Global seismic interpretation techniques are coming of age

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While enormous progress has been made, it's clear that the current group of global interpretation techniques are still evolving.

Successful applications covering different geologic settings, such as passive margins and carbonate platform settings, have also been published and, as the technology matures, additional applications and more complex settings will be put to the test.

What these two examples demonstrate, however, is not only how the mapping of a dense set of horizons can bring significant benefits to seismic interpretation but also how interpreted seismic volumes – whether they by generated through the HorizonCube, 'Age Volumes', 'PaleoScan' or 'Volumetric Flattening' – represent just the starting point for the application of new innovative interpretation workflows. And by extracting more geologic information from these seismic measurements, interpreters can generate a greater insight into the subsurface and improved exploration and field development returns.

We are on the verge of entering a golden age of seismic interpretation.

Entering a Golden Age

The advances in seismic technology over the last few years have been phenomenal, particularly in the areas of seismic acquisition, processing and interpretation.

Denser sampling in space and time, for example, and better algorithms to remove unwanted noise and image data allows geoscientists today to construct more accurate geologic models on which hugely important E&P decisions are made. Seismic interpretation is also seeing fast progress through the introduction of sophisticated attributes and innovative visualization techniques.

Yet, there remains a great deal more to come in seismic interpretation today, particularly when it comes to global seismic interpretation techniques.

These semi-automated techniques are designed to achieve fully interpreted seismic volumes through introducing the concept of geologic age into the interpretation process. It's the vast potential of these techniques and the advanced interpretation workflows built around them that will see seismic interpretation enter a true golden age.

The Growth of Global Seismic Interpretation Techniques

Global seismic interpretation include a variety of different methods, such as 'Age Volumes', 'PaleoScan', 'Volumetric Flattening' and dGB's own 'HorizonCube'. Such techniques share a number of algorithms in common with their aim being to correlate seismic positions along geologic time lines to arrive at fully interpreted seismic volumes.

Prior to the emergence of these techniques, time in geology tended to be a poorly understood feature.

While the work conducted by Exxon in the 1970's represented a huge step forward in seismic interpretation through the acknowledgement that seismic reflectors are the first order approximations of geologic time lines, the subsequent lack of supporting software algorithms led to the resulting interpretation technique – seismic sequence stratigraphy – often being a cumbersome and time-consuming process.

Things have changed, however, with the emergence of this new group of semi-automated seismic interpretation techniques that aim to generate fully interpreted seismic volumes.

Yet when we say fully interpreted seismic volumes, what do we mean? Can we get to a stage where no further interpretation is needed?

The answer, in my opinion, is a definite NO.

Fully interpreted seismic volumes mark just the starting point for the application of advanced interpretation workflows and the key objectives of extracting more geologic information from the seismic measurements. From application domains, such as seismic

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sequence stratigraphy and model building & seismic inversion through to geo-steering and geohazard interpretation, this article will provide an update on global seismic interpretation techniques today and how they are indeed coming of age.

Correlating Along Geologic Time Lines

As mentioned already, global seismic interpretation techniques correlate along geologic time lines to arrive at fully interpreted seismic volumes. This is possible because seismic reflectors are the first order approximations of geologic time lines (Vail et al., 1977). In other words, mapping horizons that follow seismic reflectors is essentially the equivalent to mapping geologic time.

The current techniques differ in how they correlate time lines and in the way the correlated information is stored. For example, Tracy Stark's'Age Volume' technique 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.

The PaleoScan software from French startup company Eliis (Pauget et al, 2009), on the other hand, builds a geologic model roughly on the scale of the seismic sampling by connecting each seismic event (min, max and zero-crossings) to the most probable neighbouring events. 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', Chevron's internal technology by Jesse Lomask (Lomask et al., 2009), is also based on correlating similarities. The correlated surfaces are 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), developed by dGB, differs from the above methods in both storage and correlation algorithms. Rather than tracking amplitudes or similarity, the underlying correlation algorithm correlates time lines in the pre-calculated seismic dip field. The tracked surfaces are then stored as a dense set of mapped horizons called HorizonCube.

The rest of this article will look at the HorizonCube algorithm in more detail as well as discuss its applications, particularly in the area of sequence stratigraphic interpretation and geohazard analysis.

