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A BREAKTHROUGH IN 3D SEISMIC INTERPRETATION

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Summary

Accompanying the advancement of computer science and technologies, new techniques have been introduced to optimise the seismic interpretation workflow. In this study, we apply the "Global seismic interpretation method", developed by Pauget et al. [1]. A 3D Relative Geologic Time (RGT) model was obtained directly from the 3D seismic volume which is the outcome of this method. Given the fact that in the 3D RGT model, the geologic time is continuous, a relative geologic age can be interpolated and assigned to every voxel of the seismic volume.

The dataset used in this study is the Maui 3D seismic volume from Taranaki basin, offshore New Zealand. A stack of 400 continuous stratigraphic horizons is produced from the Maui RGT model, even for complex areas where classical methods failed to achieve or would take a long time to complete. Integrated with seismic attribute mappings such as RMS amplitude and/or spectral decomposition, the horizon stack enables to navigate the seismic volume in stratigraphic order. Thus, the result enhances the identification of geological elements, stratigraphic insights, and paleo-depositional environments in greater detail for stratigraphic reservoir detection and characterisation. The novel methodology indicates a new way to conduct seismic interpretation, utilises all the information in the 3D seismic data, hence greatly reduces the exploration time cycle.

Key words: Seismic interpretation, seismic attributes, geologic time model, subsurface imaging, Taranaki basin.

1. Introduction

In the last few decades, seismic interpretation techniques have been rapidly developed for detailed reservoir delineation and characterisation. The traditional approach is generally an intensively time-consuming process that is heavily reliant on manually picking or auto-tracking of single horizons within the seismic volume. The tool allows tracking only one horizon at a time and is limited to areas with clear seismic signals or relatively simple geological structures.

New methods have been introduced to exploit the 3-dimensionality of the data and simultaneously auto-track every horizon throughout the seismic volume [2 - 7]. In 2009, Pauget et al. proposed a global method to build a 3D geological model directly from the 3D seismic volume [1]. This innovative method optimises the seismic interpretation workflow with greater confidence and accuracy. Continuous chronostratigraphic surfaces can be generated at every sample of the seismic data, enabling to overcome the limitation of seismic polarity changes. In this study, we have applied this advanced seismic interpretation method and its associated attributes for enhancing subsurface imaging, reservoir delineation and characterisation for the Maui 3D seismic volume from Taranaki basin, offshore New Zealand.

2. Regional geological settings

Extending 100,000 km^2 along the western margin and filled with 10 km thick Cretaceous - Cenozoic sediments, the Taranaki basin is the largest offshore sedimentary basin in New Zealand (Figure 1). Rifting started from the Late Cretaceous and completely ended in the Paleocene, along with a rapid deposition within graben areas accompanied by high heat flow. During the Paleocene - Eocene period, a passive margin developed over the entire sub-continent; a slow subsidence rate allowed sediments to accumulate

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across the shelf and coastal plain areas in the Taranaki basin [8]. The Late Eocene-Early Oligocene period marked the starvation of clastic materials [9]. Thereafter, this basin underwent a significant phase of subsidence from the Oligocene to the Early Miocene due to the development of the Australia-Pacific plate boundary zone in the eastern area. This was followed by the widespread of limestone and marl deposition in the outer shelf to upper bathyal water depths [9]. Increasing sediment loading contributed to the evolution of the shelf-slope system in the Miocene, resulting in the deposition of sandstone, interbedded mud and siltstone in the outboard areas. The plate boundary evolution also caused the basement to overthrust the Taranaki fault in the Early Miocene and the formation of the Tarata thrust zone in the Early Miocene. By the Middle Miocene, the compressional effect on the northern area and its eastern margin had decreased, coinciding with the development of the submarine volcanic arc. During the Pliocene, the volcanic arc moved southeastward onshore and the northern areas of the Taranaki basin started extending, creating accommodation space for the Plio-Pleistocene progradation and aggradation of the Giant Foresets formation in the Northern and Central grabens.

