New Methods for Slicing and Dicing Seismic Volumes*

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Abstract

Seismic Chronostratigraphy: As computing performance increased, global seismic interpretation methods became feasible. Global seismic interpretation methods are automated or semi-automated methods that aim to generate fully interpreted volumes; see also Lomask et al, 2006, de Groot et al., 2010; Hoyes and Cheret, 2011; Stark, 2004, Stark et al, 2013. These techniques enable the ability to geoslice through volumes of seismic amplitudes “at will” and derive attributes along geologic time lines, thereby facilitating the recognition of depositional features and potential shallow hazards.

The HorizonCube: In our work, we use the HorizonCube workflow in dGB’s OpendTect software as starting point. A HorizonCube is defined as a dense set of correlated 3D stratigraphic surfaces. The calculation of this HorizonCube is a crucial step in the seismic stratigraphic interpretation workflow described in this article. The primary input required to create a HorizonCube is a dip field. The dip field is available in the SteeringCube, a volume with dip/azimuth 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.

Introduction

The dip-steered auto-tracker follows the pre-calculated dip field in the SteeringCube from a seed position to generate hundreds of horizons, each representing a relative geologic timeline (de Groot et al., 2006; de Groot et al., 2010). Using the dip field to track horizons has an advantage above using the amplitude field because dip-fields are more continuous. In addition, the effect of noise can be significantly reduced by smoothing the dip field. If horizons are extended infinitely, a “continuous” HorizonCube is created. Alternatively, horizons can be terminated when they get too close to horizons tracked earlier in the process, creating a “truncated” HorizonCube. In a continuous HorizonCube horizons can diverge, or converge but they can never cross each other. Horizons that diverge will create holes in the HorizonCube that are filled in by iterating the tracking process a few times. Horizons that converge tend to do this along unconformities and condensed sections. In these areas, high HorizonCube density indicates zero seismic thickness corresponding to erosion, non-deposition, or very low sedimentation rates.

Interpretation Techniques

Global seismic interpretation techniques, such as the HorizonCube, might be perceived as the ultimate end product in seismic interpretation projects. This is 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.

HorizonCube Attributes

A set of new attributes can be computed from a HorizonCube that helps unravel the depositional history of a sequence and facilitates identification of stratigraphic features, such as pinch-outs, clinoforms, erosional unconformities and condensed sections. Example HorizonCube attributes are HorizonCube density measuring the number of events per seismic time (depth) interval; and HorizonCube thickness, measuring the thickness between two consecutive events.

A unique feature of HorizonCube attributes is that the attribute connects information over the whole area of a seismic survey, contrary to seismic attributes, which represent only local information. In other words, if we extract a HorizonCube attribute at a certain location, we obtain a data point that is related to all other values of HorizonCube attributes from the same depositional interval. This relation with “out of plane” information makes HorizonCube attributes, even when displayed on 2D sections, a great aid in understanding the 3D make-up of depositional events. This is demonstrated using HorizonCube density as an example. HorizonCube density inversely relates to sedimentation rate. Horizons near the depo-center of a particular depositional feature are spaced widely apart. Moving away from the depo-center horizons converge until the point that they effectively snap together into a single bundle in areas of non-deposition or erosion (Figure 1).

Interactive 3D Slider, Geobodies and Stratal Attributes

At the scale of a typical seismic survey, earth can be considered a set of finite geobodies, with distinct shapes and certain dimensions. For example in fluvial-marine environments, a significant petroleum play, an earth model can be constructed from geobodies, such as fan, channel, bar, sheet, drape, 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 grid 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. A grid of 2D sections remains necessary as interpreters (initially) observe, think and interpret seismic data in 2D. This approach follows the natural way human interpreters work. 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 gpu's allow us to use interactive 3D sliders. These HorizonCube based sliders slice through the seismic data in a geologically 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. Typically top and base were identified on 2D seismic grids, as explained above, using a 2D slider and HorizonCube attributes such as HorizonCube density. 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 (Figure 2). Moreover, seismic attributes such as reflection strength, frequency, AVO, coherency, average, maximum, or minimum impedance can be extracted between the stratal limits of the identified depositional event. Based on cut-off values in isopach thickness, or seismic attribute response, depositional events are then converted into geobodies for further assessment, property assignment and export to downstream applications, such as reservoir models.

Using interactive controls and on-the-fly visualization of isopachs and seismic attributes an interpreter thus achieves high productivity, and can deliver a detailed mapping and acquire a deep understanding of a large volume of data in a relatively short time.

