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Advances in velocity modelling and imaging techniques in the Taranaki Basin

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SUMMARY

This paper demonstrates recent advances in grid-based reflection tomography model building in conjunction with anisotropic pre-stack depth migration. These advances significantly benefit the imaging and resolution of 3D seismic data in a number of structurally complex basins.

Using 3D seismic imaging examples from Petroleum Exploration Permit PEP 51558 in New Zealand's Taranaki Basin, this paper demonstrate how reflection tomography techniques can utilize implicit geological constraints to resolve complex velocity variations and, thereby, reduce structural and imaging uncertainty.

One challenge associated with velocity modelling in the Taranaki Basin is to adequately resolve the large lateral velocity contrasts across major faults. This work shows how the use of steering filters during the reflection tomography process significantly improves the resolution and delineation of these fault-constrained velocity contrasts. This approach is compared with the conventional gridded tomography approach of velocity model building.

Using a detailed velocity model from the Taranaki Basin, comparisons were made between time and depth migration, as well as alternate depth migration techniques.

Key words: Depth imaging, tomography, steering filters, Taranaki Basin, PEP 51558.

INTRODUCTION

Anisotropic depth migration is now established as a crucial seismic imaging tool for resolving and de-risking prospects in geologically complex basins. The key element to successful depth migration is the quality of the derived property models and, in particular, resolving the complexity of the velocity model accurately.

In areas of structural complexity, one key objective of velocity modelling is to resolve lateral velocity heterogeneities associated with steeply dipping structures and sharp velocity contrasts, such as areas of faulting or carbonates, while still maintaining a geologically consistent and plausible model.

New Zealand's Taranaki Basin, which extends from the northern end of the South Island to just southwest of Auckland, is one such basin where the structural complexity leads to significant challenges when attempting to derive an accurate and geologically consistent velocity model for use in depth migration. In 2012, time and depth imaging was performed over a significant portion of the 1500 km^2 3D survey that was acquired in Petroleum Exploration Permit PEP 51558 in 2005, and which is located over the Northern Graben province of the basin (Figure 1).

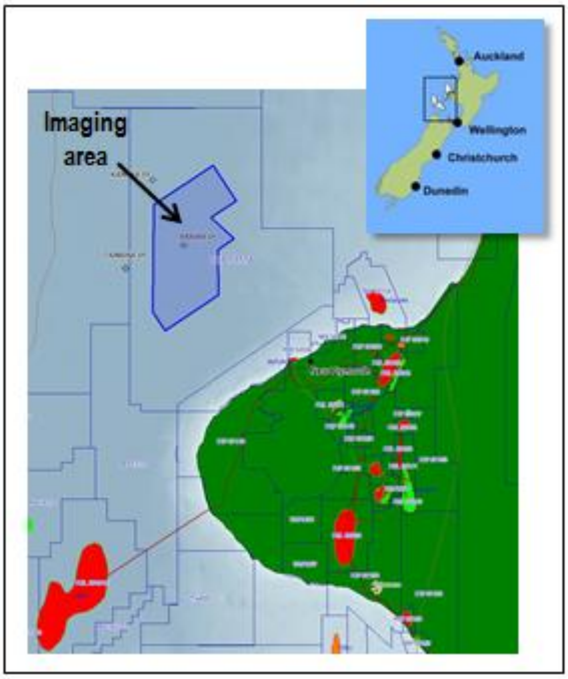

Figure 1: Depth imaging area, PEP 51558, Northern Taranaki Basin.

The geology of the PEP 51558 study area presented a number of challenges to derive an accurate velocity model for use with depth migration. The survey is located in water depths of approximately 100 m, with Late Cretaceous prospect leads located at depths below 5 km. The imaging area includes a range of Miocene volcanics and a number of shallow diagenetic traps and gas chimneys.

The most significant imaging challenge in the study area was resolving large lateral velocity variations associated with the Cape Egmont and Turi fault zones. When imaging was performed using time domain assumptions, these lateral velocity contrasts resulted in imaging distortions such as fault shadows and non-geologic pull-up effects. These distortions were addressed using a depth imaging approach, iteratively deriving a detailed interval velocity model using reflection tomography methodologies.

