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Regional velocity modelling methodology in the Gippsland Basin

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SUMMARY

A new velocity volume has been constructed across the Gippsland Basin to enable regional scale depth conversion of seismic interpretations. Average stacking velocities from seventeen seismic surveys (fourteen 3D and three 2D surveys) were used to build the 3D velocity volume. Check-shot velocity data was also used to constrain and guide the velocity distribution throughout the 3D grid. A total of 263 wells were used totalling ~14000 data points.

Seismic stacking velocities were broken up into eight separate intervals using time horizons derived from seismic interpretations. This provided a typical distribution of velocities from which to sample from during simulation in data-poor areas. A semi-variogram analysis was performed for each velocity interval to characterise the spatial variation of the velocity data. This process produced a search ellipse which facilitated distribution of the data. The ellipse was transformed to align with the seismic time surfaces so that the geometry of the ellipse was distorted to the same shape as stratigraphy (i.e. surfaces). Velocities were therefore distributed along stratigraphic horizons preserving geological integrity during the gridding process. Velocities were kriged close to data points, and simulated away from data points. The final step was to integrate check-shot velocities by kriging primary data (check-shot velocities) alongside secondary data (stacking velocities) using a locally varying mean approach.

This velocity model has applications not only for depth estimation, but also calculating layer thickness from interval velocities, density estimation, fluid overpressure analysis, assessing compaction / porosity and burial history.

Key words: velocity, seismic, depth correction, velocity volume, basin.

INTRODUCTION

A new velocity volume has been constructed for the Gippsland Basin to enable regional scale depth conversion of seismic interpretations. This is particularly important for pre-competitive regional studies where there is a need for regional depth converted basin features for resource management. The velocity model covers a region of 210km x 150km and a vertical extent of 5500ms, and has cell dimensions of 500m x 500m x 10ms. Average stacking velocities and check-shot velocities were distributed throughout the 3D grid using a geostatistical approach in GOCAD®. Pre-existing seismic time surfaces were used to guide the distribution of velocities along stratigraphic horizons and preserve the integrity of the geology during the gridding process. A top Latrobe Group surface is presented here to illustrate the depth correction capability of the new velocity volume.

INPUT DATA

Average stacking velocity data from a total of seventeen seismic surveys (fourteen 3D and three 2D) were used to build the 3D velocity volume (Figure 1). Stacking velocities from 3D surveys were preferred but did not cover the entire study area. Therefore, some 2D data was used; particularly in the deep water and southern flank of the basin. Stacking velocities used for the Gippsland Basin totalled 12,286,103 points (Figure 2a). A quality control process was performed for each survey to remove spurious velocities, and to improve the consistency between surveys, allowing them to tie with each other more effectively. Check-shot data from a total of 263 wells was also imported into GOCAD as points (~14000 points in total), and used to constrain the velocities.

METHODOLOGY

The methodology used to build the velocity volume was novel in that it used a geostatistical approach to krig velocities throughout a 3D grid. The following steps summarise the workflow:

1. Create stratigraphic grids and separate the stacking velocities into eight separate intervals

Seismic stacking velocities cover a large part of the Gippsland basin, however there is an absence of data in between these surveys (Figure 1) and fewer velocity points at deeper levels within the basin. To create a velocity volume of the entire Gippsland Basin without "no data values", data was simulated to fill in areas where there is an absence of data. Data simulation requires a representative sample so stacking velocities were broken up into eight intervals (Table 1). Each interval was used as a template to simulate velocities in data-poor areas within the same interval. The top and bottom of each interval was characterised by seismic horizons picked in the time domain. Table 1 outlines the horizons which were used to separate the velocities into intervals. An upper and lower cut-off was applied to each velocity interval before semi-variogram modelling (step 2) to remove spurious data values. Any velocity points below an accepted water velocity of 1470m/s was considered to be erroneous, and deleted. Upon visual inspection of cumulative frequency histograms, an upper cut-off was also applied (Table 1). This process removed outliers so they did not contribute to the simulation process.

2. Characterise spatial variation of velocities using geostatistics

Semi-variograms were calculated for each velocity interval to determine the correlation characteristics of the velocity data, and determine how far velocities could be statistically interpolated. The result of this process was a search ellipse which facilitated distribution of the data. Velocities generally change more with depth and therefore the ellipse was characterised by a large lateral distance, and small vertical extent (i.e. pancake shape). This meant that velocities could be statistically distributed over a large distance in the x and y direction, but not very far in the z direction. The pancake shaped ellipse forced a horizontal trend into the velocity distribution, but given that this trend was being governed by semi-variogram modelling, the trend was real, and it was therefore valid to distribute it throughout the 3D grid. This is a particularly powerful technique because it is only enforcing a trend which is driven by the data.

