Global Technique in Seismic Interpretation for Reservoir Detection and Characterization

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Summary

This paper presents how a global 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 stratal 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.

By analyzing the variations of the RGT model in 3D, new attributes enhance faults even in zones presenting a low signal noise ratio, where classical seismic attributes are almost blind. This workflow was used in the North Sea, K05 block, to reveal complex faulted deposits. Finally, in the same region, the RGT model and the seismic data were used to populate acoustic impedance values recorded along wells using a co-kriging algorithm. The results allowed to better characterize heterogeneities variations at a reservoir scale.

This novel methodology shows a potential to reduce the time cycle in the exploration for the prospect identification but also more control for advance studies in reservoir characterization, seismic inversion and geomodeling.

Introduction

Traditional seismic interpretation is generally a 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 global 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.

Overview of the 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).

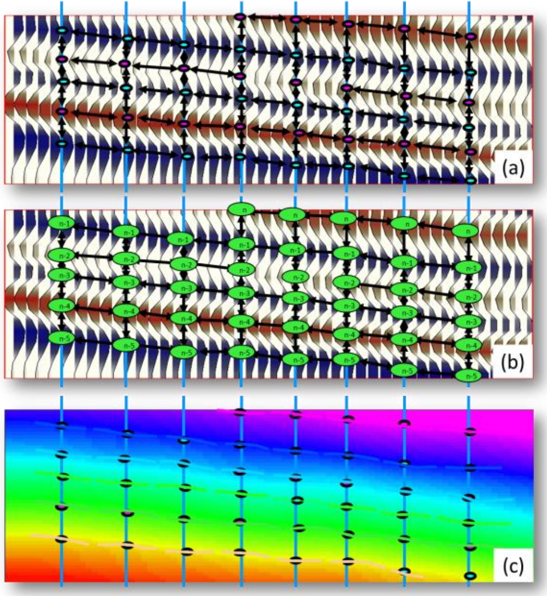

Figure 1: *Workflow of the relative geological time model method. a) Creation of a grid from seismic traces and automatic tracking of horizons. b) Relative geological times assignment. c) Resulted relative time model.*

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Detection of thin reservoirs

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. This workflow was applied on a seismic data set of the Exmouth Sub-basin along the West Australia margin. This region is characterized by a complex geology made of various stratigraphic unconformities.
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, as follows: 13Hz, 35Hz and 55Hz. Low frequencies respond to the thick geological features while high frequencies are sensitive to the thin beds.

By color blending in red, green and blue the different frequencies on 600 horizons extracted from the RGT model, it revealed internal geometries of the different turbidites channels at a very high resolution (Figure 2).

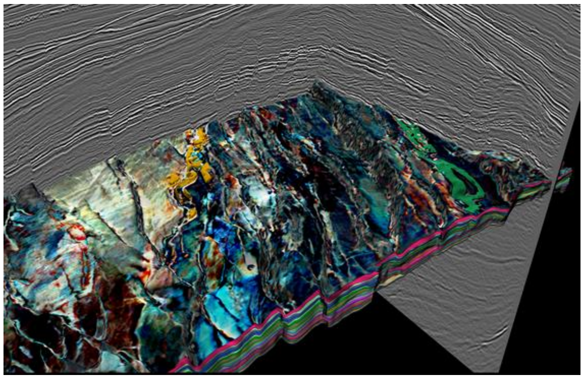

Figure 2*: 3D view of a few horizons out of the 600 coming from the horizon stack of Exmouth Sub-basin. A spectral decomposition (13Hz, 35Hz and 55Hz) is applied on each horizon to image at a high resolution the turbidites channels.*

Fault and fracture imaging

Thanks to its vertical continuity, the RGT model is a new tool for understanding the structural network, revealing subtle faults and fractures and characterizing geomechanical properties at a sub-seismic resolution.

It can be used as a dip steered filter to compute dip angle, azimuth variations as well as deepest descent gradient (DDG), which is related to the maximum surface curvature. The geometrical parameters can be computed either in the volume or on surfaces. This technique was used on a North Sea case study located in the block K05, offshore Netherlands covering an area of 1750 sq. km (Daynac et al, 2014). This zone is characterized by a large and complex faulted deposits (Figure 3).

For each horizon, a comparison of different types of attributes coming either form the seismic volume or from the 3D analysis of the RGT model was performed at the same scale.

Below the salt, seismic image quality is too poor to obtain a clear image of the fault system. Classical seismic volume attributes, such as the similarity or semblance, appear quite limited (Figure 3.b) or totally blind.

However information arising from the model, the dip angle and the DDG, computed directly from the surfaces and mapped in the reservoir level (Figure 3) allow to identify two different fault networks: a major direction trending NW-SE and a minor one trending NE-SW. The DDG has moreover detected subtle faults, which could not be seen on classical seismic attributes

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 and the compartmentalization of the reservoir level. In this specific case, the throw analysis was mainly realized to check the consistency of the horizon interpretation across faults in such a complex area.

