

Improved 3D Seismic Imaging Through Depth Migration and Tomography: An Indonesia Case Study

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Project Setting

TGS has vast seismic experience in the Asia-Pacific region, including acquisition and advanced time and depth processing. Here we present a case study of a recently completed successful project in the Tarakan Basin, consisting of a highly prospective and extensive play fairway, which includes a recent gas discovery. Understanding the complex structural and stratigraphic setting of the important oil and gas province in this basin offshore East Kalimantan Indonesia is necessary for prospect delineation and well planning.

Deposition in the Tarakan Basin began in the Middle Eocene. The current structure of the basin consists of NW-SE trending folds and NE-SW trending faults. Potential reservoirs are Pliocene – Lower Miocene fairly compacted sands and shales, and some carbonates.

TGS has completed Phase 1 (1625 km²) of a 3D depth imaging project, shown in Figure 1, over this area targeting the region from the seabed to five seconds (two-way time). Phase 2, totalling 1831 km², is in progress

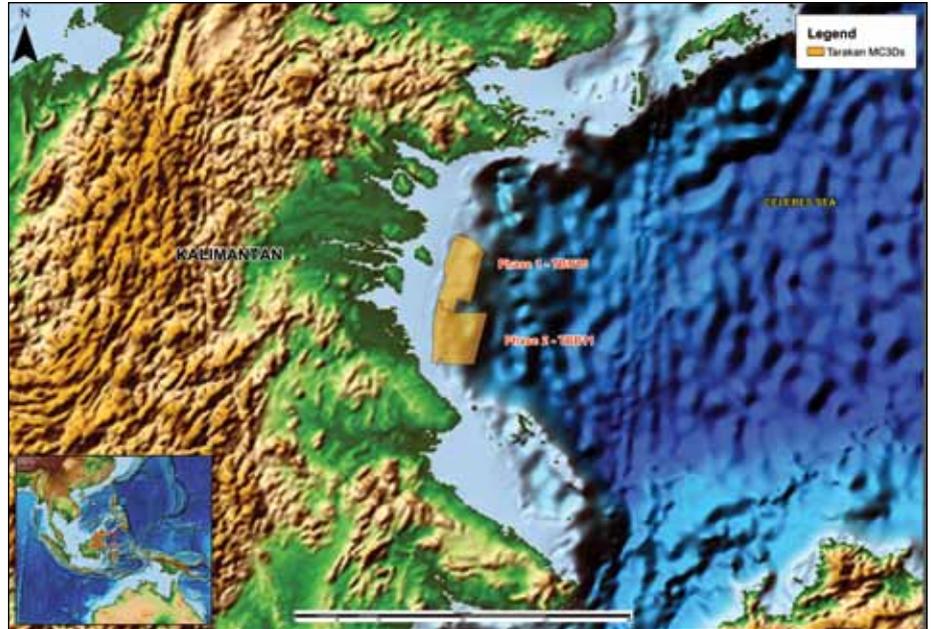


Fig. 1. 3D survey area.

and will incorporate well information to derive well-tied anisotropic pre-stack depth migration. The processing objective of Phase 1 was to improve through tomographic velocity model refinement and high-resolution

depth migration the imaging of structural and stratigraphic traps in a listric growth fault, deltaic/shelf depocentre setting. In this geologically complex area, amplitude anomalies are found within the thin reservoirs

