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Geoscience Integration and Interpretive Model Building to overcome Seismic Imaging problems in Foothills Environments

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Summary

Seismic imaging in thrust-belt environments like the foothills of the Himalayas benefits significantly from interpretive input to velocities used for time and depth migration. With low fold in the near surface, low signal-to- noise ratios on the image gathers, and complex horizon geometries, automated velocity-model-building tools fail to produce an optimum velocity model for TTI anisotropic depth imaging. In a setting with such under-constrained velocities, geologic constraints are crucial in the interpretation of our velocity model.

The goal of our imaging strategy is to get the most from each algorithm: robustness from prestack time migration (PSTM) and geological accuracy from anisotropic prestack depth migration (APSDM). The delicate nature of depth imaging makes it an effective diagnostic on subsurface interpretation, but at times it can be unstable. We view PSTM and APSDM as complementary technologies, with the clearest basic image coming from the PSTM and the accuracy needed to reduce drilling risk from APSDM.

Complex-structure data examples illustrate how integrating geologic data into our velocity analysis processes improves the clarity of PSTM images and accuracy of corrections for velocity heterogeneity and anisotropy effects with APSDM.

Introduction

Difficulties imaging subsurface structures on seismic data from thrust-belt environments arise from the shooting conditions and the complexity of subsurface velocity structure. Seismic acquisition conditions are typically over rapidly changing topography with a range of several hundreds of metres of elevation change. Along this rough topographic surface, seismic velocities can range from unconsolidated deposits in river valleys to crystalline outcrops on the mountains.

The limitations in acquiring our seismic data leads to low signal-to-noise ratios on seismic records and low data density in the near-surface.

Prestack time migration (PSTM) is the most robust algorithm in the seismic-imaging toolkit, but the inherent assumptions may result in inaccurate reflector positioning. Objectives for PSTM are to get the clearest image of the target horizon and the geologic features that control the overall interpretation.

Anisotropic prestack depth migration (APSDM) can produce more accurate positions of subsurface structures, if we can create an accurate model of the subsurface.

Prestack Time Migration

When picking velocities for NMO and prestack time migration in structured areas, we used an interactive velocity analysis tool that offers QC views of both the migrated image gathers and the final migrated stack. Stack coherency and sharpness of reflector terminations guide the velocity picks on the migrated velocity panels and flatness of reflectors with offset on the image-gather display is an additional constraint on velocity picks.

We run 40 or more constant-velocity time migrations to an output analysis grid. For each constant-velocity migration, we generate two types of output: (1) full migrated section for each control line and (2) migrated image gathers for each control point on the control lines. These two seismic data sets are then loaded into an interactive velocity analysis tool.

Figure 1 shows the integrated velocity picking approach. from a dataset in the foothills of the Himalayas (Vestrum et

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al, 2011). The image gather window (Figure 1a), shows a single CDP image gather migrated at all 40 different prestack-time-migration velocities. Where we have high signal-to-noise ratios on the prestack gathers, we may use this display to quickly refine the velocity picks at a control point. Where we have low prestack signal, the image gathers are ambiguous, or the interpreter has concerns about the velocity sensitivity of the target reflectors, we flip to the stack-panel window (Figure 1b) where we can animate through all of the constant-velocity panels to assess reflector coherency, migration operator noise, and the sharpness of reflector terminations.

Throughout the velocity-picking process, we create an composite stack of the input velocity panels (Figure 1c), which closely simulates the prestack time migration that would result from the current velocity field. We further fine-tune velocity picking by analysing percentage velocity perturbations of the composite stack.

Considering the limitation of low prestack signal on gather diagnostics, we use both diagnostics, stack and gather analyses, because with rough topography and lateral-velocity variation, there are cases where the optimum image is achieved on the final stack at a different velocity than the velocity that produces the image gather with the flattest event. Prestack time migration corrects both source-receiver offset moveout and collapses diffraction energy.

