Seismic Stratigraphic Interpretation from a Geological Model – A North Sea Case Study

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Summary

Sequence stratigraphy in the seismic interpretation workflow helps in the understanding of the basin analysis and the spatial distribution of reservoirs, seal and source rocks. Classical methods consist in identifying seismic discontinuities corresponding to the reflection terminations (downlap, toplap, onlap, and truncation) to define stratigraphic sequences and their system tracts. Such task is a labour intensive process mainly based on a limited number of auto-tracked horizons. Recently new approaches have been proposed to optimize this workflow. In this paper, we propose to analyze the thickness variations of a geological model, computed with a global approach based on a minimization process between the seismic relationships (Pauget et al 2009). Given the fact, the geological model is continous; the variation of the thickness can be computed for any seismic voxel. The thinning zones of the geological model enhance stratigraphic discontinuities and provides to the interpreter a high level of precision in the identification of the sequences.

We have applied this method on the block F3, located in the Dutch sector of the North Sea, presenting relevant large-scale sigmoidal bedding. The analysis of the thickness attribute enhanced zones of convergence of the seismic reflections packages corresponding to the observed downlaps and toplaps. A sub division into stratigraphic sequences could be achieved by mapping and thresholding the thickness values. Convergence zones of the different reflection packages were modeled in three dimensions for a better understanding of the spatial depositional process. This case study has shown the rapidity, robustness and the accuracy of the geo-model approach in the analysis of the stratigraphic sequences. These results suggest that the method could be used to optimize the level of detection of subtle traps, seals and reservoirs, at an early stage in the interpretation process.

Introduction

Sequence stratigraphy consists in building a chronostratigraphic framework to understand relationships between rocks and the stratigraphic evolution. The application of sequence stratigraphy in seismic interpretation has proven to be fundamentally important to predict traps; spatial distribution of reservoir, seal, source rocks and also in the basin analysis.

Traditional methods are based on the observation of seismic facies and their distribution to build a subsurface model. Seismic reflection packages are subdivided into seismic sequences and system tracts to understand depositional processes, environment settings and predict the lithology (Vail et al., 1987). This process is done by the delineation of discontinuities based on seismic reflection termination (onlap, downlap, top, and truncation) to subdivide seismic into genetic reflection packages, also referred as seismic sequences and system tracts.

Such task is a labour intensive and time consuming process based on manual picking or auto-tracking of single horizons within a seismic volume. Even though seed based auto-tracking 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 (Borgos et al, 2003; Stark et al, 2004; Lomask, 2006; Ligtenberg et al, 2006; Verney et al, 2008). Pauget el al, 2009, proposed a global approach to build a geological while interpreting seismic data. Applied to sequence stratigraphy, this global approach enables a high level of accuracy and flexibility. 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.

In this paper, we have applied this method and its derivative attributes for the characterization of stratigraphic sequences.

Geological Modeling and "Thickness" Attribute

Building a geological model directly from the seismic information is a fundamental improvement in the seismic interpretation. This workflow, based on a global minimization process (Pauget et al, 2009) involves two main steps. The first step consists in computing a geological model, called "geo-model" using cost function minimization algorithms, which merges seismic points according to the similarity of the wavelets and their distance. This process automatically tracks every horizon within the seismic volume and constraint a grid, where a relative geological time is computed for every point. The task of the seismic interpreter consists in refining the model by verifying and modifying relationships between points until an optimum solution is obtained. Such method has

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already been tested on numerous case studies to perform a dense strata slicing of amplitude maps for targets identification mainly in exploration (Gupta et al, 2008; Schmidt et al, 2010; Lemaire et al 2010).
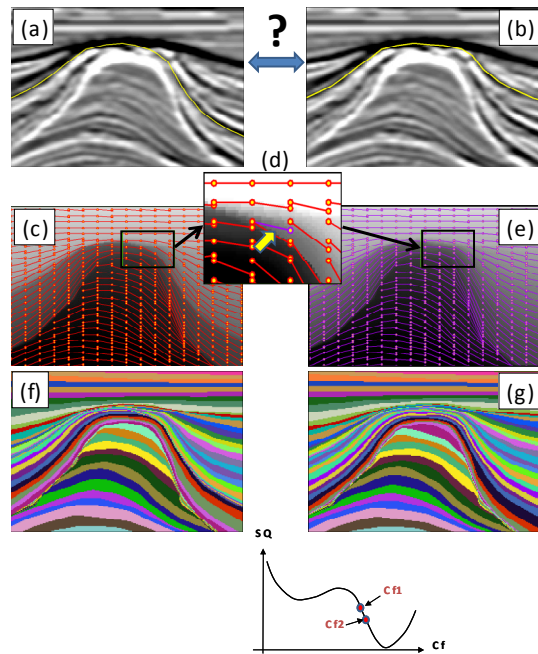

