Interpretation of Complex Faulted Deposits in the North Sea using the Relative Geological Time Model

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Main objectives

This paper shows, how a novel method, which consists in building a relative geological time (RGT) model from seismic, could be applied on the large volume located in block K05, offshore North Sea.

New aspects covered

Relative Geological Time Model, Thinning attribute for stratigraphic analysis, Fault enhancement, Rock properties modeling

Summary

This paper presents the application of a novel method, based on a Relative Geological Time (RGT) model, for the interpretation of the block K05, a large and complex zone located 120 km offshore Netherlands. The aim of this study was to understand the stratigraphic evolution of the zone, the fault network geometry and the rock properties distribution, in the reservoir level. The RGT method is a computer aided workflow using a grid, where each node is an elementary horizon patch with a constant size. The main challenge consisted in refining the model results below the salt, where the reservoir level lies, by using the well markers. A thinning attribute, derived from the model was used to delineate the stratigraphic units in the reservoir level (middle Permian). Subtle fault detection was done by using the deepest descent gradient, unseen with classical seismic attributes. The fault throw distribution, mapped onto fault planes with a very high resolution, has revealed a compartmentalisation of the reservoir level. The interpolation of acoustic impedance logs, using the RGT volume, allowed to identify heterogeneities related to fine scale gradual deposits variations, in the reservoir level.

Introduction

Interpreting faulted deposits from large seismic volumes remains a challenging manual task, where geoscientists have to make lots of assumptions. Even though seismic acquisition and images visualisation technologies have been constantly improved for the last decades, it remains difficult to interpret faulted reservoir zones presenting a low signal noise ratio. This paper shows how a novel method, which consists in building a Relative Geological Time (RGT) model from seismic volumes, was applied on the block K05 in the North Sea. This volume, located 120 km offshore Netherlands, covers about 1750 km² and a time interval of 5 seconds. The aim of this study was to use results from the RGT model to understand the main stratigraphic levels, the fault network and its influence on the reservoir geometry, and finally to evaluate rock properties distribution across the wells.

Methodology

The method to obtain a Relative Geological Time (RGT) model (Pauget *et al.* 2009) from the seismic is a two-step workflow. During a first step, a grid is computed, where each node is an elementary horizon patch with a 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. During a second step, a manual verification is done by the interpreter. During this step, stratigraphic well markers were used to refine the model in zones presenting a low signal quality. Besides having a proper seismic well tie using the synthetic seismograms, a checking of the correlation between horizons, resulting from the model, and the stratigraphic markers was realized for each well (Figure 1), until an optimum solution was obtained. This work was required especially below the salt, where the data quality is much lower. Such methodology has been already demonstrated on various case studies for exploration and development purposes (Schmidt *et al.* 2013; Vidalie *et al.* 2012; Beller *et al.* 2012; Lemaire *et al.* 2010; Gupta *et al.* 2008).

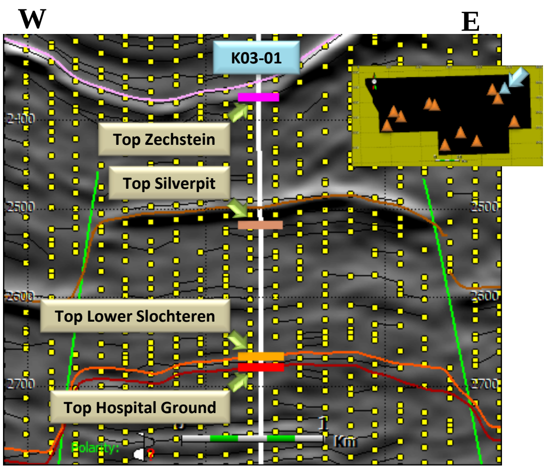

Figure 1 – Well markers constraint applied on the grid. The interpreted horizons fit the well markers which are also used as guides.

Enhancement of Stratigraphic Traps

The K05 block takes place within the structural unit named "Dutch Cleaver Bank High" platform. Carboniferous and middle Permian deposits are characterized by a horst and graben architecture and a basin shape. Conformably above the middle Permian sandstone and claystone series, lies a diapiric salt group (Zechstein Group, late Permian). The overlying Cretaceous deposits are folded and composed by a thin shaly level and a thick chalky sequence. The overburdening Cenozoic sediments fill the upper part of this region. The middle Permian level (Upper Rotliegend Group) presents a particular interest because of the reservoir deposits in the sandstone-prone Lower Slochteren (Figure 2.c).