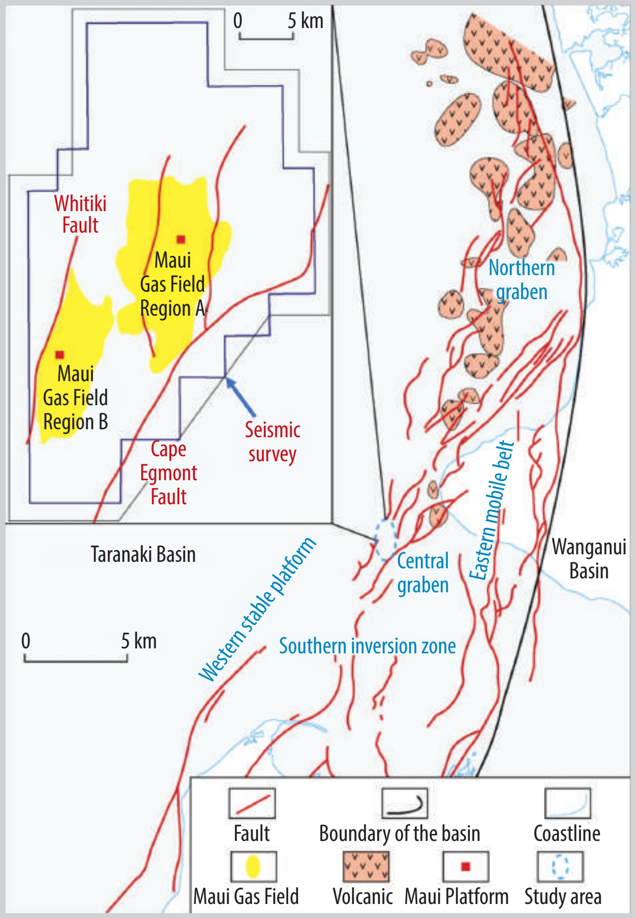


Figure 1. *Location map of Maui gas field and Maui 3D seismic survey, Taranaki basin, offshore New Zealand. Modified after King and Thrasher [9], Higgs et al. [10], and Haque et al. [11].*

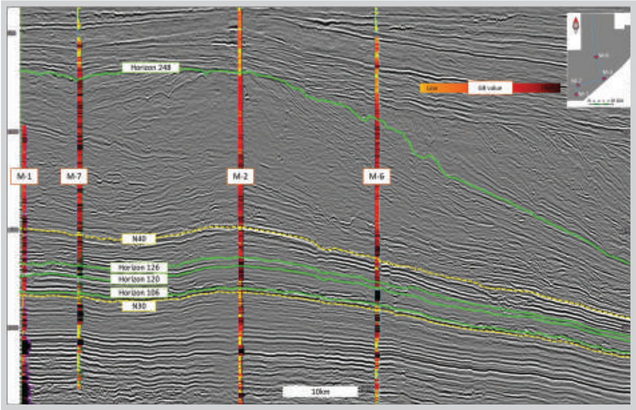


Figure 2. *Seismic arbitrary line from the Maui 3D traverses through Maui (M) 1, 7, 2, 6 petroleum wells. Dashed, yellow lines are interpreted horizons N40 and N30 in the Middle Miocene interval from Thrasher et al. [12]. Green lines are horizons 106, 120, 126, and 248 from the Horizon Stack (Figures 5, 6, and 7).*

3. Database and workflow

3.1. Subsurface data

The Maui 3D seismic data used in this study is a full offset, post-stack time-migrated volume which covers a surface area of approximately 1,000 km^2. All seismic data are zero-phase processed where acoustic impedance increases are displayed by positive amplitudes (peak reflections) and decreases in acoustic impedance are indicated by negative amplitudes (trough reflections) on the seismic section (Figure 2). The 3D seismic survey was acquired with 25 × 25 bin size, 1836 samples/trace, 3 ms sample rate and a total record length of 5,600 ms. In this area, the Maui gas field with 17 exploration and production wells is one of the largest gas condensate fields in New Zealand (Figure 1).

3.2. A global seismic interpretation method: From 3D seismic volume to 3D geological model

Building a 3D geological model directly from a 3D seismic cube plays a vital role in reducing the time cycle and enhancing the quality of seismic interpretation. This workflow, based on the cost function minimisation algorithm [1], consists of two steps.

