A Global Approach in Seismic Interpretation Based on Cost Function Minimization

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Summary

The method presented in this paper is a novel approach for geological modelling from 3D seismic seismic data. Unlike traditional seismic interpretation based on labour intensive horizons tracking, this method is global and works on links between seismic points, which offers to the interpreters a high level of flexibility in the modelling whithout being limited by faults. This technique is based on cost functions and uses an optimisation process to compute the global lower minimum, which produces the optimum seismic model. Contrary to other global methods based on horizons primitives, the modelling modelling can be easily controlled by interpreters by adjusting the links. Such approach has been already tested on various data sets, where the accuracy of model was used for the geological target detection. An example of results, on case study of offshore data in Nigeria, where several geological targets could be identified, is presented

Introduction

The most common interpretation workflow in the seismic field consists in transforming seismic data in different attributes and extracts horizons by auto-tracking. These methods are a labour-intensive and time consuming process, which presents limitations depending on the signal's quality and the complexity of the geology.

Recently global approaches have been proposed to compute geological models directly from seismic data. Two major types of methods can be considered. In the first type, the model is computed using steering information like the dip and the azimuth computed from the seismic cube (Lomask 2003, De Groot et al 2006). In the second type, the model is derived from topological relationships between small surfaces (Monsen 2008). Small surfaces can also be merged in order to refine the model (Verney 2008).

These existing methods are limited by two main parameters: the complexity of the faults system and the quality of the small surfaces extraction. Moreover these surfaces are fixed and cannot be adjusted during the computation. In this paper, we propose a new method of global modelling based on links between seismic samples. This method allows a high level of flexibility without being limited by faults. Moreover by using global optimization process on the local cost functions, it leads to an explicit optimum model.

Method

a) Creation of a regular grid

The proposed method aims to create some links between seismic samples from couples of seismic traces (see part b). The seismic traces are sampled according to a regular square grid **G** in the $\mathbf{X_{UTM}}$, $\mathbf{Y_{UTM}}$ plane and all the points along each trace are used. The size $\mathbf{S_G}$ of the grid's cell can be set to 1. In such case a cell is similar to a seismic bin and all the seismic samples are used during the model's computation. In general, for larger surveys (about 600-800 sq. km and time range of 3 sec), we use a $\mathbf{S_G}$ between 5 and 7.

b) Computation of seismic links from couples of traces

To detect links between seismic points, we first compute a correlation image from a couple of neighbour traces **(**$\mathbf{X_1}$**,** $\mathbf{X_2}$**)** sampled in the regular grid **G**. The correlation image $\mathbf{I(X_1, X_2)}$ of two seismic traces (Figure 1.c) $\mathbf{X_1}$ and $\mathbf{X_2}$**,** is the set of correlation values computed from the $\mathbf{N_1}$ points of $\mathbf{X_1}$ and the $\mathbf{N_2}$ points of $\mathbf{X_2}$. Inside this image of size ($\mathbf{N_1 * N_2}$) pixels, if $\mathbf{X_1}$ is the vertical axis and $\mathbf{X_2}$ the horizontal axis, the value of the point **P(i,j)** at the $\mathbf{i^{th}}$ column and the $\mathbf{j^{th}}$ row, will be the correlation value **Cf(i,j)** between the $\mathbf{i^{ème}}$ point of $\mathbf{X_2}$ et le $\mathbf{j^{ème}}$ point of $\mathbf{X_1}$. **Cf(i,j)** is the vector correlation between the mini traces $\mathbf{V_i}$, centered on the point $\mathbf{X_2(i)}$**,** and the mini trace $\mathbf{V_j}$, centered on the point $\mathbf{X_1(j)}$ (Figure 1.a and Figure 1.b).

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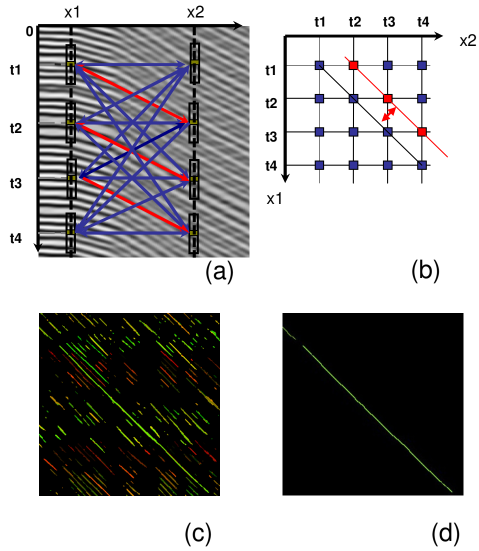

Figure 1 – (a) Two traces X1 and X2 on a synthetic seismic and (b) their corresponding correlation image. (c) Correlation image resulting from real couple of seismic traces. (d) Extraction of the best correlation segment.

