Fault Analysis based an Innovative Watertight Model Method

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Summary

This paper, presents a novel method to evaluate the fault seal properties from a watertight model, obtained directly from seismic data using a dense grid of horizon patches.

The watertight geological model is obtained from a set of faults and a grid of numerous horizon patches computed for each seismic polarity. In this approach, any change made to stratigraphic or structural units can be directly applied to the model. The objective is to define levels of reservoir at a very fine scale and understand their juxtaposition onto the fault plane to identify potential leakage.

We have compared various fault properties using a relative geological time model and the watertight model. Whereas the relative geological time allows computing the vertical throw at a seismic sample resolution, the watertight model allows superimposing the reservoir levels across the fault at various scales and therefore obtaining an Allan diagram. This was applied on a North Sea case study, where the sealing properties could be characterized in the Jurassic level, despite the poor data quality. These properties could be at a later stage integrated in a geocellular grid for reservoir simulation applications.

Introduction

During the last decades, structural interpretation and fault seal analysis have been intensively investigated with various methods.

From seismic data, a large panel of fault detection techniques have been proposed. Most of them are based on a normal vector field, which calculates the local dip and azimuth for each seismic sample and therefore allows computing various attributes such as coherence (Marfurt et al, 1999), curvature (Roberts 2001, Marfurt, 2006) and the fault probability (Lacaze et al, 2016). Despite these attributes show the main fault lineaments, they remain too heterogeneous to obtain optimal fault planes without manual editing.

More recently a new kind of fault attribute, based on the spatial derivatives of the relative geological time, shows a finer detection of the faults and fractures, related to the vertical throw (Lacaze et al, 2016).

Fault seal analysis is generally done based on 3D geological model, which represents a simplified vision of the earth from reservoir to basin scale. The 3D geological model is generally the last step of a complex process based on a few interpreted horizons and faults. The interpretation remains the crucial phase to define chrono-stratigraphic relationships between horizons. This geological model controls the geocellular grid, which will be used ultimately for reservoir simulation.

Despite the major technological advances in the algorithms and hardware for the past years, obtaining geocellular grids remains a long task using a limited number of horizons and faults. It requires many cleaning steps to remove geological artefacts.

More recently meshing methods based on input horizons and faults surfaces were proposed to obtain geological models in a more simple way. The most recent ones aim to flatten the stratigraphic units from the seismic volume into a geological domain in order to remove the deformations undergone by the geology over time and simplify the relations between horizons and faults (Mallet et al, 2004; Poudret et al, 2012). Once the grid is built in the flattened space, an inverse transformation is applied to come back to the current geological space. Those methods are used for geostatistical simulation across the geological model of rock properties from well log data (Rainaud et al, 2015). Some other techniques aim to compute stratigraphic ages thanks to an implicit function in an unstructured tetrahedral mesh (Lepage et al, 2014).

Although these methods bring much more information to the structural geologist during the seismic interpretation phase, characterizing the sealing properties of the faults remains a difficult task.

In this paper, we propose a novel method to evaluate the fault seal properties from a watertight model, obtained directly from seismic data using a dense grid of horizon patches. In this approach, any change made to stratigraphic or structural units can be directly applied to the model. The objective is to define levels of reservoir properties at a very fine scale and understand their juxtaposition onto the fault plane.

Watertight Model Method

The proposed method aims to build a watertight geological model based on a set of faults and a grid of numerous horizon patches computed from the seismic volume.

The grid of horizon patches is sorted chrono-stratigraphically with the same methodology used to obtain a relative geological time (RGT) volume (Pauget et al, 2009). Spatial resolution of the grid depends on the patch size, whereas the vertical resolution relies on the seismic trace extrema (peaks, troughs and zero crossings). The vertical links define the stratigraphic ordering and spatial relationships are built by comparing correlation factors between centres of horizon patches.

The same geological age is assigned to patches connected laterally. Horizons are hence sorted chrono-stratigraphically and never cross each other due to the uniqueness of a link (Figure 1).

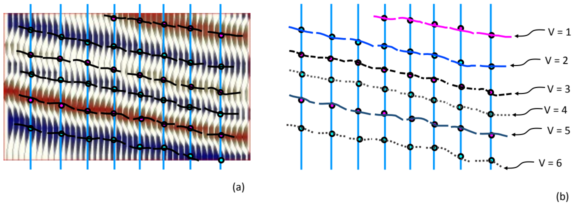

Figure 1: *Horizon patch grid. (a) Patches are computed on each polarity extrema (peaks and troughs); spatial distribution depends on the size of the patch. (b) Stratigraphic ordering of the patches with relative geological times*

Fault planes are considered as discontinuity constraints, they remove links between patches without changing the chronological order. Therefore, horizons never cross a fault. The horizon patch grid allows performing a very high resolution interpretation in the entire seismic volume. Intermediate iso-geological values can be generated by vertical interpolation of the RGT values between consecutive patches. Therefore, stratigraphic intervals can be defined at various scales everywhere throughout the seismic volumes. For each horizon, points of contacts with the faults are adjusted by extrapolating the extremities to obtain a watertight geological model in two dimensions on any inline or crossline.