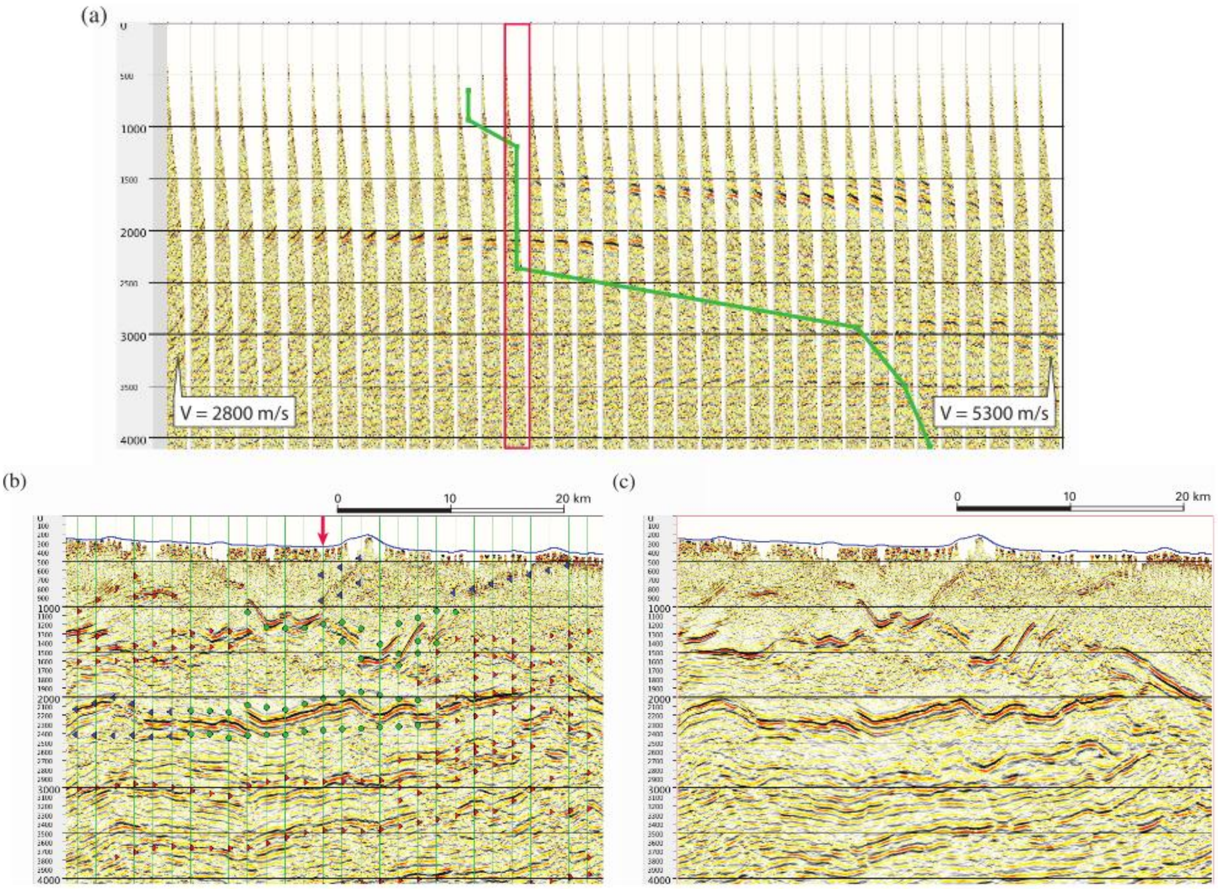


Figure 1: Interactive velocity analysis for prestack time migration. (a) Image gather display showing migrated gathers over a range of velocities for the single CDP indicated by the red arrow in (b). Velocity picks are indicated by the green line. The red box indicates the 3800 m/s gather. (b) Stack panel display showing entire section at 3800 m/s migration velocity. The green dots are picks made on the current panel. Red and blue triangles indicate velocities picked higher and lower than the current panel, respectively. (c) Composite of the velocity panels given the current set of picks, which approximates the appearance of the final 3D prestack time migration. (after Vestrum et al, 2011).

We want to ensure that we accurately collapse diffraction energy as well as achieve optimum imaging through flat gathers. When there are compromises to be made, it is important that the interpreter participates in the decision as to whether to honour the gathers or the stacks.

One example of such a trade-off between gather and stack diagnostics is when one velocity flattens an image gather and another velocity sharpens a reflector termination. The geologist or geophysical interpreter working the area will need to make a judgement as to the geological feasibility of the reflector termination in question versus the geophysical diagnostic of the flat image gather.

One may also use the same process to pick NMO velocities, using the stack panels to sharpen the reflectors when the prestack signal is too low to pick on the image gathers. Accurate NMO velocities are important for reflection-statics calculations and for coherent imaging in the poststack time migration.

Collaboration between interpreter and processor is a key lever for optimum picking of prestack time migration velocities. Geological constraints on the shapes of time-migrated structures direct the picking in noisy areas. The interpreter benefits from his or her involvement in this process by gaining an understanding of the velocity sensitivities and structural uncertainties at the target level.

Depth migration model building

Anisotropic depth migration offers the best possible image and most accurate depths and lateral-position of reflectors in general, and thrust-belt seismic data typically has the TTI imaging problem (e.g., Vestrum et al, 1999 and Stratton, 2004). The TTI anisotropy effect alone often results in hundreds of metres of lateral position error on the seismic image of subsurface structures (Vestrum and Lawton, 2010). The lateral-velocity changes that result from the presence of a large faulted block above the target will also result in lateral-position changes of the imaged structure which may be in the same or opposite direction as the anisotropy position error.