The first step consists of computing a 3D grid of horizon patches, call "3D Model Grid" (Figure 3). Millions of grid points or nodes are distributed in 3D seismic volume, onto every seismic polarity such as peaks, troughs, zero crossings, or inflection point with a constant step of seismic bin size (Figure 3a). Each node is an elementary

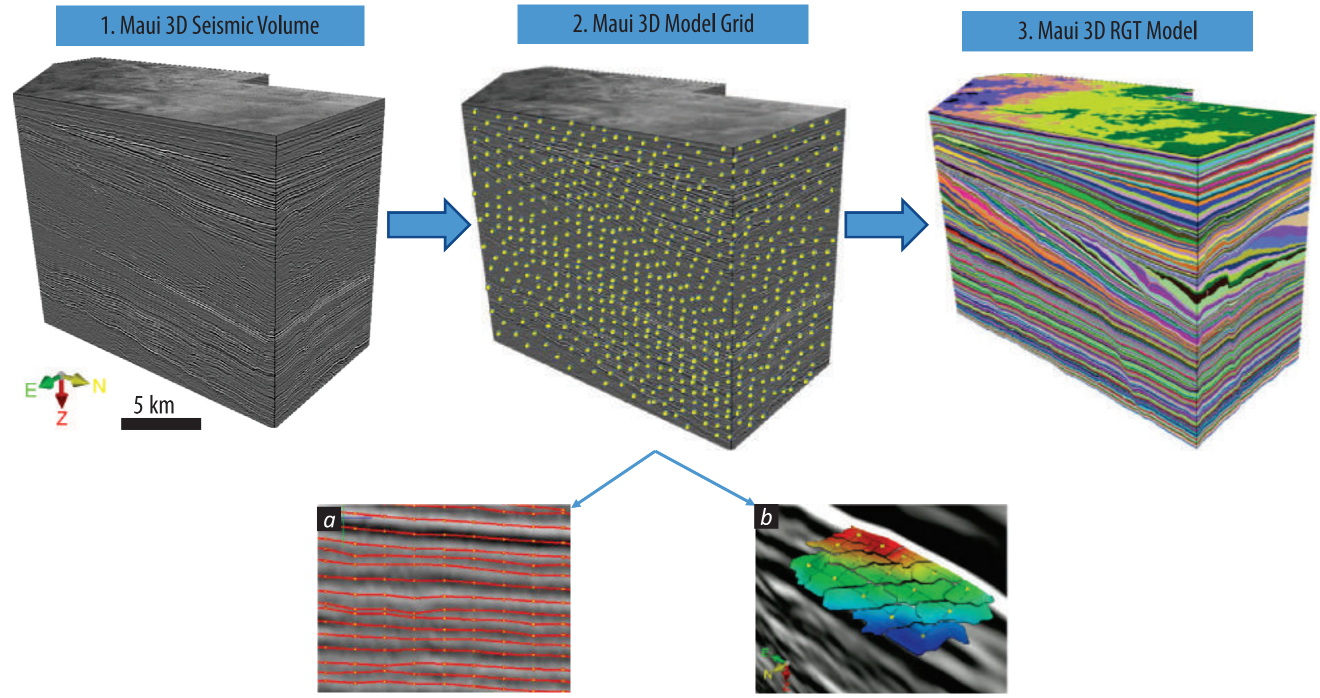


Figure 3. *Summary of the workflow: (1) Maui 3D seismic volume, (2) 3D model grid creation. Auto propagation is based on a correlation threshold in the model grid when nodes (yellow points) are connected, showing on both 2D (a) and 3D (b) viewer, (3) Maui 3D geo-model is the result of the model grid interpolation.*

