the noise that nearly overwhelmed the limited subsurface illumination and velocity model building under a low signal-to-noise condition in a complex geologic setting.

Access to shooting locations was limited during the acquisition, so there was a significant variation in fold over many of the 2D lines in this project area. We also observed that receivers in the valley recorded only noise from shots on the mountain whereas receivers on the mountain recorded reflection energy from shots in the valley. Dealing with these illumination issues with amplitude equalization and scaling improved signal quality sufficiently that we could consider velocity model building for depth migration.

Where we could define the overburden dip accurately, anisotropic Kirchhoff depth migration yielded improved imaging over the time migration. In other areas with limited signal and high noise, we found the noise generated too much Kirchhoff-operator noise. We tested Gaussian Beam migration on these datasets with promising results for this migration algorithm in noisy rough-topography settings.

Introduction

Seismic imaging in prospect areas with significant velocity variation requires prestack depth migration (PSDM) for optimal focusing and positioning. Veritas prestack anisotropic depth migration (ADM) is specifically designed to handle the tilted-transverse-isotropy (TTI) case typical in a complex-structure environment (Vestrum, 2002). Velocity model building includes estimates of the local dip of the anisotropic strata for every grid point in the subsurface velocity model.

We used a combination of first-arrival tomography (Zhu et al., 2000) and interactive tomography (Murphy and Gray, 1999) to generate and update the velocity depth models used in ADM. After each iteration of velocity analysis and depth model updating, we run Kirchhoff ADM algorithms to output migrated seismic data. The basis of the Kirchhoff method is the derivation of travel times from ray-tracing. Ray-tracing is performed for each shot and receiver location based on their exact coordinates and elevations to minimize interpolation errors associated with regularized grid-based travel times.

In the paragraphs above, the ideal approach to imaging complex structural areas with significant velocity variation is described. For this project however, the noise contamination of the data was so extreme that the focus of the processing effort was primarily on noise removal. After our best efforts to suppress the noise effects the above-mentioned approach was followed. The data quality was poor below the mountain. Poor coupling of the geophones with the rock surface, near surface geology issues, and irregular fold all contributed to the poor signal-to-noise ratio in this area.

No single approach worked consistently across the varied 2D datasets in this area. Of the seventeen lines most responded to some form of noise suppression. Isotropic and anisotropic approaches were compared. Mostly, the anisotropic solution was superior, but, in a few cases where the dip of the anisotropic strata was difficult to define, the isotropic method gave the better result. To deal with migration-operator noise, we applied an alternate migration algorithm known as Gaussian beam. Gaussian beam generates less operator noise and on two lines proved very effective.

Method

The critical first step in building the velocity model is to properly define near-surface velocities. Since seismic reflection data typically contains very little information–typically no information–about the near-surface velocity, we must rely on seismic refraction data. We use the velocities derived from applying first-arrival tomography to the first break pick times. This technique gives an accurate near-surface model suitable for depth imaging. Figure 1 shows the near-surface models. The model describes the near surface velocities from the topographical surface down to a floating pseudo-datum. The pseudo-datum defined during the time processing as the base of the weathered layer and used for statics correction. In depth migration, the velocities above this base of weathering are used in the velocity model to offer a dynamic, rather than static, weathering correction.

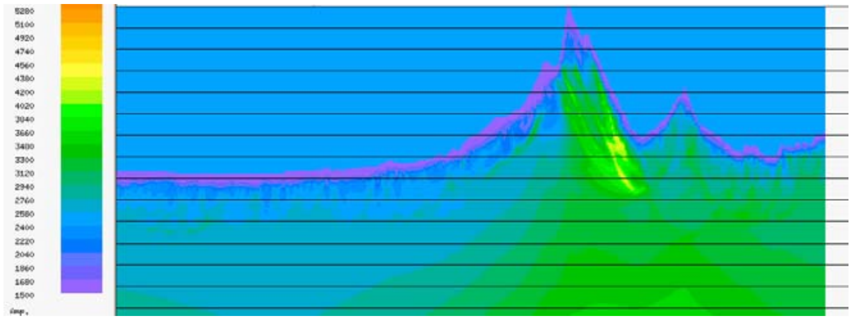

Figure 1: Near-surface velocity model from first-arrival tomography (pseudo-datum not shown)

This near-surface velocity model is then attached to the top of the full geological interpretation supplied by Cepsa from the time-processed stack. The depth velocity model (Figure 2) shows the near-surface model from the first-arrival tomography combined with the geologic interpretation. Note that the refraction statics calculated during the time processing are not applied to ADM input data. Instead, the depth migration ray-tracer is used to calculate the travel times through all layers including the near surface. The ray-traced travel times give a more accurate correction for near-surface velocity variation than the vertical-ray assumption used to calculate refraction statics.

