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Method to Generate a Watertight Geological Model Directly From a Seismic Volume

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Summary

This paper presents a novel method to compute a watertight geological model directly from seismic data. Whereas existing workflows rely on complex process based on a few horizons and faults, the approach is based on a grid made of numerous horizon patches and a set of faults. Spatial resolution of the grid depends on the patch size and the vertical resolution relies on the seismic trace extrema. A chronostratigraphic ordering is done using the Relative Geological Time approach (Pauget et al, 2009). Based on this grid, 2D watertight geological models are created along seismic lines, sampled at a regular step in the inline and crossline directions, by defining stratigraphic units without limitation. A 3D triangular meshing is then performed by synchronising the relative geological times between intersecting 2D models. Therefore this method creates watertight models with higher level of accuracy and directly from the seismic data. It provides an interactive, fast and robust workflow where any change of the interpretation is applied directly on the model. It then allows extracting fault polygons, characterize sealing properties. Moreover, geocellular grid could be generated for reservoir simulation applications.

Introduction

During the last two decades, 3D geological models have progressively become major constituents of oil and gas exploration and production. Those models represent a simplified vision of the earth from reservoir to basin scale.

The computation of watertight geological models arises from a complex process based on a few horizons and faults obtained by seismic interpretation. The interpretation is a key step to define geochronological relationships between stratigraphic and structural units. Generally, for reservoir simulation application, the geological model relies on a geocellular grid, where rock properties coming from the well data are estimated for each cell. Despite the major advances in the algorithms and hardware in the past few years, computing geocellular grids remains a long task using a limited number of horizons and faults and is sensitive to interpretation artefacts.

In this paper, we propose a novel method to compute a watertight geological model directly from seismic data using a dense grid of horizon patches. Any change made to stratigraphic or structural units can be directly applied to the model. The objective is to reduce the time between seismic interpretation and geological modelling and improve the simulation of reservoir properties.

State of the art

Generally, the generation of a geological model can be summarized as a 3-step workflow: 1) interpretation of horizons and faults from the seismic data, 2) definition of geological relationships and 3) tetrahedral meshing of a watertight model. A traditional seismic interpretation task is an intensive and time consuming process based on manual picking or auto-tracking of single horizons. It is often limited to regions showing clear seismic reflections, forcing geoscientists to make many assumptions. Moreover, since a horizon is an instantaneous record of a geological time, crossings are forbidden to avoid geological artefacts. For the faults, although a large number of detection techniques have been investigated, their interpretation remains mostly a manual process. The intersection between fault and horizon is then obtained by adjusting the point of contact of the horizon in the neighbourhood of the fault.

The stratigraphic sorting of horizons and the management of faults intersections is a tedious task requiring many manual checks, and eventually traditional geological modelling does not take into account numerous and complex surfaces.

Thus, the generation of the geological model is done by meshing cells based on input horizons and faults surfaces. Various techniques have been proposed to simplify that step. 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 (Fig 1). 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).

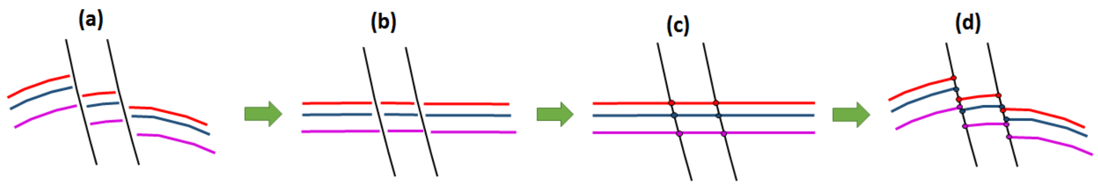

***Fig 1**: Contacts adjustments between horizons and faults with compensation of geological deformation. (a) Before adjustment. (b) Flattening. (c) Adjustment of the contacts Horizons-Faults in the flattened space. (d) back-transformation to the current geological space.*

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 (Pauget, 2016).

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 (Fig 2).

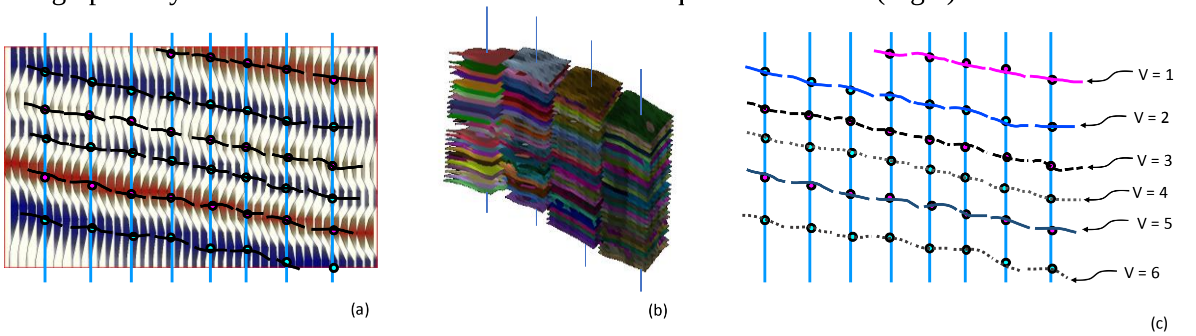

***Fig 2** : Horizon patch grid. (a) Patches are computed on each polarity extrema (peaks and troughs), spatial distribution depends on the size of the patch. (b) 3D representation of the patch grid. (c) Stratigraphic ordering of the patches with relative geological times.*