Every point of the correlation image **I (X_1, X_2)** corresponds to a link between a point of X1 and a point of X_2. A point with a high correlation value corresponds to a link of high probability. When a set of connected high probability links is drawn on a line segment, we obtain a "correlation comb", which links several seismic reflectors. The algorithm aims to detect the best "correlation comb" with the greatest correlation value (Figure 1.c and Figure 1.d).

c) Computation of global positions

The resulting correlation combs provides a set of links called a configuration which is used to compute a global position for every point of the sampling grid **G**. The algorithm of global positions computation is described in the Figure 2. The seismic grid **G** is scanned until a point **P** devoid of global position is reached. Starting from **P**, we search, respectively upward and downward on the same trace, the first points **P1** and **P2** with a global position. Then three options are considered:
- if only **P1** exists
then **GlobalPos(P) = GlobalPos(P1)-step;**
- if only **P2** exists
then **GlobalPos(P) = GlobalPos(P2)+step;**
-if both **P1** and **P2** exist then **GlobalPos(P) = (GlobalPos(P1) + GlobalPos(P2))/2**
("**step**" is the global position increment value).

All the points **P1** of **G** linked to a point **P2** having a global position **Global Pos(P2)**, will receive the same global position. An initialization to 0 is done on the first point of the grid (see Figure 2.a).

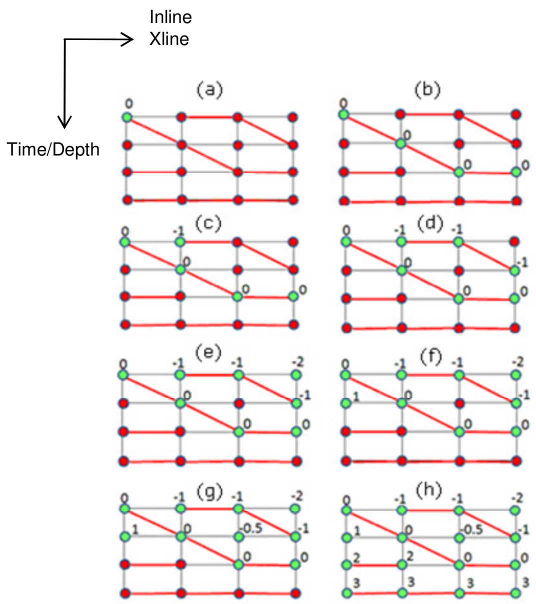

Figure 2 – Application of the algorithm computing global positions on a small seismic grid.

At this stage, only the sampled seismic traces have a global position. To affect global positions to the rest of the seismic points in the volume, small square surface patches of size S_G*S_G are propagated from each point of the grid (see Figure 3). The global positions of the patches centers are then reported on each point belonging to the patches (see Figure 3.d). The result of this process is a geo-model block where every seismic bin is globally referenced in the entire seismic volume.

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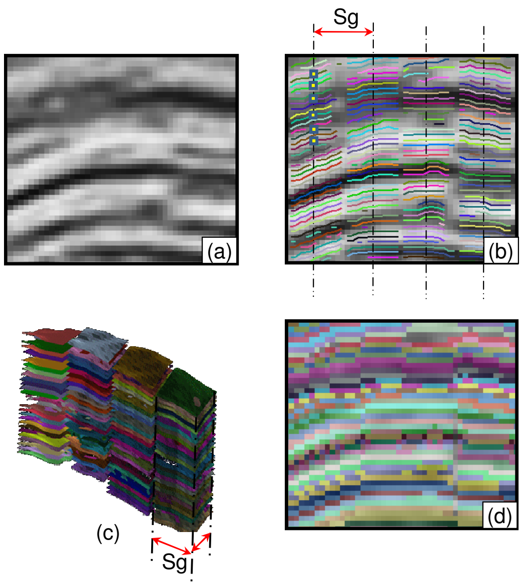

Figure 2 – Application of the algorithm computing global positions on a small seismic grid.

d) Computation of the best model by cost function optimisation

Links detection of step (b) provides an initial configuration that needs to be enhanced. This step aims to obtain the configuration with the lowest cost function SQ which represents the consistency of the model according to the underlying seismic signal. SQ is the weighted sum of the seismic vector distances Dst(Vi, Vj) between couples of points, where i and j have the same global position. Assuming that the geological variations increase with the distance, the weights follow a Gaussian low, as described below.

$$\text{Cost} = \sum_{\text{i=1}}^{\text{N}} \sum_{\text{j=1}}^{\text{N}} \left[\frac{1}{\sigma\sqrt{2\pi}} \exp^{\frac{-(p(i)-p(j))^2}{2\sigma^2}} Dst(V_i, V_j) \right]$$

with j≠i and GlobalPos(j) = GlobalPos(i)

Where N is the number of points inside the grid G and P(i), P(j) the UTM position of the points i and j. In general we can use $\sigma = S_G$.
To find the best configuration, the algorithm moves locally some links until SQ reaches the global minimum. The figure 4 shows how the change of a single link can modify the entire model. Unlike other methods based on fixed small surfaces, the ability to modify links offers an advantageous flexibility to control the modelling on every seismic point of the grid.

