3D Seismic Imaging in the Pakistan Foothills: A case history

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Summary

In a tectonically complex area of northwest Pakistan, MOL Pakistan and its partners acquired two 3D seismic surveys. Extreme topography led to irregular shooting geometry. Varied surface access over this terrain required a mix of vibroseis and dynamite source types to maximize subsurface coverage. With the combination of difficult surface conditions over a structurally complex subsurface, the data processing and merging of these two surveys required close attention to detail throughout the processing sequence, and we had to rely on the most robust algorithms in the data-processing toolkit. There was no single technology that stood out in the processing, but careful attention to details in the application of the fundamental processes created a readily interpretable seismic volume.

Introduction

The project area is on the Kohat Plateau of northern Pakistan, as shown in Figure 1. The geologic setting of the exploration block is described in detail by Lorincz et al (2008) and Wilson et al (1993). The regional structures are three-dimensional in nature resulting from transpressional forces in the collision zone between the Eurasia and India plates. In addition to compressional and transpressional tectonics, structures are influenced by the presence of ductile salt and clay diapir systems.

From the shaded relief in Figure 1, one may observe the mountain-front setting with significant ranges to the north and west of the project area that result from the multiple tectonic forces.

Figure 1: Location of project area highlighted by the green circle. The shaded relief shows the rough topography of the region and evidence of significant compressional tectonic activity.

MOL Pakistan contracted TBI to process and merge two 3D seismic surveys located in Exploration Block TAL in NWFP Province of Pakistan. The main aim of the project was to get a more detailed structural image at the reservoir level. The problems to overcome in this project area include:

Complex thrust tectonics
Weathering and elevation corrections
Shot-generated noise
Irregular shooting geometry from rough terrain and surface conditions
Merging of two oblique surveys with multiple source types

The problems listed above are typical to thrust-belt surveys. We took a toolbox approach to solving each problem as it arose, using a combination of recently developed technology and fundamental processes established by generations of trial-and-error in foothills exploration.

In processing 3D seismic data from this tectonically complex area, no single technology stood out as the “magic bullet” to improve the image, but careful attention to details in the application of the fundamental processes created a readily interpretable seismic volume.

The 3D surveys

The two seismic surveys, Manzalai and Makori, were acquired with a mix of dynamite and vibroseis, depending on surface access, so the two source types needed to be phase-matched before the two surveys could be merged together. Figure 2a shows the source and receiver layout of the two surveys. Throughout the surveys there are gaps in the source lines where surface conditions limited the surface access for source locations. Figure 2b shows the elevation over the survey area. Note that the orientation of the topographic ridges varies along the survey area. The rough topography affected the positioning of the shot points, as shown in Figure 2a, and 1000 m of elevation variation means that we need to migrate these data from a rough topographic surface with strict quality control over weathering statics.

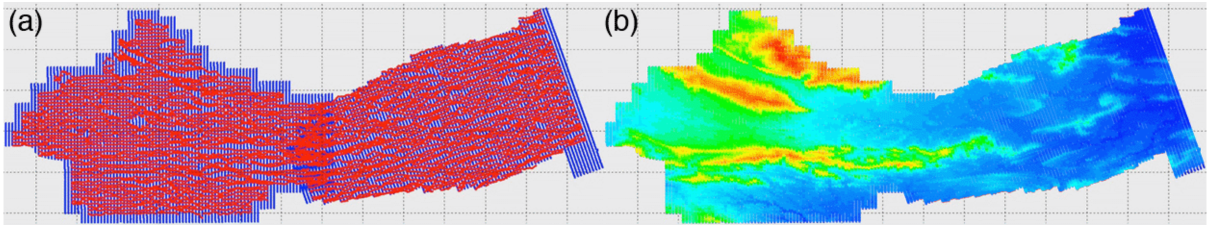

Figure 2: (a) Shot and receiver map for both 3D surveys. Blue indicates receiver locations and red indicates shot locations. Variable shot-point coverage depends on surface conditions. (b) Elevation map. Elevation ranges from 500 m (blue) to 1500 m (red).

The shooting geometry is spatially irregular and the elevation variation is large. Kirchhoff migration is the most robust seismic-imaging algorithm in the processor’s toolkit. It acts as a natural interpolator in irregular geometries and methods for Kirchhoff prestack time migration from surface topography are well established (e.g., Gray and Marfurt, 1995). The numerical efficiency of the algorithm combined with currently available computing technology allows us to run dozens of prestack migrations to be used in velocity analysis, as discussed in detail below.