TOMOGRAPHY

An initial velocity model was built for a 600 km^2 subset of the PEP 51558 3D volume based on pre-stack time migrated (PreSTM) interpreted velocities, converted to depth interval velocity and smoothed along geological constraints. Initial anisotropy parameters for the area were estimated using the calibrated sonic logs and key formation markers from the available well data and propagated for the entire area using horizon-guided interpolation techniques.

Starting with this initial model, pre-stack depth migrated gathers were computed and multi-parameter residual moveout (RMO) picks were generated and entered into the gridded tomography (Woodward *et al*., 2008) model updating routine. The common industry practice for building detailed earth models with tomography begins by solving the observed RMO with a long wavelength non-directional smoother in *x*, *y* and *z*, iteratively moving to smaller wavelength smoothers until a predetermined smoothness or resolution for the update is reached. With the desired update chosen for each iteration, the prestack depth migrated gathers are regenerated and the velocity update process is repeated.

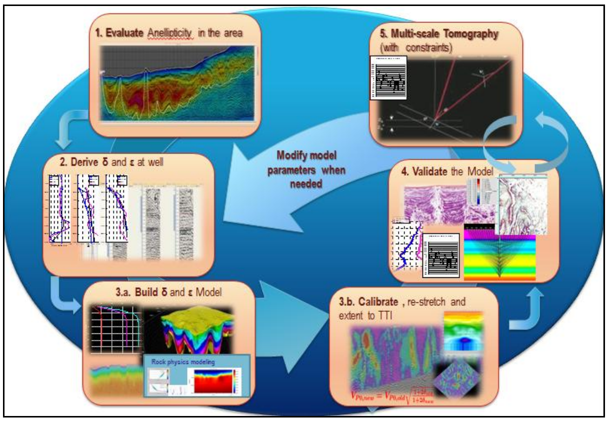

Figure 2: Generalised workflow for anisotropic model building and depth imaging.

Three velocity model updates were performed in this way for the imaging area to provide a reasonable baseline velocity model. For the fourth model update, steering filters (Bakulin *et al*., 2009) were incorporated into the tomography solver and the updated velocity model results were compared to an update using the conventional gridded tomography approach.

STEERING FILTERS

The steering filter tomography approach replaces the conventional non-directional smoothing approach by including, within the tomography solver, a directional smoothing consistent with the geologic dip direction of the seismic data (Clapp *et al.*, 1998). The dip information is derived by either estimating the dip from a seismic stack or by estimating the structural dip from interpreted horizons. By utilizing implicit geological constraints imposed by steering filters into the tomography solver, more geologically consistent and structurally constrained model updates are obtained. This process may also help to speed-up the convergence in the model areas that are poorly constrained by the data alone, for example, zones of limited illumination or complex topology zones representing sharp velocity contrasts.

For the study area, a dip field was generated from seismic information after depth migration using the third velocity model update from tomography. The dip field was carefully conditioned to eliminate noise-based dip artefacts while preserving the genuine structural dip information.

Figure 3 compares the residual velocity, or delta V, obtained using the two tomography approaches for one inline of the survey's model. The residual velocities derived from tomography incorporating steering filters clearly show a strong conformance to geology and improved delineation at the fault intersections, providing a more geologically plausible model.

The model obtained using tomography with implicit geological constraints shown in Figure 2 was selected as the fourth model update for the study area's velocity model. To complete the velocity model, two further iterations of model updates were performed using tomography with steering filters.

