Interpretation of complex geo-bodies using a relative geological time model: Exmouth Sub-basin, Australia

Clémence Prazuck, Benjamin Durot, Vianney Savajol and Sébastien Lacaze, Eliis*

Summary

This study aims to combine a novel global interpretation method, using a relative geological time model and spectral decomposition imaging techniques, into a powerful workflow capable of extracting from seismic data very fine geomorphological features. The workflow was applied to a public domain 3D marine seismic data set covering the Exmouth Sub-basin in Northwestern Australia. The analysis at a sub-seismic scale of horizons stacks allowed the interpretation of complex geo-bodies, which would have remained undetected with classical methods.

Introduction

The Exmouth Sub-basin is characterized by a complex geology made of various stratigraphic unconformities and a dense fault system. For those reasons, the interpretation of such a region with classical methods remains an intensive task, where only a few horizons could be obtained with many assumptions. The novel global approach presented in this paper was applied to the Exmouth Sub-basin dataset to build a full interpreted volume and better resolve geological ambiguities and identify sedimentary features.

Geological settings and data

The 1,000-km² seismic survey HCA2000A 3D covers the Jurassic and the Cretaceous depocentres of the Exmouth Sub-basin. The Exmouth Sub-basin is part of the North Carnarvon Basin, along the West Australia margin. From the late Paleozoic to the Early Jurassic, the basin evolved as a sag basin. The dense fault system in the lower part was developed by rifting during the Jurassic-earliest Cretaceous, associated with the breakup of East Gondwana (Tindale, 1998). Thick Jurassic syn-rift marine sediments were deposited in the new accommodation resulting from the extension. Uplift and erosion to the South of the basin provided a supply of sediments for the Lower Cretaceous sandstones, which prograded across the sub-basin.

The geological features from the Jurassic and Cretaceous periods represent potential targets for exploration. Previous work on this area has shown proven reservoirs in the Barrow Group and Dupuy Sandstone. The Muderong Shale is a regional seal and the Jurassic-Cretaceous faulted parts represent a good structural trap within the Mungaroo.

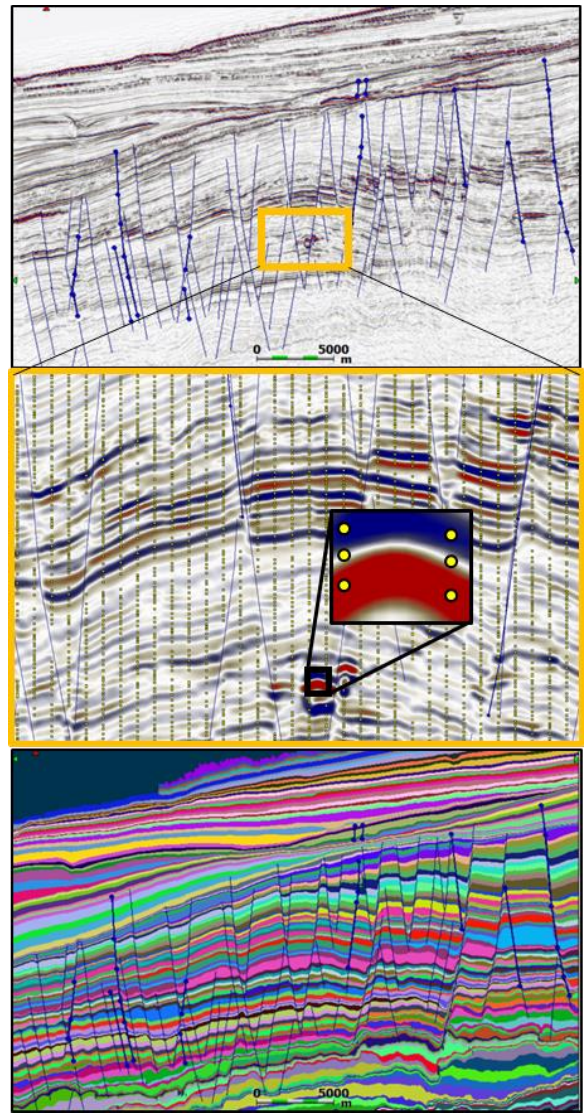

Figure 1: a) Inline 1500 from HCA 2000A 3D survey, Exmouth Sub-basin, Australia. b) Zoom of the model-grid with nodes (peak, trough, zero crossing). c) Display of the continuous relative geological time model on inline 1500, with a discrete color bar to enhance layers.