A vertical derivative, also called "*Thinning*" attribute was generated (Figure 2.b) from the RGT model (Figure 2.a). It reveals the instantaneous variations of the geological layers in the volume on each seismic voxel. The "Thinning" cube is sensitive to the convergence and divergence of the geological horizons and therefore appears to be particularly suitable to reveal unconformities and sequence boundaries (Lacaze et al, 2011).

The zones presenting a maximum of thinning are clearly correlated to the main stratigraphic boundaries (Figure 2.c and d). The geometry of the Upper Rotliegend Group, containing the reservoir Lower Slochteren formation, is well delineated. The top of this group corresponds to the base of the salt whereas the bottom is characterized by an aggradation of sediments on the Base Permian Unconformity (BPU). Below that sequence, Carboniferous deposits, top-lapping on the BPU, are characterized by internal heterogeneities possibly related to dynamic changes of sediments deposition.

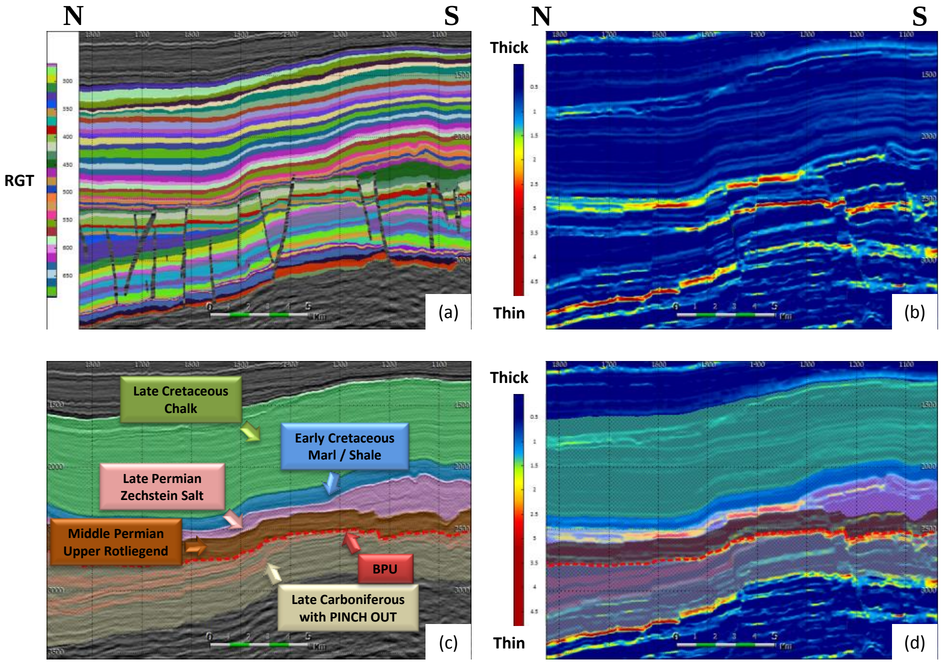

Figure 2 – The thinning attribute (b) corresponds to the first derivative of the RGT Model (a). (d) Delineation of stratigraphic units is done based on levels showing a maximum of thinning (in red). (c) Reported on a seismic cross-section, it becomes easier to relate each stratigraphic unit to a geological age.

Structural Analysis of the Fractured Reservoir

The continuity of the RGT model represents a new input to understand the structural network, to characterize fault properties and also to reveal subtle faults.

The deepest descent gradient (DDG) and the dip angle were computed directly from the model and mapped on a dense number of horizons in the reservoir level. These attributes allow distinguishing two different fault networks: a major direction trending NW-SE and a minor one trending NE-SW. In the Upper Rotliegend Group level, the DDG has detected subtle faults, which could not be seen on classical seismic attributes such as similarity or semblance.

The fault throw, related to the vertical displacement of every horizon in the RGT model (Figure 3.a) was also computed onto each fault plane. Such high resolution mapping of the throw distribution provides a way to characterize sealing properties and the compartmentalisation of the Upper Rotliegend Group level (Figure 3.b and c).

