Global Seismic Interpretation Techniques Are Coming of Age

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SUMMARY

In recent years, a group of seismic interpretation techniques have emerged that aim to arrive at fully interpreted seismic volumes. Collectively, these techniques are known as: 'global seismic interpretation techniques'. The classification 'fully interpreted seismic volume' is misleading as it suggests that no further interpretation is needed. In actual fact the fully interpreted volume marks the starting point for advanced interpretation workflows aimed at extracting more geologic information from seismic measurements. This paper gives an update on global seismic interpretation techniques and how they are used to add value to seismic data. Application domains include seismic sequence stratigraphy, model building & seismic inversion, geo-steering and geohazard interpretation.

Key words: Global Seismic Interpretation, Sequence Stratigraphy, Wheeler Transform, Inversion, Geohazards

INTRODUCTION

Techniques, such as 'Age Volume', 'PaleoScan', 'Volumetric Flattening' and 'HorizonCube', are collectively referred to as global seismic interpretation techniques. The algorithms behind these techniques have in common that they aim to correlate seismic positions along geologic time lines to arrive at fully interpreted seismic volumes. Correlating along geologic time lines is doable because seismic reflectors are first order approximations of geologic time lines (Vail et al., 1977). In other words, mapping horizons that follow seismic reflectors is basically equivalent to mapping geologic time. The current group of global seismic interpretation techniques differ in how they correlate time lines and in the way the correlated information is stored. For example the 'Age Volume' assigns a value representing relative geologic time to each seismic sample position (Stark, 2003). The age assignment is based on correlating instantaneous phase signals from trace-to-trace. PaleoScan (Pauget et al, 2009) builds a geologic model on the scale of the seismic sampling by connecting each sample to the most probable neighbouring sample. The correlation algorithm minimizes a cost function between seismic links to obtain an optimum configuration. This cost function depends on the relative distance between points and the seismic similarity. 'Volumetric Flattening' (Lomask et al., 2009) is also based on correlating similarities. The correlated surfaces are subsequently used to flatten the original seismic volume, or derived attribute volumes as flattened volumes. This kind of flattening is also known as Wheeler transformation while the flattened volumes are called Wheeler cubes. The HorizonCube (de Groot et al., 2010) differs from the above methods in both storage and correlation algorithm. Instead of tracking amplitudes or similarity, the underlying correlation algorithm correlates time lines in the pre-calculated seismic dip field. The tracked surfaces are stored as a dense set of mapped horizons called HorizonCube.

In the following section, the HorizonCube algorithm is explained in more detail. Thereafter a number of HorizonCube applications are discussed such as: Wheeler transformations, sequence stratigraphic interpretations, and detailed geologic model building. Since all global seismic interpretation techniques are linked by geologic time, a similar type of advanced interpretation application can in principle be conducted using any fully interpreted volume as input.

HORIZONCUBE ALGORITHM

The HorizonCube is a data element that combines a 3D (or 2D) stack of horizons, typically spaced in the order of the seismic sampling interval (note that the horizon spacing will be laterally varying to reflect thickness changes). An example of what a HorizonCube looks like is presented in Figure 1.

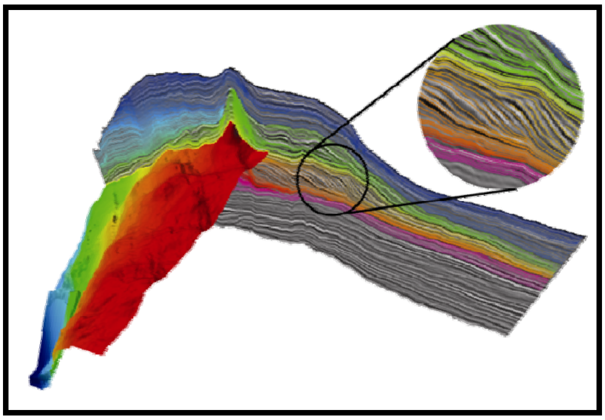

Figure 1 - The HorizonCube is a 3D (or 2D) stack of horizons. The HorizonCube in this display is a 'truncated' one, meaning horizons stop when they get too close together. One of the horizons is displayed in its entirety. Of the other horizons, only their intersection with the seismic line is shown. The inset shows the prograding clinoforms, a typical structure best captured with data-driven tracking.