Figure 1 – *Geological Model Method using a global minimization process (Pauget et al, 2009). In (a) and (b) Example of two possible seismic interpretations. Two links configurations (c) and (e) corresponding respectively to the models (f) and (g), after Pauget et al 2009.*

The analysis of the geological model in three dimensions enables to compute a new kind of attributes to enhance stratigraphic as well as structural event. One of these attributes is called the "*Thickness*" and corresponds to the vertical derivative of the geological model, which reveals the instantaneous variations of the geological layers in the volume on each seismic voxel (Figure 2).

Like other methods analyzing the thinning of seismic reflection packages at a large scale (van Hoek, et al 2010), the "thickness cube" is sensitive to the convergence and divergence of the geological horizons and enhances vertical variations associated to erosion zones, channel incision and/or stratigraphic discontinuities. Applied to the seismic sequence stratigraphy, low values of "thickness", correspond to the termination of the reflection packages. The thickness variations are assumed to be a measure of the density of flow of the dip field (van Hoek et al, 2010). Such approach helps to subdivide the sequences into system tracts, at an early stage in the interpretation workflow.
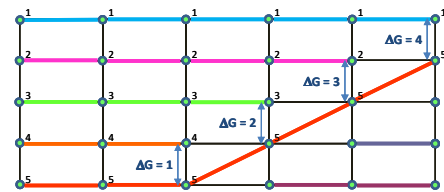
$$Thickness = \frac{\Delta\ Pseudo\ GeoTime}{\Delta\ TWT} = \frac{\Delta G}{\Delta\ TWT}$$
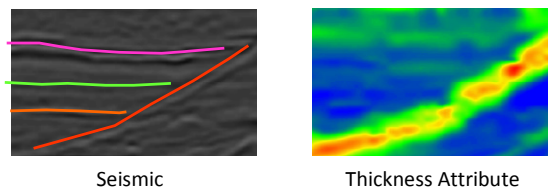
Seismic   Thickness Attribute

Figure 2 – *Definition of the "thickness" attribute. (a) A value of thickness corresponds to the derivative of the geological model computed for every seismic voxel. (b) and (c) The thickness attribute enhances stratigraphic discontinuities, after Pauget et al, 2009.*

North Sea Case Study Example

The block F3 is a well-known offshore zone located in the Dutch sector of the North Sea. Oil and gas reservoirs were discovered in the Upper-Jurassic to the Lower Cretaceous interval. The upper part of this block shows Miocene, Pliocene and Pleistocene sediment deposits characterized by large-scale sigmoidal bedding, related to the fluviodeltaic system that drained large parts of the Baltic Sea region (Sørensen et al, 1997; Overeem et al, 2001). Several interpretations of this area have been realized in the past (Schroot et al, 2003). A detailed stratigraphic interpretation of this zone with OpendTEct SSIS software identified sequence boundaries and their sub division into system tracts (de Bruin et al, 2006; de Groot et al, 2010).

In this study a geological model interpretation was achieved using the software PaleoScan™. A thickness attribute derived from the geological model showed the condensation of the seismic reflections packages corresponding to the distal clinoforms. The lowering of the thickness enabled to distinct discontinuities between the different stratigraphic packages and the seismic reflection terminations (toplaps and downlaps) (Figure 3).