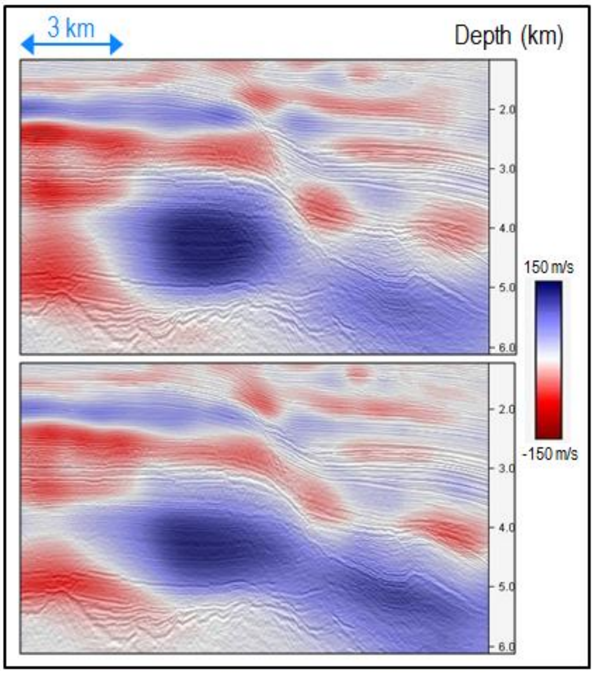

Figure 3: Residual velocity inline section display using conventional gridded tomography (top), compared to tomography with implicit geological constraints (steering filters) for the fourth update of the PEP 51558 3D model (bottom).

Figure 4 shows examples of the final velocity model after six tomographic updates compared to the initial velocity model overlaid on their corresponding images. Starting from a smooth model based on PreSTM interpreted velocities, it was possible to derive a detailed and geologically plausible velocity model for imaging that represents the complex structures and faulting of the study area. Improved resolution and continuity is apparent directly below the fault at 5.5 km on the final image compared to the initial image.

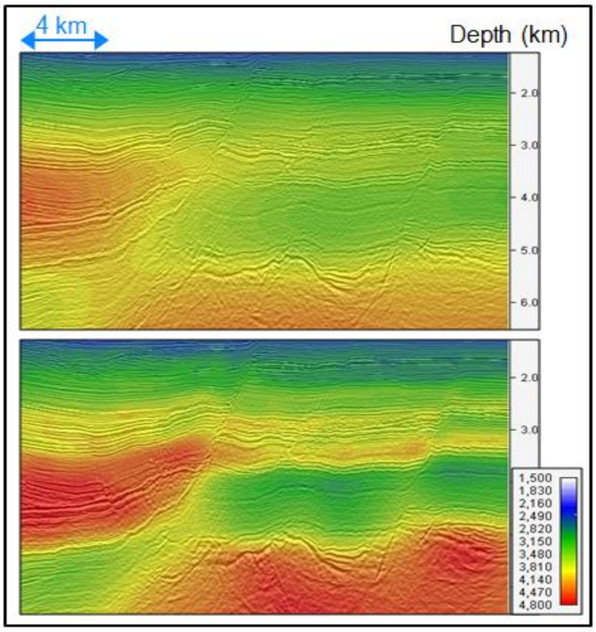

Figure 4: The study area's initial velocity model (top) compared to the final velocity model after six tomographic updates (bottom) overlaid on their corresponding images.

MIGRATION

With the detailed velocity model in place, the final imaging was performed using anisotropic Kirchhoff pre-stack depth migration. Figure 5 compares an inline section at the prospect level between the final Kirchhoff depth migration and the final Kirchhoff time migration performed earlier in the project.

Figure 5 highlights how, after performing depth migration with a detailed velocity model, the geometry of the Late Cretaceous half-grabens are much more clearly resolved. There is also a significant improvement in the imaging and lateral positioning of the Basement level faults.

The apparent syncline structure observed below 4 km after performing depth imaging became a flatter and more simplified structure, confirming that this was caused by the previously unresolved shallow velocities and time migration assumptions.

