Summary

Global seismic interpretation techniques aim to arrive at fully interpreted seismic volumes. "Fully" in this context is misleading as it gives the impression that we are dealing with an end-product and there is no more interpretation to be done. This is not the case. The correlated geologic time lines of these volumes open up new ways to analyze seismic data, thereby increasing our understanding of the depositional history and improving our ability to find stratigraphic traps and build highly accurate geologic models.

In this paper first the link between seismic reflections and geologic time and how this link is used in Wheeler transformations (seismic flattening) is described. Next the HorizonCube algorithm is presented. A HorizonCube consists of a dense set of horizons that are generated by a dip-steered auto-tracker. The vertical separation between horizons in a HorizonCube varies spatially. This feature is exploited in a new set of attributes called HorizonCube attributes. Special about these attributes is that they reveal local information in the context of a globally consistent spatial-temporal framework. Examples are HorizonCube density and HorizonCube thickness attributes which are both useful in the interpretation of unconformities, condense sections and sedimentation rates.

Furthermore, in this paper an interactive workflow is described that utilizes the geometric shapes of the horizons to extract 3D bodies from the HorizonCube. Examples of slicing and digging through a HorizonCube are given in this paper.

Geologic Time

The algorithms behind Global Seismic Interpretation 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., 1971). In other words, mapping horizons that follow seismic reflectors is basically equivalent to mapping geologic time lines.

It should be realized however, that not all seismic reflectors are true geologic time lines. Figure 1 (a) shows a seismic line with a number of stratigraphic surfaces that were mapped using conventional amplitude and similarity trackers. The display in the middle (b) shows geologic time. It was generated by auto-tracking hundreds of horizons by following the pre-calculated dip (see later for details). The bottom display (c) shows the Wheeler transformed seismic data. This display is the seismic equivalent of the geologic Wheeler diagram that maps Stratigraphy versus Absolute Geologic Time. The seismic Wheeler display is constructed by flattening the seismic response along HorizonCube horizons and ordering the flattened response vertically from old to young. The vertical axis thus resembles Relative Geologic Time. The gaps represent hiatuses caused by erosion, or non-deposition and condensed sections. The lateral are not present in the geologic Wheeler diagram. In the seismic display they occur when auto-tracking horizons follow the same path and jointly get below the seismic resolution.

Note in the Wheeler display how the depositories continuously shift over geologic time from the land side (left) to the basin side (right) and backwards. Such cyclic depositional patterns are more easily recognized in the Wheeler scan than in the structural domain (A), which makes the Wheeler scan an important instrument for interpreting systems trends.

HorizonCube Processing

The HorizonCube workflow in dGB's OpenTect software is used as starting point. A HorizonCube is defined as a dense set of correlated 3D stratigraphic surfaces. The primary input required to create a HorizonCube is a dip field. The dip field is available in the SteeringCube, a volume with dip-direction information at seismic resolution. Previously mapped horizons can be used as boundary constraints. By providing a fault framework as input, any significant faulting will be accounted for in the tracking of the HorizonCube.

A new starting point

Global seismic interpretation techniques, such as the HorizonCube, might be perceived as the ultimate end-product in seismic interpretation projects. This is almost certainly not the case. In fact the HorizonCube is an enabling technique and a starting point for new applications and workflows to extract more geologic information from seismic data (de Groot, 2013). Hereafter, two methods are described to support this statement.

The HorizonCube workflow in dGB's OpenTect software is used as starting point. A HorizonCube is defined as a dense set of correlated 3D stratigraphic surfaces. The primary input required to create a HorizonCube is a dip field. The dip field is available in the SteeringCube, a volume with dip-direction information at seismic resolution. Previously mapped horizons can be used as boundary constraints. By providing a fault framework as input, any significant faulting will be accounted for in the tracking of the HorizonCube.

A new workflow to extract 3D bodies

At the scale of a typical seismic survey, earth can be considered a set of finite geo-bodies, with distinct shapes and certain dimensions. For example in fluvial-marine environments, a significant petroleum play, an earth model can be constructed from bodies, such as fan, channel, bar, sheet, drapes, levee, etc. Many of these shapes are recognizable on seismic data, especially if we slice through the data along mapped seismic horizons.

Since we have mapped all seismic horizons in a HorizonCube, we have captured a wealth of information regarding vertical and lateral extent (or limits) of these depositional patterns in the seismic data at our hands. However, we need to realize that a HorizonCube consists of hundreds, even thousands of auto-tracked horizons. That is a lot of data to analyze, which means that we need new workflows to extract the desired information that is intrinsically captured in the geometry of these horizons.