Conclusions

Global seismic interpretation techniques based on mapping seismic chronostratigraphy capture a wealth of geologic information from seismic data. The challenge is to unlock this information by mining the data in an intelligent and efficient way. One solution to the challenge described above is the computation of HorizonCube attributes a new set of attributes that capture local and global information in a spatial-temporal framework. This is a unique difference with conventional seismic attributes. The second solution to this challenge is the 3D Slider: a workflow that combines 2D and 3D visualization techniques with interactive analysis. The tool allows the interpreter to rapidly scan thousands of auto-tracked horizons, to identify pairs of horizons corresponding to top and base of depositional features of interest, to compute and visualize isopach thicknesses and attributes and to extract geobodies.

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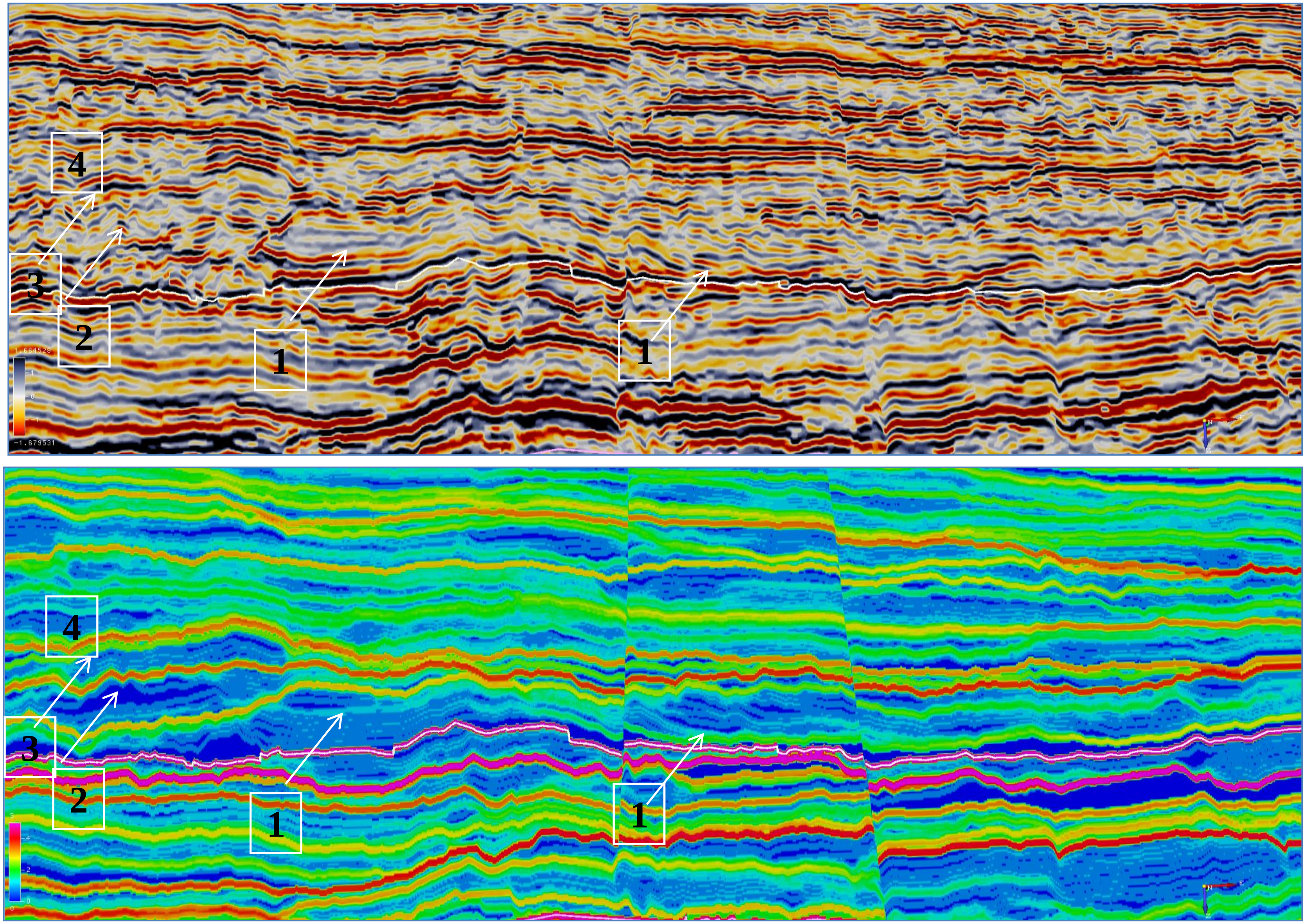

Figure 1. Seismic section (upper image) and equivalent HorizonCube density attribute (lower image) from deep water East-Africa. Hot colors represent high HorizonCube density and condensed section, blue color represent low HorizonCube density and expanded sections with high depositional rates. The HorizonCube density attribute provides a clear view of the depositional architecture, easily identifying four mounded features in a back-stepping configuration. Data courtesy: ION Geophysical.

