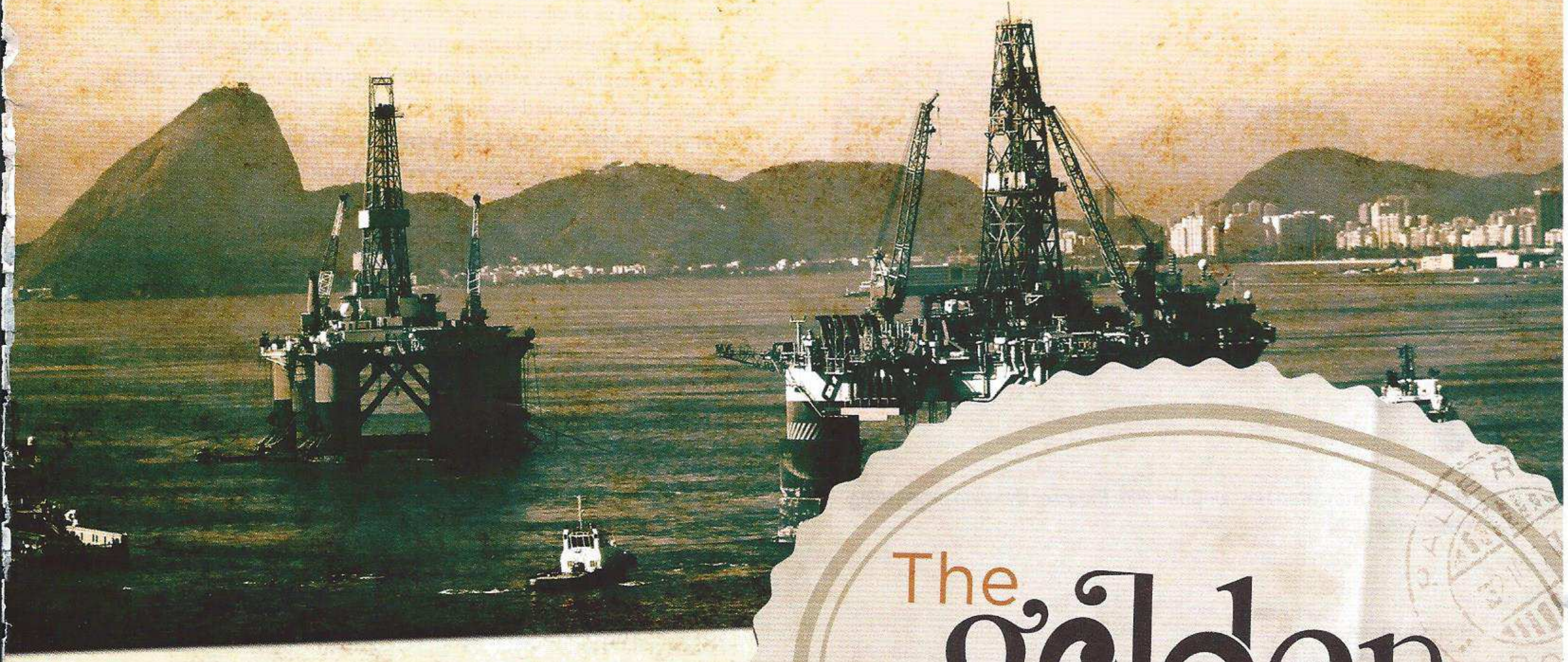

The golden era

Paul de Groot, dGB Earth Sciences, the Netherlands, looks at the growing sophistication and application of global seismic interpretation techniques.

From denser sampling in space and time, through to better algorithms to remove unwanted noise and image data and the introduction of sophisticated attributes and visualisation technologies, the last few years have seen significant advances in seismic acquisition, processing and interpretation.

It is, however, the introduction of the concept of geologic age into the interpretation process and the advanced workflows built around it to create fully interpreted seismic volumes that is likely to have the biggest impact on seismic interpretation over the coming years. The best is very much still to come!

While they may differ in how they correlate time lines and in the way in which the correlated information is stored, there are a number of semi-automated seismic interpretation methods today that share the common goal of correlating seismic positions along geologic time lines to arrive at fully interpreted seismic volumes.