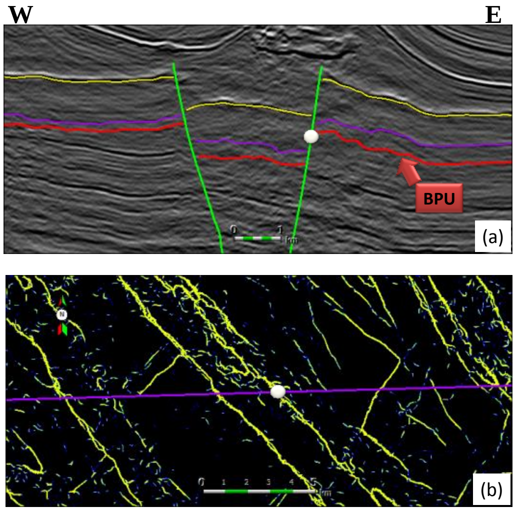

Figure 3: *a) Mapping of the deepest descent gradient on a RGT model horizon of the reservoir level (Upper Rotliegend). (b) Seismic section in the vicinity of the pointed fault. The horizon intersection is highlighted in red color.*

Reservoir Characterization

The RGT model can also be used to predict the rock properties distribution across the wells. In that domain, applications are various depending on the method of propagation.

By using the interpolation between wells such as the inverse distance weighting method.

$$u(x) = \frac{\sum_{k=0}^{N} w_k(x) u_k}{\sum_{k=0}^{N} w_k(x)},$$

$$\text{with} \quad w_k(x) = \frac{1}{d(x, x_k)^p}$$

Where *u(x)* corresponds to any interpolated value at position *x*, $w_k(x)$ corresponds to the weighted values related to the seed *k*, $d(x,x_k)$ corresponds to the distance between the two locations.

It performs a detailed geological correlation across the wells, where the distribution of rock properties strictly follows the geological trend (Figure 4.a). To some extent, it can also be used to propagate the interval velocities for time depth conversion application. Such a technique has also other applications to generate synthetic seismic volumes, to check the quality of the well to seismic tie.

For quantitative interpretation, the co-kriging method is more appropriate. In this case both RGT and seismic volumes are used to populate acoustic impedance. The kriging of the log values is first done along each relative geological time and the seismic data are then used to adjust and improve the results according the variations of the seismic facies.

Cokriging method :

$$Z_x = m_Z + \sum_{i=1}^{n} \lambda_i (Z_i - m_Z) + \sum_{i=1}^{m} \alpha_i (Y_i - m_Y)$$

where Zx is the unknown main property at the location x. (Z being the main property and Y the secondary property).

Applied on the acoustic impedance logs of the same case study in the K05 area, it highlights vertical geological heterogeneities at a very fine scale (Daynac et al 2014). It has shown gradual deposits variations of the below of the salt layer (Upper Rotliegend Group level) and an alternation of deposits exists within the Late Carboniferous too. Although there is a clear correlation of acoustic impedance values within the main stratigraphic levels, it shows at fine scale thin variations in the reservoir level. The obtained AI volume could be then used as an a priori model to constraint the inversion of seismic data.

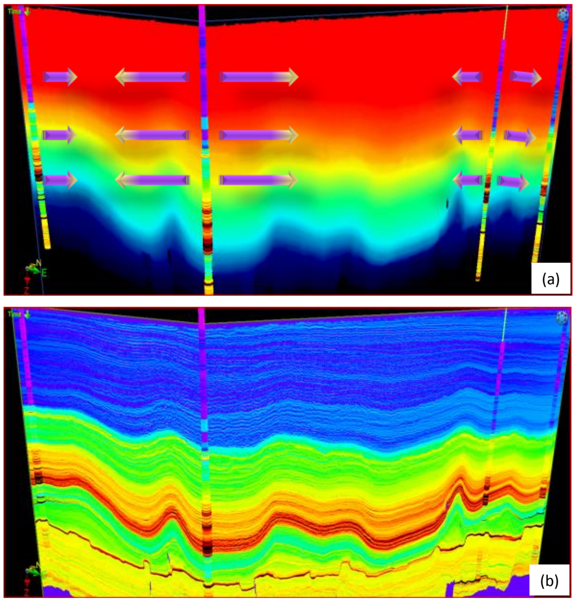

Figure 4: *(a) Arbitrary line of the RGT model across the wells. (b) Results of an AI modeling by co kriging the RGT and the seismic volumes.*

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 where turbidites channels were clearly delineated thanks to spectral decomposition co blended on many horizons slices.

For fault characterization, attributes derived from the RGT model such as dip or curvature are also essential to identify subtle events difficult to interpret when the signal noise ratio is too low. On a North Sea case study, these attributes were used to understand the geometry of the fault system whereas similarity and semblance were blind due to a poor signal quality in the deeper levels. Finally for reservoir characterization, the rock physics properties recorded along wells can be propagated by using a cokriging method. Applied on acoustic impedance in the same zone, the method quantifies the heterogeneities variations at a fine scale, in the reservoir level located below the salt.

Based on the RGT model other applications and workflows are investigated in seismic inversion and geomodeling in order to minimize the risk in the E&P decision making process.

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