Integration of Geologic Data into Structural Imaging of the Andean Subthrust, Peru*

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Abstract

The prospectivity of the subthrust structures in the Ucayali Basin, Peru, has exploration uncertainty resulting from the velocity structure in the hanging wall of the overthrust. Given the structural uncertainty and the under-constrained velocity model in this complex-structure environment, we decided to reprocess the lines through to anisotropic depth migration. Geologic constraints not used in the original models, resulted in improved imaging of the subthrust features. Through the model testing, we observed that the closure on the subthrust prospects is robust even with a less optimal velocity model. With a depth-migration velocity model that is consistent in 3D across the grid of 2D lines, and a geologically constrained velocity model, we have increased confidence in the mapping of the subthrust structures.

Introduction

Block 107 in Peru is located within complex fold and thrust system of the Subandean Pachitea sub-basin. Exploration targets on the block focus on a large sub thrust play below the San Matias Fault (SMT). A network of 2D lines cover the block, with the predominant orientation at right angles to the major thrust.

Early in the interpretation phase, it was recognized that anisotropic pre-stack depth migration would be necessary to correctly image the subthrust structures. The challenge in the depth migration is interpreting the velocity structure in the hanging wall of the fault, to ensure that the time pull-up below the fault is not overcorrected or undercorrected by the depth-migration velocity model. These data have a low signal-to-noise ratio where the geological complexity is the highest. Combined with low fold near the surface, the depth-migration velocity model is underconstrained. Geologic constraints were used to build the velocity model and iteratively tested varying velocity in the different layers of the structure to optimize the imaging. We further constrained the model by interpreting the velocity structure for the 2D lines in 3D, in an effort to minimize velocity variability in the strike direction.

Limited well data and geological fieldwork were used in the initial PSDM work. The initial interpretation of the regional detachment, based on field data, carried higher velocity rocks in the hanging-wall thrust, which is reflected in the velocity models. Recent palynology work along the

SMT and seismic correlations indicated the detachment is in a younger stratigraphic unit with corresponding slower velocities. This led to a second round of depth migration work, which would more accurately reflect the geology.

Geologic Setting

The Pachitea sub-basin is part of the Ucayali Basin in the Andean foreland (Figure 1) of Peru. The sub-basin is defined by the thick-skinned basement uplifted Shira Mountains to the east and the Andean Mountain front to the west. A prominent topographic feature in the Pachitea sub-basin is the San Matias Mountains, which represents the surface expression the San Matias Thrust (SMT).

The Ucayali basin contains a thick sedimentary sequence of Paleozoic through Tertiary rock, which overlies the Precambrian basement. Within this sequence are the proven source rocks of the Triassic-Jurassic Pucara and Permian Ene formations. Multiple reservoir targets include the Vivian, Agua Caliente, Raya and Cushabatay sands of Cretaceous age. Discovered hydrocarbon accumulations on trend have been in thrust-related hanging-wall structures. The footwall play has not been tested. The structural style of the SMT is the result of the interaction between inversion of Paleozoic high-angle normal faults and overlying thin-skinned tectonics (Espurt et al., 2008; Hermoza et al., 2006.).

As illustrated in Figure 2, the thrust fault above the exploration target carries clastic strata to the surface that dips between 30° and 45°. With 2.0 to 2.5 km of dipping clastics above the exploration target, tilted transverse isotropy (TTI) can cause lateral-position errors on the seismic reflectors and velocities from moveout analysis that create errant depths on the final migrated image. (Schultz, 1999; Vestrum et al, 1999; and Vestrum and Lawton 2010).

Model Building Method

The interpretation team observed velocity pull-up below the fault on the PSTM seismic sections. With the geologic complexity above the target reflectors, the team decided to use prestack depth migration (PSDM) instead of a simple vertical time-to-depth conversion. PSDM has seismic-imaging constraints and the potential to improve the image coherency below the overlying geologic complexity. The velocity model interpretation included anisotropy, assuming a higher velocity parallel to bedding than in the direction perpendicular to bedding, and we interpreted TTI dips based on the structural model.

With limited prestack information for velocity analysis in the shallow section where the velocity structure is the most complicated, we iterated through 4 to 10 different velocity models on each line to optimize the imaging below the fault. To further constrain the velocity model, we correlated the structural interpretation from line to line in a 3D sense, and kept the velocity constant for a given rock unit at the same depth.

We observed that the same rock unit required a lower velocity to optimize the imaging when the thrust fault carried it to a shallower depth. We concluded that the velocity is dependent on both compaction gradient and lithology, which would explain why the same rock unit would exhibit a lower seismic-imaging velocity at a lesser depth. Another explanation may be that the lower velocity in the hanging-wall rock layers could be due to fracturing.