Merged volumes

To merge the two source types over the two surveys, we implemented a process called model-based wavelet processing (MBWP), which is a technique for modelling the seismic wavelet. This process accounts for the effects on the wavelet during acquisition and processing so that we can accurately predict the shape of the wavelet, and use this prediction to correct data to zero phase. Two independent filters were derived one for dynamite and one for vibroseis for each survey and were applied prior to the data merge.

Another consideration on the merge of the two volumes is the statics calculation. We calculated one refraction-statics solution from the first breaks throughout the model. Once we had a phase match between the two source types over the two surveys and a refraction-statics solution, we calculated residual statics over the entire survey.

Prestack time migration

Kirchhoff prestack time migration is the current workhorse of seismic imaging tools in land environments. Although new seismic-imaging technologies continue to emerge with great potential to reduce exploration risk, the stability and efficiency of the well-established methods are especially needed in foothills seismic imaging (Vestrum and Gittins, 2009). This quote from French (1990) continues to ring true 20 years later: “In practical seismic imaging, we don’t throw older technology away when new processes take over.”

Kirchhoff migration is a summation process. Interpolation happens naturally within the algorithm as input samples are summed over the migration operator. Irregularities in shooting geometry and rotation of the acquisition grid into the merged orientation are inherently managed through the Kirchhoff-migration process.

This velocity-analysis methodology is illustrated by the screen captures from the velocity-analysis program, VELANAL from Techco Geophysical, shown in Figure 3. Each of the 70 constant-velocity prestack migrations generated two types of output: (1) full migrated section for each control line and (2) migrated image gathers for each analysis point along the control lines.

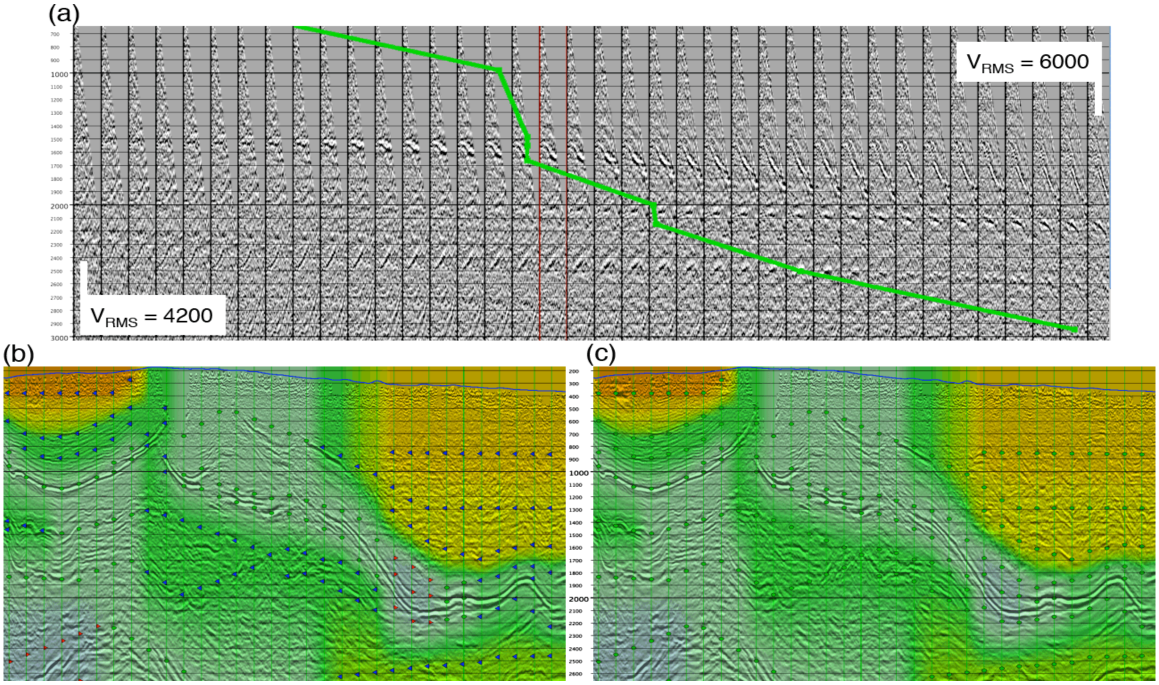

Figure 3: Interactive PSTM velocity analysis. (a) Image-gather display showing a single CDP migrated over 70 velocities. Velocity picks shown in green. (b) Stack panel display showing one velocity panel. Green dots are picks made on the current panel. Red and blue triangles indicate picked velocities higher and lower than the current panel, respectively (c) Composite display. The colour overlay represents the picked velocity field.