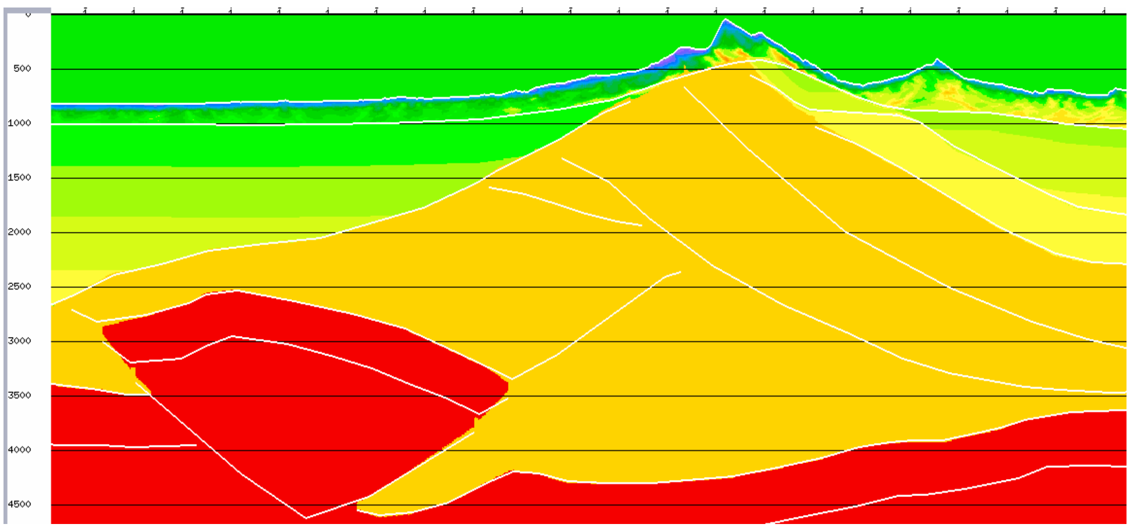

Figure 2: Initial model combining the near surface velocity model and structural interpretation.

A large part of the effort on this project was devoted to the analysis and suppression of the noise. Eight of the lines in this project were merge lines comprised of two or three input segments. The individual segments had varying acquisition parameters. The major differences were fold and offset, as shown in the fold graph for one of the merged datasets (Figure 3).

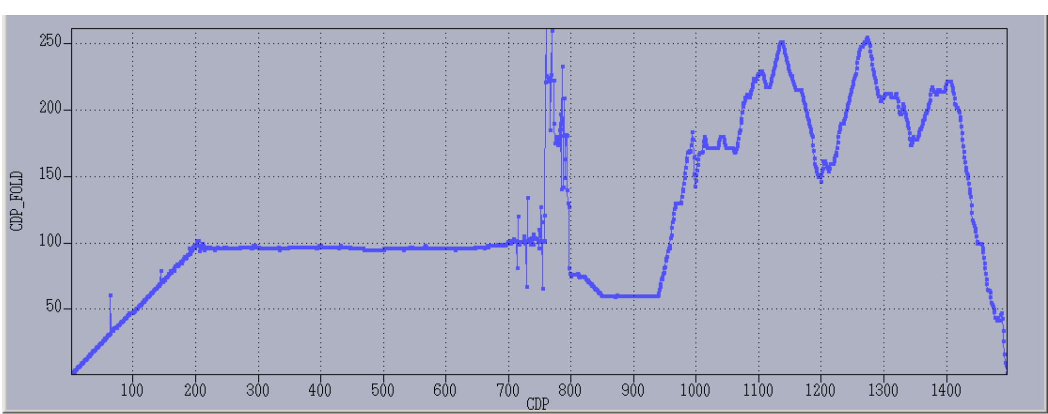

Figure 3. Fold variation along a merged output line.