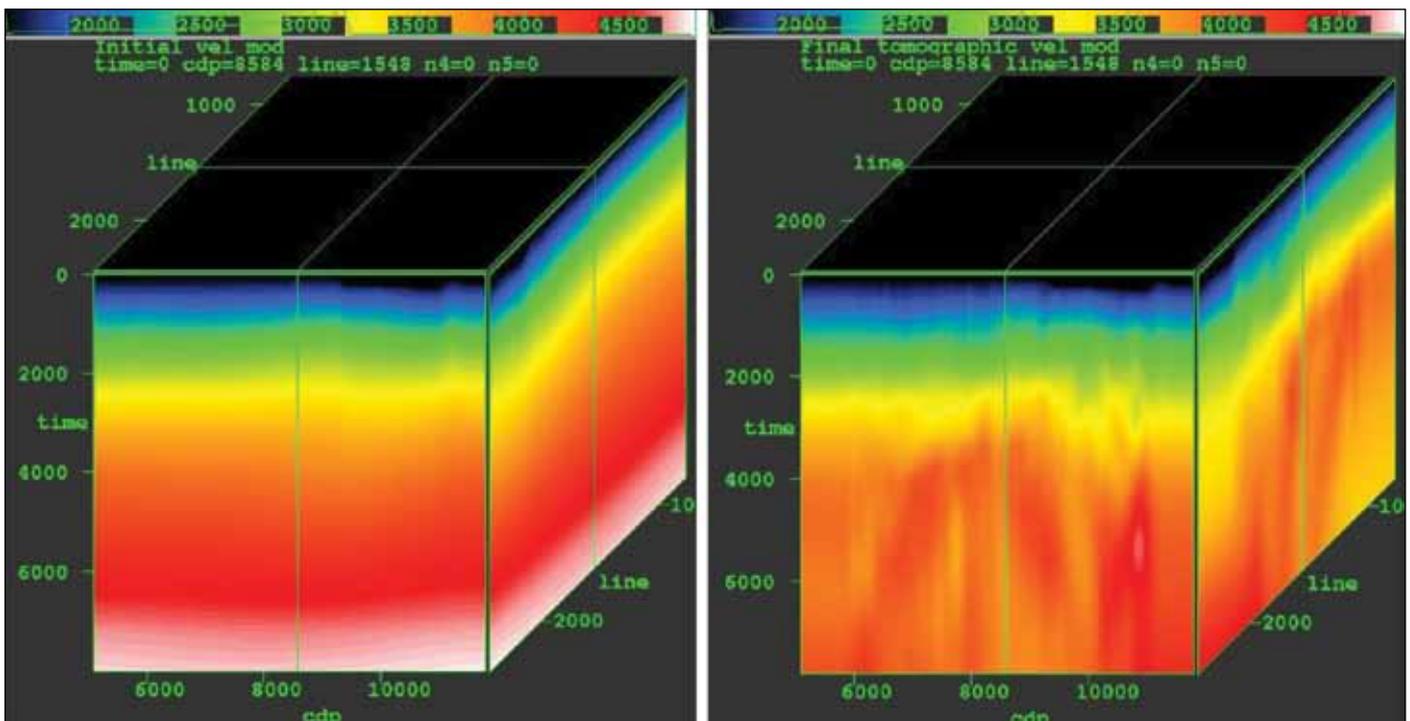


Fig. 2. Left: Initial depth migration velocity model (before tomography); right: final velocity model (after four iterations of tomography). The line shown on the front of each cube is the line through the middle of the model as indicated by the yellow arrow. The line shown on the right side of the cube is the crossline as indicated by the orange arrow. Though the final model went deeper, for comparison in this figure, the model was truncated at 8 km to match the initial model.

and against and along the steeply dipping faults. The project work flow resulted in high quality images and more accurate placement of events, including well-defined faults, which improved the stratigraphic resolution of the Tarakan Sub-basin which is an underexplored and typically poor data area.

Acquisition and Pre-processing

The seismic for this project was acquired in 2010 and 2011, and the configuration consisted of a single vessel, dual sources and up to eight 6 km streamers, with a nominal bin size of 6.25 m in the inline direction and 25 m in the crossline direction. The survey orientation was NE-SW. In addition to a normal work flow, the pre-processing of the data, which was performed by CGGV, for input to the depth migration consisted of Tau-p domain deconvolution and 3D Surface Related Multiple Elimination (SRME).

Initial Velocity Model Building

The initial velocity model (Figure 2) for input to the first tomography iteration was created by starting with the fast-track time migration velocity model and inserting water velocity. The water velocity was determined using CDP gathers from both shallow and deep water areas. Water depths range from around 20 m to 500 m. After thorough testing, a velocity of 1525 m/s was found to be optimum for this area. The model was then smoothed with a depth-varying smoother with heavier smoothing down deep.

Tomographic Velocity Updates

Tomography is an inversion technique that uses residual curvatures of the migrated gathers, the dips and coherency of the migrated stack, and ray tracing through the migration velocity model to derive the necessary updates to apply to the velocity model so that the next migration will have flatter gathers and will place seismic events more accurately in space. A hybrid tomography approach combining both grid tomography and geological constraints was used in this project. The tomography is done in an iterative fashion, applying incremental changes to the model, followed by a new depth migration after each tomography iteration.

