Interpretive input to Foothills depth migration

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2005 CSEG National Convention

Summary

Foothills depth imagers, this author included, continually stress the importance of interpretive input to velocity models used in Foothills depth migration. If done properly, the insights an interpreter gains from velocity model building is well worth the additional interpretation effort. In the worst case, the interpreter will put far more effort than required into the velocity-model interpretation and/or the depth imager will not have enough geologic information to properly constrain the velocity model. The goal of understanding the data requirements for and taking a team approach to model building is to produce an optimum seismic image for minimum effort with the maximum learning opportunity for all of the team members.

Introduction

Anisotropic depth migration in thrust-belt environments has the greatest potential to provide the clearest image and most accurate lateral position of subsurface (e.g., Ball, 1995; Vestrum and Muenzer, 1997; Di Nicola-Carena, 1997; Ferguson and Margrave, 1998; Vestrum et al., 1999; Stratton, 2004).

Depth migration in thrust-belt environments like the foothills of the Canadian Rockies requires an interpretive approach to building a depth-migration velocity model (Vestrum et al., 2004). 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.

It is reasonably easy to see our need for geologic input, but, if we are to succeed at effectively building an accurate velocity model within a reasonable time frame, we must optimize our process for collecting and integrating the geologic input to the velocity model. If we are to get the most out of the model-interpretation process, we must consider questions like:

- What kinds of interpretive input are important?
- How much detail does the depth imager require?
- How do we review the interpretation during the velocity-updating process?
- What is our process for including input from the structural geologist?

Some of the answers to these questions will vary on a project-by-project basis, but I attempt here to outline a framework for communicating the geologic requirements of a depth migration project.

Anisotropic depth migration gives the clearest image and most accurate position of subsurface structures. If the model-building process is managed properly, the interpreter will also reap the benefits of improved communication with the structural geologist and a deeper understanding of the geologic setting and the structural trends of the area.

The nitty gritty

The beginning of a project is where the requirement of geologic information is the heaviest. The initial wish list for input data includes the basics: well-log data, horizon picks, and cross sections showing the major geologic units.

A cross section of the regional structural style is useful to identify the major geologic boundaries that separate different velocities or dip orientations. The most common example of a cross section used to guide the velocity-model interpretation is a coloured seismic section with the major stratigraphic boundaries and faults drawn on. It is important to interpret the shallow seismic events because we will want to model the geology through which the seismic energy passes before imaging the subsurface targets.

In a 2D project, a depth imager may be able to get all of the initial interpretation horizons from the cross section mentioned above. With a 3D depth-imaging project, the imager will definitely need 3D horizons of the major velocity boundaries. Whether in 2D or 3D, the trick here is in how to decide on the level of accuracy required in the interpretation. The geologist may have picked a dozen sedimentary cycles over the first kilometre of rock below the surface, but many of these layers may be thinner than the seismic wavelength and have such small velocity contrasts as to have a limited affect on the seismic data. The tricky thing with interpreting horizons is in striking the balance between excessive effort for limited return and not enough interpretation information to properly describe the dip domains or the major velocity boundaries. One way to consider velocity sensitivity of the model is to think about the difference in depth that one would observe if a layer was left out or a boundary was shifted. If the velocity contrast is 5% and the layer is 50 m thick, then leaving the layer out of the model would result in a 2.5 m depth error (5% of 50 m). Synthetic models and exploration data examples further illustrate the sensitivity of the seismic image to various changes to the velocity model.

The important thing to remember about the initial velocity model is that it is best to keep it simple. The horizons will shift when translated into the depth domain and the model-building team can decide at any point during the model-building process to add in new horizons for additional velocity boundaries or for more control on the dip of the anisotropic strata. If the depth-migration project goes well, even the intermediate results should show steep-dipping events that were not imaged on the time volume and the model-building team will want to re-interpret some of the key horizons with this new information.