Sedimentary trends are typically assumed to be aligned along bedding planes. Because velocity is strongly affected by compaction it follows this same trend, so a 3D grid was created and the geometry was initialised such that the top and bottom of cells were oriented parallel to stratigraphic boundaries. The ellipse created during semi-variogram modelling was transformed to align with the stratigraphic grid so that at any given point, the geometry of the ellipse was distorted to the same shape as stratigraphy. This enabled velocities to be distributed along stratigraphic horizons and preserved the geological integrity during the kriging process.

3. Krig stacking velocities

Once a search ellipse was created, the velocity data could be distributed throughout the stratigraphic grid. This was performed separately for each velocity interval, the results were visualised, and a quality control check was done on the 3D grid. In this study kriging only distributed data throughout the 3D grid where there were data points which fell within the semi-variogram search ellipse. Therefore, there were areas throughout the 3D grid which contained “no data values”. Sequential Gaussian Simulation (SGS) was used to simulate data across the whole 3D grid, including in cells which had “no data values”. SGS was improved in this example because velocities were simulated throughout a grid for only one formation. This means Latrobe Group velocities for example, were being used to simulate velocities for Latrobe Group where there was no data. However, kriging was a much more robust technique for 3D gridding, so a script was written to use the kriged value if it existed. If not, the SGS value was used instead. This process produced a stratigraphic grid which was full of velocities and contained no “no-data-values”. The grid honours stacking velocities by kriging where these points exist, it simulates using representative values from relevant formations for areas where there are no points and it honours the geometry of the stratigraphy.

4. Co-krig stacking velocities and check-shot velocities

Once the stacking velocities were kriged throughout the 3D grid, the data was constrained to the check-shot data. This step was necessary because stacking velocities derived as a bi-product of seismic processing are typically considered less reliable than those derived from check-shot velocity surveys. Therefore, a technique which would honour check-shot velocities in preference to stacking velocities, but honour stacking velocities in the absence of other data was required. Kriging with a locally varying mean accommodated this requirement and allowed assignment of primary data (check-shot velocities) and secondary data (stacking velocities). This was performed for each velocity interval, however a minimal effect was observed in the deeper formations because wells in the Gippsland Basin do not typically intersect formations deeper than the Latrobe Group. The result of kriging with a locally varying mean was to ‘slow’ down the velocities slightly (Figure 3).

5. Velocity volume creation

The final step was to combine the velocities from each interval, and transfer them to a regularly spaced 3D grid (i.e. the velocity volume). The velocity volume was created with the same resolution in the x-y direction as the stratigraphic grid (500mx500m), and a vertical resolution of 10ms. Figure 2b shows a fence diagram of the velocity volume.

RESULTS

Figure 4 shows the top Latrobe Group surface depth corrected by the new velocity volume. Field outlines determined by detailed local scale depth correction (performed by Exxon) have been draped on the top Latrobe Group depth surface. These field outlines show a good correlation with the geometry of the corrected depth surface, not only for major fields such as Barracouta, Snapper and Bream, but also Kingfish which is known to be a difficult field to depth convert since it has a high velocity channel running through its northern margin.

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Velocity interval	Top bounding surface	Bottom bounding surface	Velocity cut-off (m/s)
Water	Sea-level	Sea-bed	1470-1550
Sea-bed	Sea-bed	Top Mid-Miocene	1470-3100
Mid-Micocene	Top Mid-Miocene	Top Lakes Entrance	1470-3500
Lakes Entrance	Top Lakes Entrance	Top Latrobe Group	1470-3500
Latrobe Group	Top Latrobe Group	Top KT	1470-3500
KT	Top KT	Top Strzelecki	1470-4100
Strzelecki	Top Strzelecki	Basement	1470-5000
Basement	Top Basement	6000 ms	1470-6500

Table 1 – Velocity interval, bounding top and bottom surfaces and the velocity cut-off range for each interval.