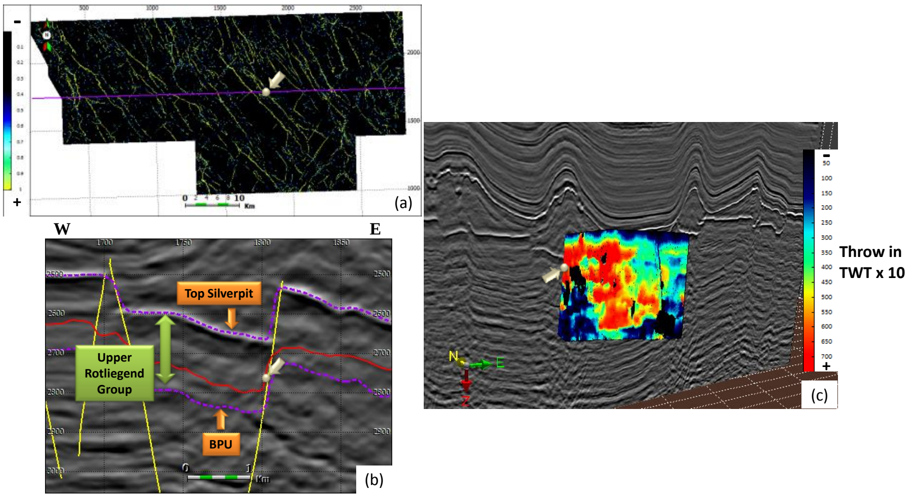

Figure 3 – (a) Mapping of the deepest descent gradient on a RGT model horizon of the Upper Rotliegend Group level. (b) Seismic section in the vicinity of the pointed fault. The horizon intersection is highlighted in red color. (c) 3D mapping of the throw distribution.

Estimation of the Rock Properties Distribution

Rock properties, such as acoustic impedance (AI), recorded along the wells, were propagated inside the RGT model, by applying a simple interpolation using the inverse distance method between wells. The value of each voxel is weighted by the distance to the wells (Figure 4.a). This process enables to perform a detailed geological correlation across the wells, where the distribution of rock properties strictly follows the geological trend.

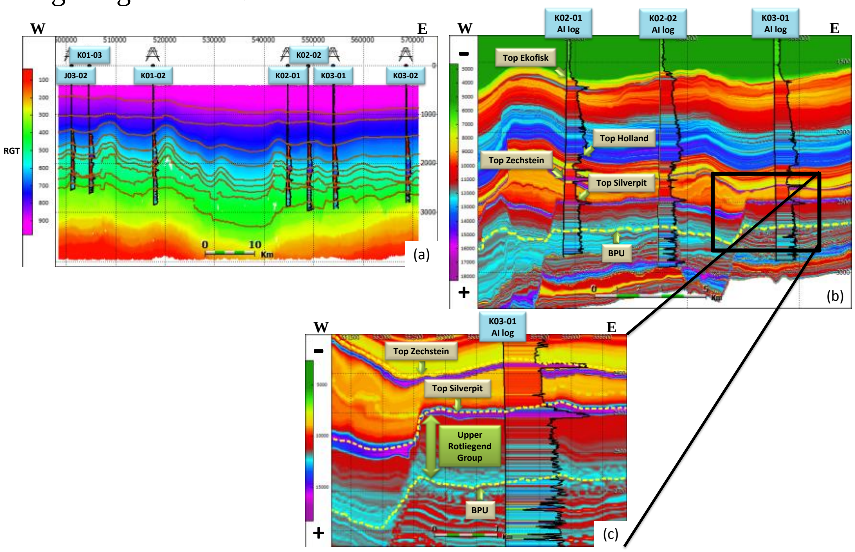

Figure 4 – (a) Random line of the RGT across the wells. (b) Propagation of the AI across the wells using the inverse distance method. Each stratigraphic formation presents distinct AI properties. (c) A zoom on the Upper Rotliegend Group level shows a vertical heterogeneity with a gradual decreasing of the AI value from the bottom to the top.

Applied on the AI, it highlights vertical geological heterogeneities at a very fine scale (***Figure 4***.b). This is related to the gradual deposits variations in the Upper Rotliegend Group (Figure 4.c), from the sandstone-prone Lower Slochteren to the claystone-prone Silverpit formations, which are each other's lateral equivalent (Geluk, 2007). Furthermore, an alternation of deposits exists within the Late Carboniferous too. Such result could be used as a priori model for seismic inversion (Figure 4.b), at a later stage.

Conclusions

A large volume located in the Block K05 of the North Sea, defined by a complex fault system, was interpreted using a novel approach based on relative geological time. During the interpretation, the model was constrained by stratigraphic markers to refine the model below the salt, where the reservoir lies. Stratigraphic units were delineated in the vicinity of the reservoir level (middle Permian) with a very high resolution by analysing the thinning attribute. The structural interpretation was performed using the deepest descent gradient, enabling a detailed understanding of the fault trends and also the detection of subtle faults, unseen with classical seismic attributes. Moreover the throw distribution onto fault planes has enhanced the compartmentalisation of the reservoir formation. Regarding the reservoir characterization, acoustic impedance logs, recorded along wells, were propagated inside the RGT model and have corroborated the gradual deposits variations in the Upper Rotliegend Group level, from the reservoir Lower Slochteren formation to the seal Silverpit formation. At a later stage, such results could be used for geomodeling and seismic inversion applications.

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