For well-log data, ideally the depth imager would have these data in both digital and paper form. On paper, a synthetic seismogram with the major tops and a velocity curve are invaluable to get an initial view on the stratigraphic setting. Digitally, sonic and calculated velocity curves are nice, but essential are tops with consistent picks and naming conventions for the area. Using velocity curves from wells can be problematic because the sonic tool will typically measure the velocity at some angle oblique to bedding in structured settings. The best control on a velocity model is in the correlation between the seismic wavelet and the stratigraphic top from the well. We cannot produce a depth migration with flat image gathers and accurate ties to the well depths without a reasonable estimate of the anisotropic parameters for the model. The most useful information we get from the well-log data is the depth tie, which is a key constraint on the velocity model.

Model updating

The structural geologist is a key player in collecting the raw information required above. Far more than that, the structural geologist should take a key role in the model-building team. As the model-building process progresses, there will be times when improved imaging requires a modified interpretation of key velocity boundaries and there will be times when imaging pitfalls can only be overcome with a better understanding of the geologic structures. Stratton (2004) showed how using a structural-geology constraint changed the dip interpretation in the model and resulted in a more accurate lateral position of her exploration target and improved imaging of the steep back limb.

A model-building team should consist of two interpreters and two depth imagers. On the interpretation side, one can take the role of structural interpreter and the other can focus on the exploration objective. This is typically split out along the discipline lines of geology and geophysics On the depth-imaging side, one team member can focus on applying the model updates and migration parameter testing. The other imaging team member should be a senior depth imager that can co-ordinate the model interpretation. He or she would ensure that new model interpretations are properly applied to the velocity model and that the whole team understands the sensitivities of the seismic image to the various parameter changes and the various imaging diagnostics used to guide the interpretation. The model-building team should decide together what are the realistic objectives for the project, agree on a project timeline, and decide on what criteria they will use to measure when they have reached the project objectives.

The team should meet at least once each week to review the current model interpretation and the imaging diagnostics from the depth-migrated volume. Between meetings, all team members should hold each other accountable for action items discussed at the previous meeting and ensure that everyone has the information needed to complete his or her task. For example, if the team needs input from structural interpreter on a particularly unconstrained region of the velocity model, the depth imager should ensure that the structural interpreter knows the region of interest and the detail required for the model update. The structural interpreter should then follow up with the depth imager and the imaging supervisor to make sure they understand the information and they can intelligently include the new information into the velocity model.

Interpretive model building can sometimes lead to a model-update dead end, where it seems that the team is making little progress toward an improved image with accurate well ties. Here is where a trial-and-error approach to a re-interpretation of the velocity model can help break out of a locally optimized model. The process works like this: build a few velocity models with alternative interpretations and run a limited output set of the volume for each velocity model. Compare the resulting outputs to find the new test model that offers the best image; this model may be a kicking-off point for an improved model-updating session. You may find that one of the trial models offers improved imaging of certain structures where another trial model offers improved imaging of structures at a different depth or position along a line. Here it is best to try to combine the two models to get the best of both images. Perhaps some lateral-variation of the velocities is required or perhaps a tweak of anisotropic parameters will help reconcile the two velocity problems. Schmid et al. (1996) diagnosed an anisotropy problem on the Husky/Talisman dataset, where structures with raypaths that cut across beds in the overburden required a different velocity to flatten the image gathers than structures with raypaths that run closer to parallel to bedding. This velocity-anisotropy diagnosis was later confirmed and the problem resolved in Vestrum et al. (1999).

Finalizing the model

Once the model-building team decides that they have met the objectives on the project, they are ready to finalize the model. All parties should insist that the depth imager and/or imaging supervisor write a detailed processing report. This report should include the major diagnostic displays that were generated during the process and examples of parameter tests. It is also important to capture the major turning points–if any–in the interpretation of the velocity model. If everyone contributes a few key points to the processing report, it can be a valuable learning document for future projects and future prospecting on the same volume. A good processing report also helps to show the detailed work that went into the project, helping everyone understand the value in the process.

Conclusions

Building a velocity model in a thrust-belt environment is an interpretive exercise that requires geological and geophysical constraints. A team approach to building the thrust-belt velocity model is the most effective

Anisotropic depth migration gives the clearest image and most accurate position of subsurface structures in thrust-belt seismic data. If the model-building process is managed properly, the interpreter will also reap the benefits of improved communication with the structural geologist and a deeper understanding of the geologic setting and the structural trends of the area.

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