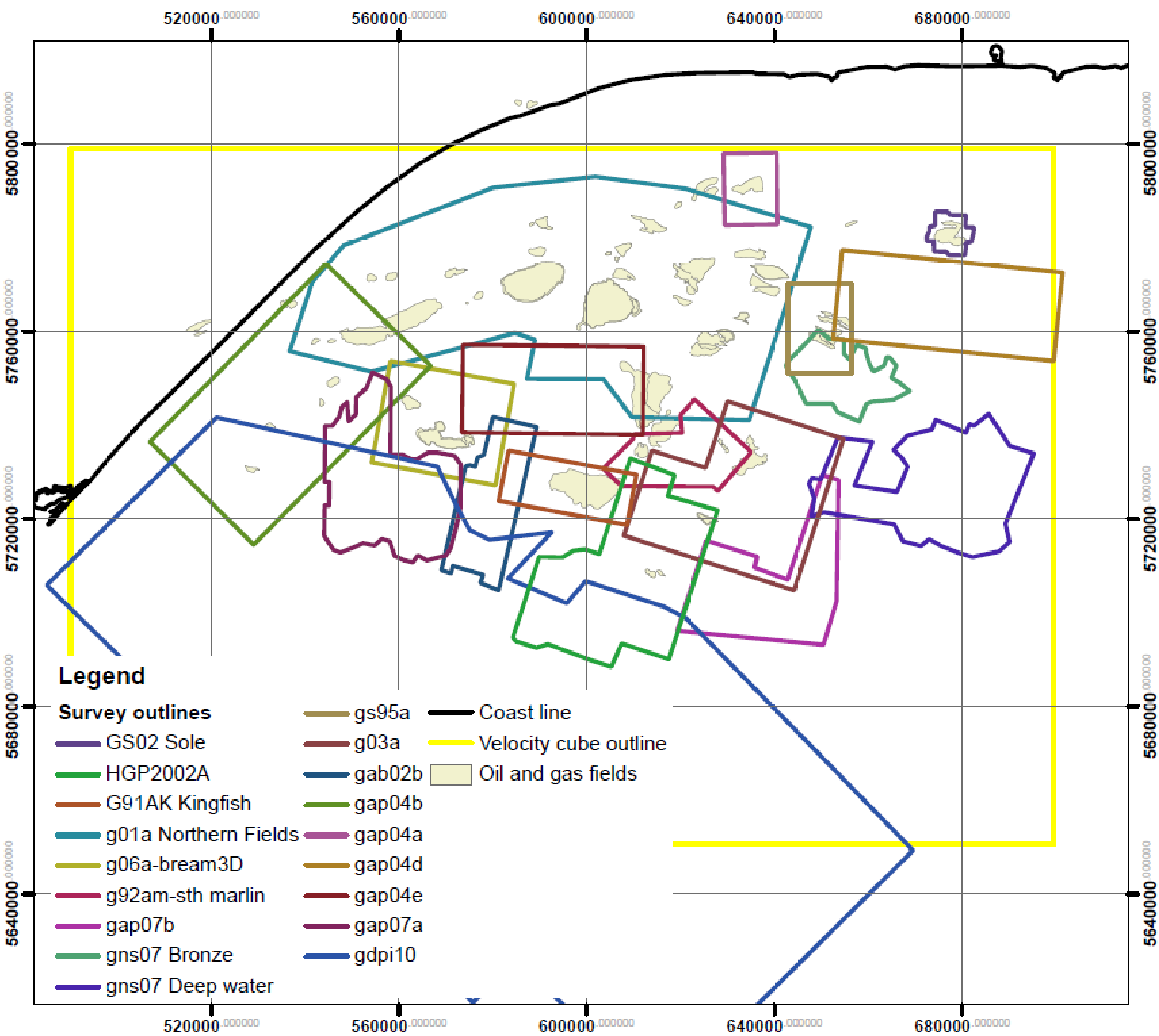

Figure 1 – Map showing the areal extent of the regional Gippsland Basin velocity volume. Polygons outline the extent of specific surveys used to build the velocity volume.

