Comprehensive Seismic Interpretation to Enhance Stratigraphy and Faults

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Abstract

This paper presents how a comprehensive method in seismic interpretation can facilitate and improve processes in exploration and development.

The relative geological time (RGT) volume is obtained directly during the seismic interpretation phase by auto tracking all possible horizons within the seismic volume and refining their relationships. It provides a new way to perform a strata slicing into the seismic volume even in regions, where classical techniques are limited. We have applied this workflow; combined with spectral decomposition to reveal at high resolution turbidites channels in the Exmouth Sub-Basin, located offshore West Australia.

For fault characterization, attributes derived from the RGT model such as dip or deepest descent gradient are essential to identify subtle events difficult to interpret when the signal noise ratio is too low. These attributes were used to understand the geometry of the fault system whereas seismic based attributes like variance and semblance were blind due to a poor signal quality in the deeper levels.

By relating the stratigraphic plays with the structural network at a high resolution, this approach allows to better assess prospect leads in the exploration phase as well as characterizing reservoirs. A future work will consist in analyzing the sealing properties of each fault in a watertight model.

Introduction

Traditional seismic interpretation is generally an intensive and time consuming process based on manual picking or auto-tracking of single horizons within a seismic volume. Even though seed auto-tracked by correlation of wavelet amplitudes is a strong improvement; it is often limited to regions showing clear seismic reflections with a relatively simple geology, obliging geoscientists to many assumptions. Recently new approaches have been proposed to exploit the three dimensionality of the data to simultaneously track every surface throughout the volume. Some of these methods are based on the classification of the reflector extrema (Borgos et al, 2003), phase unwrapping (Stark et al, 2004), seismic flattening (Lomask, 2006), horizon cube (de Groot et al, 2010), seismic DNA (Bakke et al, 2011), chronostratigraphic models (Labrunye, 2013) or horizon volumes with constraints (Wu and Hale, 2014).

Pauget el al, 2009, proposed a comprehensive approach to build a geological model while interpreting seismic data. Continuous surfaces can be computed anywhere inside a stratigraphic interval without being limited by the seismic polarity changes, whereas other techniques are limited to 2D analysis and/or a limited number of horizons.

We have used this method for different applications in reservoir detection in thin beds, fault and fracture imaging and reservoir characterizations.

Method

The RGT model comes from a global seismic interpretation method, which can be summarized as a two-step workflow. During the first step, horizons are automatically tracked within the entire seismic volume to constrain a grid and a relative age is assigned for each point. The seismic interpreter then checks the auto-picked horizons and refined them locally inside the grid until an optimum solution is obtained (Figure 1). Such a method has already been tested on various case studies with different geologies (Gupta et al., 2008; Lemaire et al., 2010; Lacaze et al, 2011, Schmidt et al., 2013).

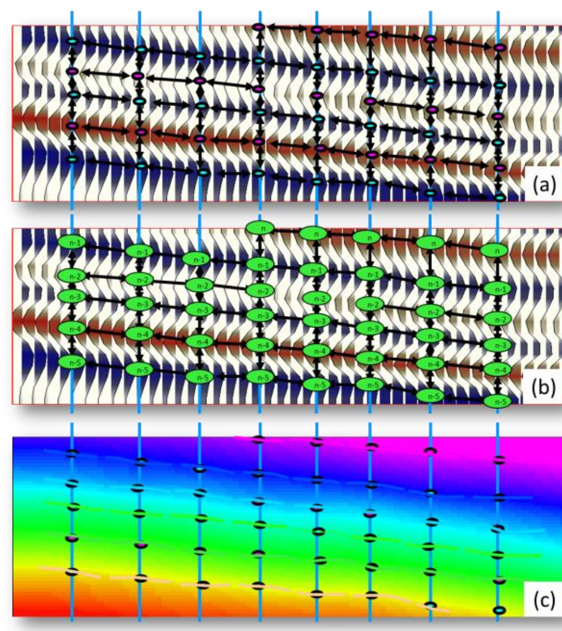

Figure 1- *Workflow of the relative geological time model method. a) Creation of a grid from seismic traces and automatic tracking of horizons. b) Relative geological times assignment. c) Resulted relative time model.*