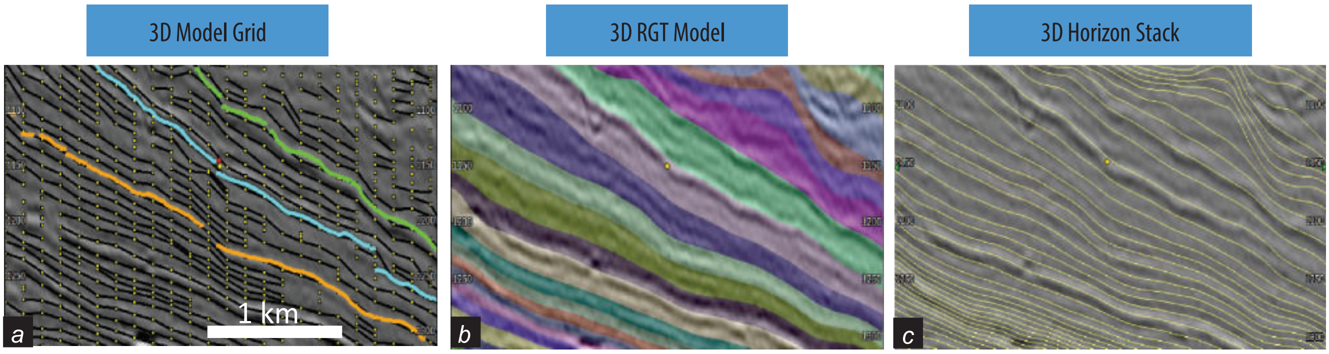


Figure 4. *(a) the 3D model grid where key horizon patches can be editable and highlighted in colours, following the interpreter's ideas, (b) 3D RGT model is blended with 3D seismic volume, showing the same geometry. Instead of having seismic amplitudes, there are relative age values assigned to each voxel of the 3D RGT model, (c) The horizon stack comprises dense stratigraphic horizons, representing the geologic time values in the RGT model.*

horizon patch in 3D with the seismic bin size square (Figure 3b). Using the afore-mentioned algorithm, all elementary horizon patches are linked based on the similarity of the seismic wavelets and their distance. For example, if two wavelets are 3 seismic bin size apart and 30% similar, the nodes on these wavelets will be linked. As a result of this process, all possible horizons within the seismic volume are auto propagated in one attempt (Figure 3a, 3b), acting as a framework for the 3D geological model. The fact that the same geologic age is assigned to patches connected laterally, so each auto-tracked horizon, having its relative age, is sorted stratigraphically and never crosses each other thanks to this advanced algorithm.

In the second step, the 3D relative geologic time (RGT) model is computed from the interpolation of the 3D model grid (Figure 3), in which the relative geologic time is obtained for every sample of the seismic volume. The role of the seismic interpreter involves refining the RGT model by modifying and constraining the relationships of the horizon patches in the 3D model grid until an optimal result could be achieved.

3.3. Horizon stack and stratal slicing

From the RGT model, a horizon stack comprising of unlimited chrono-stratigraphic or iso-geological time surfaces can be created for imaging geological elements and thin stratigraphic events even at a sub-seismic scale. Those surfaces are only 5 - 7 ms apart and represent