The ‘Age Volume’ technique, for example, assigns a value representing relative geologic time to each seismic sample position (Stark, 2003) with the age assignment based on correlating instantaneous phase signals from trace-to-trace.

Another technique based on the PaleoScan software from French startup company Eliis (Pauget et al. 2009) builds a geologic model on the scale of roughly the seismic sampling by connecting each seismic event (min, max and zero-crossings) to the most probable neighbouring events.

Then, there is Chevron’s ‘Volumetric Flattening’ (Lomask et al., 2009) that is based on correlating similarities where the correlated surfaces are used to flatten the original seismic volume with the flattened volumes called Wheeler cubes.

Finally, there is dGB’s HorizonCube (de Groot et al., 2010). Rather than tracking amplitudes or similarity, the underlying correlation algorithm within the HorizonCube correlates time lines in the pre-calculated seismic dip field with the tracked surfaces then stored as a dense set of mapped horizons called HorizonCube.

From application domains, such as seismic sequence stratigraphy, attribute generation and model building through to geohazard interpretation, this article will demonstrate how the HorizonCube is helping take seismic interpretation and the concept of geological age to new levels of sophistication.

The article will also demonstrate how much can be learned from when the system is applied to other seismic interpretation techniques and will argue that fully interpreted seismic volumes mark just the starting point in extracting more geologic information from seismic.

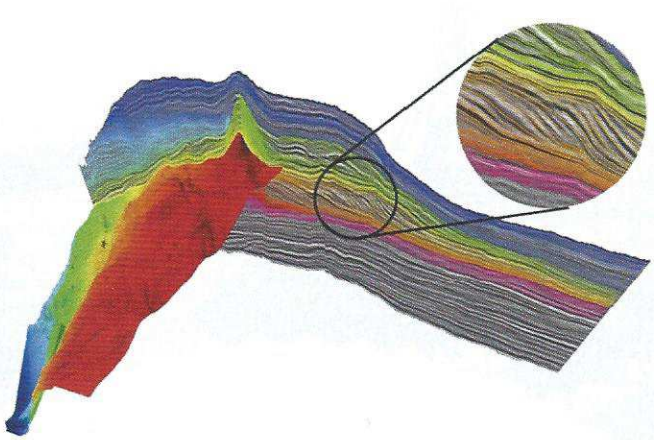

Figure 1. *A truncated HorizonCube with the inset showing prograding clinoforms.*

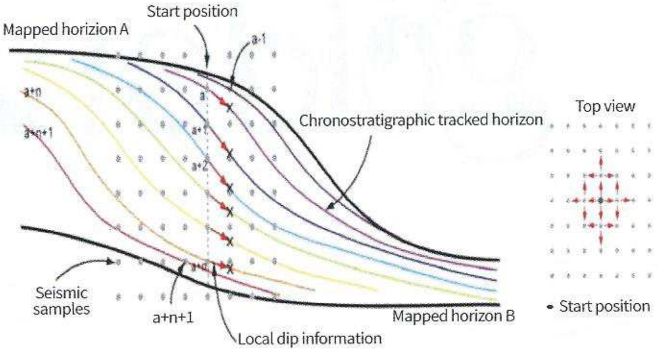

Figure 2. *A continuous HorizonCube showing tracking starts from single seed positions vertically separated by one sample position.*

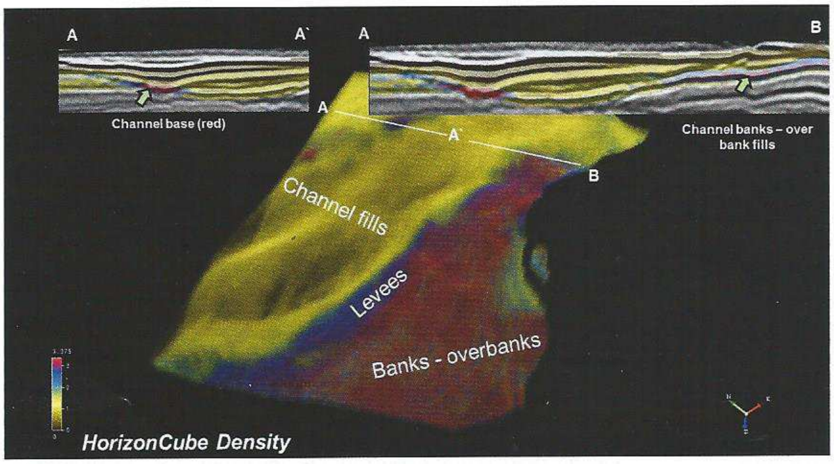

Figure 3. *A deepwater channel system off the Australian North West Shelf.*

A different system

The HorizonCube provides fully interpreted seismic volumes where horizons are automatically tracked between a given set of framework horizons and faults and where the tracking is carried out by using a seismic dip volume.

