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Creating a 3D Geologic Model for 2D Depth Migration in the Peruvian Andes

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SUMMARY

The exploration block is located in the northern part of Ucayali Basin, in the backarc of the Andes mountains. The exploration target is in a compressive structure with high-angle faults caused by the reactivation of a normal fault. Typical to many foothills exploration settings, the block has comprehensive 2D coverage but not 3D surveys at the present time.

The exploration team chose anisotropic PSDM for the seismic data to correct for the pull-up below the structure. The data was low in data density and high in noise content, which made data-driven tomographic inversion unstable. The interpretive model-building process needs as many geologic and seismic constraints as possible to converge to an optimum velocity model.

Our desire to impose additional geologic constraints to the velocity model coupled with our concern about having a consistent velocity model across the block led us to build a 3D model from which we could extract a 2D model for each individual line. The method was highly effective for lines parallel to dip across the crest of the structure, but the models extracted from the 3D volume for lines oblique to the structure required further attention.

Introduction

The exploration block is located in the northern part of Ucayali Basin, inside the Pachitea Sub-basin. In plate-tectonics terms the study area is located in the backarc of the Andes mountains, as illustrated in Figure 1. The exploration target is in a compressive structure with high-angle faults caused by the reactivation of a normal fault. Above the exploration targets is a broad monoclinal fold. The folding and faulting of the strata above the target imposes lateral velocity variation and dipping anisotropy, which caused imaging and position problems on the time-migrated images. This block has comprehensive 2D coverage. The acquisition design intentionally worked to avoid out-of-plane effects, by shooting the majority of the lines along the dip direction and strike lines over the crest of the monocline to tie the lines.

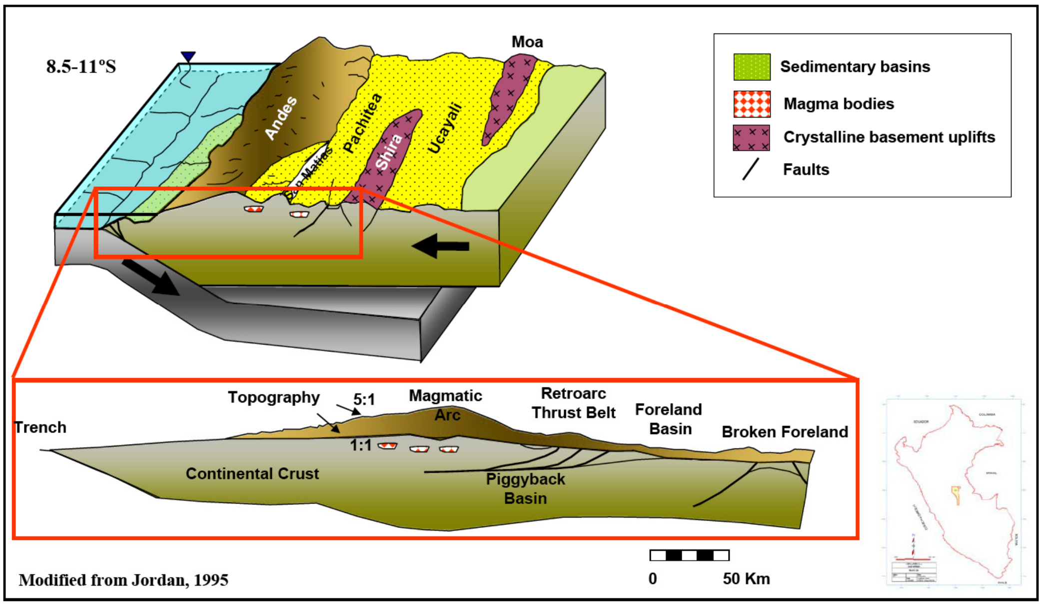

Figure 1 *Tectonic setting of the intramontane foreland basin (modified from Jordan, 1995).*

2D seismic data is still common in foothills areas due to rough surface conditions and surface access. The foothills of the Peruvian Andes has the added challenge of heavy vegetation to complicate field logistics. It is worthwhile improving technology and workflows for 2D data to ensure that resource companies can minimize exploration risks when faced with the limitation of 2D seismic coverage.

Concerns about potential imaging problems and lateral-position errors caused by velocity heterogeneity and anisotropy led the team to apply prestack depth migration (PSDM) to correct for these wave-propagation effects. Another strong motivation for the application of PSDM was to have the seismic data mapped into the depth domain, so the vertical scale of the seismic section was in depth instead of time. If the velocity model on a 3D volume images reflectors that tie the well depths and the velocity model follows the geologic strata in a spatial sense, the seismic depths in unexplored areas of the volume can be reasonably predictive for the depths of new drilling targets (Vestrum et al, 2009). On this block, we were concerned that underconstrained velocity variations from line to line could create false structure in the final 3D map of the reservoir.