Results

In the initial model-building process, there was concern about how much of the footwall structure was due to velocity pull-up and how much of the structure was actual structurally thickened reservoir rock. We tested the velocity model with high velocities in the hanging wall to see how the seismic imaging and the reflector depths would respond to the higher-velocity scenario. The objective of this model test was to see how the structure would be shaped if there were higher velocities in the hanging wall of the fault. We evaluated the results based on the geophysical criterion of how well the seismic responded to the different velocity models and the geological criterion if the shape of the footwall structures made geologic sense in each case.

Figure 3 shows the two models overlaid on the seismic images for one of the 2D lines. Figure 3a represents the high-velocity scenario, and Figure 3b represents the velocities from optimizing the image. Note that with the higher velocities in the hanging-wall (Figure 3a), there is still a footwall structure at the top of the green layer. Comparing the imaging of the hanging-wall reflectors between the two models, there is more seismic noise in the red zone of the hanging-wall on Figure 3a and there are more coherent reflectors on the hanging-wall of the seismic section in Figure 3b.

Conclusions

This area of the Peruvian Andes is geologically complex, yet has strong seismic signal quality. Even in the footwall of the major thrust, we were able to interpret many structural details on the final seismic images. We took an interpretive approach to depth migration, creating a structural model over the entire block so that the velocity structure could be consistent from line to line, avoiding the pitfall of creating artificial velocity structures. We tested a variety of models, to avoid interpretation bias to the final depth structures, and we found that the closure on the footwall structures is robust, and deviating from our optimized model resulted in degradation of the seismic image. The final interpretation of the block is integrated with the velocity model interpretation supported by palynological data from the field and regional seismic correlations.

Acknowledgements

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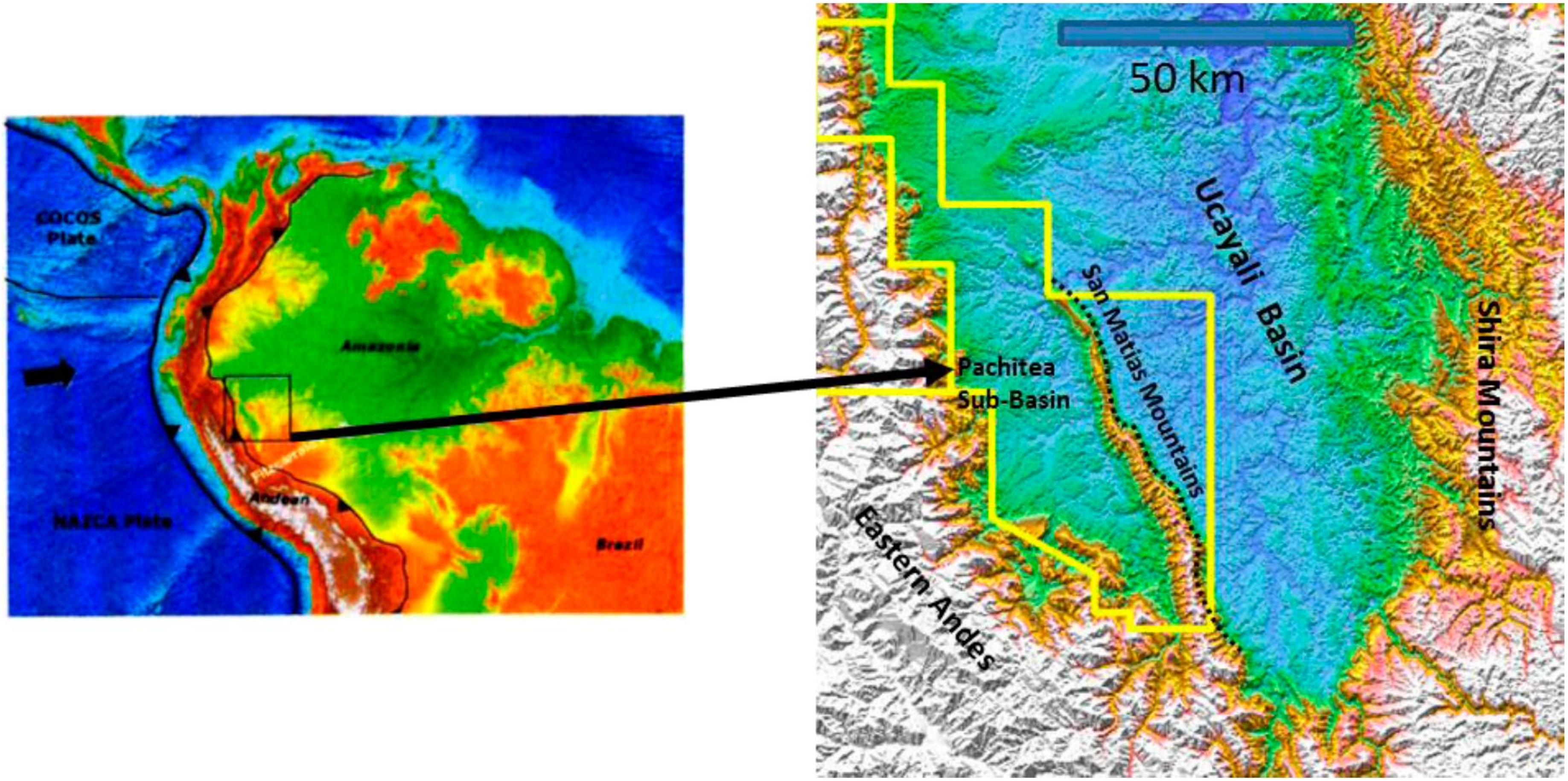