To generate a HorizonCube, a (dip-) SteeringCube is generated which calculates local dip and azimuth values of the seismic reflectors. The SteeringCube is the main input to a 3D auto-tracker algorithm that tracks the dip/azimuth field to generate a dense set of horizons throughout the 3D seismic volume. The dip/azimuth field is smoothed, which reduces the impact of random noise, and allows the user to control the detail that needs to be captured by the horizon tracker.

Dip fields are used for this tracker, because they are more continuous than amplitude fields, and less prone to noise. The area in which the HorizonCube is calculated is bounded by at least two framework horizons that are either mapped with a conventional amplitude / similarity tracker, or by a dip-steered auto-tracker. The latter tracker can handle faults that need to be interpreted up-front.

The HorizonCube tracker can either be instructed to continue tracking throughout the volume - even if horizon spacing becomes small, or to stop tracking if the horizon spacing comes below a user-defined threshold. This results are either in a continuous HorizonCube (Figure 2) in which all horizons exist at every X, Y position, or in a truncated HorizonCube (Figure 1). All horizons within a truncated and continuous HorizonCube represent correlated 3D stratigraphic surfaces that are assigned a relative geological time.

Figure 2 illustrates the multi-horizon tracking workflow that results in a continuous HorizonCube. Horizons start from a single seed position.

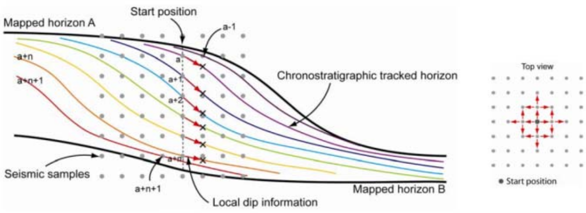

Figure 2 - Principle of data-driven tracking of the HorizonCube using a dip field extracted from the seismic reflectors.

When horizons converge, they continue together and when they diverge extra horizons will be tracked in a second or later iteration. When faults are present, the fault throw is calculated by finding the intersection of the fault and the framework horizons. The displacement at the intersections is used to compute the throw at all positions along the fault plane.

APPLICATIONS

Fully interpreted seismic volumes open the way to advanced seismic interpretation workflows that allow more geologic information to be extracted from seismic data. Figure 3 shows a number of possible applications in different domains.

Fully interpreted volumes such as the HorizonCubes are used, among other things, to assist in well correlations, in unravelling depositional histories, and finding stratigraphic traps using sequence stratigraphic interpretation principles. Other applications include detailed geologic model building and improved seismic inversion and reservoir property prediction schemes that start from more accurate low frequency models. Also, in geohazard interpretation, in geo-steering, and in finding sweet-spots in unconventional plays, fully interpreted volumes have proved to add value to seismic data.

EXAMPLE

The example discussed in this paper uses a technique to extract slumped deposits from a fully interpreted volume. The slumped deposits are identified as potential stratigraphic traps in a sequence stratigraphic interpretation study offshore, the Netherlands.

First the HorizonCube was used in a Wheeler transformation of the seismic response (Qayyum and de Groot, 2012). The Wheeler scene helped to decompose the target Pliocene interval into a series of systems tracts comprising three incomplete cycles. From a hydrocarbon exploration perspective the most interesting systems tract is the Falling Stage Systems Tract of the lowermost sequence (lowest blue interval in Figure 4).

In this interval, an interesting reflection pattern is apparent with slightly elevated amplitudes. The package is interpreted as a series of slumped deposits that could potentially trap hydrocarbons. Mapping these slumped deposits is an easy exercise that exploits the presence of a dense set of horizons. Using an interactive slider, the user outlines a slumped feature by setting horizons at top and base. The software then automatically calculates the isopach thickness between the selected horizons and extracts the body between top and base and a user-defined thickness contour. The resulting slumped target bodies are shown in Figure 5.

CONCLUSIONS

What this paper has demonstrated are the significant benefits that mapping a dense set of horizons bring to seismic interpretation. Among other benefits, the HorizonCube method improves well correlation, model building, sequence stratigraphic interpretation and geohazard interpretation.