Horizons can be tracked in two different modes, both of which represent correlated 3D stratigraphic surfaces assigned a relative geological time. Firstly, they can be tracked as truncated horizons (Figure 1) that stop when they get too close together. This helps to identify stratigraphic lapouts (onlaps, downlaps and top laps). In Figure 1, for example, the inset shows prograding clinoforms – typical structures best captured through data-driven tracking.

Secondly, Horizons can be tracked as continuous horizons, tracking throughout the volume even if horizon spacing becomes infinitely small, staying together when they converge and never crossing each other. Figure 2 illustrates a continuous HorizonCube in which all horizons exist at every X, Y position, where horizons start from a single seed position separated in time by one sample position. Such horizons help identify unconformities and condensed sections – particularly useful in 3D attributes visualisation and reservoir modelling.

Applications

Fully interpreted seismic volumes, such as those generated from the HorizonCube, open the way to the application of a number of advanced seismic interpretation workflows that enable more geologic information to be extracted from the seismic data.

The system can be applied 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, the system can be used in geohazard interpretation, finding sweet-spots in unconventional plays and geo-steering.

Creating a new set of attributes

From the continuous set of seismic horizons, a new family of attributes can be computed that visualise geologic features previously hidden. Such attributes include isochron thickness (highlighting not only sedimentary bodies but also local pinch-outs, condensed intervals and local unconformities), HorizonCube density attributes that help define the zones of pinch-outs, condensed sections and unconformities, arbitrary layers that divide mapped seismic horizons into fix layers with a unique ID for each layer and derivatives that can measure subtle geometrical changes and discontinuities.

From a stratigraphic interpretation standpoint, the mapped seismic horizons in truncated form can be sub-divided into sequence stratigraphic units through the co-visualisation of a structural domain and a Wheeler domain in conjunction with well data. In both domains various data, such as wells and seismic, can be combined to interpret a set of sequence stratigraphic units, such as systems tracts and sequences.

Typical attributes that are extracted using this sequence stratigraphic framework include:

stratigraphic unit IDs (identification numbers) and isochrons. The IDs of interpreted stratigraphic units can either be unique (each system's tract unit is assigned a unique ID) or common (each identical systems tract is assigned a common number). An isochron attribute calculates the thickness of a stratigraphic unit. The unit of this attribute depends on the seismic survey type (TWT or in depth). This is a key attribute for understanding how sedimentation filled a sedimentary basin as a function of geologic time.

The relative rate of preservation – the ratio between an isochron volume and a known geologic time-span for a particular unit – can also be calculated with the results being relative measurements of the rate of preservation per geological time unit. Finally an attribute can be generated that defines the difference between two isochron grids as a volume at a certain trace location.

Figure 3 illustrates a deepwater channel system of the Australian North West Shelf. Five channel stages were identified based on observations of features such as: crosscutting relationships, timing and geomorphologic patterns. The same interval can also be studied using the density attribute, which is able to illustrate the channel base, levees and banks of channel systems. Workflows, such as these, support the building of better stratigraphic models to predict reservoir quality sands and to perform reservoir characterisation.

Geohazard analysis

HorizonCubes can also be applied in shallow hazard interpretation workflows where, through the Wheeler transformation (Wheeler, 1958), any attribute of interest can be flattened to perform a more complete analysis of shallow hazards.

Attributes can be flattened 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. Windowed amplitude extractions are recommended to take account of any imperfections.

In this way, it enables interpreters to slice through volumes of seismic amplitudes and derived attributes along geologic time lines, thereby facilitating the recognition of depositional features and potential shallow hazards. To date, eight exploration well site locations have been assessed for shallow hazards using the HorizonCube methodology.

