Implications of HorizonCubes in shallow hazards interpretation

Eric Bouanga[1], James Selvage[2*], Farrukh Qayyum[1], Charles Jones[2], Sarah Brazier[2] and Jonathan Edgar[3] demonstrate how the HorizonCube method can be applied in shallow geohazard interpretation.

Recent research and surveys have recognised the applicability of conventional 3D seismic for pre-drilling shallow hazard analysis. Selvage et al., (2012) introduced a shallow hazard analysis framework to leverage the spatial bandwidth in 3D seismic for assessing shallow hazards. The proposed method is applicable for a variety of depositional settings ranging from shallow water to ultra deepwater conditions.

The benefits of conducting shallow hazard analysis in 3D seismic data as opposed to 2D data include: increased spatial accuracy, the improved reliability of post- and pre-stack amplitudes and enabling volume-based and amplitude-versus-angle (AVA) based attributes to be interpreted.

3D seismic data also allows global interpretation methods (i.e., methods that aim to generate fully interpreted volumes; see also de Groot et al., 2010; Hoyes and Cheret, 2011; Stark et al., 2013) to be applied in shallow hazard interpretation workflows. These techniques enable the ability to slice through volumes of seismic amplitudes and derived attributes along geologic timelines, thereby facilitating the recognition of depositional features and potential shallow hazards.

This article will provide an overview of how one global interpretation method – the HorizonCube – can be applied in shallow geohazard interpretation.

The HorizonCube

dGB Earth Sciences' HorizonCube is a global interpretation technique (de Groot et al., 2010) that is nowadays routinely used in shallow hazard studies.

The HorizonCube is a dense set of auto-tracked correlated 3D stratigraphic surfaces, created by an auto-tracker, with each horizon representing a (relative) geologic timeline. It combines a 3D (or 2D) stack of horizons; typically spaced in the order of the seismic sampling interval (the horizon spacing will be laterally varying to reflect thickness changes). An example of a HorizonCube is shown in Figure 1.

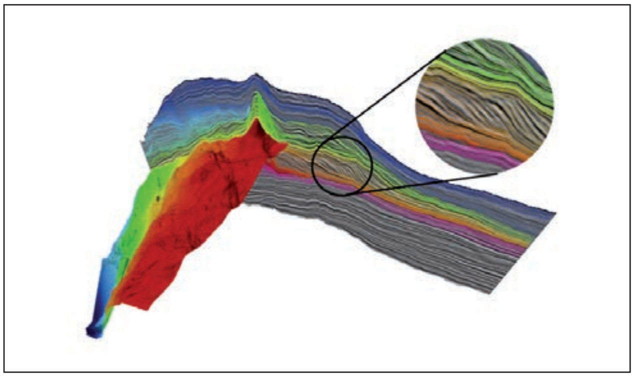

__Figure 1__ An example of a HorizonCube. The HorizonCube creates a dense set of auto-tracked correlated 3D stratigraphic surfaces.

By greatly increasing the number of mapped horizons through semi-automated techniques and through the creation of fully interpreted seismic volumes, interpreters can maximise the potential of high-resolution seismic in reservoir characterisation with applications for sequence stratigraphy, geological model building, well correlation, inversion and geosteering. This article, however, will focus on the HorizonCube's applicability in shallow hazard analysis.

Generating an HorizonCube and its applications in geohazard analysis

To generate an 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.

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 goes below a user-defined threshold. The result is either a continuous HorizonCube in which all horizons exist at every X, Y position, or a truncated HorizonCube. All horizons represent correlated 3D stratigraphic surfaces that are assigned a relative geological time.

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HorizonCubes have key applications for shallow hazard analysis prior to the drilling of new wells. In a typical shallow hazard application, an HorizonCube is created over the upper part of a conventional 3D seismic data set in a small area (typically covering 60-150 km^2) centred on the intended drilling site (Figure 2). The focus is on the shallow section up to 2000 m below the water bottom. A dense set of horizons are mapped through a data-driven approach by tracking dip and azimuth information.