Geological Settings

The method was applied to a 1,000 km^2 3D seismic dataset (HCA2000A) located along the north-western Australian margin in the Exmouth sub-basin, part of the North Canarvon Basin. This region is characterized by a complex geology made of various stratigraphic unconformities. The seismic survey covers Late Permian to Neogene sediments. The Late Permian to Triassic was dominated by subsidence during the pre-rift stage. The rifting stage took place in the Jurassic and the Cretaceous, and is associated with the breakup along a northeast-southwest trend of the East Gondwana until the Cenozoic. Thick marine sediments and sandstones were deposited during that time period. The Cenozoic is represented by the basin evolving towards a passive margin carbonate shelf (Tindale et al.,1998).

Spectral Decomposition for Stratigraphic Analysis

An unlimited number of horizons representing iso-geological ages are derived from the RGT model to interpret thin stratigraphic events at a sub-seismic resolution. Seismic amplitude mapping with classical filters, such as RMS or envelope amplitudes, highlighted subtle stratigraphic features unseen with classical methods.

Although RMS amplitude mapping revealed the main stratigraphic events, a spectral decomposition was applied to the initial full stack. This technique allows defining specific frequencies in order to highlight possible geological targets. In practice, the process consists in the convolution of the seismic trace with a given kernel function associated with the frequency. Several methods based on that simple process are usually applied to seismic data. In the case of the Short Time Fourier Transform (STFT), the trace is convolved with a windowed sine function oscillating at a given frequency. A window length has to be chosen for a required time accuracy. The larger the window, the greater the frequency accuracy will be. In the case of the wavelet transform, the trace is convolved with a wavelet, usually a Ricker or a Morlet wavelet, with a peak frequency corresponding to the required frequency. With the wavelet transform the time precision can automatically be adjusted according to the frequency used. Such a process applied to the entire spectrum of the trace produces a variogram from which remarkable frequencies can be selected. Once they are defined, the same convolution is applied to every trace to generate several spectrally decomposed volumes that are used to produce amplitude maps for RGB blending analysis.

In this data set, a “Short Time Fourier Transform” decomposition was performed with a 52ms vertical window size. For each channel, three characteristic frequencies (20Hz, 35Hz, 47Hz) of its spectral signature were extracted and mapped on horizons extracted from the RGT model.

By color blending in red, green and blue the different frequencies on a large number of horizons extracted from the RGT model, it revealed internal geometries of the different turbidites channels at a very high resolution (Figure 2).

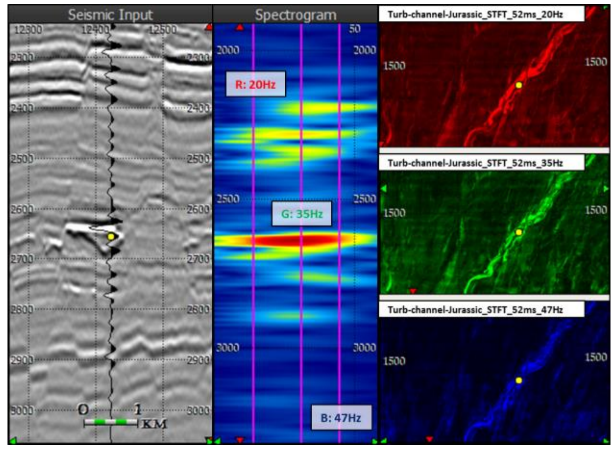

Figure 2- *Extraction of the three characteristics frequencies of the Jurassic channel. (a) Seismic section with a focus on a specific turbiditic channel (b) Computed spectrogram of the specific channel and the 3 selected frequencies (low, mid, high) (c) Results of the spectral decomposition around those 3 selected frequencies (red, blue, green), which are combined to obtain a final RGB blended image*