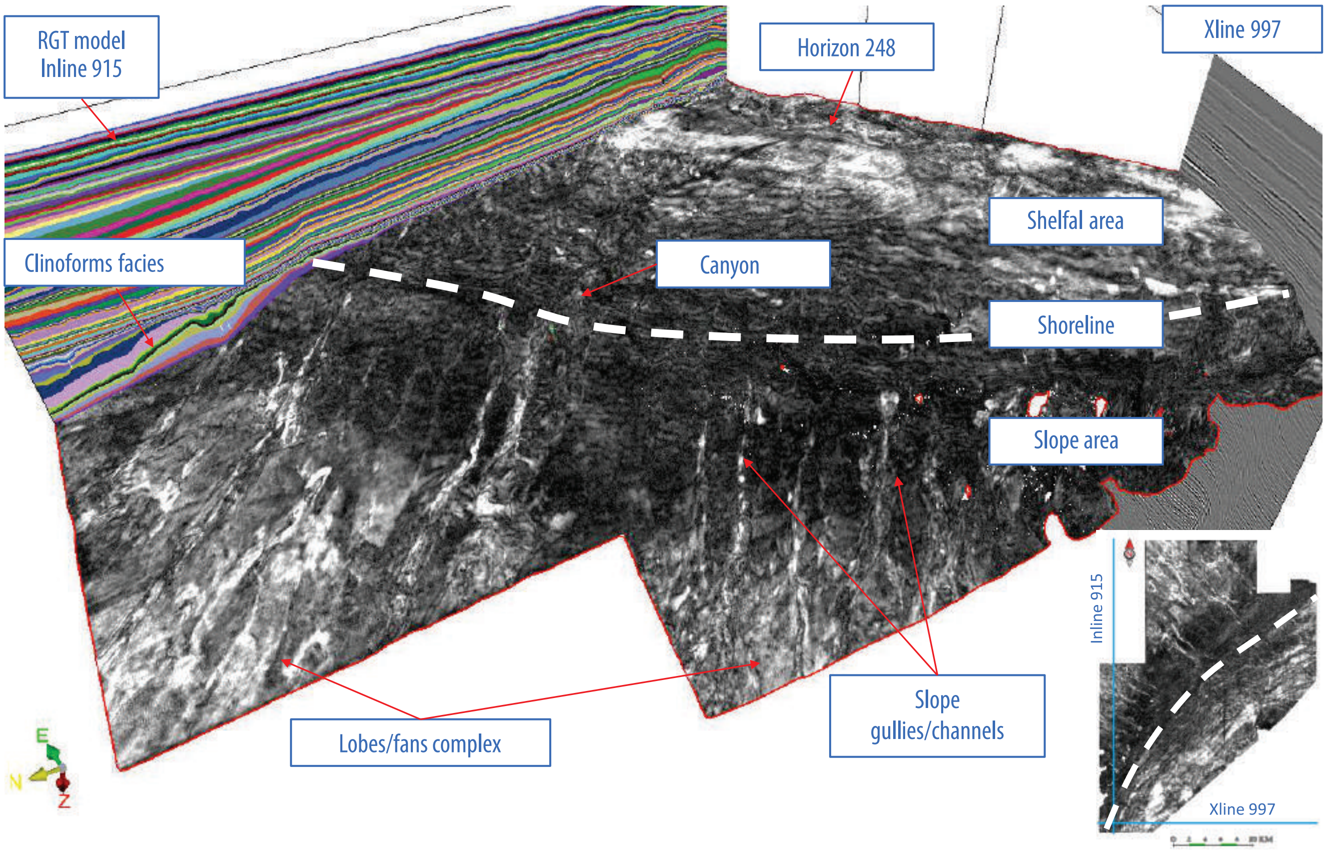
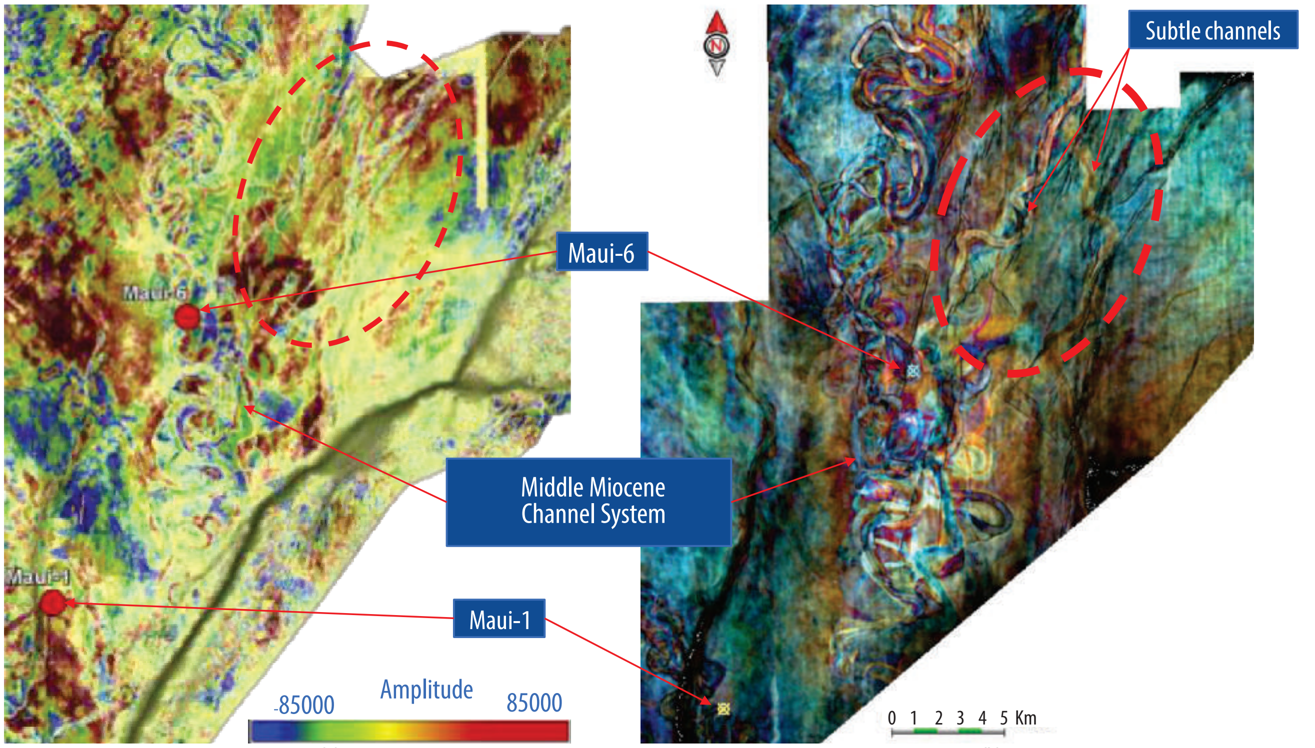