Figure 2 (top) illustrates the input seismic data set for generating an HorizonCube where the volume is extracted from the larger 3D exploration seismic volume centred on the proposed drilling location. In Figure 2 (bottom), the HorizonCube creates a pseudo-stratigraphic framework for flattening any attribute that may help to assess the risk associated with identified shallow hazards.

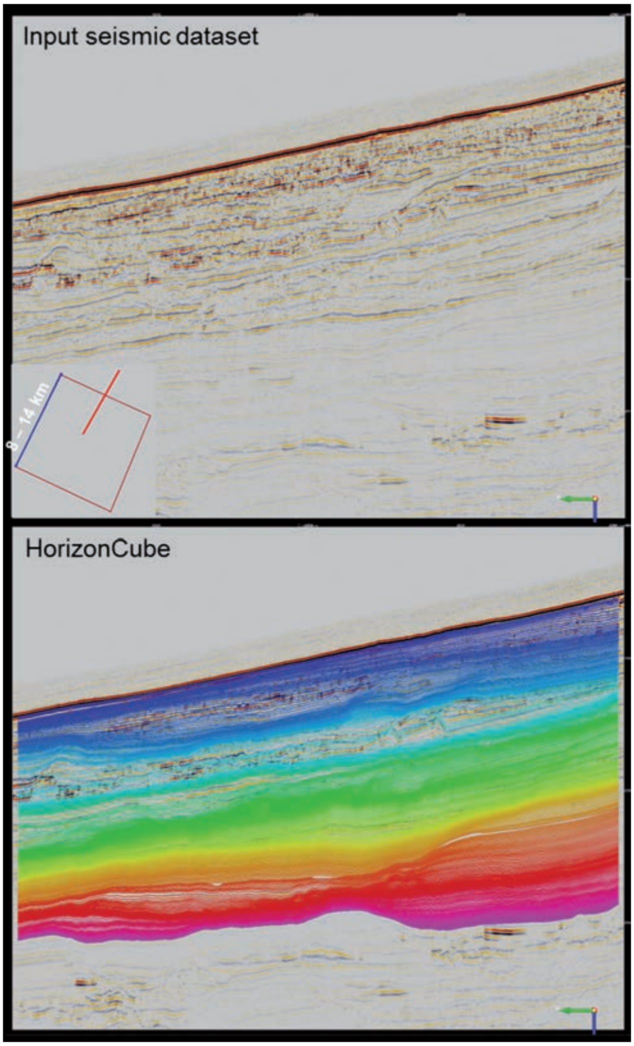

Figure 2 Top: The input seismic data set for generating an HorizonCube. Bottom: A pseudo-stratigraphic framework created by the HorizonCube for flattening any attribute that may help to assess the risk associated with identified shallow hazards.

In some cases the character of the seismic prevents an acceptable result from a data-driven approach. In these situations, a model-driven approach is adopted that bases itself on relationships to bounding horizons and includes 'proportional', 'parallel-to-upper', and 'parallel-to-lower'. Figure 3 shows a HorizonCube example which adopts both approaches to create a continuous set of dense horizons.

Figure 4 illustrates the complete process for generating a HorizonCube which consists of the following:

- Step 1: A number of horizons are tracked, using either traditional amplitude- & similarity-based auto trackers or a tracker that follows dip. These 'anchor horizons' divide the seismic volume into zones with similar seismic character, enabling the parameters for producing intermediate horizons to be tailored to the seismic character within a zone. Figure 4 (top left), for example, illustrates a seismic section with an overlay of anchor horizons tracked using traditional amplitude tracking techniques. The anchor horizons are used to divide the seismic into different zones, labelled as zones 1, 2 and 3.
- Step 2: A seismic dip and azimuth volume is created as can be seen in Figure 4 (top right) where a seismic dip field is calculated from the seismic volume.
- Step 3: Iterations of the HorizonCube algorithm are run until a dense set of horizons are created. Figure 4 (bottom left) shows the dense set of pseudo-stratigraphically consistent horizons.