In the deepwater setting illustrated here and where the HorizonCube was applied in partnership with BG Group, the goal was to accurately map the complex shallow section around proposed well locations.

The seabed in question is characterised by active canyons with the depositional environment reflected in the cross-cutting channelised and turbiditic deposits evident in the shallow seismic. Here, 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-prone channels and deep-seated faults that could provide a gas migration pathway can also be studied and can be further risked based on potential pinchout and isolation of sand bodies.

Figure 4 illustrates a pseudo-stratigraphic amplitude slice shown from an 8 km by 12 km volume for one of the drill site locations. Such slices are extracted from the continuous HorizonCube on a step of every 20. The proposed exploration well location is marked by an orange circle. A starting point for shallow hazard identification is to pan through every pseudo-stratigraphic slice. This preliminary reconnaissance identified a meandering channel system that warrants further investigation with different flattened seismic attributes.

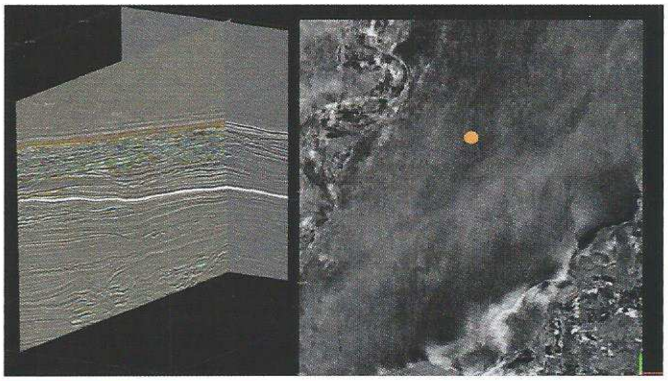

Figure 4. *A pseudo-stratigraphic amplitude slice shown from an 8 km by 12 km volume for one of the drill site locations.*

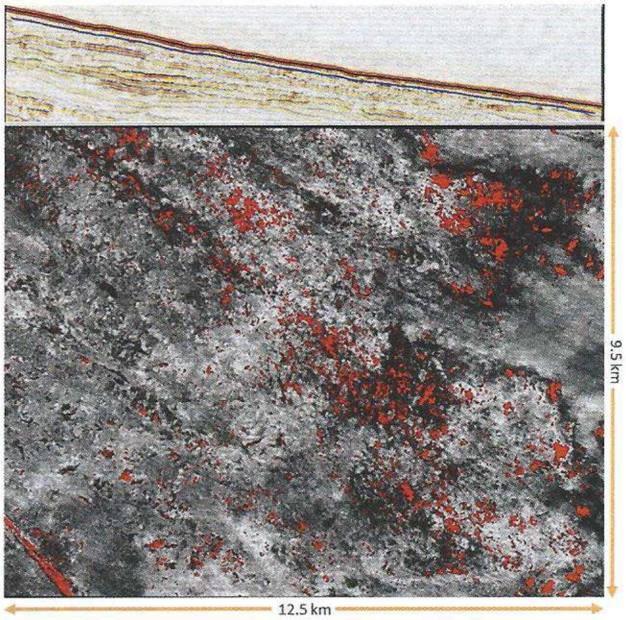

Figure 5. *An amplitude extraction from a pseudo-stratigraphic slice is shown.*

In Figure 6, an amplitude extraction from a pseudo-stratigraphic slice is shown. An RMS amplitude extraction was clipped to show the brightest amplitudes in red. These features may be associated with shallow gas. These anomalous amplitude features trend perpendicular to the horizon slice time contours. The time contours can be analysed for whether the anomalous amplitudes conform with structural highs because such conformance may indicate a greater risk of shallow gas.

Through the use of this system, the stratigraphy of an entire shallow section can be followed in considerable detail. This leads to an improved understanding of shallow hazards and greater flexibility in the choice of well location.

Entering a golden era

Interpreted seismic volumes – whether they be generated through the HorizonCube, 'Age Volumes', 'PaleoScan' or 'Volumetric Flattening' – represent just the starting point for the application of new and innovative interpretation workflows. As this article illustrates, there are many applications built on interpreted seismic volumes that can lead to an improved understanding of the subsurface.

The result will have a significant impact on future drilling, well and reservoir management strategies as we enter a new and hopefully golden era of seismic interpretation.