The channels are part of the Dupuy Sandstones of the Jurassic and are identified as potential reservoirs (Regional geology of the Northern Carnarvon Basin, Australia 2012, Offshore Petroleum Exploration Acreage release, 2012). The sedimentary complexity of the channels is better understood allowing a finer extraction of 3D geo-bodies using spectral decomposition (Figure 3). The channels are oriented NE-SW with a length of 37km for the western channel and a length of 25km for the eastern channel.

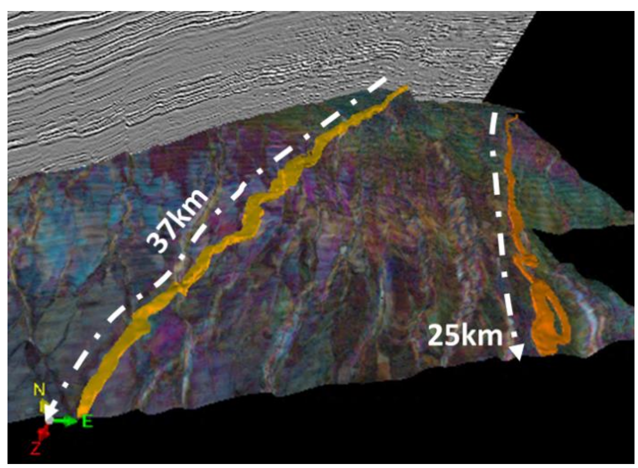

Figure 3- *3D view of a few horizons out of the 600 coming from the horizon stack of Exmouth Sub-basin. A spectral decomposition (13Hz, 35Hz and 55Hz) is applied on each horizon to image at a high resolution the turbidites channels.*

Fault and Fracture Imaging

Interpreting faults is usually a delicate task which requires the computation of various attributes.

In the Exmouth sub-basin, the Jurassic and Cretaceous deposits are highly fractured due to the rifting phase and therefore constitute a challenging work for structural interpretation.

Seismic attributes have been used extensively to image faults for the past decades. Even though algorithms, imaging technologies and hardware are improved year after year, detecting faults from the seismic remains a complex task, which still requires a manual picking.

Therefore, dip-steered coherence analysis (Marfurt et al, 1998), such as variance, provides a significant image of the structural discontinuities but still depends on the seismic signal heterogeneities in the vicinity of the fault. This is the reason why such an attribute cannot be used to extract automatically the fault planes but has to be used as a guideline to constrain the manual fault interpretation.

Another complementary technique consists in taking into account a RGT model as an input for fault imaging complementary to seismic attributes. This technique provides a high-resolution fault image relying to geology (Lacaze et al, 2016).

By applying spatial derivatives, structural discontinuities can be clearly highlighted, at a sub-seismic resolution. Indeed, as vertical derivatives are sensitive to stratigraphic discontinuities, spatial derivatives of the relative ages show clearly the occurrence of faults and fractures even in zones characterized by a poor seismic signal to noise ratio (Figure 4). Although such results are promising, it is required to check first the quality of the RGT model, which may need some manual refinement by the interpreter, prior the attribute computation.

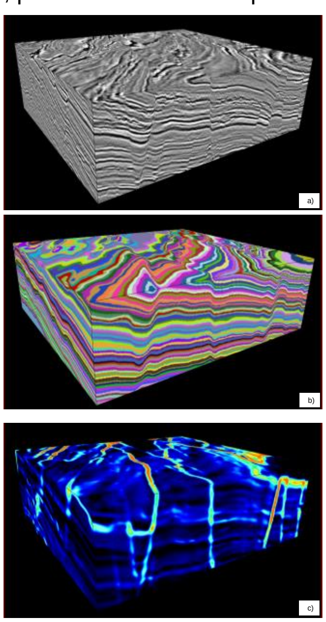

Figure 4*: Fault attributes derived from the RGT model. (a) Seismic (b) RGT model (c) Spatial gradient of the model*.

