

Model Building Complexity in the Presence of a Rugose Water Bottom – Gippsland Basin Australia

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## Introduction

Situated offshore south-eastern Australia, the Gippsland Basin contains some 21 oil and gas fields currently in production, including Australia's largest oil discovery, the Kingfish field producing over a billion barrels of crude to date. Complex geology and extensive velocity anomalies lead to convoluted acoustic ray-paths, false seismic structures and limited imaging clarity of 3D seismic volumes. Time to depth conversion of apparent structural closures increase drilling risk due to velocity model uncertainties.

Depth imaging has been performed by various contractors using a variety of sub-surface modelling tools and imaging algorithms. Trials have shown the extreme sensitivity of imaging clarity and structural closure to the derived velocity model. A rugose seafloor coupled with (a) a non-uniform water-layer velocity field, and (b) complex high velocity shallow carbonates, introduce small scale velocity anomalies that, if not captured during model-building, will compromise the image of deeper target levels.

Recent model building and imaging efforts have seen extensive improvements in the worst affected areas, over and above previous imaging attempts. This paper highlights the model building techniques employed within a deep water complex structural setting. We aim to discuss the derivation and impact of a spatially variant water-layer model, an initial sediment model and the diverse nature of velocity-model building techniques. The knowledge gained at Gippsland may assist depth imaging in other deep water complex imaging environments.

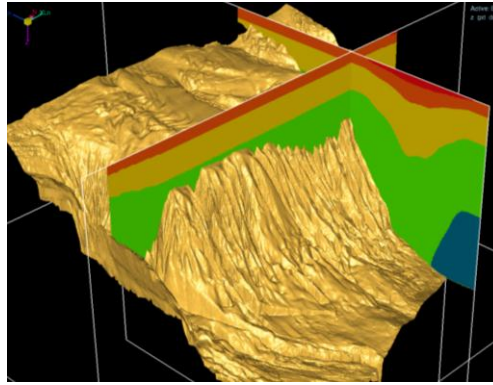
## Initial Water And Sediment Velocity Model

It has become standard practice to create an initial velocity model for depth imaging based on final pre-stack time migration RMS velocity volumes converted to interval velocity in depth. The water bottom is picked and gridded as a hard constraint, based on an initial migration (Jones et al. 2010). This may be appropriate in some geological settings. In Gippsland Basin multiple seismic surveys acquired over time in different seasons are used to image a steeply dipping rugose sea floor. Alternative approaches are required to define initial water layer and sediment layer velocity models separated by an accurate sea bottom horizon.

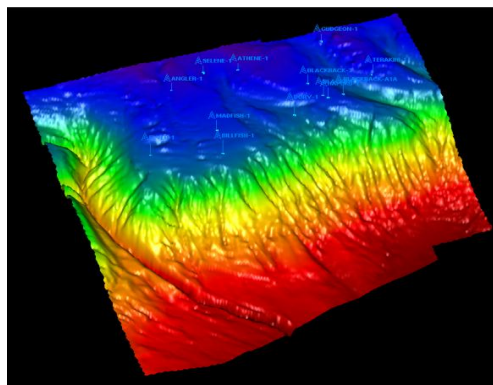
The water column is a dynamic medium whose velocity response changes with depth due to properties such as salinity, temperature and density. These variations coupled with the physical limitations of measuring an accurate water depth during marine seismic acquisition combine to limit the validity of water depth maps in deep water settings with rugose steeply dipping sea beds.

Empirical relationships have been defined that may model water velocity variations with depth in certain regions. In this study we treat the water column as a separate layer during the modelling process. All wells in the area are on the shelf region and cannot be used to verify the accuracy of the water model in minimising seafloor depth misties in the deeper water. In Gippsland Basin we use a data driven approach to model the water layer velocity both laterally and vertically.