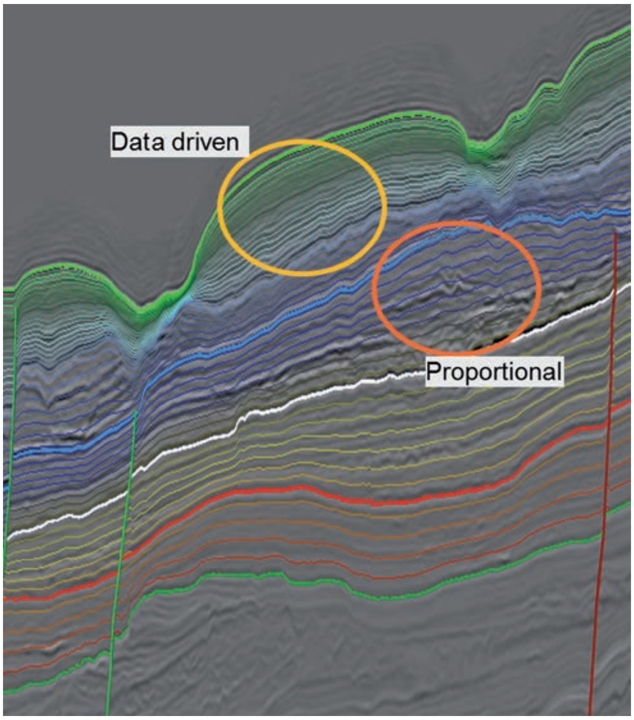

Figure 3 An example seismic section showing an overlay of HorizonCube horizons. Both data-driven and model-driven approaches were utilised to produce a continuous set of dense horizons.