Figure 5. *From the RMS amplitude attribute horizon stack, the geological features of the marginal marine depositional environment in the Giant Foresets Formation were highlighted in great detail on horizon 248 (see Figure 2 for a stratigraphic position).*



(a) *(b)*

Figure 6. *Comparison between (a) horizon from N30-N40 interval using the isoproportional slicing method in Kroeger et al. [17] and (b) horizon 106 from the horizon stack with colour-blended spectral decomposition with three different frequencies (see Figure 2 for a stratigraphic position). Note that on horizon 106 of the horizon stack, the subtle channels in the dash, red circle area, and the overall geometry of the Middle Miocene channel system were revealed more robustly.*

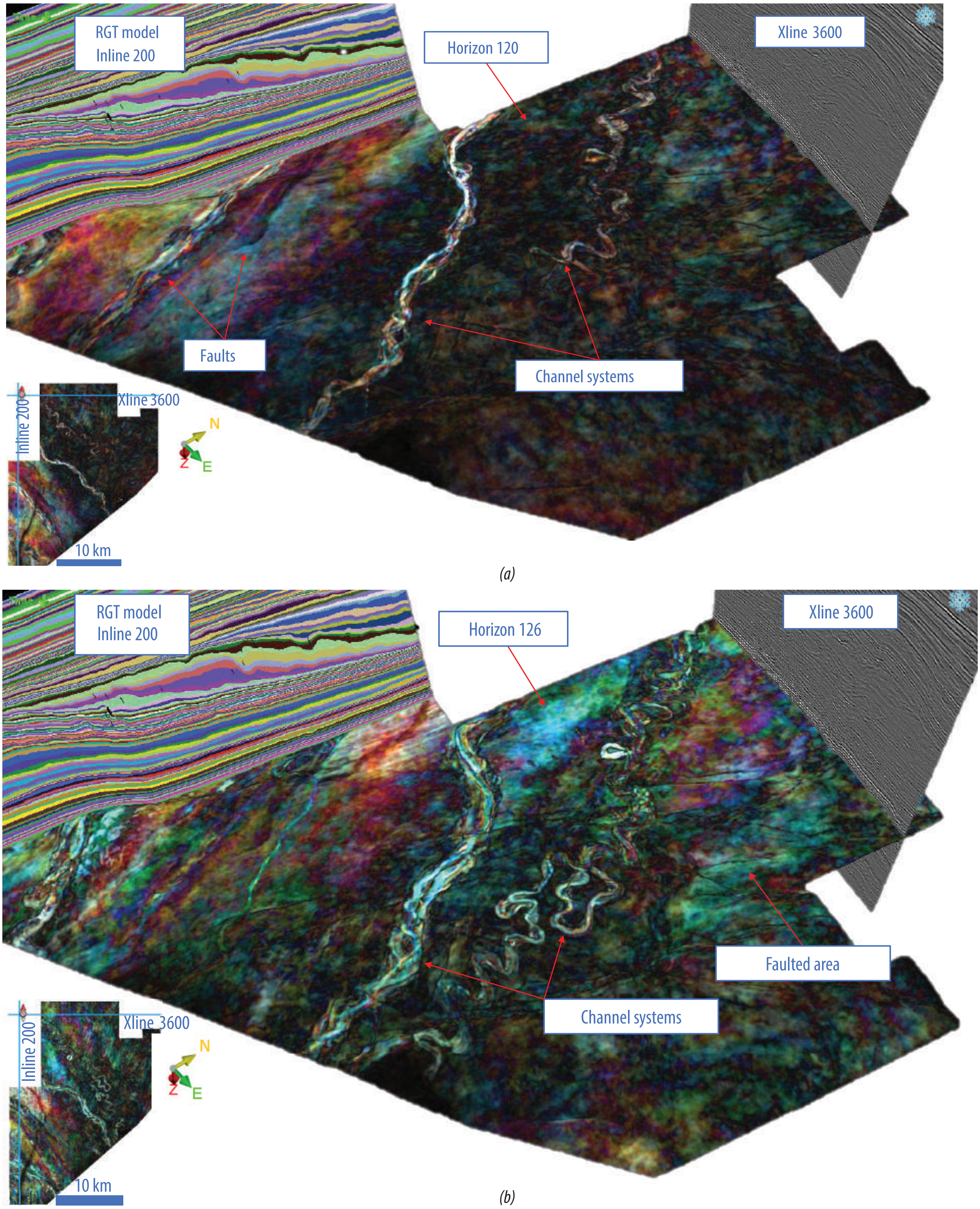


Figure 7. *Using spectral decomposition seismic attribute and the colour blending tool to detect the geological features on horizon 120 (a) and horizon 126 (b) of the horizon stack (horizon 126 is above horizon 120 in stratigraphic order or "younger" in the relative geologic time domain). The evolution of the Middle Miocene, meandering channel system, from horizon 120 to 126 is highlighted in both time and space (see Figure 2 for a stratigraphic position).*

stratigraphic horizons (Figure 4), contrary to horizontal slices (i.e. time slices) from the seismic volume. Several seismic attributes can be extracted on those horizons such as RMS amplitude and colour-blended spectral decomposition attribute. These attributes are calculated from a fixed window size in seismic samples along each horizon (e.g. a window size of 5 with a vertical sampling of 4 means the time window is 20 ms, the attribute will be mapped from 10 ms above and 10 ms below each horizon). This method has been used successfully on numerous case studies with different basin settings for thin-bed reservoir detection and characterisation, along with enhancing fault and fracture imaging [13 - 16].

4. Results and discussion

Using PaleoScan™ software, all possible horizons in the seismic volume are auto-tracked in one attempt either in peak, trough, and zero-crossing, reducing the time cycle on manually picking and seed-based auto-tracking horizon methods. A 3D RGT model is the outcome obtained directly from the Maui 3D seismic volume. In this process, the interpolation of the 3D model grid plays a key role, assigning relative ages to every voxel of the seismic volume to create both vertical and lateral continuity in the 3D RGT model.