Furthermore, much can be learned from the HorizonCube when applied to other seismic interpretation techniques. Since all global seismic interpretation techniques are linked by geologic time, these applications can be used across many other global seismic interpretation techniques with any fully interpreted volume generated from one of these techniques in principal used as input.

The HorizonCube Algorithm

The HorizonCube is an emerging global interpretation technique that provides fully interpreted seismic volumes where horizons are automatically tracked between a given set of framework horizons and faults.

The HorizonCube combines a 3D (or 2D) stack of horizons, typically spaced in the order of the seismic sampling interval. An example of what a HorizonCube looks like is presented in figure 1.In this example, the HorizonCube is a 'truncated' one, meaning that horizons stop when they get too close together. One of the horizons is displayed in its entirety and of the other horizons, only their intersection with the seismic line are shown. The inset shows the prograding clinoforms, a typical structure best captured through data-driven tracking.

In order 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

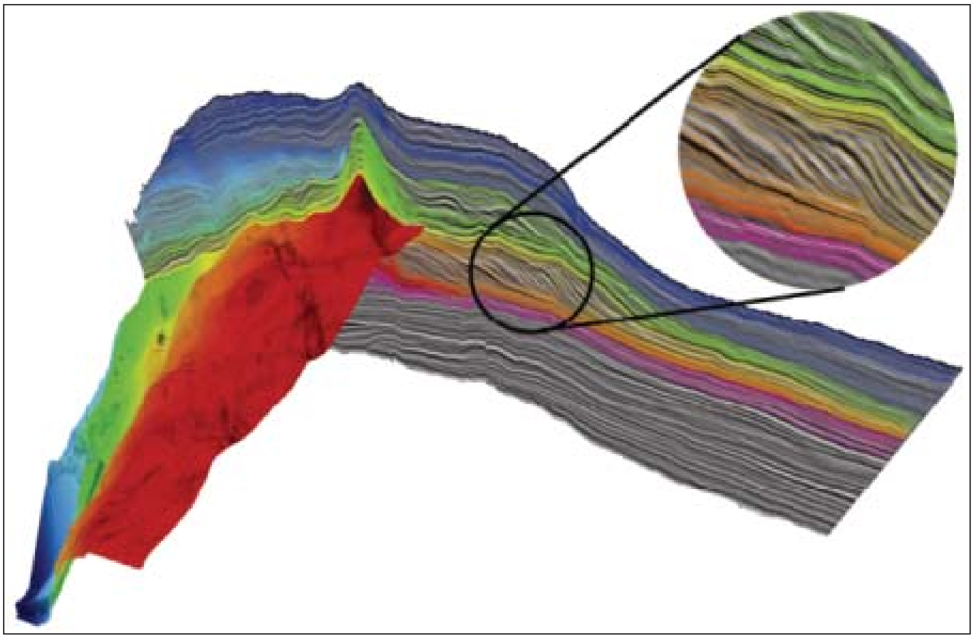

Fig.1

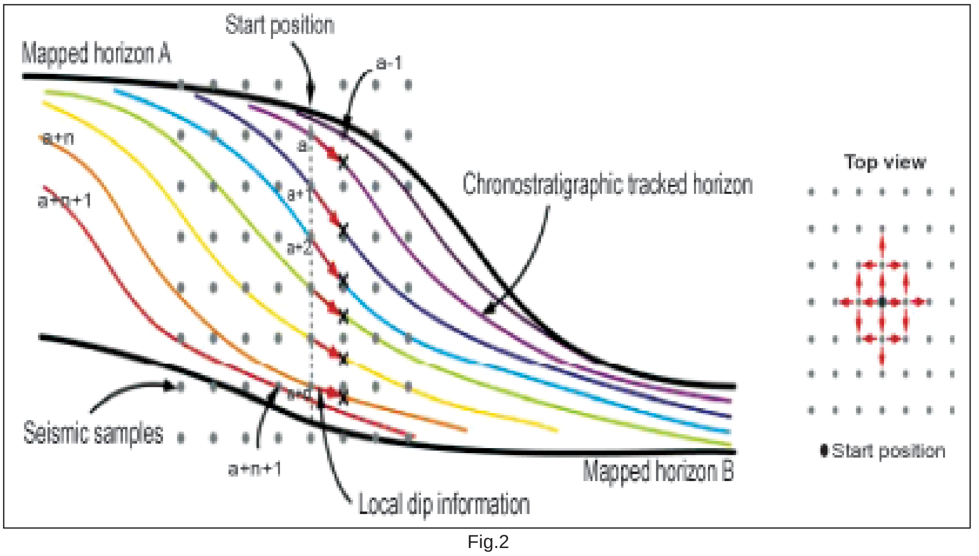

Fig.2

captured by the horizon tracker. The tracker can also stop horizons if the vertical spacing falls below a certain threshold to generate a truncated HorizonCube.