Time-depth water velocity readings taken during seismic acquisition at Gippsland are sparse and limited in depth extent. An initial depth variant water column velocity profile is created from publications released from the US Navy. Empirical curve fitting relationships are used to extend these profiles to maximum water depth. This depth variant, but laterally constant model drives an initial migration. Seabed RMO errors in the deeper areas are used to vertically update this model at regularised bin intervals of 25x25 metres. Additional smoothing produces an acceptable water layer model from which the initial migration is recomputed. A water bottom horizon is picked and gridded as a hard constraint before flooding with an initial sediment velocity model. To ensure accurate modelling of the incised canyons when moving into the deep water no smoothing is applied to the water bottom profile.



**Figure 1:** The final water layer velocity model is depth and laterally variant. Lateral variations are relatively minor over the shelf areas but increase dramatically over the steep bank moving into deeper water. An additional high resolution 3D pre-stack depth migration is used to define a seabed horizon inserted as a hard constraint between the water and sediment layer velocities of the initial interval velocity depth model.

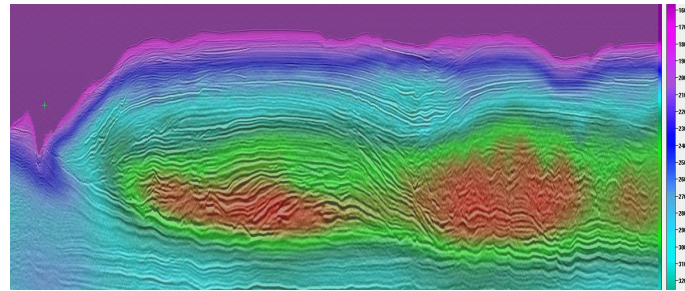


**Figure 2:** The water bottom rugosity over the survey area is displayed in this final gridded seafloor model. A large trench and incised canyons are clearly visible. The water depths range from 150 to 2580m. An accurate seafloor model is a prerequisite for shallow sediment model building. Building an accurate seafloor model is dependent upon an accurate water layer velocity representation. In Gippsland Basin a data driven approach is used in constructing the seafloor model.

### **Shallow Sediment Velocity Model**

A wide variety of approaches are now used to build velocity models using pre stack depth migration imaging. These methods revolve around extracting detailed information about velocity errors from migrated data for input to subsequent tomographic inversion and model update. The pitfall in these methods is their ability to produce non-geological models, if not constrained adequately (Etgen et al, 2002).

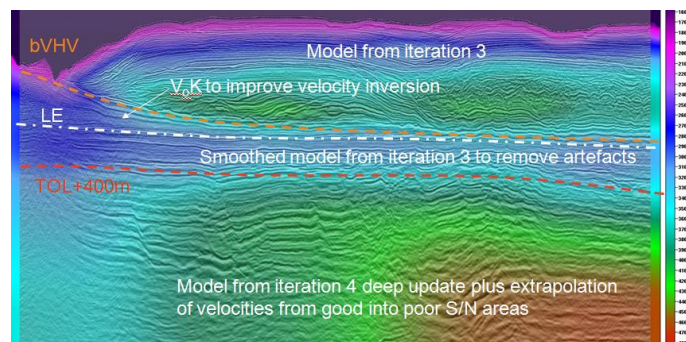
In this study area previous model building attempts had difficulty imaging structures below 2.5km in depth. A shallow high velocity carbonate sequence made velocity model update by tomographic inversion very unstable. The high velocity layer coupled with ray-path distortions from the rugose water bottom introduced unstable cyclic anomalies after tomographic update.



**Figure 3:** Shallow velocity model with seismic section overlain. The shallow carbonate sequence exhibits seismic velocities up to 4000m/sec which decrease over the next 1km of depth to 3000m/sec. Anomalous interval velocities are shown in this update which appear cyclic in nature on the right side of the section. These are believed to be caused by the tomography not handling the surface-channelling features over a steep sea-bottom gradient (out of plane of the section). Inversion cell sizes are reduced to counter this effect however had little influence on the result.

