Added value of using a 3D faulted *a priori* model with seismic inversion. A real case study of the Alwyn North field (UK North Sea).

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Abstract

Usually stratigraphic inversion is performed using an *a priori* model built without taking into account a 3D fault network. The model is then filled by extrapolating physical attributes from well logs, following a given mode of deposition within each geological unit of the geometrical framework. The aim of this work is to evaluate the added value of stratigraphic inversion using a 3D faulted *a priori* model.

As we know, in faulted areas, usual methods of *a priori* model building do not respect the 3D fault geometry and the dip of the stratification between both sides of the fault, so we addressed this difficulty by using an efficient flattening methods applied to each stratigraphic units.

We brought into focus a three-step workflow to build a 3D faulted *a priori* model, using only the original 3D fault geometry and interpreted seismic horizons. The resulting workflow output is a complete series of cubes filled up by several kinds of mandatory properties, not only geometrical like Azimuth, Dip of stratification, geological unit labels, but also physical attributes like elastic Impedances.

To achieve our goal, we considered the faulted and no-faulted *a priori* model to perform stratigraphic inversions of the Alwyn North Field case study (UK North Sea). Then we compared both inverted acoustic impedance overlaying the Top-Brent horizon with the initial interpreted fault network. The inversion results obtained with a faulted *a priori* model are enhanced in the faulted area.

Introduction

Usually stratigraphic inversion is performed using an *a priori* model built without taking into account a fault network. The latter is constructed by extrapolating the acoustic impedances from well log data, following a given mode of deposition within each geological unit of the geometrical framework. The aim of this work is to evaluate the added value of inversions using a faulted *a priori* model. It is built considering a 3D-sealed surface framework using the original geometry of picked horizons and faults. In a first attempt, we focus our work with post-stack inversion considering acoustic impedance, nevertheless it could be easily generalized to pre-stack inversion with elastic parameters like *P*- and *S-wave* elastic impedances. Also our work about *a priori* model building could be applied either in Time and Depth domain according to seismic imaging.

Let us consider the *a priori* model as a stratigraphic model based on the flattening of simple thin layers following the mode of deposition in the *(U,V,D)* domain (*cf* Figure 2 for definition). This assumption gives accurate results when fault slopes can be embedded into the representation of the horizons located at the Top and the Bottom of an unit. Moreover in faulted areas the model does not respect the dip of the stratification between both sides of the fault.

We have applied a three-step workflow on a real case study (the Alwyn North Field of the UK North Sea), to build a faulted *a priori* model, more details in [Rainaud *et al*., 2015]. As a result we are able to find, for each pixel of the seismic cube, a specific property in the *(U,V,D)* domain like rock impedances and geometrical attributes like Dip and Azimuth. The output of the three-step workflow is a complete series of cubes filled up by several kinds of mandatory properties necessary to perform our stratigraphic inversion.

Method

In faulted areas, usual methods of *a priori* model building do not respect the 3D fault geometry and also **the dip of the stratification between both sides of the fault** (Figure1, upper part), we could address this difficulty by using an efficient flattening methods applied to each stratigraphic units [Borouchaki, 2008], extracting and unfolding a stratigraphic unit to update property population [Horna *et al*., 2010] or realize a global transformation [Dulac, 2009]. In many cases, the uncertainty of the contacts localization between seismic horizons and faults picking can produce surface modelling artefacts due to the lack of information. We have set some tool-based geological rules to characterize the horizon-to-fault contacts which helps to associate topologically both sides of a horizon separated by a fault (fault gaps in each horizon are topologically identified).

If, before a tectonic modification, the picked horizon was corresponding to a conformable horizon, this latter can be flattened after fault gaps removing and it will be possible to apply the flattening method defined in Rainaud *et al.*[2015]. But in some cases, the picked horizon cannot be considered as an isochron surface everywhere and this is happening in case of erosion, onlap or intrusive geobodies. Then starting from only the most reliable information, a first complementary characterization and modelling of the more important stratigraphic limits is done to complete the structural information, even in the areas which this information does not exist anymore in the present geology.