Figure 1. (Left) Location of study area. (Right) DEM data illustrating morphological features in the Block 107 area. Dashed line represents the surface expression of the San Matias Fault.

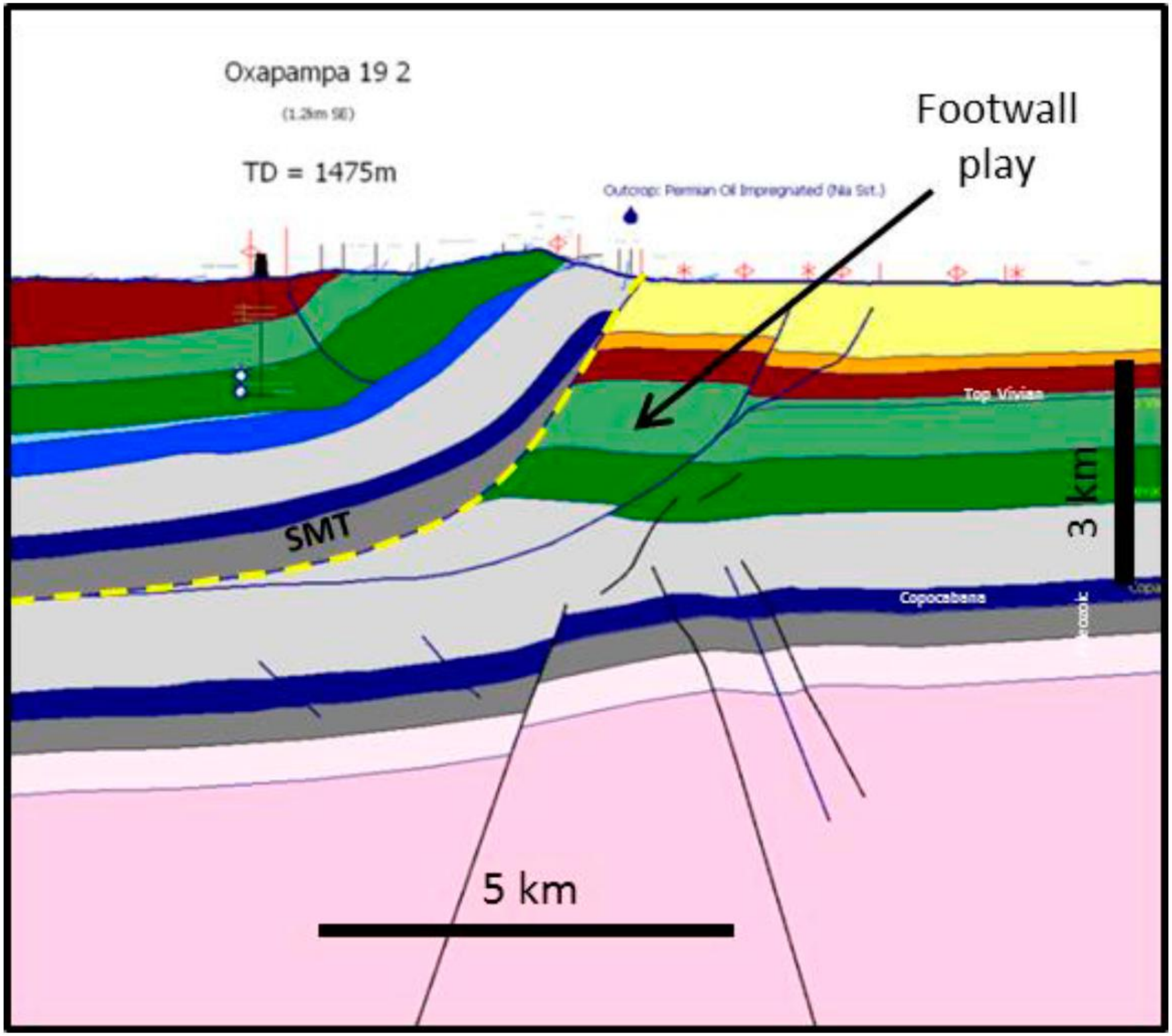

Figure 2. Schematic of original interpretation showing Paleozoic in the hanging wall of the SMT.