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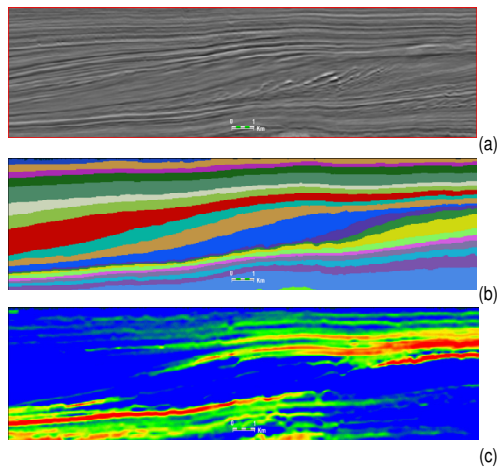

(a)

(b)

(c)

Figure 3 – (a) *Seismic section of the block F3 in the North Sea, showing distal deltaic clinoforms downlaping on the underlying reservoir. (b) Geological model obtained with the global approach of Pauget et al, 2009. (c) "Thickness" cube showing the condensation of the geological layers.*

Thin beds deposits in the different sequences could be mapped by stratal-slicing continuous stratigraphic surfaces throughout the sigmoidal reflection packages (Figure 4).
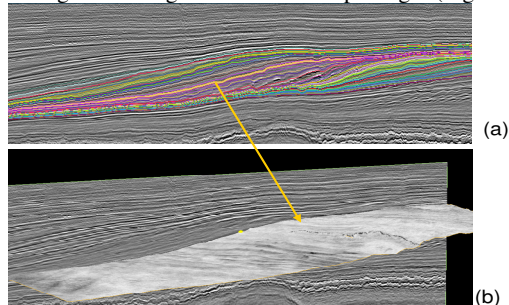

(a)

(b)

Figure 4 – (a) *3D modeling of horizons through the* sigmoidal bedding *and (b) seismic amplitude mapped on a horizon enhancing the sediment deposits inside the clinoforms.*

A stratigraphic interpretation based on multiple horizons tracking from a dip steering cube, realized in a 3D wheeler diagram (de Bruin et al, 2006). In this interpretation, four main system tracts were identified and reported on the geo-model: transgressive system tract (TST), high stand system tract (HST), falling stage system tract (FSST) and low stand system tract (LST) corresponding to the transgression and regression phases. These packages are respectively bounded at their top by 1) a maximum flooding surface, 2) a sub aerial unconformity, 3) correlative conformity and 4) a basal surface of force regression.

In this work, the detection of the sequence boundaries was realized on the basis of the zones presenting the lowest

values of the thickness cube. These surfaces were modeled in 3D and compared simultaneously with the seismic sections. The results of this subdivision identified four stratigraphic packages, concordant with the main sequences proposed by de Bruin et al, 2006 (Figure 5).
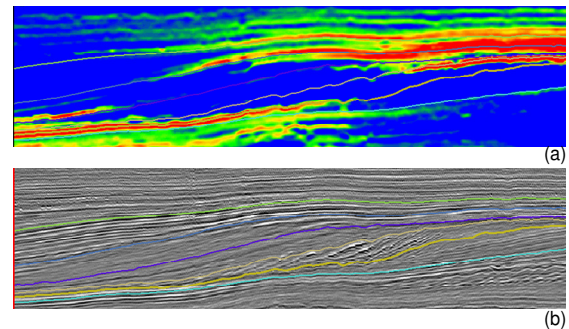

(a)

(b)

Figure 5 –*Identification of stratigraphic sequences from the thickness attribute. (a) Stratigraphic surfaces correspond to the lowest values of the thickness attribute (b) the validation of the sequence boundary can be done on the seismic section.*

Since a relative geological time is computed for each seismic voxel, the seismic image can be flattened and represented in a 3D wheeler diagram. We have identified the different chronostratigraphic events previously detected from the thickness attribute and reported the interpreted system tracts (Figure 6). These sequences show the distal thinning corresponding to the downlap, the sub-aerial erosion zone and the maximum flooding surface bounding the top and the base of this interval. Such kind of visualization enabled a better understanding of the evolution the system tracts, the transgression and regression phases, interactively between the seismic and the wheeler domain.
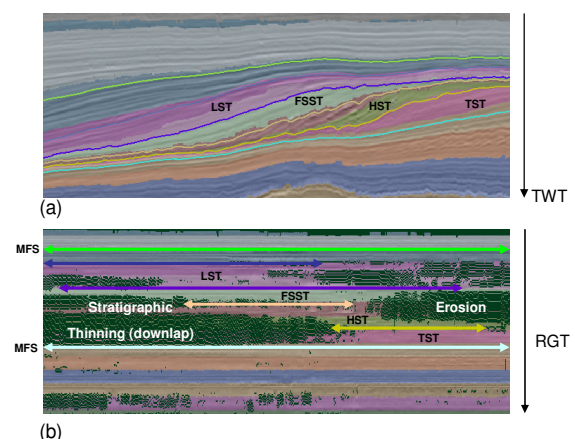