For example, in some situations, a picked horizon can be considered as an erosion for one geological unit A and as a deposition surface for a younger unit B, located on top of unit A. In this case, we can provide some geological tool-based rule to generate the missing parts of the chronological top of the unit A. Then it will be allowed to flatten it to build up the original deposition environment on this unit A. By adding this “synthetic” information, we are constraining separately each stratigraphic unit and it is only during the final composition of the faulted *a priori* model that we apply geological based priorities rules to reconstitute a complete faulted *a priori* model.

We have implemented the following three-step workflow to build the faulted *a priori* model starting from horizons, unconformities and faults picking:

(1) Topological modelling of the stratigraphic unit limits based on their relative geological age. Each topological model (for each stratigraphic limit and picked unconformity) includes a fault gaps connection set which is the result of the intersection of a fault network with these interfaces. A 3D-sealed surface framework is then exported.

(2) Each geological units is flattened and replaced in its original Depositional domain called *(U,V,D)* domain in the following, using an isometric unfolding based on the minimization of the elastic tensor deformation (Poudret *et al.*[2012] and Bennis *et al*. [2012]). To achieve this process, geological units are meshed by hexahedrons in the *(U,V,D)* domain according to fault geometry and then these hexahedrons are replaced in the actual seismic reference domain *(X,Y,Time)* or *(X,Y,Depth)*.

(3) Well trajectories are transformed in the *(U,V,D)* depositional domain and then well logs information are extrapolated using determinist or geostatistical algorithm. Then, the result is transferred to a stratigraphic inversion software.

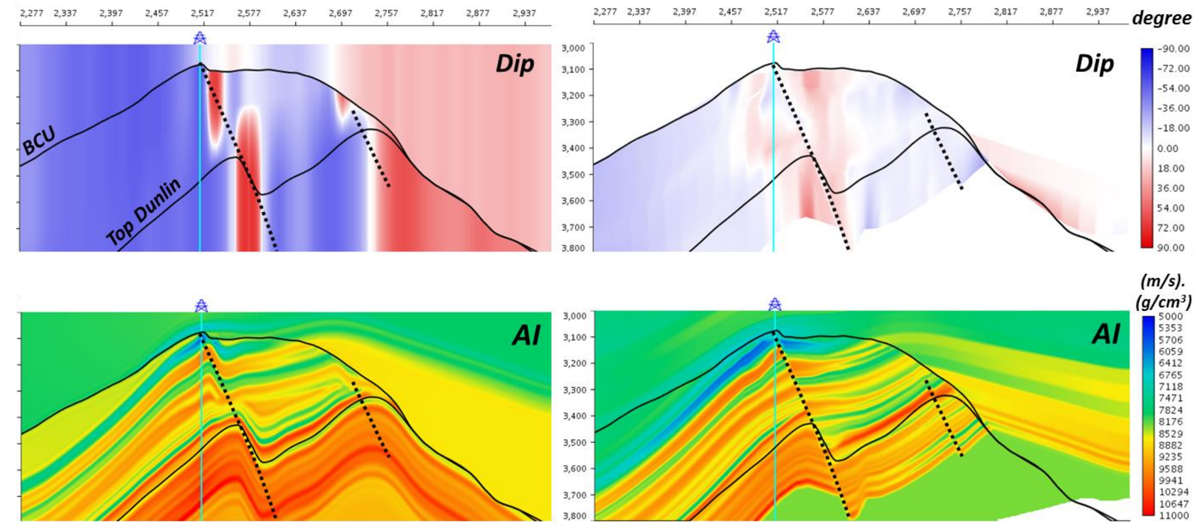

Figure 1 *InLine 2322 Dip associated to no-faulted a priori model (top left) and the faulted one (top right). Dip of stratification is respected between both sides of the faults (black dashed lines). Impedance from no-faulted a priori model (bottom left) and from the faulted one (bottom right.)*

This drives us to build for each of the stratigraphic unit a flat volume in the depositional *(U,V,D)* domain. This volume can be enveloped in a one cell thick Cartesian grid (Figure 2, left part), respecting roughly the InLine, XLine and vertical seismic sampling, so easy to build. We then use the pillars from the Cartesian grid to define a hexahedral mesh along the fault network (Figure 2, right part). A particular aspect of our method consists in using these two meshes together, even if they are not totally coincident. By construction, for each hexahedron cell of both meshes, we can have an image in the *(U,V,D)* domain and its corresponding image in the seismic domain to fill the faulted *a priori* model.