Method and workflow

Classical interpretation techniques on such a dataset would require a long and intensive work, made of manual picking and auto-tracking, with many assumptions about the complexity of the fault system. A global method was used to understand the relationships between horizons in the entire volume and obtain results in a shorter time frame.

Construction of a geological model while refining the seismic interpretation:

In the common seismic interpretation process, each individual horizon can be either interpreted manually or extracted using auto-tracking methods. From the resulting horizons, a geological model can be defined. This workflow is generally time consuming and presents several limitations depending on the signal's quality and the geological context. The approach used in this study is different: a geological model is obtained by creating a grid made of numerous horizons patches with a defined size and computed on each seismic polarity in the entire seismic volume. The horizons are then linked automatically by using a minimization process depending on traces similarity and relative distance. Relative geologic ages are computed for each horizon to convert the seismic samples into a relative geologic time volume (Pauget et al, 2009).

From a practical standpoint, the method is a two-step workflow. During the first step, a model grid is computed, where each node is an elementary horizon patch of constant size. This process automatically tracks every horizon within the seismic volume to constrain the grid and a relative geological time is computed for every point. In the second step, the interpreter refines the connection between the horizons to build and improve in real time the relative geological time model (Figure 1).

Workflow:

The structural interpretation was the first step of the study. In such an approach, faults are a key parameter to obtain a proper interpretation. They are used as discontinuity constraints in the model grid to avoid wrong propagation effects across faulted areas, where the seismic signature is sometimes fuzzy. Within a couple of weeks, approximately 1,000 fault patches were picked, mostly in the Jurassic and the Cretaceous. The structural network is characterized by a major direction trending NE-SW and a secondary system oriented NW-SE. After a semi-automatic merge of the patches based on the geometry of the fault planes, the number of faults was reduced to 600.

The second step consisted of the stratigraphic interpretation. It was performed on the grid made of approximately 6 million horizon patches, covering the entire area and the 3- second time window, going from the seafloor to the Lower Jurassic. Initial elementary patches were created on each peak, trough and zero-crossing, with a maximum spatial size of 7 traces. After performing the first automatic interpretation, two weeks were spent refining the connections between patches to improve the relative geological time model obtained from the grid.

Once validated, an unlimited number of horizons representing iso-geological ages were derived from the relative geological time model to interpret subtle stratigraphic events with sub-seismic resolution. Seismic amplitude mapping with classical filters, such as RMS or envelope amplitudes, highlighted subtle stratigraphic features unseen with classical methods.

Results

Horizon stack to scan through time to understand the evolution of the basin:

600 geological horizons were extracted from the geological time model in the zone of interest (Figure 2).

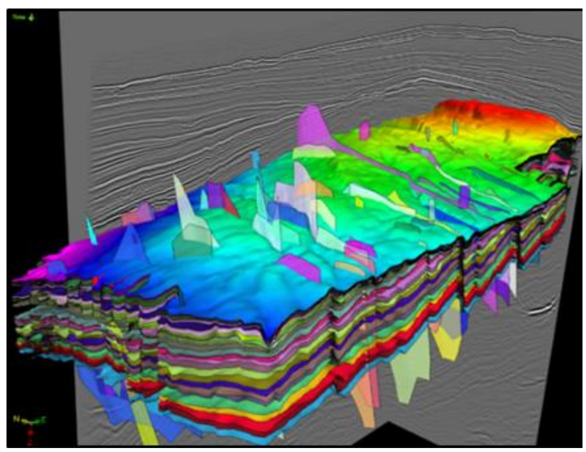

Figure 2: 3D view of a few horizons out of the 600 coming from the horizon stack throughout Cretaceous iso-age faulted horizons of Exmouth Sub-basin.

Spectral decomposition and RGB blending vizualization of the horizon stack

Although RMS amplitude mapping revealed the main stratigraphic events, a particular attention was given to frequency content and RGB visualization of the horizon stack. The RGB color blending technique, classicaly used in interpretation, consists in corendering seismic information with the true colors red, green and blue to better reveal geological objects. Combined with frequency filters, it allows to interpret frequency variations around the area of interest and can help define the location and the quality of potential reservoirs.