Dip fields are used for the 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.

As an alternative, the tracker can also be instructed to continue tracking throughout the volume even if horizon spacing becomes infinitely small. This results in a continuous HorizonCube in which all horizons exist at every X, Y position (figure 2), where there is a multi-horizon tracking workflow and where Horizons start from a single seed position. Such horizons help identify unconformities and condensed sections – something that is particularly useful in 3D attributes visualization and reservoir modeling.

All horizons within a truncated (figure 1) or continuous HorizonCube (figure 2) represent correlated 3D stratigraphic surfaces that are assigned a relative geological time. When horizons converge, they continue together and when they diverge extra horizons will be tracked in a second or later iteration.

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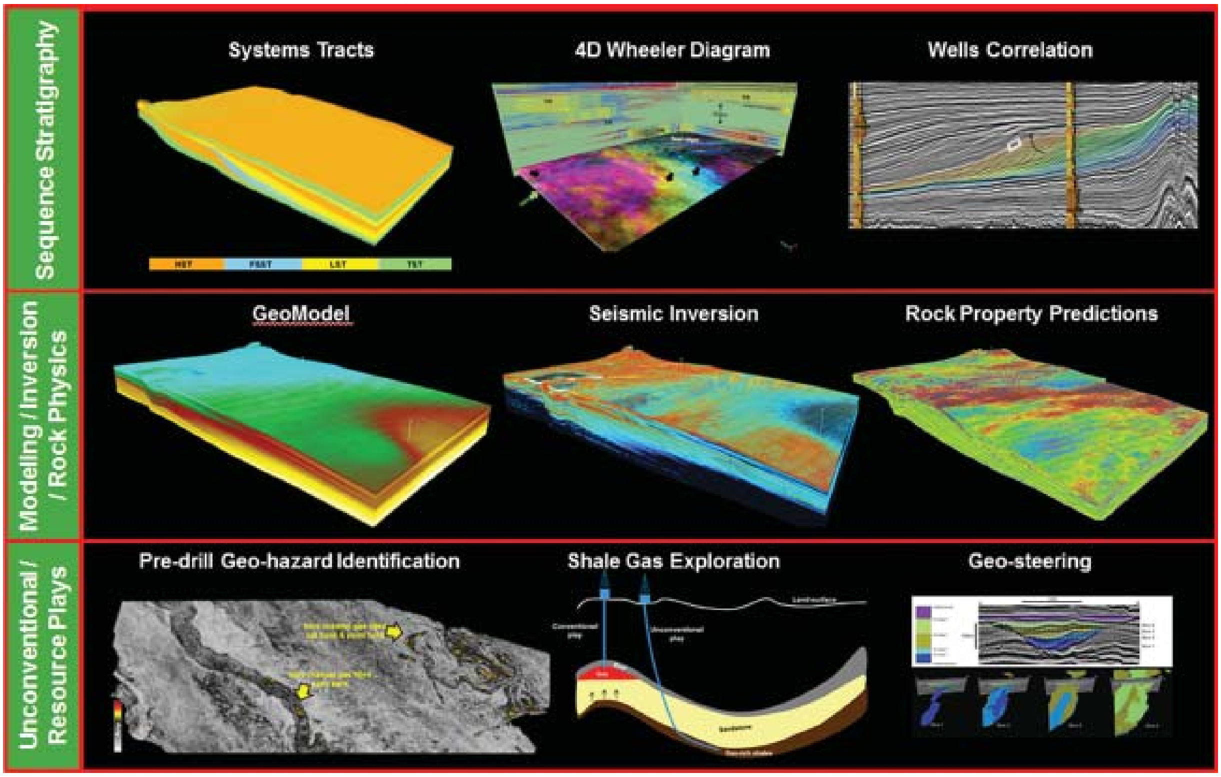

Fig.3

Applications

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As figure 3 illustrates, there are a number of different applications for these fully interpreted seismic volumes, such as assisting in well correlations, unravelling depositional histories, and finding stratigraphic traps using sequence stratigraphic interpretation principles.