Moreover, there is a range of surface attributes such as dip, azimuth, curvature, which allows to detect subtle faults and fractures, at a sub-seismic accuracy. The deepest descent gradient (DDG), which consists in calculating the dip differences in the direction of greatest variation, detects the fault break points and reveals subtle faults and fractures.

By co-rendering the DDG and the seismic envelope, the hierarchy between major and minor faults could be clearly highlighted in the reservoir level. Their incidence on the Jurassic channels identified earlier in the rift depocenter is more understandable at finer scale. The Figure 5 shows a NNE-SSW fault network crossing the western channel in multiple locations

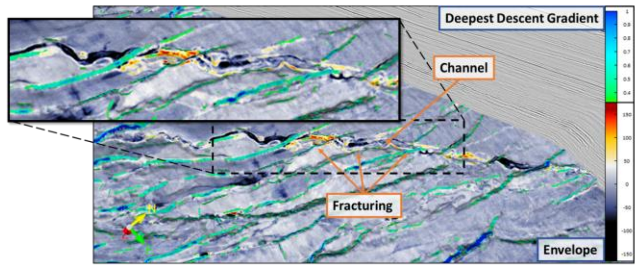

Figure 5: Co-rendering in 3D of the seismic envelope and the Deepest Descent Gradient on a horizon at the reservoir level.

Besides, whereas seismic attributes only show local variations, the RGT model derivative is directly related to the vertical throw of the fault.

The fault throw, related to the vertical displacement of every horizon in the RGT model, was also computed and mapped onto each fault plane. Such high-resolution mapping of the throw distribution provides a preliminary way to characterize the seal properties. We can observe on Figure 6 that the faults in the north-eastern part of that channel have a greater throw and might induce a compartmentalization of the reservoir deposits

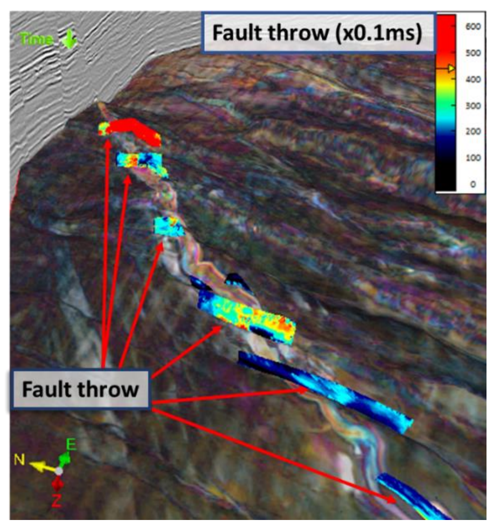

Figure 6: *Co-rendering in 3D of spectral decomposition in RGB and the fault throw attribute at the reservoir level.*

Conclusions

This paper has shown how a relative geological time (RGT) model obtained during the interpretation process can improve workflows for exploration and development applications. It allows producing a dense number of horizons even in complex levels to identify subtle events, unseen with classical methods. An example was given in the Exmouth Sub-Basin essentially focused on the Jurassic channels from the Dupuy Sandstone, which are known as potential reservoirs. Turbidites channels were clearly delineated and extracted as geobodies thanks to spectral decomposition color blended in RGB on a large number of horizons, derived from the RGT model.

For fault characterization, attributes derived from the RGT model such as dip or deepest descent gradient are essential to identify subtle events difficult to interpret when the signal noise ratio is too low. These attributes were used to understand the geometry of the fault system whereas seismic based attributes like variance and semblance were blind due to a poor signal quality in the deeper levels.

A future work will consist in converting the RGT model in a watertight model to analyze faults juxtaposition and characterize sealing properties in the reservoir level.

Acknowledgments

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