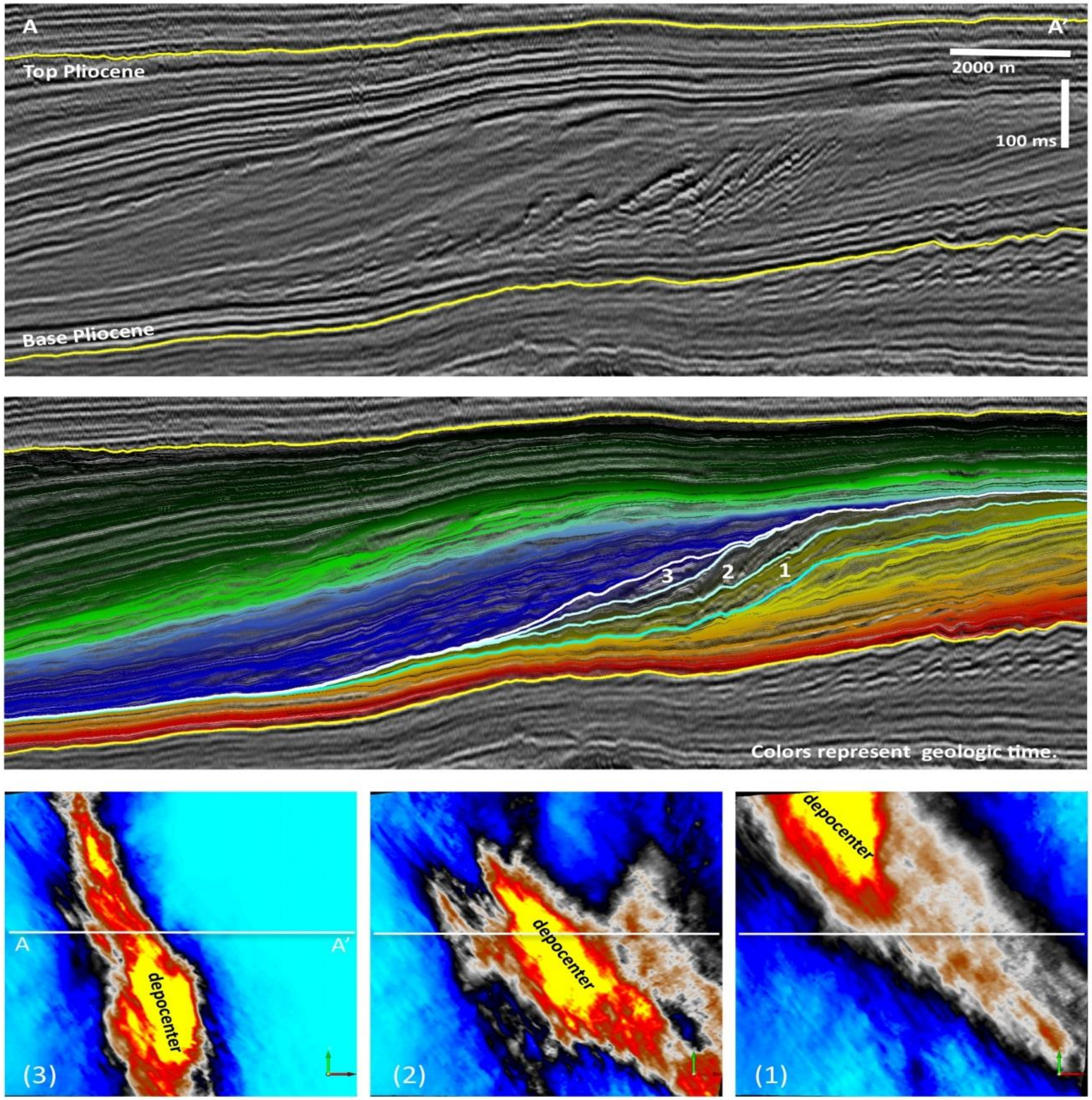

Figure 2. Analysis of prograding clinoforms in a Tertiary delta in the North Sea F3 Block. After identifying each clinoform using a 2D grid, the 3D slider is used to create isopach maps and map the forward and sideways progression of depo-centers. Each of the depo-centers is subsequently converted to a geobody. Image courtesy Jeannette Wolak, Tennessee Tech University.