Four tomographic velocity updating iterations were performed for the project, each using a new Kirchhoff pre-stack depth migration as input. In order to derive residual curvature estimates for the shallow data, finer offset and depth sampling were deemed necessary at the beginning of the velocity updating phase. The first iteration of tomography used a high resolution depth migration input with 5 m

depth steps and 60-fold gathers with an offset increment of just 100 m. Additionally, the first update was constrained to just the region from the water bottom to 4 km. The inversion grid was 200 m by 200 m by 50 m. The second tomography iteration used 30-fold gathers with a 200 m offset increment, migrated at a 10 m depth step. The second tomography iteration was inverted on the same grid, but it went down to 12 km. The third iteration was similar, except the tomography inversion grid was run on a finer grid of 100 m by 100 m by 50 m. Most of the updates occurred in the middle to deep zones and in the areas of the growth faults. After checking the Kirchhoff migration following iteration three, it was determined that more detail was desired for the fault regions. To further refine the velocities, especially in the

fault zones, a fourth and final iteration was run on a fine grid.

For each tomography iteration, residual curvature of the gathers is determined through event scanning. These curvatures along with the dip fields derived from the migrated stacks are input into the tomography ray tracing step. The output of the tomographic inversion is a velocity perturbation cube which is added to the previously used depth migration velocity model. Figure 3 shows the delta velocity field from the final tomography iteration as well as the velocity model after these velocity updates were added back to the previous one. One can see that the fault in the middle of the line was recognised and defined by the tomography. Once the delta velocities were derived, geologically constrained



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smoothing was performed so as to retain the fault detail that was derived by the tomographic update. The interpretation is drawn on the model in Figure 3. After smoothing, the delta velocities were added back to the previously used migration velocity model to create the final model for migration. Figure 2 (right) shows the final velocity model following the four tomography iterations.

Migrating with the Updated Velocity Model

The final velocity model was used to perform a final Kirchhoff pre-stack depth migration, which was run at 60-fold, with a 25 m by 25 m output bin size, 100 m offset increment and 5 m depth steps. Figure 4 shows a comparison of the time migration with the final Kirchhoff pre-stack depth migration that was run using the newly updated velocity model. Improvement in fault definition, coherency and geologic sensibility of the events can be seen as a result of the new velocity model and depth migration's ability to handle lateral velocity variations. The project included a Wave Extrapolation Migration (WEM) as well. Having both types of migrations allows the interpreter to enjoy the strengths of the Kirchhoff, which include steep-dip imaging, and the strengths of the WEM, which include imaging well below the faults.

Conclusion

High resolution tomography and Kirchhoff pre-stack depth migration improved the seismic imaging when compared to the previously run time migration in this area. The higher quality imaging gives interpreters a better tool to further understand the area's petroleum system and numerous leads and prospects already identified in the region. Further work in the area will account for anisotropy using well information, leading to more accurate vertical placement of seismic events. These more advanced data sets will allow for ever more accurate geologic interpretations of the Tarakan Basin, giving explorers the chance to gain a better understanding of the potential of this important hydrocarbon province. ■