Seismic data from foothills areas tends to be low in data density and high in noise content, which often makes data-driven velocity-model-building methodologies unstable. The model-building process needs as many geologic and seismic constraints as possible to converge to a velocity model that optimizes the seismic image and maps the seismic reflectors to depths that correlate with the geologic depth from wells. For this project, the processors worked closely with the interpretation team and structural geologist to ensure that the final model was geologically constrained in 3D.

Our desire to impose additional geologic constraints to the velocity model coupled with our concern about having a consistent velocity model across the block led us to build a 3D model to use for 2D depth migration of each individual line.

Method

The velocity-model interpretation team consisted of a structural geologist, the seismic interpreter, and a seismic quality specialist from the exploration company and two processors specializing in depth imaging from the data-processing company. As mentioned above, with the low signal-to-noise ratios on the data, the team used a geologically constrained, interpretive approach to building the subsurface velocity model for depth migration, as described by Vestrum (2007).

Starting with a few 2D lines and the regional structural interpretation of the structure (Figure 2), the data processors iterated through a range of velocities and gradients to get an approximate velocity profile for the data. The second step was to calibrate the velocity model so that the migrated reflector depths tied the well tops without further depth scaling. Historically (Schultz, 1998), depth migration required additional depth scaling after PSDM, but since correcting for seismic anisotropy in depth imaging, we expect the migration velocity to yield reflector depths that are accurate to within a seismic wavelength or less (e.g., Kirtland Grech et al, 2003, Isaac and Lawton, 1999, Vestrum et al, 1999).

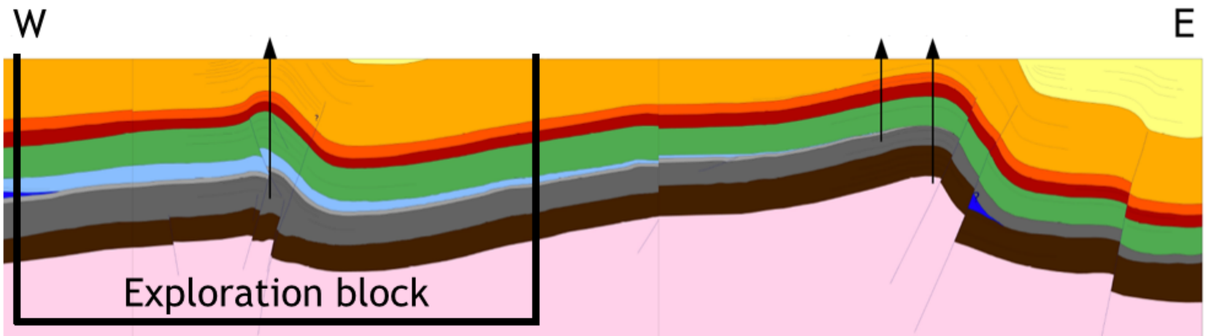

Figure 2 *Regional cross section from structural modelling showing the exploration block.*

The initial phase of the project was just three lines: the line with an existing well for calibration, the line with the proposed location for a new well, and the strike line that tied the two lines. With these three lines, there was no problem treating each line separately. Once the second phase of the project began, we saw the need to build a 3D velocity model for efficiency and for consistency in the velocity structure across the block.

The initial 3D velocity model used only the interpretation from the first three lines from the initial phase, because those were the only three lines that we had depth migrated with a calibrated velocity model. We used horizons interpreted from the lines as velocity boundaries and as a guide to calculate the dip of the TTI anisotropy for the anisotropic velocity model. We then extracted a 2D velocity model, including velocity and anisotropy parameters, from the 3D volume for each 2D line in the project. The 2D velocity model, in depth, was then used to depth migrate each 2D line. Once in depth, the lines could be loaded into the 3D interpretation tool to further refine the structural model and the team could continue with iterative velocity-model updates. Figure 3 shows a 3D image of one of the velocity boundaries interpreted on the 3D volume partway through the model-interpretation process.