The fold variation shown in figure 3 varies wildly from 100 to 250 from on CDP to the next. To compensate for this irregularity going into the migration, amplitude scaling was applied to the input gathers. We scaled the gathers to compensate for geometry irregularity so that the amplitude of the migrated gathers is preserved. An area weighting method is used for the weights calculation. The weights applied to the data are calculated based not only on the fold at the image location, but also on all traces constructively contributing to the final image from an area surrounding the image location at each offset bin.

Operator noise from the Kirchhoff migration method is more apparent on data with poor signal to noise. Under the mountain the signal to noise ratio is very low. The first things tested were migration aperture and operator dip angles. 45-degree operator dip and 2500-m aperture were chosen as optimal migration parameters for removing noise and preserving steep dips.

After handling the illumination problems as well as we could, we moved on to velocity model building and anisotropic depth migration. Velocity model updating is done using the interactive tomography method. This technique uses model-based moveout corrections to quantify errors in the depth migration velocity model. Ray-tracing between a reflecting horizon and the source and receiver locations is used to compute the effects of provisional depth-velocity updates on the residual moveout exhibited by the depth image gathers. Without remigrating, velocities that flatten events on the image gathers are interpreted. Then, after full depth migration using the updated velocities, the residual moveout on the next deeper event(s) is analyzed. This cycle is repeated for each horizon until the velocity model is complete.

The final migration results are shown in Figure 4. Both time and depth migrations have the same input data and were both applied prestack. Note the increase in reflector continuity below the mountain on the depth migrated section.

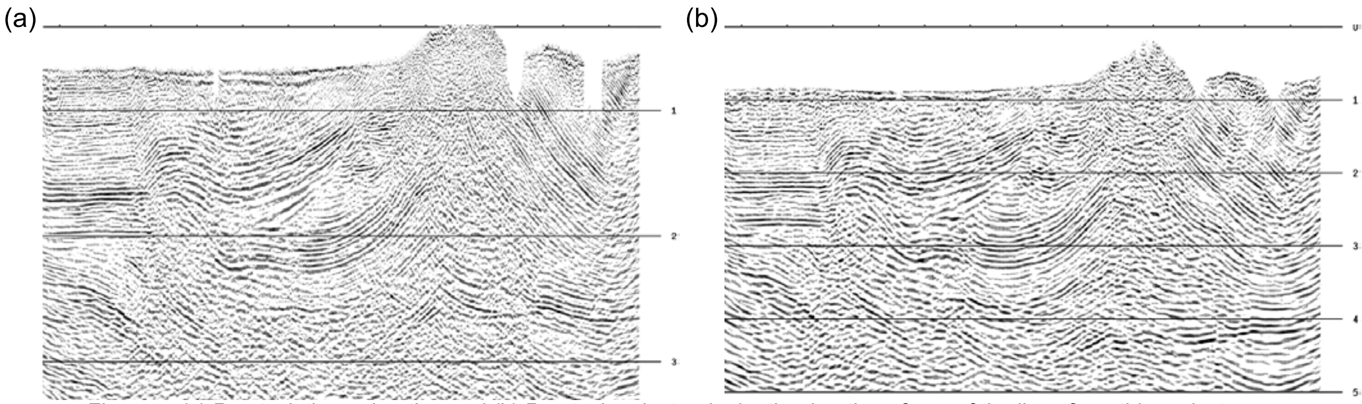

Figure 4. (a) Prestack time migration and (b) Prestack anisotropic depth migration of one of the lines from this project area.

Conclusions

This project area has very little signal in the core of the main structure and very steeply dipping events on either side. Anisotropic depth migration with the near-surface velocity model derived from first-arrival tomography provides superior steep dip imaging and better focusing and positioning compared to the conventional time migration. The main effort on this project was directed at analyzing and removing the noise that dominated the zone of interest in this area. Future acquisition in this area would benefit from longer lines across the structure and long long offsets.

References

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