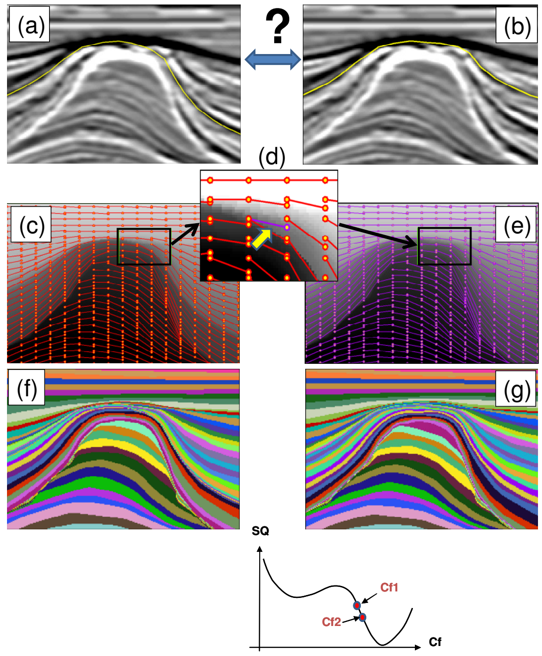

Figure 4 – (a) and (b) Example of two possible seismic interpretations. Two links configurations (c) and (e) corresponding respectively to the models (f) and (g). In this case, the difference between the two configurations is just one link (d). The Global cost SQ is lower for the second configuration, which is then assumed to be better.

Case Study Example

The proposed method has been tested on a 3D seismic offshore data set from Nigeria (Gupta et al, 2008). The size of the volume was approximately 600 sq. km with a 3.5 sec time range (Figure 5). The target was to map the turbidites deposits in a complex geology showing large faults network with an important shale diapir complicated to image. For this work, the geo-model was processed within one month.

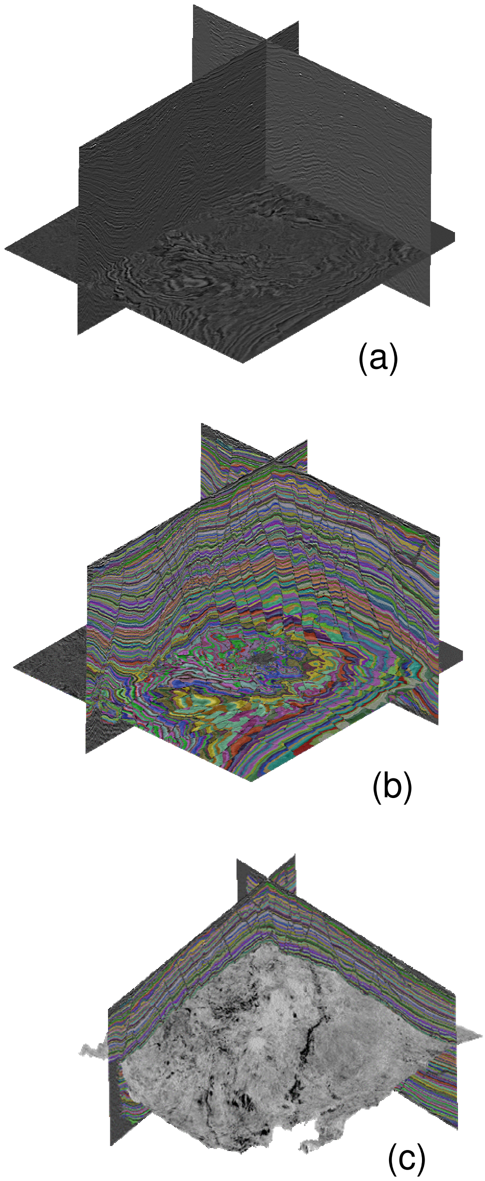

Figure 5 – (a) Seismic cube, (b) resulting geo-model, (c) horizon extracted from the geo-model (data courtesy of BG-Group).

Conclusions

The method presented in this paper is a novel approach for global geological modelling from 3D seismic data based on relationships between seismic bins. The sets of links between seismic points are automatically detected using correlation images obtained from couples of seismic traces. The quality of the links is estimated by a cost function that measures the consistency of the model according to the underlying seismic signal. The method finds the best model by moving locally some links until it reaches the global minimum. This new method presents a high level of accuracy and flexibility; it can manage complex geological settings. It can be used to optimize and refine the interpretation process compare to conventional methods. This technology has been already successfully tested on various seismic data. In the future, on the basis of the models, several applications related to the faults modelling will be derived.

Acknowledgments

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