### Hybrid Velocity Model Update

A combination of manual velocity picking, model smoothing and hybrid model update helped to stabilise the velocity model in the carbonate sequence where interval velocities approached 4000m/sec. Over a vertical relief of less than 1km interval velocities reduce to 3000m/sec in the underlying sediments. Such rapid variations in vertical velocity are sometimes difficult to capture in a purely gridded tomographic approach. In contrast to a layer stripping approach for model building, gridded tomography removed the restrictions associated with using fixed vertical velocity gradients (Whitfield et al. 2008). The hybrid approach to model building differs from the purely gridded approach by introducing layer constraints at major velocity boundaries (Jones et al. 2007). At Gippsland solving the velocity model to the base of the carbonate sequence was imperative to avoid introducing structural anomalies in the deeper sediments whose residual depth error is beyond the maximum acceptable range solvable by subsequent tomographic updates. Without adequate well control in the deeper sections, quantitative structural misties could not be evaluated. Residual depth-curvature on pre stack imaged gathers is used to judge the accuracy of the model update in the deep water.

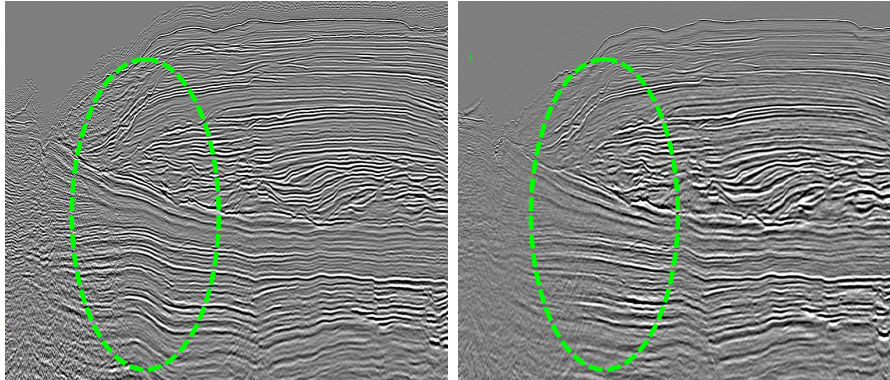


**Figure 4:** The hybrid approach to model building used during iteration 5. The shallow model is geologically plausible and is inserted to the base of the interpreted carbonate layer (bvHV). A gradient function is inserted below bvHV to the top of the interpreted Lakes Entrance (LE) formation. A smoothed version of previous model 3 is inserted below this constraint to 400m below the Top Latrobe (TOL) sequence. Extrapolation of faster velocities towards the trench is used to complete the update. This model is used to drive a final tomographic update.

### Imaging Examples Below A Deep Submarine Canon

Huang et al. (2010) describe building an accurate velocity model (and using the optimum migration algorithm for the geology present) as a principal requirement in order to obtain high-quality and reliable subsurface images. In Gippsland we were able to build on the knowledge of previous

modelling and imaging studies. In this respect it is important to extend the lateral reach of the carbonate sequence on the left side of the section towards the sea-bottom trench to eliminate false structures being imaged below the trench. Vintage data from the 2008 pre stack depth migration effort show non-geologically plausible structures differing by up to 90m in vertical relief with the current dataset below the deep trench feature.



**Figure 5:** Building on the knowledge from previous depth imaging efforts in this area enables the extension of the of the high velocity carbonate layer towards the sea-bottom trench (refer Figure 4). Without this extension the introduction of non-geologically plausible structures with large vertical relief are probable – as shown in the 2008 vintage pre stack depth migration result (left). These apparent false structures are removed when using the current imaging model (right). (Scaling between the two sections is not balanced).

## Conclusions

Gippsland Basin exhibits unique geological complexities that impact on seismic imaging quality and risk analysis. Model building strategies need to be adaptable and multi-faceted in their approach. We believe that a combination of layer stripping, gridded and hybrid model building coupled with focused tomographic inversion helps to produce a geologically plausible velocity model at Gippsland.

## Acknowledgements

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