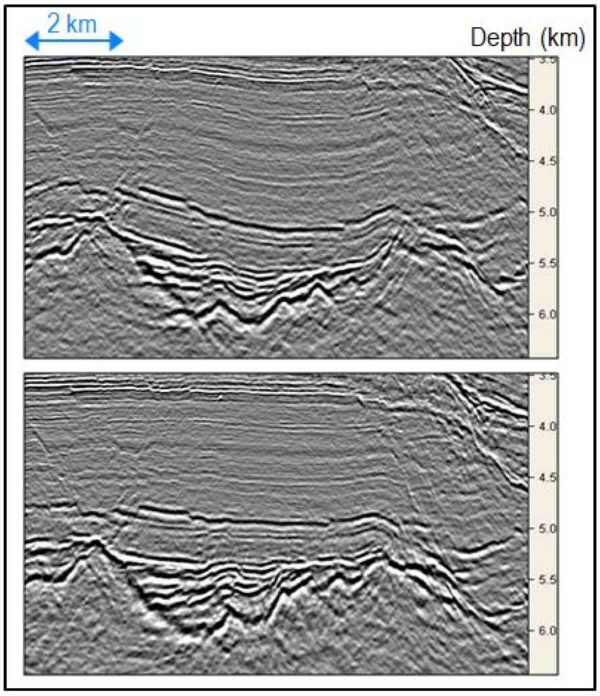

Figure 5: PEP 51558 pre-stack time migrated section stretched to depth using smoothed PreSTM velocities (top) compared to the pre-stack depth migration section using the final velocity model (bottom).

BEAM

In the presence of the large lateral velocity variations observed in an area known as the Arawa Ridge in PEP 51558, and with a detailed velocity model in place, imaging trials were performed using adaptive beam migration (ABM).

ABM is an implementation of a pre-stack depth migration based on Gaussian technology. It provides a high-end full beam migration that is inherently multi-arrival, making it suitable for complex imaging environments such as the Taranaki Basin.

Figure 6 compares a section migrated using Kichhoff pre-stack depth migration with the same section migrated using a frequency limited (35 Hz) ABM from the Arawa Ridge area of PEP 51558. The ABM section shows more clearly resolved faults over the Late Cretaceous half-grabens and more definition to the Basement structure. This improved definition may make the interpretation of the Late Cretaceous prospects simpler.

This comparison also shows that~~, for~~ even with a limited maximum offset (4500 m) and the level of velocity complexity present in the PEP 51558 model, Kirchhoff pre-stack depth migration remains a robust imaging tool in this geological setting.

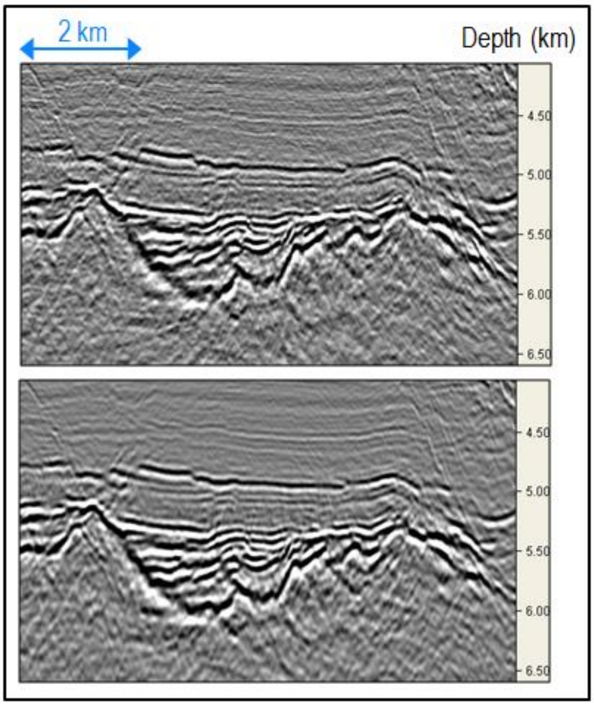

Figure 6: Kirchhoff pre-stack depth migrated section (top) compared to adaptive beam migration (bottom) in PEP 51558.

CONCLUSIONS

We demonstrated a method of using geological constraints as an additional pre-conditioner in reflection tomography to resolve complex lateral velocity variations. By employing steering filters as an implicit constraint in tomography, model updates are derived with a strong conformance to distinctive geological units and complex structural features, making it a more geologically plausible model and providing improved delineation between strong velocity contrast such as faults and carbonates.

By performing pre -stack depth migration using this detailed velocity model, we observe significant enhancements to both the imaging and the positioning of key structural features compared to pre-stack time migration. The combination of deriving a detailed geologically consistent model with pre-stack depth migration significantly reduces structural and imaging uncertainty for prospects identified in the PEP 51558 area of the northern Taranaki Basin.

Adaptive Beam Migration for the final imaging provides an alternative to Kirchhoff that can increase interpretation confidence for deep prospects. Comparisons to Kirchhoff pre-stack depth migration also indicate that Kirchhoff is a robust and effective migration algorithm in the Taranaki Basin.

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