The extension to the 3D domain relies on the synchronization of a set of 2D models computed in two perpendicular directions (inline and crossline) and sampled spatially with a regular step in each direction. The synchronization is performed by linking iso-geological values between intersecting 2D models (Pauget, 2016). By defining stratigraphic intervals, the 3D model can be divided into cells, whose elementary size depends on the spatial sampling step in the inline and crossline directions and on the thickness of the stratigraphic interval, which corresponds to the distance between two consecutive ages.

Upon synchronization of the 2D models, a triangular mesh is applied to each horizon and the intersection with faults is characterized by polygons. That representation of the horizon can be used for various applications in reservoir modeling. As RGT values are defined everywhere throughout the seismic volume, a watertight geological model can be directly meshed in 3D with various resolutions function of the stratigraphic layering (Figure 2).

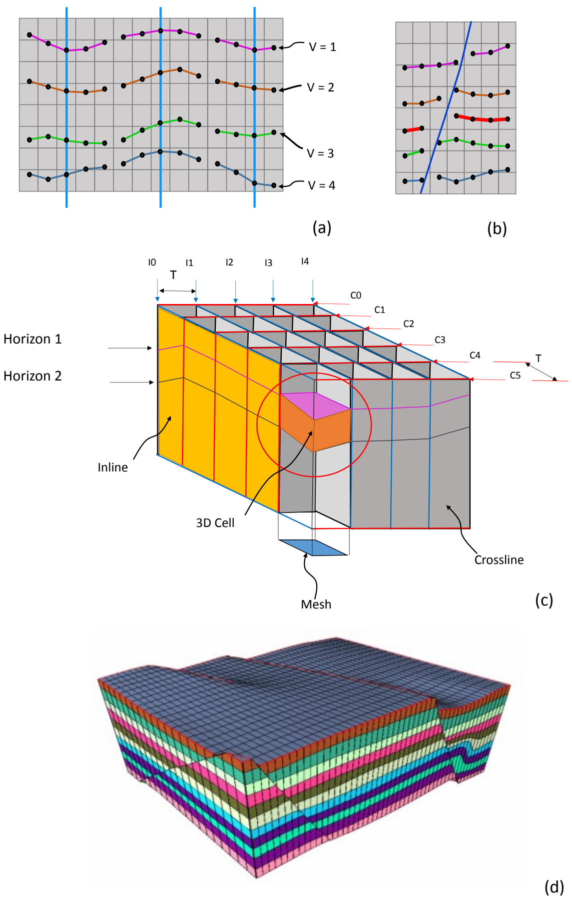

Figure 2: W*atertight model from a grid of horizon patches. (a) Chronostratigraphic ordering of the horizon patches. (a) Fault disconnects links without changing values. (c) Definition of a cell in 3D delimited by a mesh and the distance between two horizons representing consecutive geological times. (d) 3D watertight model after triangular meshing.*

Fault Seal Analysis

The method was applied to the block F03, which is a well-known offshore zone located in the Dutch sector of the North Sea. The interpretation of the zone was first done to analyze the stratigraphic units in the Pleistocene sediment deposits characterized by large-scale sigmoidal bedding, related to the fluviodeltaic system that drained large parts of the Baltic Sea region (Lacaze et al, 2011).

In this work, we have studied more specifically the Upper-Jurassic to the Lower Cretaceous interval, which is underlying the base cretaceous unconformity and where oil and gas reservoirs were discovered. That zone is characterized by a low signal to noise ratio and a complex normal fault system trending North-South. A dense grid of horizon patches, with a spatial resolution of 7 seismic samples, was computed on all the seismic polarities (peak, trough and zero crossing) (Figure 3). From the RGT model, various units corresponding to the reservoir levels were delineated at a fine scale, in the interval where it is generally difficult to obtain horizons with classical interpretation techniques. A fault pattern was applied to cut these stratigraphic units and manage their intersections to obtain a sealed model. This model was then computed in the entire zone of interest going from the lower Cretaceous to the mid Jurassic.