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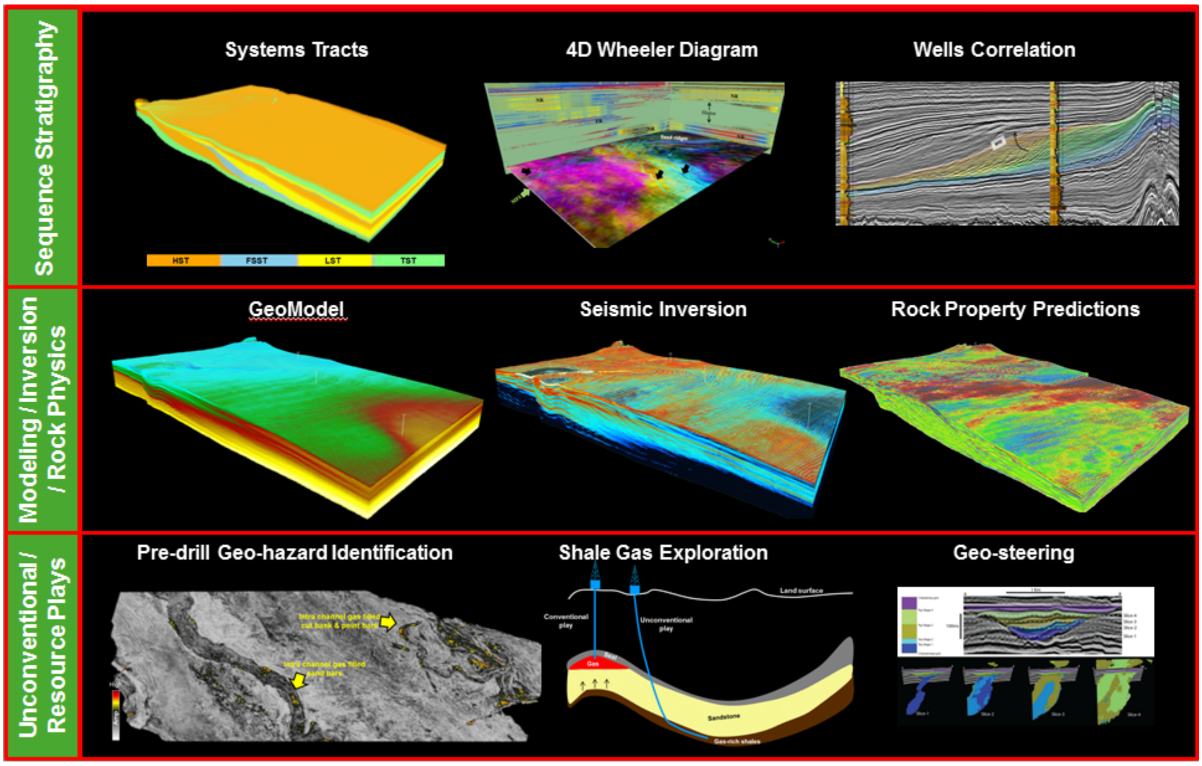

Figure 3 - Examples of HorizonCube applications in different domains.