Detailed geologic model building and improved seismic inversion and reservoir property prediction schemes can also be carried out with the starting point being more accurate low frequency models. Finally, geohazard interpretation and geo-steering can also play an important role in finding sweet-spots in unconventional plays.

A Sequence Stratigraphic Study – Offshore Netherlands

One such application is a sequence stratigraphic interpretation study offshore, the Netherlands where a technique is used to extract slumped deposits from a fully interpreted volume generated from the HorizonCube. Theses lumped deposits were then identified as potential stratigraphic traps.

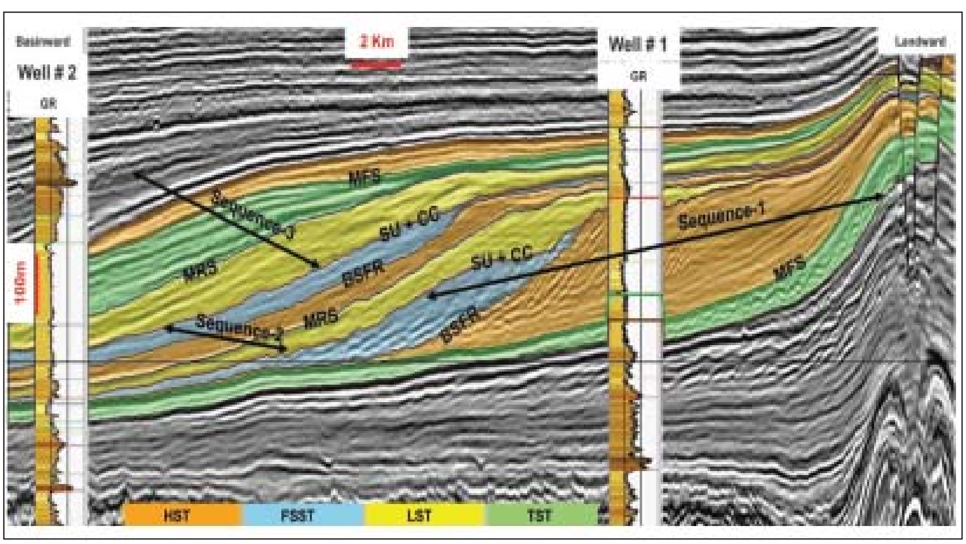

Fig.4

In this case, the HorizonCube was used in a Wheeler transformation of the seismic response and helped decompose the target Pliocene interval into a series of systems tracts comprising three incomplete cycles. In terms of exploration potential, the most interesting systems tract was the Falling Stage Systems Tract of the lowermost sequence (lowest blue interval in figure 4).

In this interval, an interesting reflection pattern was observed in lines parallel to the line shown in figure 4. The pattern showed slightly elevated amplitudes and was interpreted as a series of slumped deposits that could potentially trap hydrocarbons.

Exploiting the presence of a dense set of horizons due to the HorizonCube and mapping the slumped deposits was a seamless exercise with the interpreter using an interactive slider and setting horizons at top and base to outline the slumped feature. The software then automatically calculated the isopach thickness between the selected horizons and extracted the body between top and base and a user-defined thickness contour. The resulting slumped target bodies are shown in figure 5.

Today, the HorizonCube is routinely used in shallow hazard studies. In a typical shallow hazard application, for example, a HorizonCube is created over the upper part of a conventional 3D seismic data set in a small area (typically covering 60-150 sq.km) centred on the intended drilling site

Pre-Drilling Geohazard Analysis

Global interpretation methods can also be applied to shallow hazard interpretation workflows, enabling the interpreter to slice through volumes of seismic amplitudes and derive attributes along geologic time lines, thereby facilitating the recognition of depositional features and potential shallow hazards.

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The focus is on the shallow section up to 2000 meters below the water bottom. A dense set of horizons are then mapped through a data-driven approach by tracking dip and azimuth information or, if the character of the seismic prevents an acceptable result, through a model-driven approach.