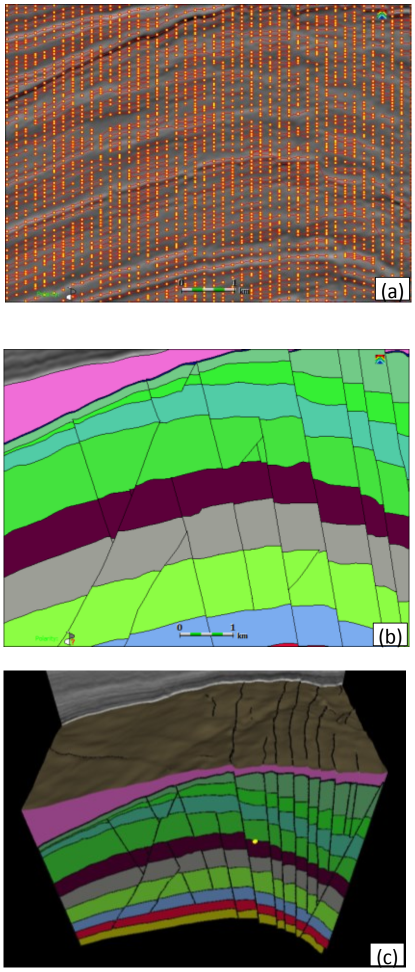

Figure 3: *Watertight geological modeling on the North Sea F03 data. (a) Horizon patch grid. (b) 2D watertight model based stratigraphic units. (d) 3D sealed model using a triangular meshing.*

We have compared various properties of faults using both RGT and the watertight models.

The RGT model allows computing the absolute value of the throw for every fault plane by calculating the vertical distance of the relative ages across the fault. This provides a high resolution throw distribution, which generally shows maxima of throw at the center of the fault plane and low values of throw at the intersection with crossing faults (Figure 4.a and b). Potential reactivation of the fault can also be characterized by heterogeneous distribution of throw maxima.

Although the instantaneous throw brings a lot of information for the geo-mechanical properties of the fault, as the RGT values do not intersect the fault plane, it is not possible to estimate the sealing properties.

By using the watertight model, the intersection of the different stratigraphic units against the fault plane can then be calculated. The reservoir stratigraphy of both the hanging wall and footwall locations can be superimposed on the fault plane to obtain an Allan diagram.

We have used this technique to delineate the main stratigraphic intervals in the reservoir zone, located in the Jurassic interval located just below the base Cretaceous unconformity in this region. The delineation of the stratigraphic intervals could be done at various scales as it is governed by a continuous RGT model. We could then evaluate the sealing properties of the fault. In this interval, the reservoir levels are not connected across the faults despite relative high values of throw. In case of a leakage, the Allan Diagram would show the zone of connection between two reservoir levels and therefore give a precise estimation of the sealing properties of the fault (Figure 4.c and d).

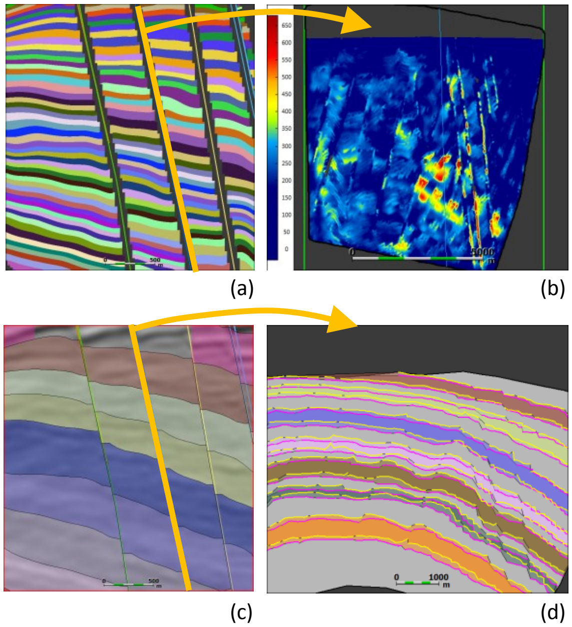

Figure 4: *Comparison of fault properties from the RGT and the watertight models. (a) RGT Model. (b) Vertical throw obtained by calculating the vertical distance of the RGT iso values across the fault plane. Hot values show high throws. (c) Watertight model section. (d) Allan diagram showing the hanging wall and the foot wall of each stratigraphic unit superimposed on the fault plane.*

Conclusions

In this paper a new method to analyze fault seal properties based on watertight model was presented. Unlike other methods, which require a complex process, the watertight model relies on a grid of large number of horizons. These horizons are first sorted chrono-stratigraphically and allow having a higher level of accuracy directly from the seismic data. It provides an interactive, fast and robust workflow where any change of the interpretation can be applied directly on the model. This method was used in the North Sea case study to delineate the reservoir stratigraphy, at a fine scale and in a poor data quality zone, to understand the juxtaposition across the faults. Reservoir stratigraphy of both the hanging and footwall was superimposed at various scales on the fault plane to obtain Allan diagrams and characterize precisely sealing properties. This information could be at a later stage integrated in a geocellular grid for reservoir simulation applications.

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