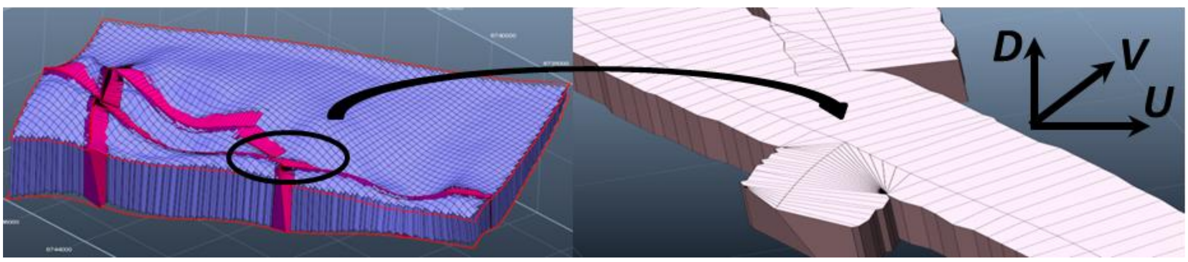

Figure 2 *The thick Cartesian grid (left) containing a geological unit in the depositional (U,V,D) domain. A zoomed area of the hexahedron mesh along part of the fault network (right). U and V are horizontal parametric coordinates and D is the geological age.*

At the end, we can associate the seismic pixel location to one node of the corresponding hexahedron defined in the *(U,V,D)* domain. Then, we are able to transfer information between the two domains. This transfer mechanism is based on shape transform functions that estimate the parametric position of a point in a hexahedron [Dhatt *et al.*, 2001]. Consequently we can transfer the information (property) associated to one point from seismic domain to the depositional *(U,V,D)* domain and *vice versa*. Using this method, we can also transfer well trajectories from seismic domain to the *(U,V,D)* domain and we use this information to fill the Cartesian grid with properties according to mode of deposition [Rainaud *et al*., 2015]. In the flattened space, it becomes easy to accurately compute the wells correlation distances, playing a decisive role in log data extrapolation of rock properties.

Results

When applying our inversion workflow, we have used the no-faulted *a priori* model and the faulted one (Figure 1, bottom part). All parameters are the same in both cases. The reduction of the cost function has the same behavior and we have a good random distribution of the residuals compared to the observed seismic at the same scale (Figure 3, left and middle part).