Fault planes are considered as discontinuity constraints, they remove links between patches without changing the chronological order. Therefore, a horizon never crosses a fault. The horizon patch grid constitutes a very high resolution seismic interpretation. Intermediate iso-geological values can be generated by vertical interpolation of the RGT values between consecutive patches. To some extent, a RGT volume can be derived from using this process. Therefore, by defining 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 (Fig 3).

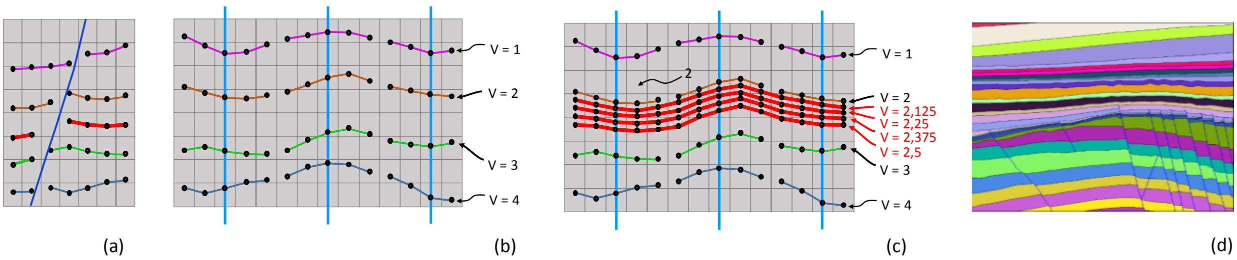

***Fig 3** : Effect of the fault on the horizon patch grid. (a) Fault disconnects links without changing values. (b) Chronostratigraphic ordering of the horizon patches. (c) Intermediate geological times computed by vertical interpolation between the patches. (d) Adjustment of the horizons across the faults to obtain a 2D watertight geological model.*

The extension to the 3D domain relies on the synchronisation 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 synchronisation is performed by linking iso-geological values between intersecting 2D models. 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 (Fig 4).

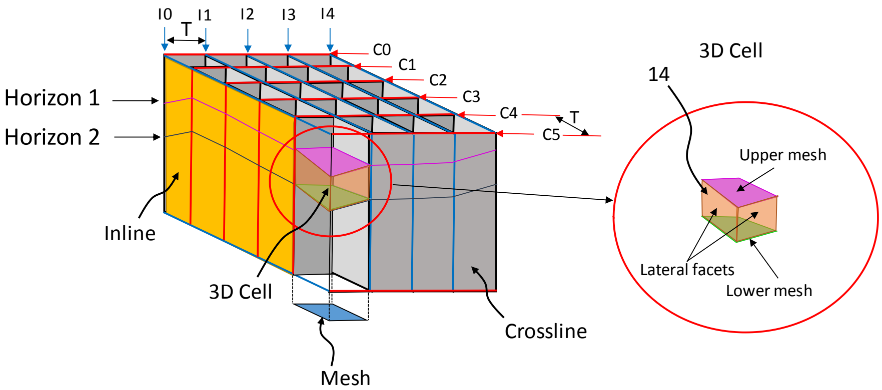

Fig 4 *: Definition of a cell in 3D delimited by a mesh and the distance between two horizons representing consecutive geological times.*

Upon synchronisation 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 relative geological times 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.