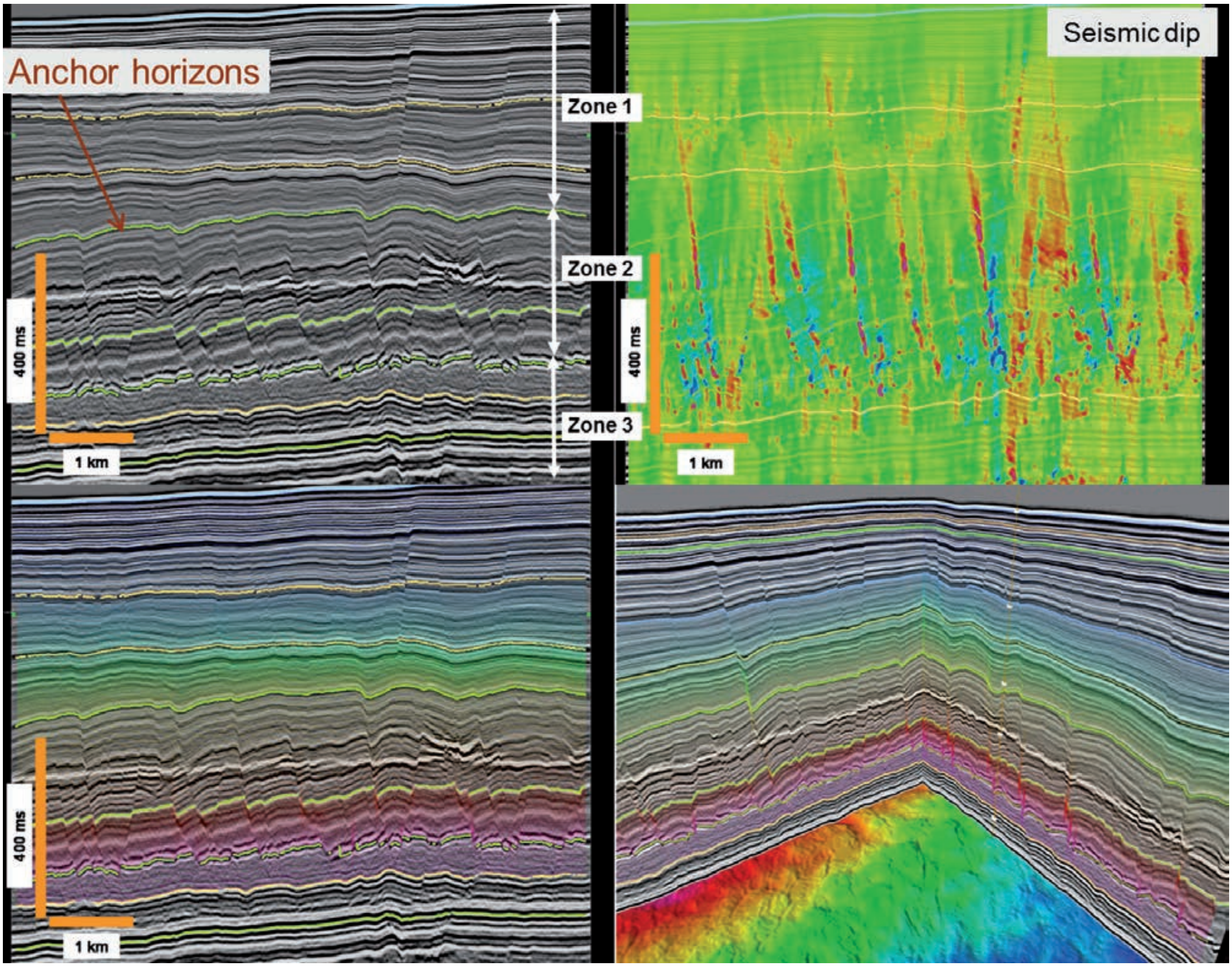

***Figure 4** Top left: Seismic section with an overlay of anchor horizons used to divide the seismic into different zones. Top right: Seismic dip field calculated from the seismic volume. Bottom left: Final HorizonCube result showing the dense set of pseudo-stratigraphically consistent horizons. Bottom right: The HorizonCube creates a 3D framework by which any attribute of interest can be flattened.*

- Step 4: The seismic volume and other seismic attributes can then be analysed in 3D following the seismic dip. Figure 4 (bottom right) shows how the HorizonCube has created a 3D framework by which any attribute of interest can be flattened.

Applying the Wheeler domain

Once a satisfactory HorizonCube is constructed, it can be used to stratigraphically flatten any attribute of interest through what is commonly known as the Wheeler transformation (Wheeler, 1958). The Wheeler transformation warps the z-axis (time or depth) of Cartesian space such that every horizon in the HorizonCube is flat and their spacing is regular. Within this flattened space the seismic data and selected attributes can be easily and efficiently sliced in a pseudo-stratigraphically consistent manner.

Looking for anomalies in the Wheeler domain increases the interpreter's understanding of the spatial distribution and timing of sediment deposition. Attributes could 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 the HorizonCube.

Wheeler transformed attribute volumes create less interpretation ambiguity compared to time (or depth) slices, or parallel to seabed slices (Figure 5).

This is because the HorizonCube follows gross dip in a truly 3D sense (Figure 6). 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.

It is important to note, however, that the HorizonCube does not need to be globally consistent in terms of chronostratigraphy, as would be required in sequence stra-