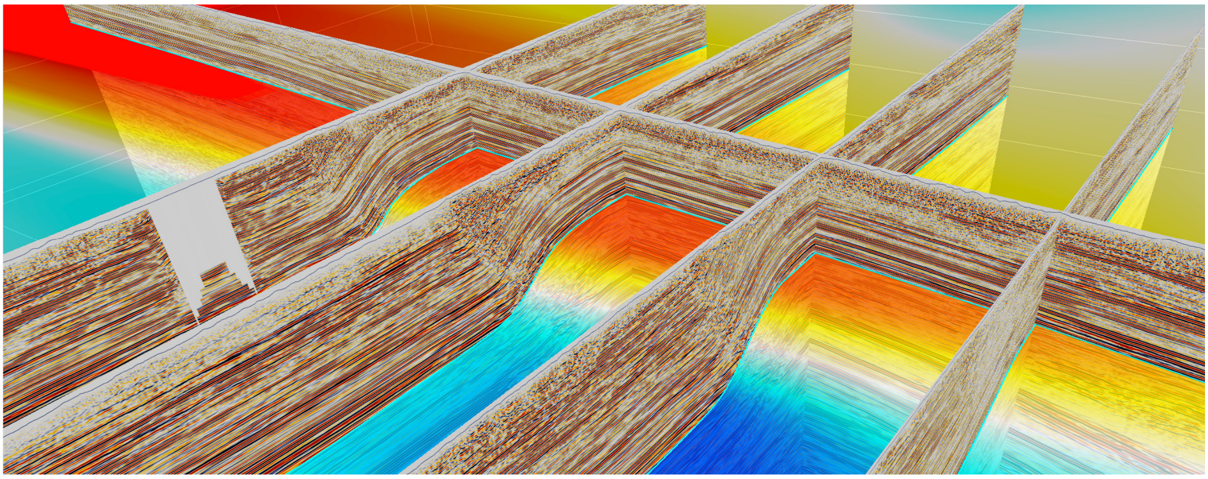

Figure 3 *Interpretation display of 2D lines used to interpret the 3D model. The red areas are structural highs and the blue areas are structural lows. The cyan line running along each 2D line is where the interpreted horizon intersects the 2D line.*

Results

One pitfall we encountered with this method was in the lines oblique to the structure. (Fortunately, there were only a few lines that did not follow the dip direction or followed the crest of the structure along strike.) Since reflection energy was coming out of the 2D acquisition plane on these lines, the velocity model extracted from the 3D velocity model did not match the shape of the structures in 2D. The interpretation team is experienced with interpreting 2D seismic data in foreland basins, so we decided to optimize the image rather than holding strictly to the 3D model. For the velocity models on the oblique lines, we adhered to the velocities and gradients from the 3D model, but we modified the structural shape of the velocity boundaries to reflect the shape of the reflectors on the depth-migrated sections. Even though the positions of these reflectors are inaccurate because of out-of-plane issues, the velocity model that followed the reflector positions produced a more coherent image than the velocity model that honoured the 3D structure.

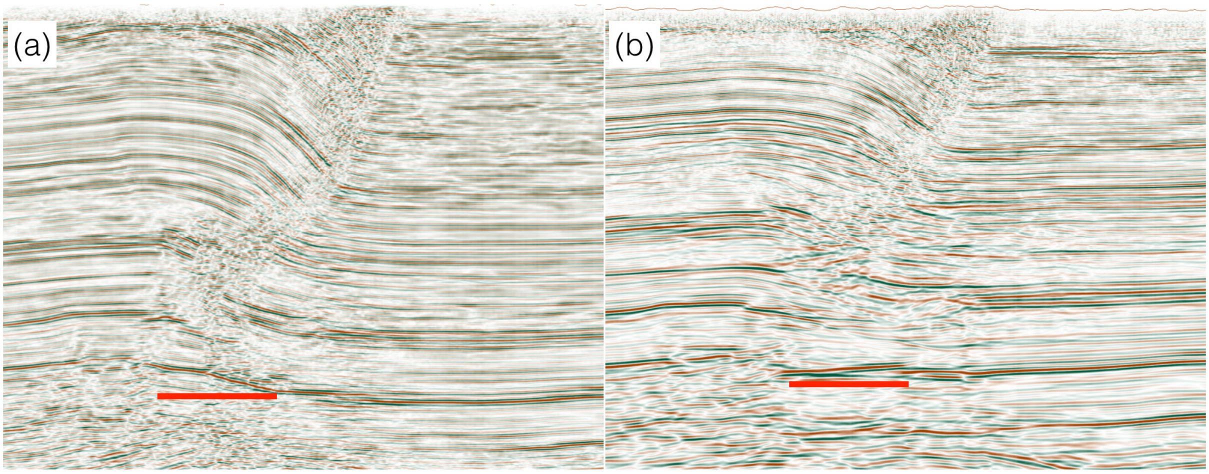

Figure 4 *2D dip line with (a) prestack time migration displayed in time and (b) prestack depth migration displayed in depth. The horizontal red line is drawn just below the footwall reflector, showing the high-velocity pull-up in time (a) that is corrected in depth (b).*

Figure 4 shows a comparison between the time and depth images over the block. The differences in image quality between the two images are subtle, but the depth image (Figure 4b) is displayed at the depth scale from the 3D velocity model that was used to migrate the data. The PSDM corrects for vertical and lateral-position errors caused by the anisotropy in the dipping layers and the lateral velocity heterogeneity that results from going off of the structure. The red line shows the interpreted position of the footwall on both Figure 4a and Figure 4b. The velocity pull-up on the footwall reflector in Figure 4a is from the lateral velocity variation below the structural high.

Conclusions

Depth imaging is, generally, an interpretive process. In this project, the iterations included further refinements of the geologic model, which, in turn, improved the velocity model. We build the velocity model in 3D as an additional constraint on the 2D models and to ensure consistency across the block for mapping the target.

The final 2D depth images minimized the velocity pull-up below the major structural high. When each 2D line was treated separately, small differences in the velocity model from line to line led to shifts up and down from line to line along the trend. The 3D model minimized misties at line intersections and eliminated any non-geological velocity variation along the block.

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