Here the solution is found in a combination of 2D seismic views, 3D surfaces and interactive controls that allow the user to rapidly scan the data and to identify top and base horizons corresponding to depositional events (Figure 5). A grid of 2D sections remains necessary as interpreters (initially) observe, study and interpret seismic data in 2D. This approach follows the natural way humans interpret data. Moreover, it has the added advantage that, after making a 3D interpretation, the 2D sections serve as quality control.

The calculation speed of modern cpu's and gpus allow us to use interactive 3D sliders. These are HorizonCube based sliders that slice through the seismic data in a geometrically meaningful way, i.e. by slicing along geologic time lines. The user controls two 3D sliders to select the horizons of interest: one slider selects the top of the interval of interest while the other represents the base (Figure 6). Typically top and base were identified on the dip lines, as explained above, using a 2D slider and HorizonCube attributes such as HorizonCube density (Figures 3 and 5). Now, in the 3D slider module, on-the-fly computation of isopach maps is performed and the results are visualized on one, or on both of the selected horizons. Moreover, seismic attributes such as reflection strength, frequency, AVO, coherency, average density, maximum or minimum impedance can be extracted between the stratigraphic limits of the identified depositional event. Based on cut-off values in isopach thresholds, or seismic attribute response, the depositional events are then converted into bodies for further assessment, property assignment and export to downstream applications, such as reservoir models.
A new workflow to extract 3D bodies (Cont.)

The power of geo-slicing is demonstrated in a deep-water geo-hazard interpretation project offshore East Africa (Bouanga et al., 2014). To date eight exploration well sites locations have been assessed for shallow hazards using the HorizonCube methodology. The main motivation for using the HorizonCube in this example was to accurately map the complex shallow section around the proposed well locations.

The present sampled is characterized by active canyons and this depositional environment is reflected in the cross-cutting channelized and heterolithic deposits evident in the shallow seismic. Interpretation of the appropriate hazard level associated with high amplitude features within the shallow section is significantly enhanced by the ability to slice through volumes along horizon slices. Potential connection between sand- and clay-channels and deep-seated faults that could provide a gas migration pathway can also be studied. These can be further risked based on potential pinchout, isolation of sand bodies within encasing shales and/or confinement of sand bodies to structure. Looking for anomalies in the Wheeler domain increases the interpreter’s understanding of the spatial distribution and timing of sediment deposition. Attributes can be flattened to assess shallow hazards, such as: gas-filled shallow channels, fault and lithology variation relative to seismic amplitude, pickmarks, bottom simulating reflectors, and faulting or truncations based on similarities. Windowed amplitude extractions are recommended to take account of any imperfections in the HorizonCube.

Wheeler transformed attribute volumes create less interpretation ambiguity compared to time (or depth) slices, or parallel to seabed slices (Figure 8).

This is because the HorizonCube follows gross dip in a truly 3D sense. By using the Wheeler domain it becomes possible to see many stratigraphic details which can help increase understanding of the depositional environment and better analyse shallow hazards.

Example - Slicing

The McMuray Formation represents a fluvial estuarine depositional system, hosting rich bitumen and water-sand reservoirs. The generalized stratigraphy can be summarized as an overall aggrading system with multiple parasequences of rapidly propagating fluvial systems, followed by erosion and channel incisions during episodes of base level fall (Ranger and Pemberton, 1987). The unconformable sands of the McMuray Formation in the study area are at depths of about 450 m, with a pay thickness of up to 40 m and porosity between 27 to 30 % (Tonk, 2010). The sands are inter- bedded to varying degrees with muds. Depending on the depositional environment, the muds can be localized or extended over large regions.

Oil is produced by Steam Assisted Gravity Drainage (SAGD), which uses horizontal well pairs to extract the bitumen. The upper horizontal well is for steam injection and the lower well for oil drainage. SAGD can only be operated efficiently if the subsurface geocellular team is able to image/models/predict the subsurface with high accuracy. Knowledge of the depositional facies, geometry of the reservoir (including top and base of the SAGD pay interval and thickness), distribution and lateral continuity of potential mud baffles and barriers are critical for a successful SAGD operation. The key for successful placement of the SAGD injector-producer pairs is understanding reservoir heterogeneity.

Figure 10 is a 3D impression of the HorizonCube covering the Murray Formation in the study area (Brouwer et al., 2011). The workflow described above that involves 2D and 3D HorizonCube slices was applied in this study to extract channelized sand-prone bodies that could be targeted for SAGD development (Figures 11-12).

Acknowledgements

The authors would like to thank all past and present sponsors of the OpenTect SSIS consortium for their support to develop the HorizonCube technology and Sequence Stratigraphic Interpretation System applications in OpenTect. Special thanks to BIG Group and StatOil for granting permission to show the examples presented in this paper.

References


de Groot P., 2013, Global Seismic Interpretation Techniques are coming of age. DEW Journal, November Issue, 41-47.