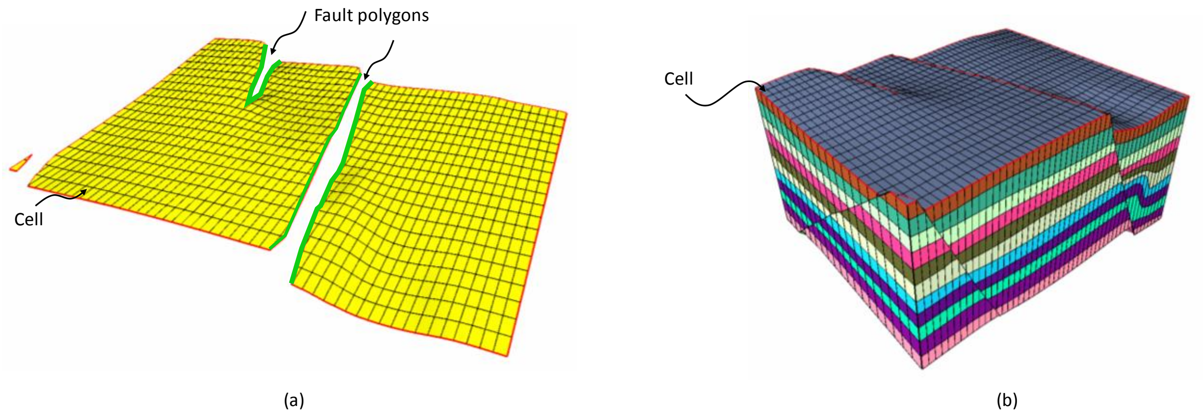

Fig 5 *: 3D triangular meshing. (a) Horizon meshing where each rectangle cell shows the spatial distribution of the 2D models, the green line represents the fault polygons. (b) 3D watertight model after triangular meshing.*

Case Study Example

The method was applied to the block F03, which 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, which is underlying the base cretaceous unconformity. That zone is characterized by a low signal to noise ratio and a complex normal fault system trending North-South. First, the interpretation produced a horizon patch grid used to define relevant stratigraphic intervals in the Jurassic (Lacaze et al, 2011). The 3D meshing of the model enabled to extract fault polygons and juxtapose stratigraphic units across the fault planes to characterize sealing properties in the reservoir zone (Fig 6).

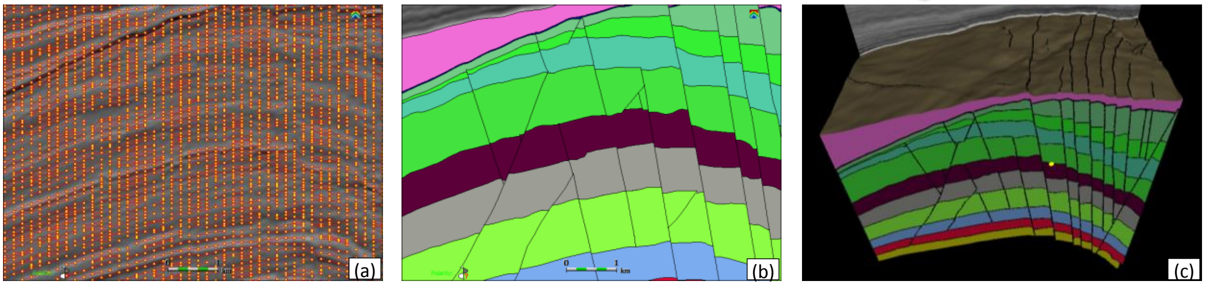

***Fig 6** : Watertight geological modeling on the F03 data. (a) Horizon patch grid. (b) 2D watertight model based stratigraphic units. (d) 3D triangular meshing.*

Conclusions

In this paper, we have presented a novel method to generate watertight geological model from seismic volumes using a grid made of a large number of horizon patches. Stratigraphic relationships throughout the seismic volume are understood and the intersections between faults and horizons are well managed without any artefact. From that grid, watertight geological models are first computed in 2D on lines sampled at a regular step and meshed in 3D by synchronisation of the relative geological times. Whereas traditional techniques are limited to a couple of faults and horizons, this technique creates watertight geological models with 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. Stratigraphic intervals can be defined at various scales without limitation. Fault polygons can be extracted and the juxtaposition of the stratigraphic layers could be displayed in an Allan diagram to characterize sealing properties. In the same way, a geocellular grid could be computed and populated with rock properties for reservoir simulation applications.

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References

Lacaze S., Pauget F., Lopez M., Gay A., Mangue M. [2011] Seismic Stratigraphic Interpretation from a Geological Model – A North Sea case Study. *SEG Annual Meeting*.

Lepage, F., and Souche, L. [2014] Geologic Model via Implicit Function. *US 2014/0222403 A1*.

Mallet, J-L. [2004] Space-Time Mathematical Framework for Sedimentary Geology. *Journal of Mathematical Geology*, **36**, 1−32.

Pauget, F., Lacaze, S., and Valding, T., [2009] A global approach to seismic interpretation base on cost function and minimization. *SEG, Expanded Abstract*, **28**, no. 1, 2592-2596.

Pauget F. [2016] Procede de fabrication d'un modèle géologique vectoriel. *Provisional Patent Application FR 16 59725.*

Poudret, M., Bennis, C., Dumont, C, Lerat, O., Rainaud, J.F. [2012] New flattening-based methodology for more accurate geostatistical reservoir populating. *SPE/EUROPEC EAGE*.

Rainaud, J.F., Clochard, V., Crabié, T. and Borouchaki, H. [2015] Using a ChronoStratigraphic Unfolding Workflow to build an *a priori* model for Stratigraphic Inversion with accurate Horizon and Fault Fitting. *SEG Technical Program Expanded Abstracts*, p. 1927-1931.