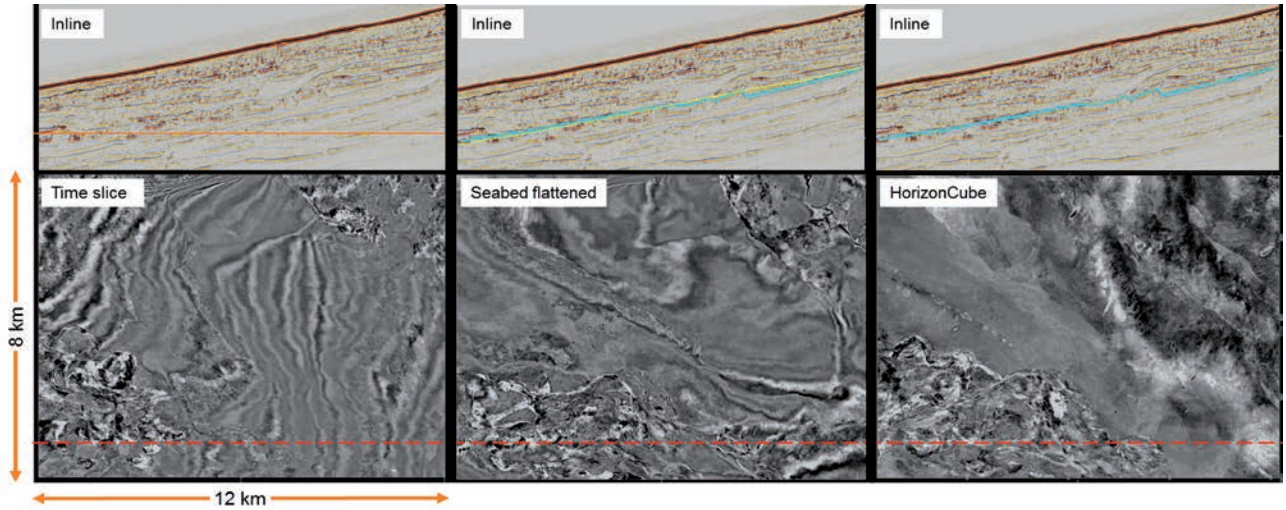

***Figure 5** A comparison between time slice, seabed flattened and HorizonCube amplitude extractions. The location of the inline is shown by the red dashed line. Indicated on the inline section (top left) bright amplitudes are seen, but understanding their geometries is not straightforward on a time slice (bottom left). A seabed parallel extraction (middle bottom) shows that these amplitudes are associated with a complex channel system. The HorizonCube slice shows this complex channel system clearest. This is because the HorizonCube follows the seismic dips in 3D (Figure 4) whereas the shallow geology may not parallel the seabed in all directions (Figure 6).*

tigraphy studies. As long as the events are locally following geologic timelines, the anomalies that the interpreters are looking for will show up in the Wheeler domain. We refer to slices in the Wheeler domain defined by an HorizonCube as 'pseudo-stratigraphic'. These slices can cut through erosional features, do not conform to a constant stratigraphy (such as channels), but are able to highlight potential shallow hazards.

Applications

To date eight exploration well site locations have been assessed for shallow hazards using the HorizonCube methodology. Examples from a deep-water setting are shown here. 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 seabed is characterised by active canyons and this depositional environment is reflected in the cross-cutting channelized and turbiditic 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–prone 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 conformance of sand bodies to structure.

In Figure 7 a sequence of pseudo-stratigraphic amplitude slices is shown from an 8 km by 12 km volume for one of the drill site locations. The slices are extracted from the continuous HorizonCube on a step of every 20. The proposed