The image-gather window (Figure 3a), shows a single CDP image gather migrated at all 70 different prestack-time-migration velocities. In low-signal areas, we went to the stack panel window (Figure 3b) where we animated through all of the constant-velocity panels to assess reflector coherency. This analysis required collaboration with the interpretation team who learned about the velocity sensitivities of the image.

The final imaged volume is shown in Figure 4. The irregularity in surface coverage is evident by the gaps in the near-surface image. We were able to image reflectors throughout the seismic volume, and the image slices in Figure 4 show the significant complexity of deformation in this area.

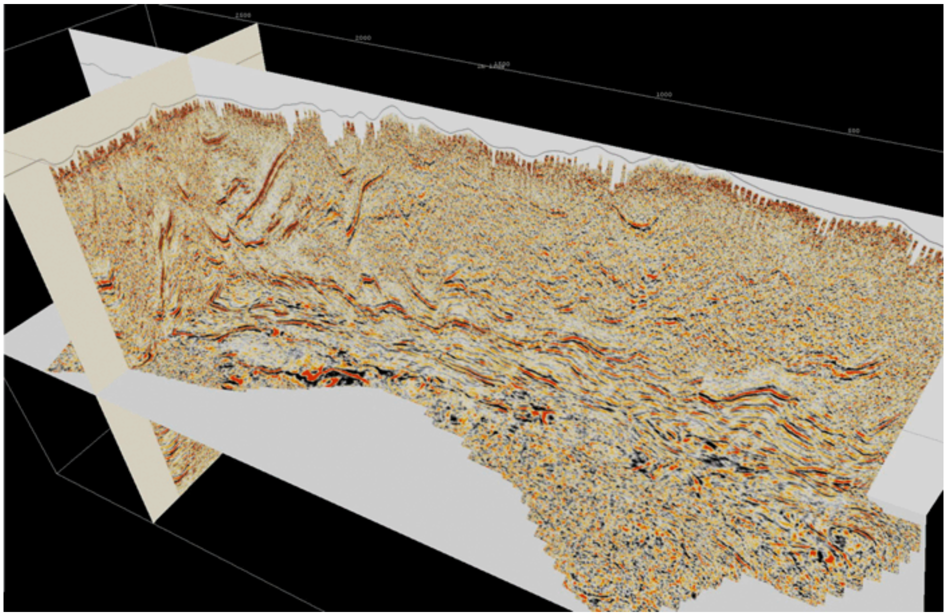

Figure 4: Slices through the final 3D PSTM volume showing structural complexity.

Conclusions

Seismic data processing and merging 3D seismic data volumes with multiple source types in this tectonically complex area required the most robust algorithms in the seismic toolkit to create an interpretable seismic-image volume. No single technology or technological advancement could improve the image as much as careful attention to parameterization and quality control in the application of the fundamental processes.

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References

Gray, S., and Marfurt, K., 1995, Migration From Topography: Improving the Near-Surface Image. Can. Journ. Expl. Geophys., **31**, 18-24.

French, W., 1990, Practical seismic imaging. The Leading Edge, **9**, no. 8, 13-20.

Lorincz, K., Ali, A., Csiki, I., and Csontos, L., 2008, Tectono-stratigraphic Framework of TAL Block, Pakistan Based on Seismic Interpretation. 70th EAGE Conference & Exhibition, Extended Abstracts, P264.

Vestrum, R.W., and Gittins, J.M., 2009, Technologies from foothills seismic imaging: replacements or complements? First Break, **27**, no. 2, 61-66.

Wilson, W.P., Sercombe, W.J., Drowley, D.D., Van Nieuwenhuise, R.E., Albertin, M.L., and Stratton, M.A., 1993, Structure Identification in a Deformed Belt – A Wrench System in Pakistan. 55th EAEG Meeting & Technical Exhibition, Extended Abstracts, A028.

Zhu, J., Lines, L., and Gray, S., 1998, Smiles and frowns in migration/velocity analysis. Geophysics, Soc. of Expl. Geophys., **63**, 1200-1209.