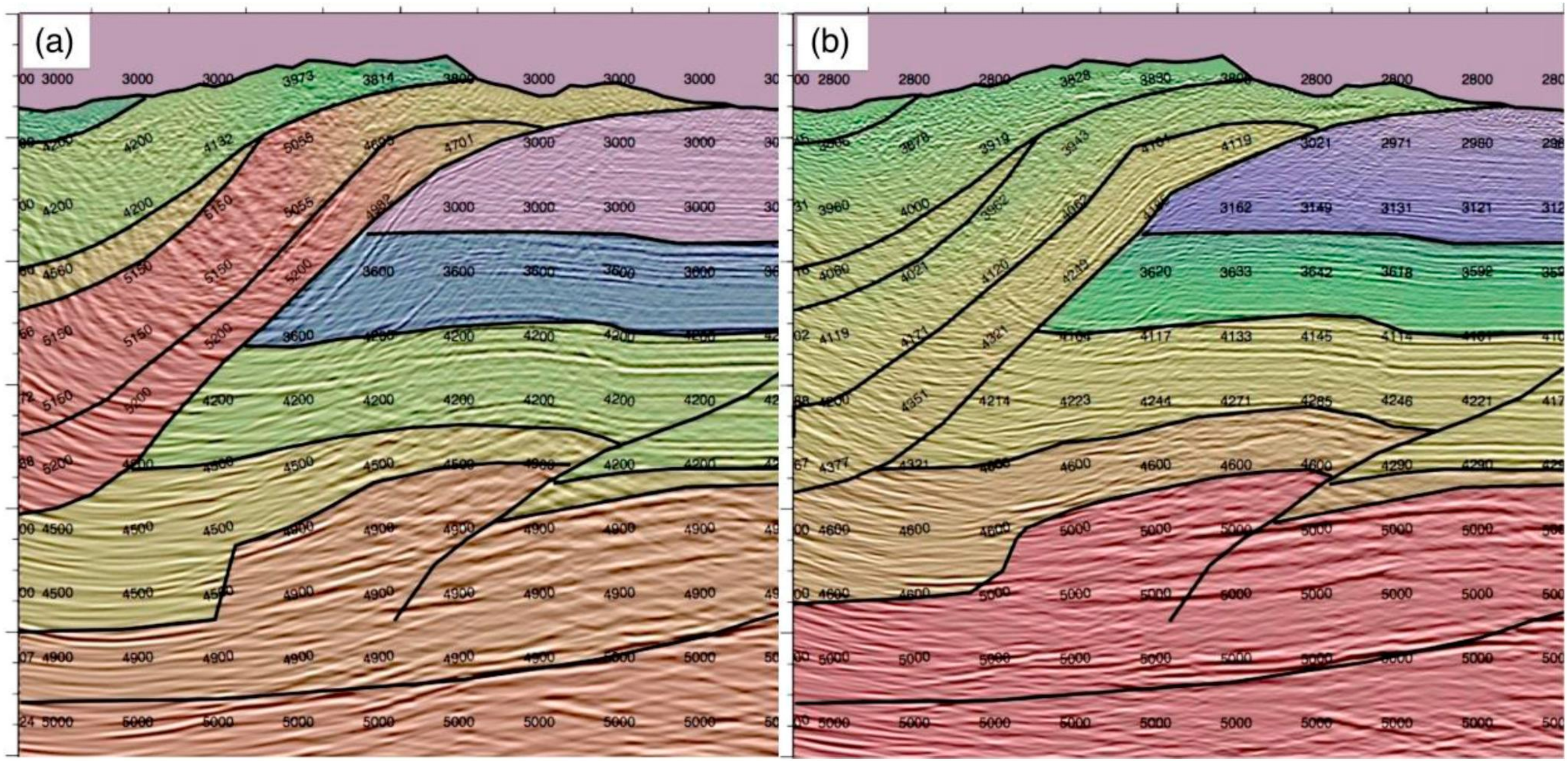

Figure 3. Velocity-model overlays for the two model scenarios: (a) high velocities in the hanging-wall to determine if the footwall structure is a velocity pull-up and (b) velocities in the hanging-wall from seismic analysis constrained by the structural model. The colour scale represents the velocity in a rainbow colour scheme, from violet at the low velocities to red at the high velocities. The grid of numbers shows the exact model velocity at each grid point. The orientation of the numbers is parallel to bedding of the TTI model dip, to give an indication of the dip model for the anisotropic depth migration.