In this study, 400 continuous chronostratigraphic surfaces representing relative geological ages are extracted from the 3D RGT model. This unique technique allows the seismic volume to be navigated stratigraphically, revealing stratigraphic insights at a very high resolution, even with thin-bed events or in complex depositional environments (e.g. shallow or marginal marine, Figure 5) that cannot be shown when using the traditional approach.

In the conventional workflow, seismic attributes are only mapped on manually picked key horizons or their shifted ones, which can be time-consuming and not feasible in complex intervals. Here in the same amount of time, hundreds or thousands of horizons with different seismic attributes can be extracted from the RGT model taking into account all the samples of the seismic volume. Also, different from iso-proportional horizons which are generated in the interval between two specific horizons, the horizon stack provides continuous surfaces inside the complex stratigraphic intervals but still strictly follows the geological events and seismic facies of the data, thus it is better for subsurface imaging in those locations (Figure 6).

This innovative workflow has made seismic interpretation more efficient, delivering to geologists a fully consistent, data-driven geo-model along with high-quality horizons (Figures 6 and 7) and faults for further modelling purposes.

5. Conclusion

In this paper, a new interpretation technique has been presented which utilises 3D seismic data and directly transforms it into a 3D RGT Model. This allows generating a dense library of stratigraphic horizons, even in complex intervals to identify subtle events, unseen from conventional methods, which are based on manually picking and seed-based auto-tracking horizons [18].

From an example of Maui 3D, located offshore Taranaki basin, a 3D RGT model was obtained in a short time frame, producing 400 chrono-stratigraphic surfaces. These surfaces mapped with seismic attributes such as RMS amplitude and spectral decomposition using colour-blended method help the interpreters to build up a geological history of the area. The results suggest that this approach could be applied not only to subsurface imaging, the detection of subtle stratigraphic events, but also for modelling purposes, at both regional and reservoir scales. The new workflow drastically accelerates the entire exploration cycle and shapes a new form of seismic interpretation in the future [18].

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