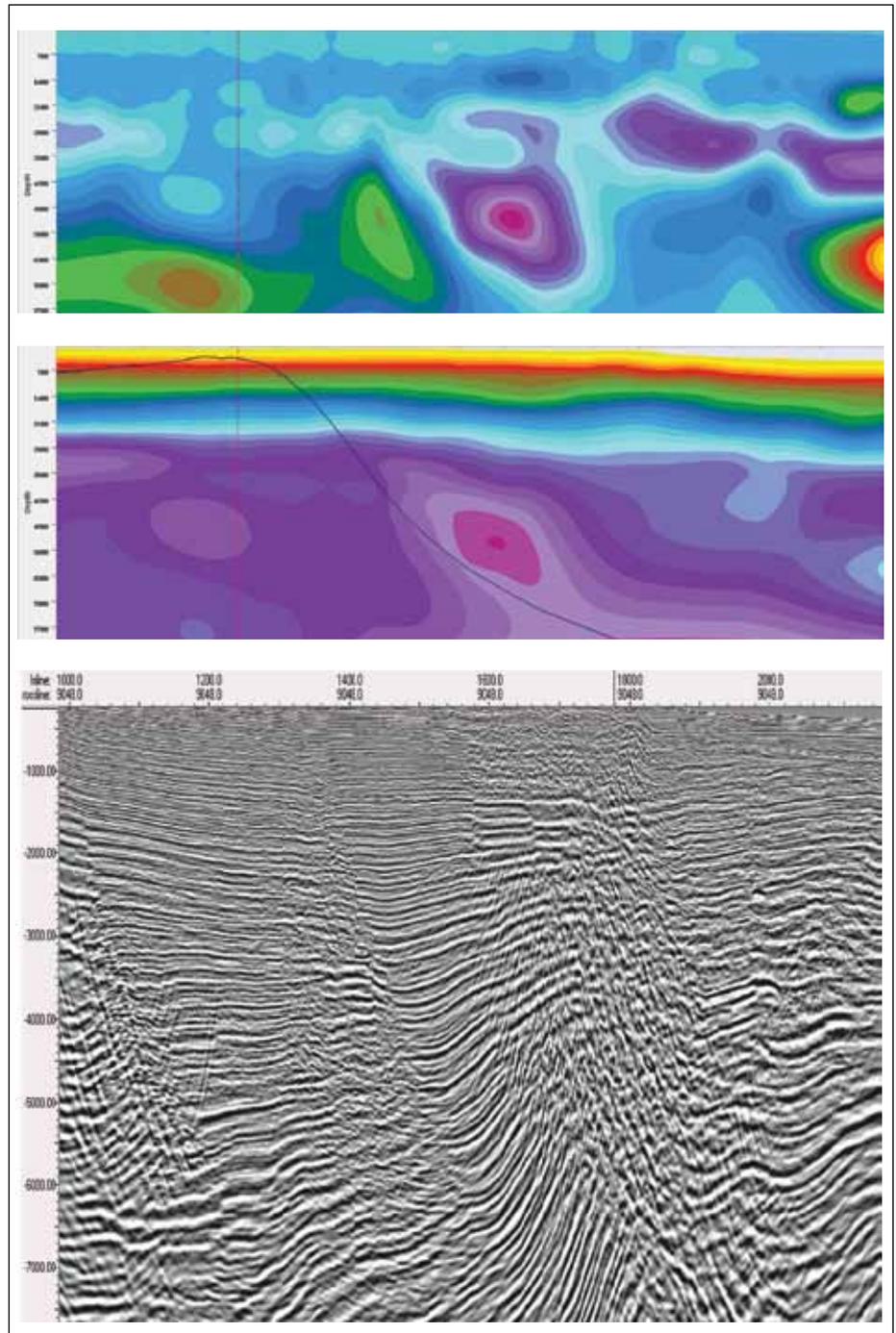


Fig. 3. Top: delta velocities output from fourth tomographic inversion (note fault definition); middle: updated velocity model with fault interpretation; bottom: Kirchhoff pre-stack depth migration using updated model (middle) – zoomed in on fault.

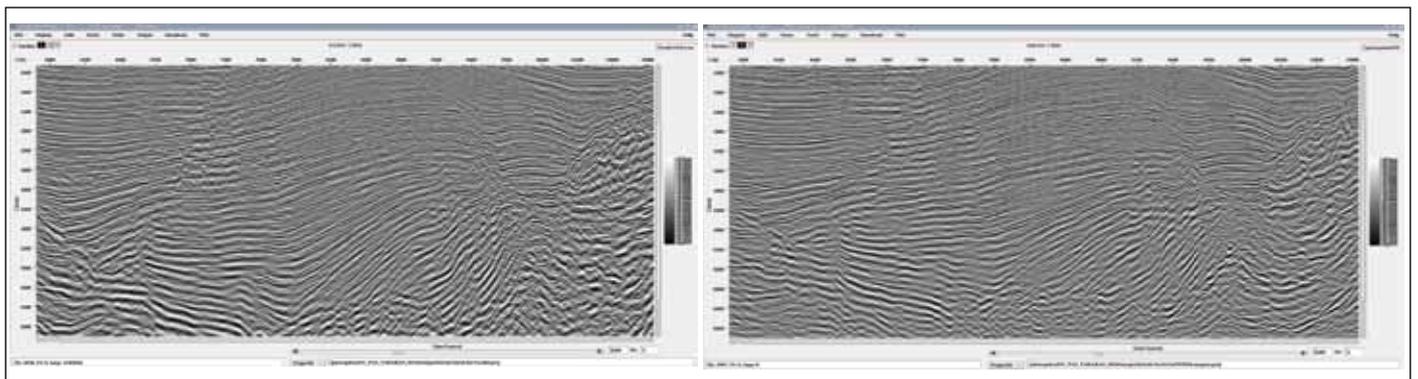


Fig. 4. Left: pre-stack time migration; right: Kirchhoff pre-stack depth migration (converted to time for comparison).