Once a satisfactory HorizonCube is constructed, it can be then be used to stratigraphically flatten any attribute of interest through the Wheeler transformation. Looking for anomalies

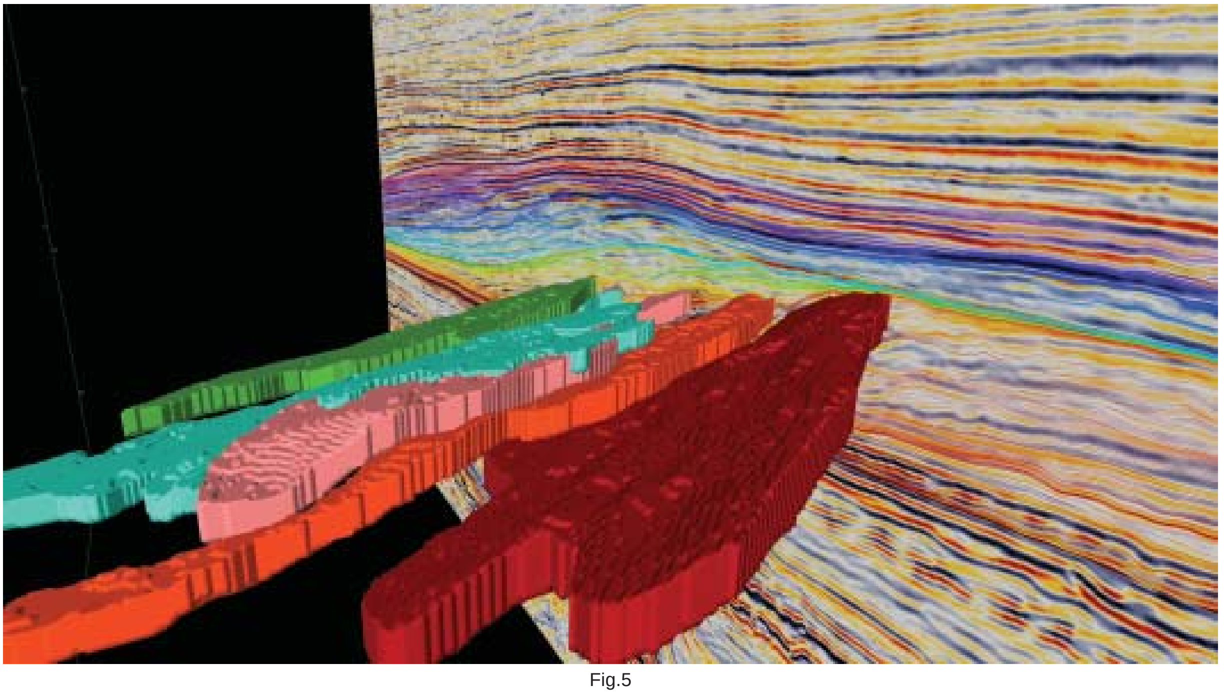

Fig.5

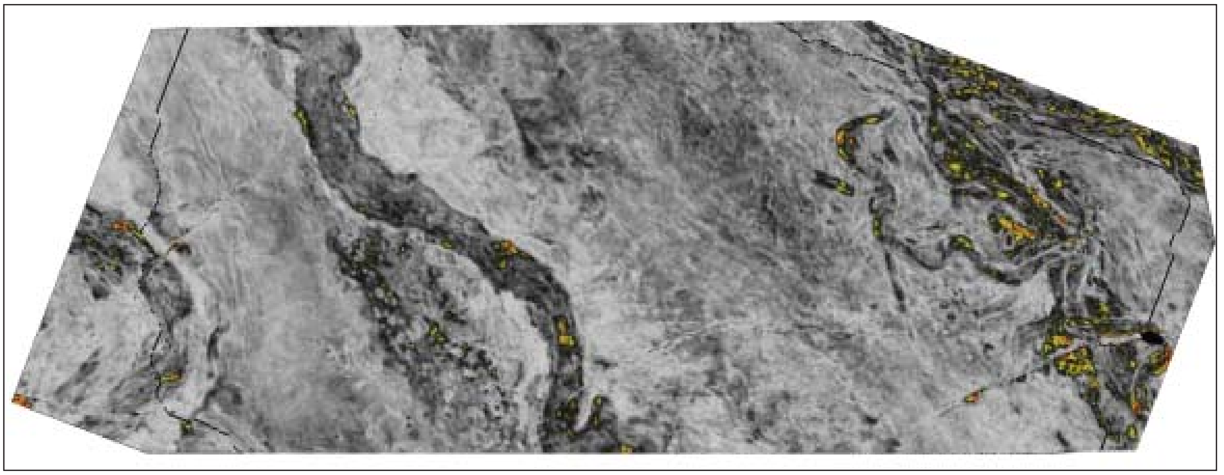

Fig.6

in the Wheeler domain increases the interpreter's understanding of the spatial distribution and timing of sediment deposition. Attributes can be flattened, for example, to assess shallow hazards, such as gas-filled shallow channels, fluid and lithology variation relating to seismic amplitude, pockmarks, bottom simulating reflectors, and faulting or truncations based on similarities. An example is shown in figure 6 where the flattening of the RMS amplitude unravelled intra-channel gas filled and gas filled cut bank areas (in yellow).

The Wheeler transformed attribute volumes create less interpretation ambiguity compared to time (or depth) slices, or parallel to seabed slices (figure 7).This is because the HorizonCube follows the stratigraphy more closely.