In this case, a simple spectral decomposition was applied to the initial full stack volume using band-pass filters. Three frequency components were assigned as follows: low frequencies centered around 13Hz in red, middle frequencies centered around 35Hz in green, high frequencies centered around 55Hz in blue. Low frequencies respond to the thick geologcial features while high frequencies are sensitive to the thin beds.

Figure 3 illustrates how the mapping of spectrally decomposed seismic signal on numerous horizons can be used to visualize geological objects at basin scale. It shows in map view and 3D view the variations of the RGB channels along three stratigraphic horizons. The purple Cretaceous horizon (Figure 3a) highlights two channels with a SW-NE trend. The migration of those two channels is easily detectable by visualizing a few horizons around that level. Furthermore, the variation of point bars location (low amplitude event) can be analyzed through time. The horizons (b) and (c) both show in 3D an eocene turbiditic channel and a delta prograding Westward during the Middle Cenozoic. Those channels may be related to some proven hydrocarbon accumulations, which have been found in the Cretaceous channel (Figure 3b) along the Eskdale-1 and 2 wells (BHP Petroleum PTY Ltd., WA-255-P(2) Eskdale2 Well Completion Report, Interpretive Volume, March 2005). To some extent, new identified channels in the whole stratigrapic interval could be assumed to be potential reservoirs.