Depth migration in thrust-belt environments requires an interpretive approach to building a depth-migration velocity model. With low fold in the near surface, low signal-to-noise ratios on the image gathers, and complex horizon geometries, automated velocity-model-building tools fail to produce an optimum velocity model for TTI anisotropic depth migration. In a setting with such under-constrained velocities, we must use as many geologic constraints in the interpretation of our velocity model.

Figure 2 shows a series of seismic images from the Colombian Andes. The first seismic image (Figure 2a) is the prestack time migrated section for baseline comparison.

The second image (Figure 2b) shows the anisotropic depth migration of these 2D data with the initial model interpretation. One can observe the typical improvements in imaging between the time migration (Figure 2a) and the depth migration (Figure 2b). There is improvement in reflector continuity below the structural complexity on the left half of the section.

With improved imaging of this seismic line and a further understanding of the structural style in this area, the structural geologist changed the structural interpretation of the velocity model. After revising the structural interpretation using other 2D lines from the area and the surface geology, the new velocity model resulted in an improved seismic image. The seismic image with the new structural velocity model is shown in Figure 2c.

Improved imaging resulted in a change in the structural-geology interpretation. The improved structural-geology interpretation resulted in further improvements in the seismic image.

Conclusions

Structural-geology constraints improve seismic imaging in both time and depth migrations. Close interaction between data processor and structural geologist brings continuous improvement to both geologic understanding and seismic imaging.

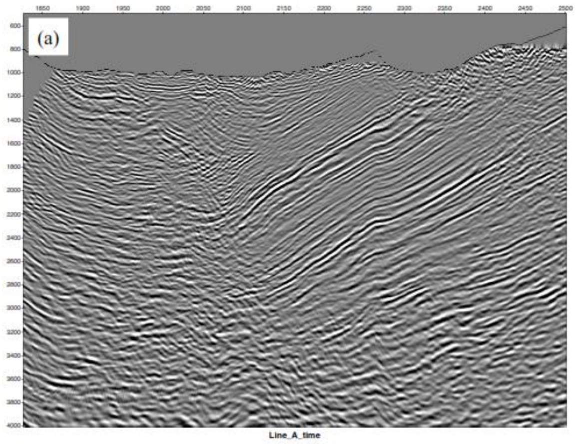
References

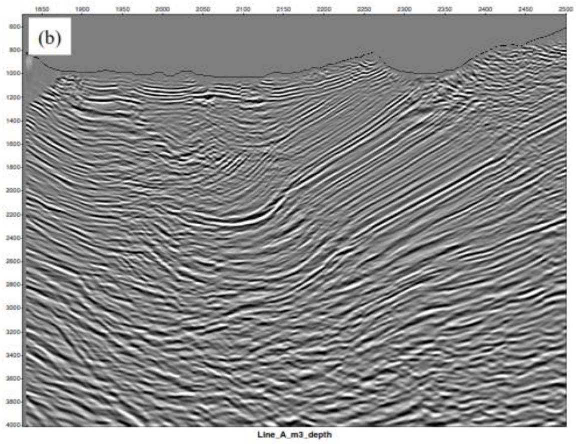
Stratton, M.A., 2004, Impact of the effects of anisotropy in Canadian foothills exploration: A case history: 74th Annual Internat. Mtg., Soc. Expl. Geophys.

Vestrum, R.W., Dolgov, V., Wittman, G., Csontos, L, and Gittins, G., 2011, 3D seismic imaging over two structurally complex seismic surveys in the foothills of Pakistan: First Break **29**, no. 4, 61-70.

Vestrum, R.W., and Lawton, D.C., 2010, Reflection point sideslip and smear in imaging below dipping anisotropic media: Geophysical Prospecting **58**, 541–548.

Vestrum, R. W., Lawton, D.C., and Schmid, R.S., 1999, Imaging structures below dipping TI media: Geophysics, **64**, no. 4, 1239-1246.





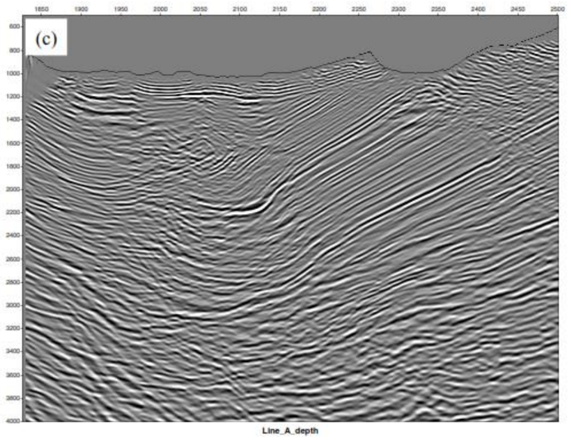


Figure 2: Migration results for 2D dataset from a thrust-belt environment. (a) Prestack time migration scaled to depth for comparison. (b) Anisotropic depth migration using simple structural velocity model. (c) Anisotropic depth migration using revised structural velocity model.

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