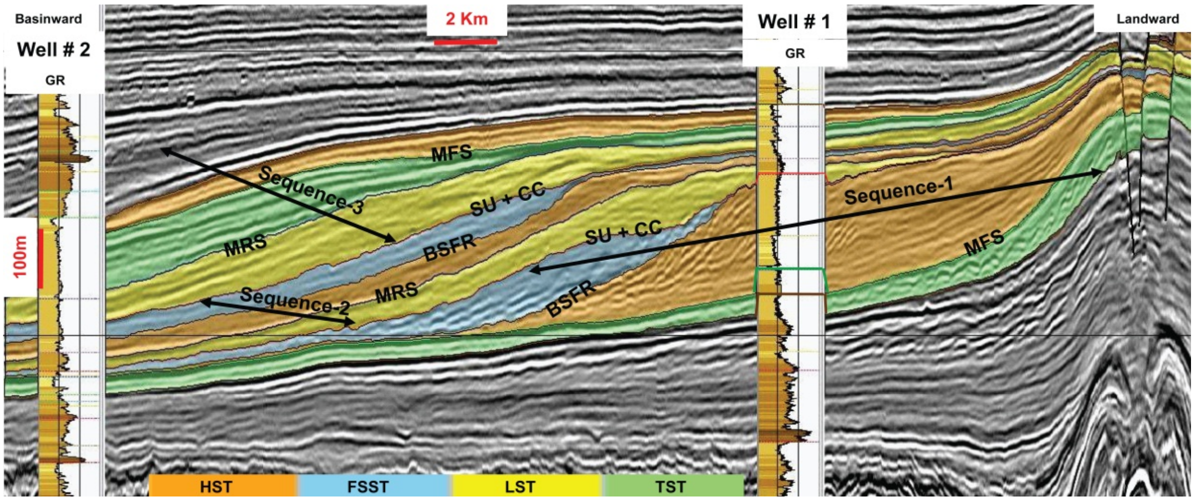

Figure 4 - HorizonCube based systems tracts sub-division of Pliocene interval (Dutch Sector, North Sea).

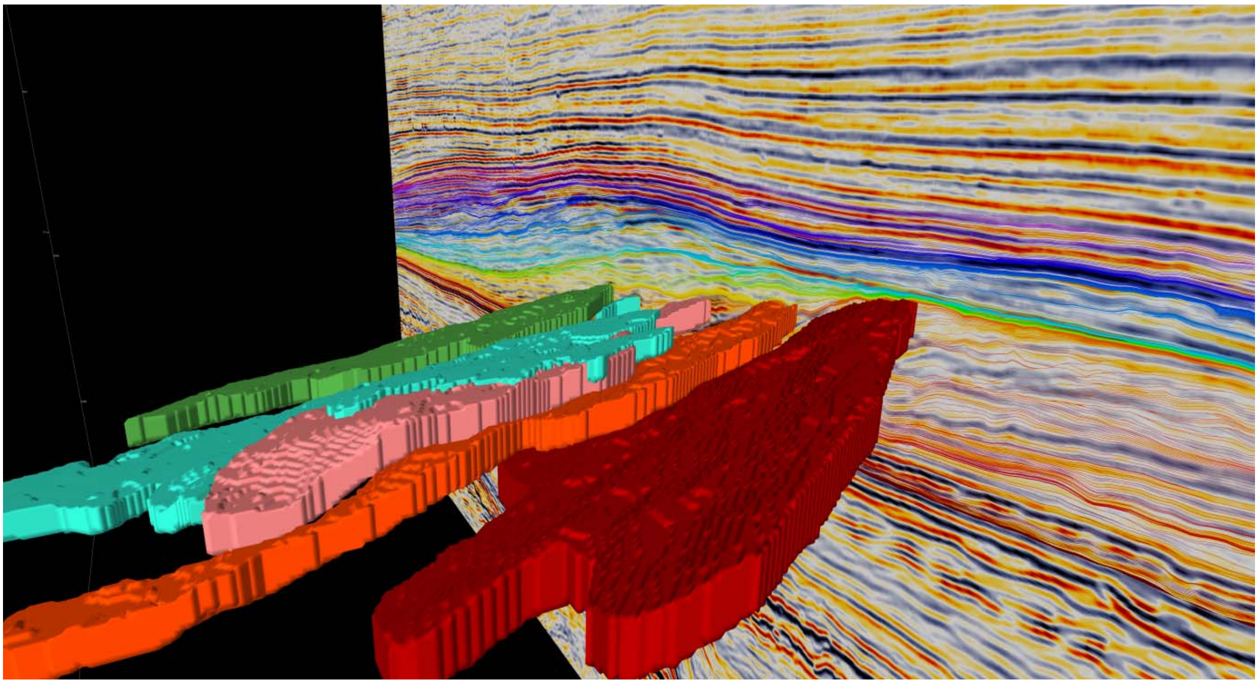

Figure 5 - Slumped 3D Bodies in the FSST of Sequence 1 (lowest blue interval in Fig. 5). These potential stratigraphic traps were extracted from the HorizonCube with the help of an interactive slider.