(a)

(b)

Figure 6 – *(a) Geological Model in two way time (TWT) and (b) its wheeler diagram in relative geological time (RGT). The wheeler*

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diagram in PaleoScan™ consists in flattening the seismic reflections based on the geological model. System tracts of this zone (de Bruin et al, 2006) were reported on the GeoModel view (a) and the wheeler domain: transgressive system tract (TST), high stand system tract (HST), falling stage system tract (FSST) and low stand system tract (LST).

An analysis of the spatial evolution of the reflection termination (downlap, toplap and onlap) was realized by mapping the thickness values on the stratigraphic surfaces. By lowering the thickness, the regions of convergence and the different system tracts were modeled in 3D, for a better visualization of the deltaic clinoforms donwlaping on the underlying reservoir (Figure 7).
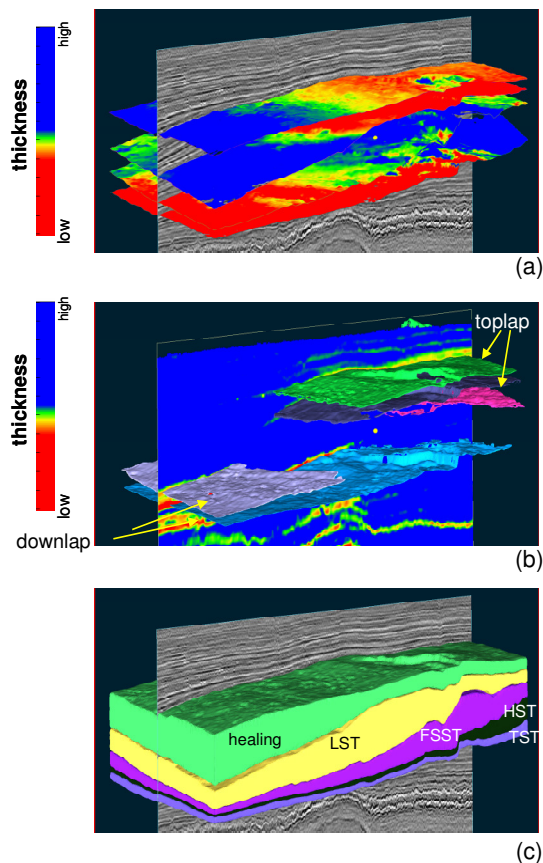

(a)

(b)

(c)

Figure 7 – *(a) Thickness values mapped on the different stratigraphic discontinuity surfaces. (b) 3D modeling of the thinnest regions representing the termination of the seismic reflection (downlap, toplap) and (c) 3D modeling of the system tracts.*

Conclusions

We have presented a new method to interpret seismic stratigraphy based on the analysis of the thickness variations of the geological model. Whereas most of the current techniques are based on the 2D analysis of seismic section, such approach enables a subdivision of the seismic reflection packages into 3D chrono-stratigraphic sequence, with a high level of precision and at an early stage in the interpretation process.

We have applied this workflow on the block F3, located in the Dutch sector of the North Sean, which is mainly characterized by large-scale sigmoidal bedding and distal deltaic clinoforms. Based on the thickness attribute, sequence boundaries and system tracts could be rapidly identified and modeled in 3D. Moreover, a mapping and modeling of the seismic reflection termination was achieved in 3D to better understand the spatial evolution of the sediment deposits. This workflow reduces the time cycle and offers a level of flexibility and accuracy to interpret stratigraphic sequences. These results suggest that such approach could be applied to the detection of subtle traps, seals and reservoirs but also for basin modeling applications, at a regional scale.

Acknowledgments

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