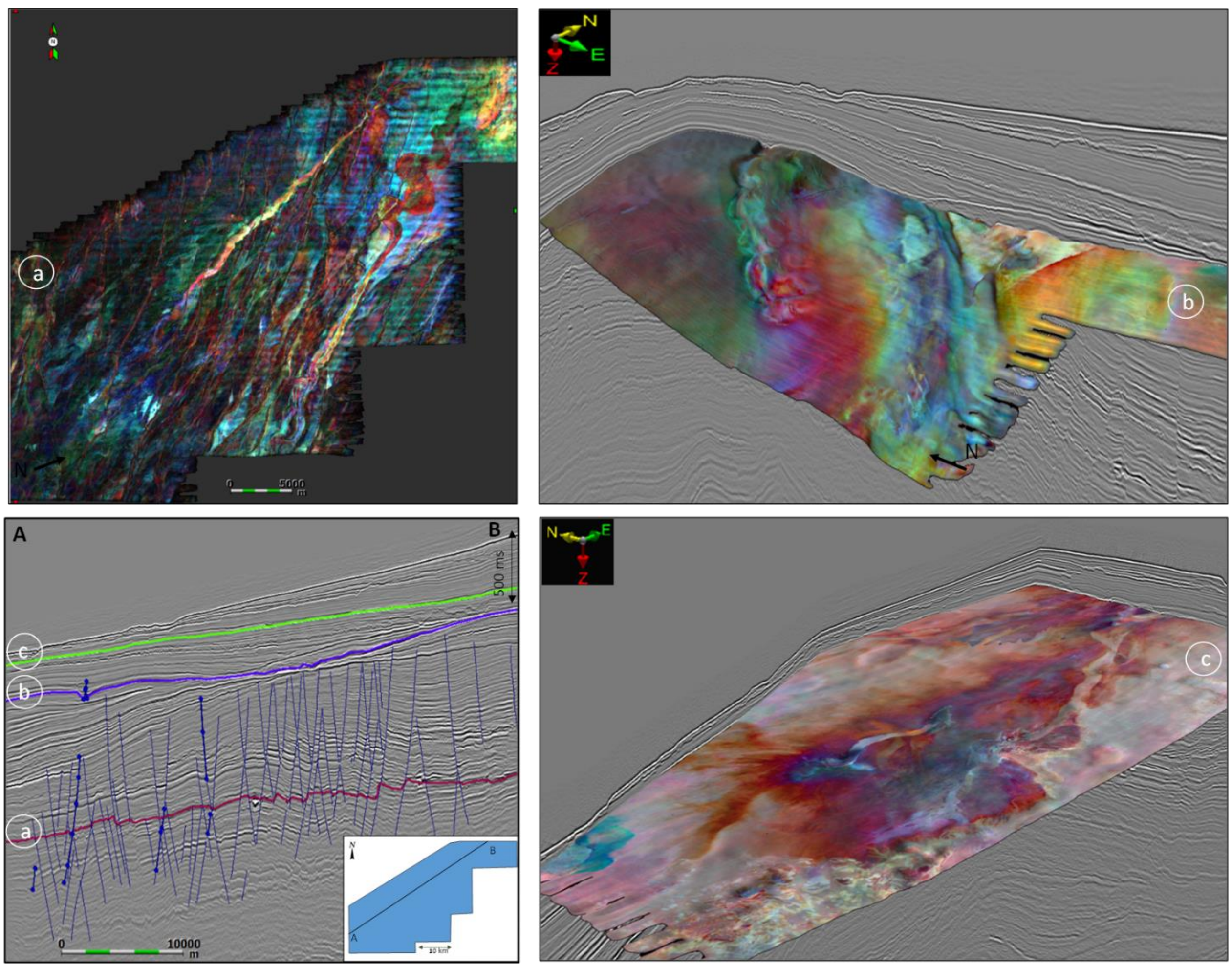

Figure 3: a) Map view of two parallel Cretaceous channels, spreading Westward in the faulted Jurassic. Low frequency signals (red) are mostly located on the Northeast part of the two channels. b) Eocene turbiditic channel displayed in 3D. The channel extends along a NW-SE direction and is parallel to the stratigraphic slope. c) Cenozoic prograding delta displayed in 3D. Higher frequency signals (green and blue) highlight the internal structure of the channel and lower frequency signals (red) surround the channel's incisions.

The 2D seismic view (bottom left) shows on inline 1500 the positon of the three horizons (a, b and c) extracted from the horizon stack. Faults are displayed in blue.

Conclusions

The Exmouth Sub-basin, located offshore Western Australia, is characterized by a complex geology made of stratigraphic unconformities and heavily faulted zones in the Cretaceous and the Jurassic depocentres. A large area of that region was interpreted from the seafloor to the Jurassic by using a novel approach, which consists in building a geological time model while interpreting horizons and faults. Hundreds of faults were first interpreted to constrain the grid made of numerous auto-tracked horizon patches. Based on the first automatic solution, the model was improved during a couple of weeks by refining the connections between the horizons in the entire volume. The amplitude mapping on numerous horizons, derived from the geological model, revealed multiple stratigraphic events with sub-seismic resolution.

Spectral decomposition of the initial seismic signal was performed with band-pass filters centered around 13, 35 and 55Hz, which were blended with RGB channels and displayed on map and 3D views. Within a month time, such a workflow had revealed numerous complex turbiditic channels located mainly in the Cretaceous and had allowed the understanding of their migration through time. It would be interesting in the future to correlate the geologic time model with rock physics properties obtained from the wells to characterize the petroleum systems in the region.

Acknowledgement

The authors would like to thank Geoscience Australia for their permission to use the Exmouth seismic data of the block HCA2000A.

References

Gupta, R., T. Cheret, F. Pauget and S. Lacaze, 2008, Automated geomodelling a Nigeria case study: 70th Conference and Exhibition, EAGE, Extended abstracts, DOI: 10.3997/2214-4609.20147601.

McArdle, N., D. Iacopini, M. A. KunleDare, and G. S. Paton, 2014, The use of geologic expression workflows for basin scale reconnaissance: A case study from the Exmouth Subbasin, North Carnarvon Basin, northwestern Australia: Interpretation, 2, SA163–SA177.

Pauget, F., S. Lacaze and T. Valding, 2009, A global approach in seismic interpretation based on cost function minimization: 79th Annual International Meeting, SEG, Expanded Abstracts, **5**, 2592-2596.

Schmidt, I., S. Lacaze and G. Paton, 2013, Spectral decomposition combined with geo-model interpretation: creating new workflows by integrating advanced technologies for seismic imaging and interpretation: 75th Conference and Exhibition, EAGE, Extended Abstracts, **2**, 1309-1313, DOI: 10.3997/2214-4609.20130567.

Tindale, K., N. Newell, J. Keall, and N. Smith, 1998, Structural evolution and charge history of the Exmouth Sub-basin, Northern Carnarvon Basin, Western Australia: in P. G. Purcell, and R. R. Purcell, eds., The sedimentary basins of Western Australia 2: Proceedings of Petroleum Exploration, Society of Australia Symposium, 447–472.