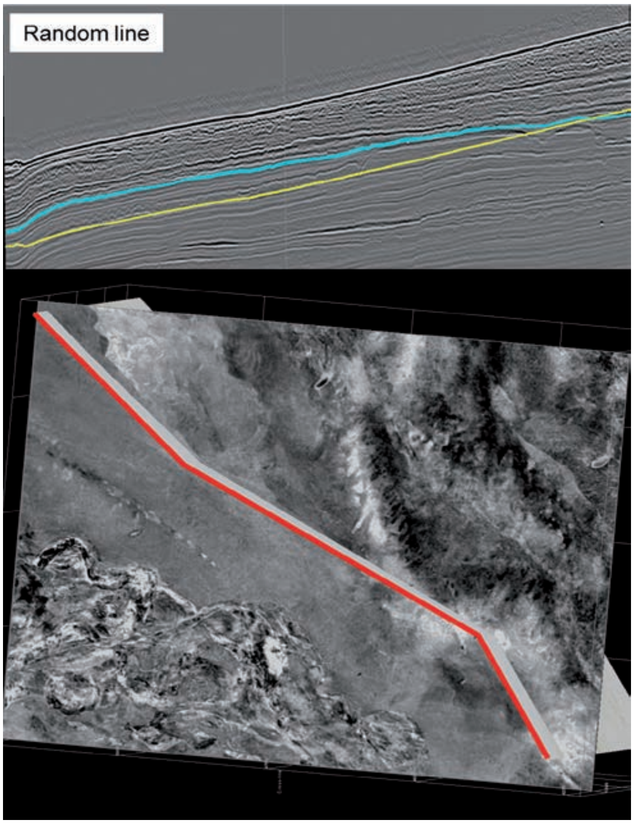

***Figure 6** The HorizonCube follows the seismic dip in 3D meaning that amplitude extractions have less ambiguity when compared to time slice and seabed flattened amplitude extractions. The seismic section (top) is a random line shown in red (bottom) from the 3D seismic volume. The yellow line shows a parallel to seabed horizon whose amplitude extraction is shown in Figure 5. The blue line shows the horizon extracted from the HorizonCube, which honours the gross dip in 3D. Windowed RMS (Root Mean Square) amplitude extractions can also be used to take account of any imperfections in the HorizonCube.*