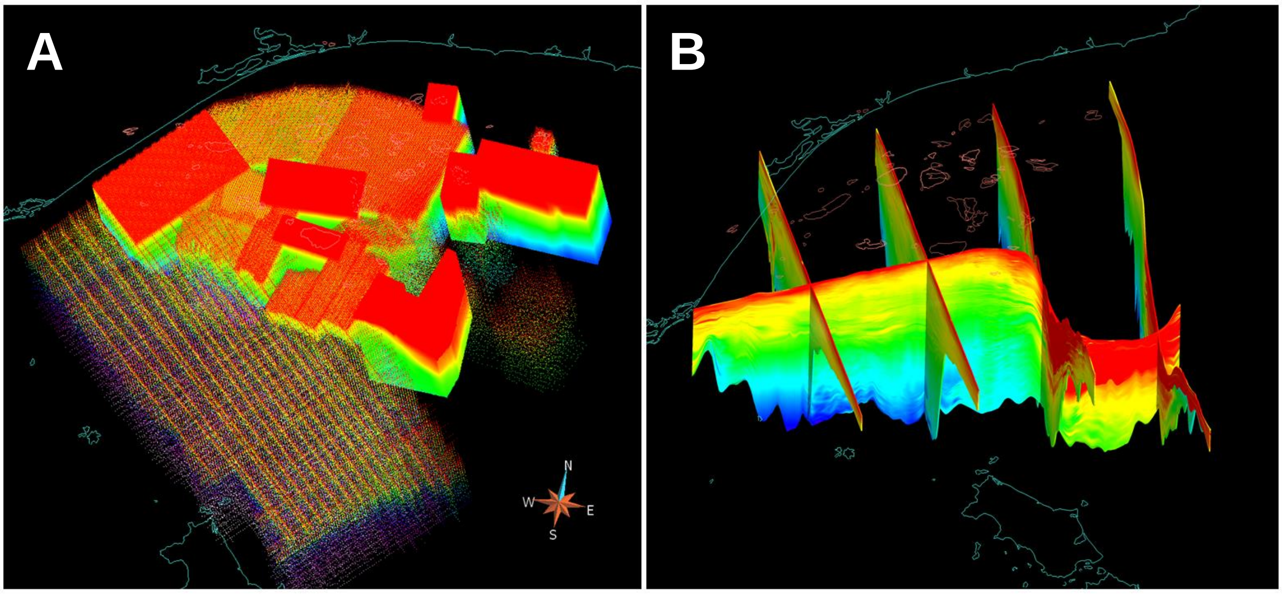

Figure 2 – (a) Perspective view of the stacking velocities used to build the 3D velocity volume (total of ~12.2 million points); (b) Perspective view toward the north of the new velocity volume for the Gippsland Basin.

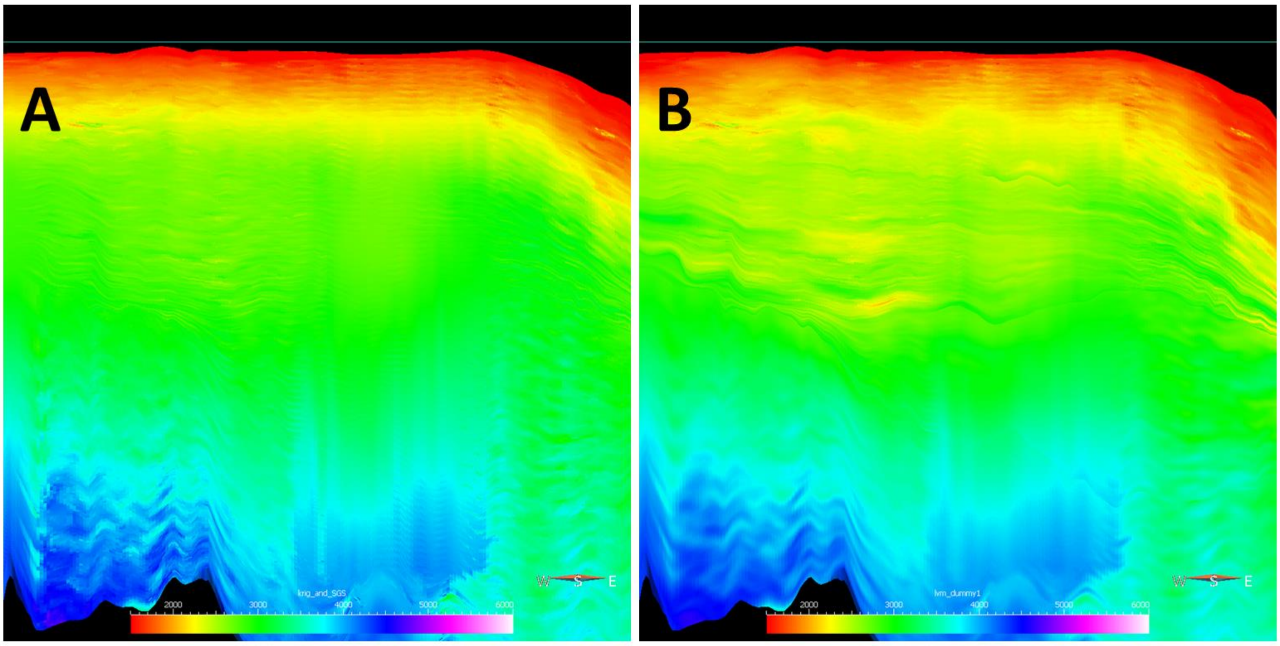

Figure 3 – Comparison of kriged velocities. (a) View north of kriged stacking velocities only (b) view north of kriged stacking velocities with check-shot velocities incorporated. Velocities with the check-shot surveys incorporated are slower than those with stacking velocities only. A minor amount of smoothing was applied to deeper formations such as KT, Strzelecki and basement.