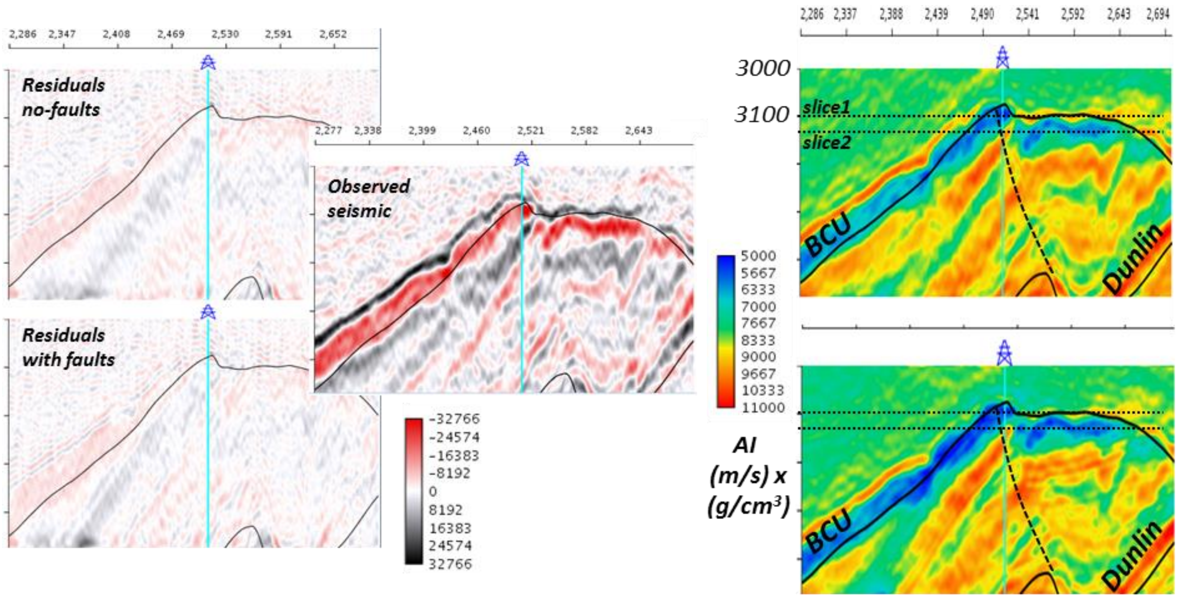

Figure 3 *Comparison of residuals (left) compared with the observed seismic (middle). Comparison of inverted Acoustic Impedance using a no-faulted a priori model (top right) and a faulted one (bottom right).*

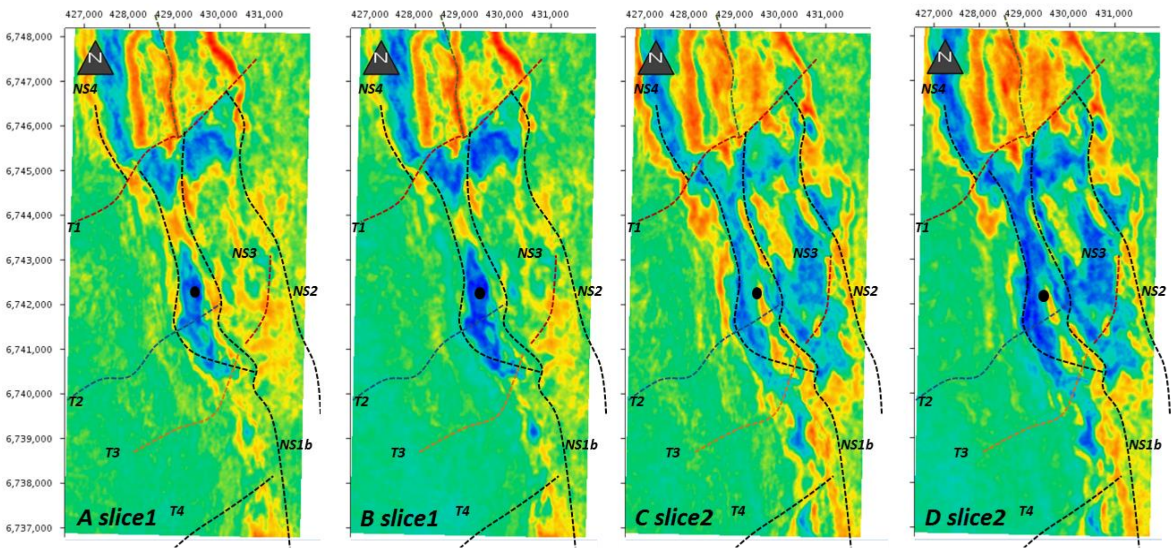

Figure 4 *Inverted impedance using no-faulted a priori model (A, C) and using a faulted one (B, D). One can note the better delineation of the TopBrent (blue colors) with inversion using the faulted a priori model (B, D). Slices A, B are at 3100 and slices C, D are at 3130.*

To better check the added value of taking into account the fault network, we have extracted horizontal slices at 3100 and 3130 through the Brent formation using inverted impedance results. Using the faulted *a priori* model, we can see lateral variations with enhanced impedance contrast for the whole Brent formation (Figure 4, blue color of B and D).

Conclusions

We have used an assembly of stratigraphic units embedded in a faithful fault network to build a faulted *a priori* model taking into account effect of erosive surface like Base Cretaceous Unconformity. During the process we unfold separately the stratigraphic units respecting their modes of deposition. Then by using transform functions between these different domains, we are also able to transfer well log information in the *(U,V,D)* domain. After, we extrapolate log data using deterministic and/or geostatistical algorithms to fill the hexahedron meshes. The previously computed transformation allow us to going back to the initial structural domain where cubes are filled at seismic scale with physical properties like impedances and geometrical attributes like dip and azimuth belonging to deposit mode. The inversion results obtained with a faulted *a priori* model are enhanced in the faulted areas. Further work will consist to take into account variable inversion parameters (such as correlation length) according to distance with the fault network.

Acknowledgements

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