To date up to ten exploration well site locations have been assessed for shallow hazards using the HorizonCube methodology. In one such example, the HorizonCube was used in a deep water setting to accurately map the complex shallow section around proposed well locations.

With the starting point for shallow hazard identification being to pan through every pseudo-stratigraphic slice, preliminary investigation identified a meandering channel system that warranted further examination with different flattened seismic attributes.

The efficiency of the HorizonCube methodology also means that a suite of pseudo-stratigraphic slices can be generated over a large area when compared to typical shallow hazard studies.

The Best is Still to Come!

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Successful applications covering different geologic settings, such as passive margins and carbonate platform settings, have also been published and, as the technology matures, additional applications and

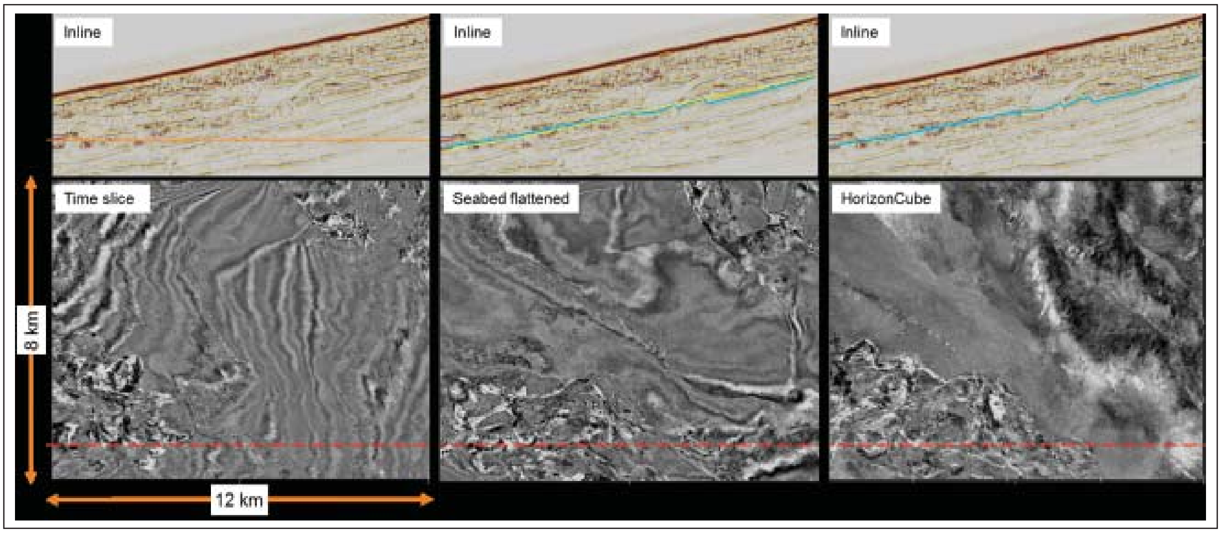

Fig.7

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about the author

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