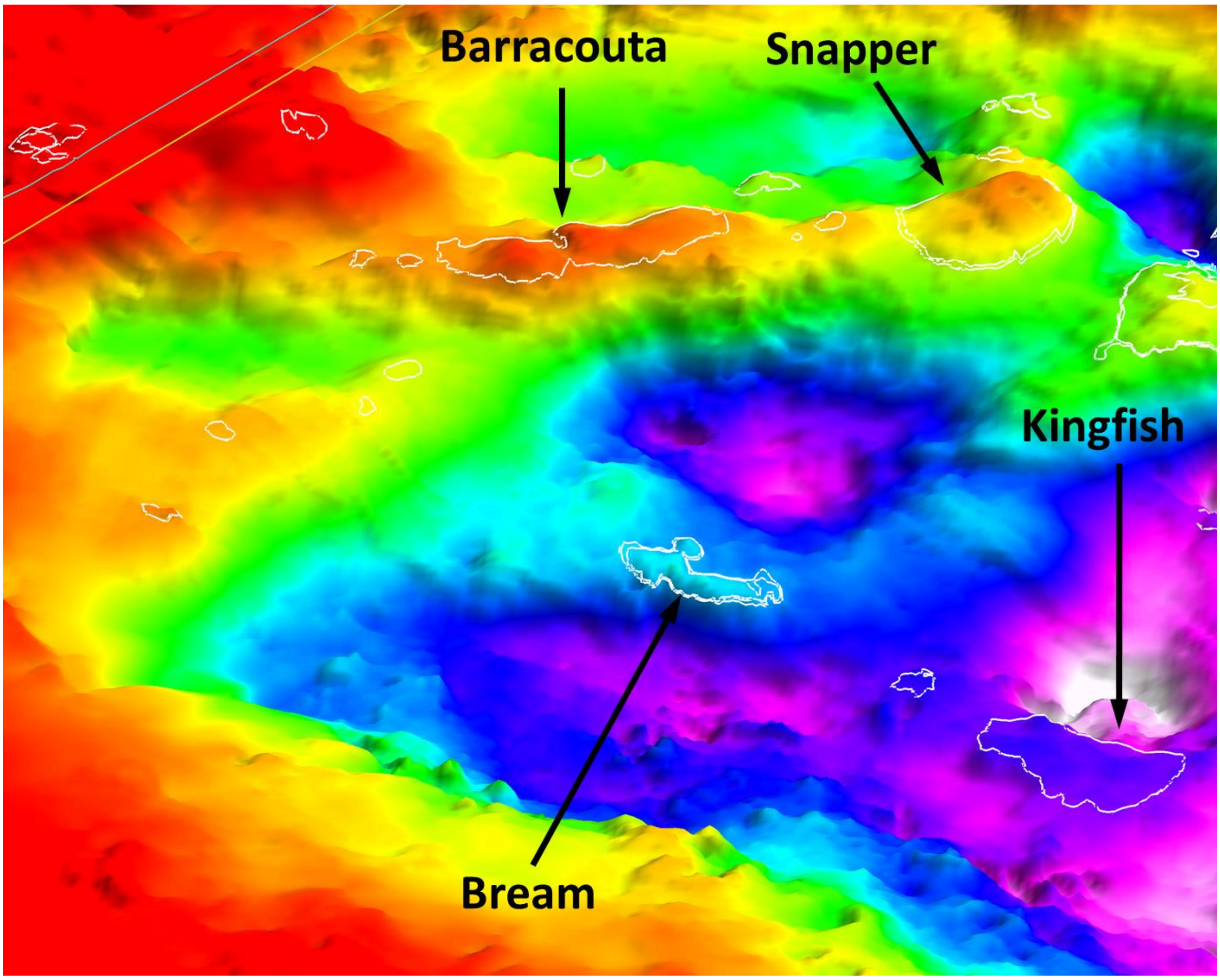

Figure 4 – Depth converted surface for top Latrobe Group (perspective view looking north). White lines represent oil and gas field outlines.