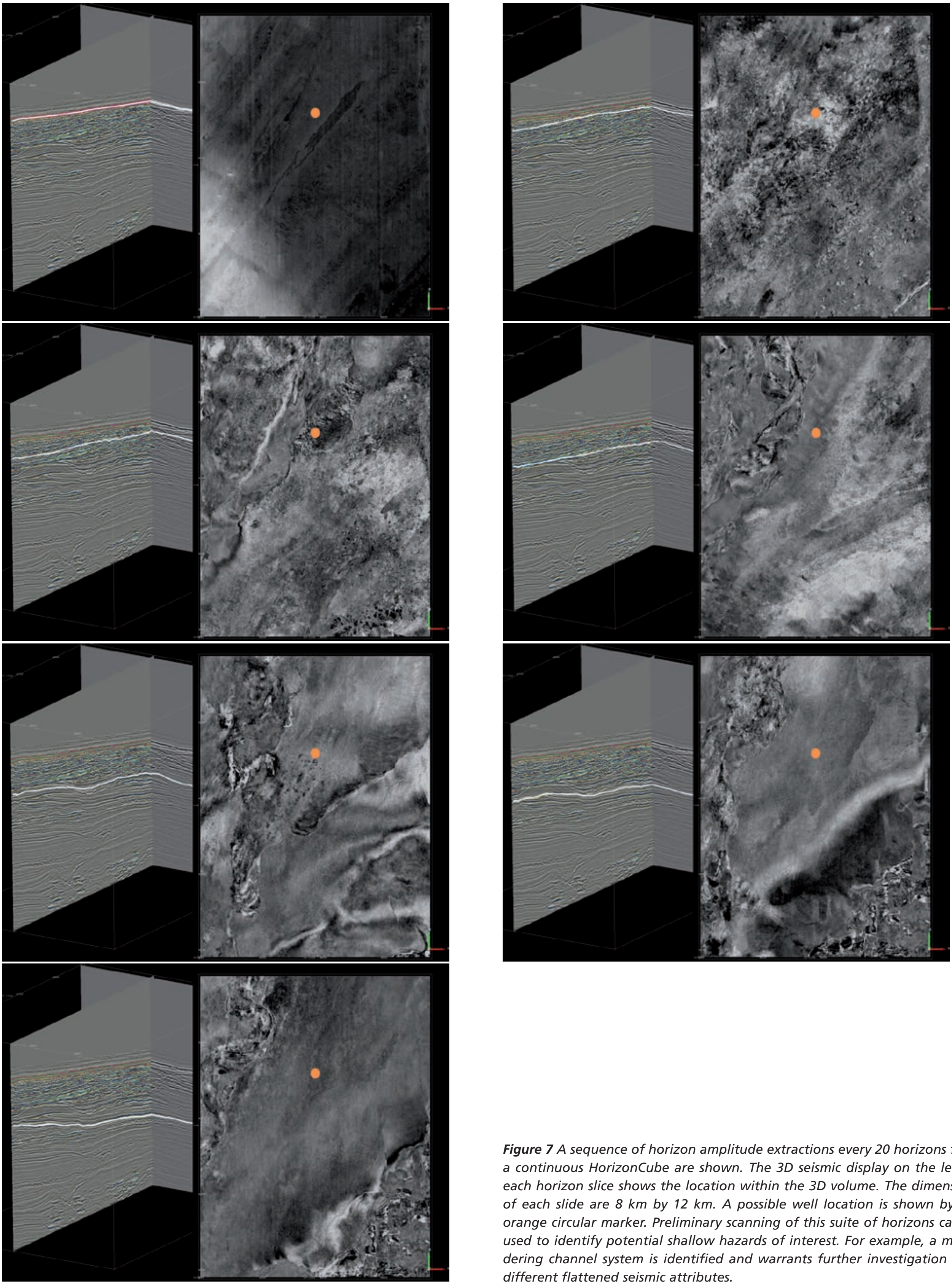

Figure 7 *A sequence of horizon amplitude extractions every 20 horizons from a continuous HorizonCube are shown. The 3D seismic display on the left of each horizon slice shows the location within the 3D volume. The dimensions of each slide are 8 km by 12 km. A possible well location is shown by the orange circular marker. Preliminary scanning of this suite of horizons can be used to identify potential shallow hazards of interest. For example, a meandering channel system is identified and warrants further investigation with different flattened seismic attributes.*

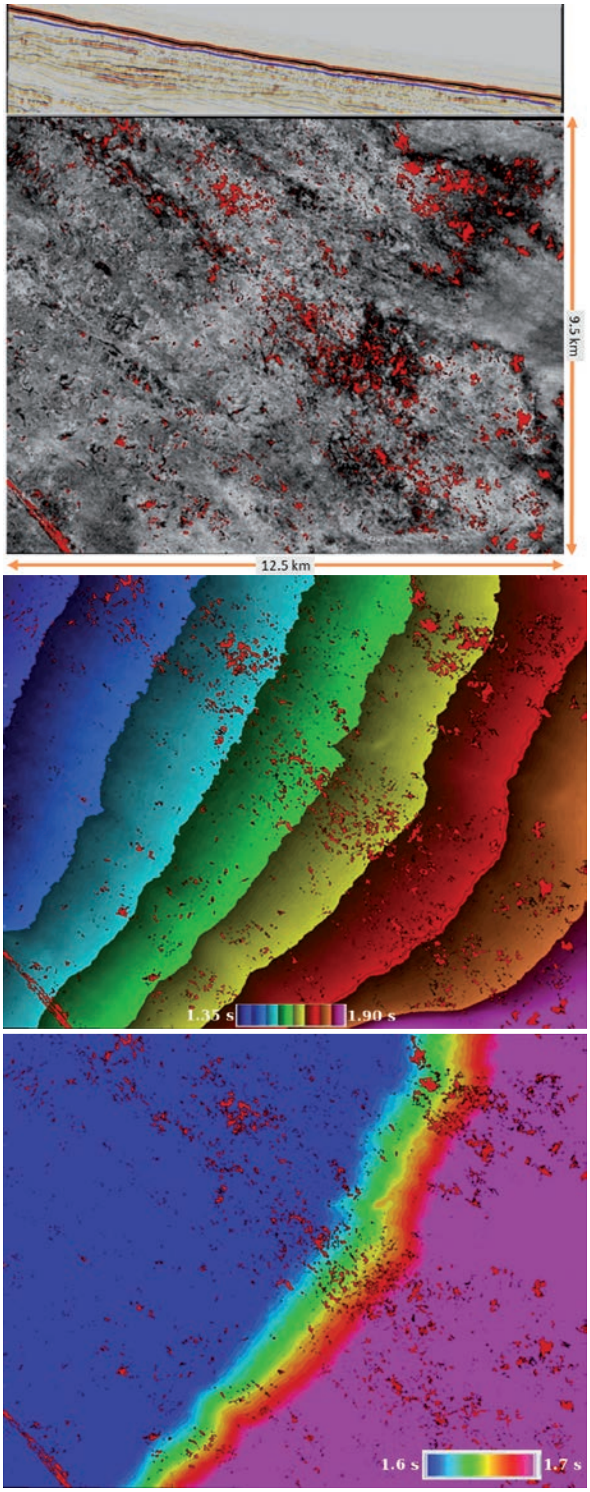

Figure 8 *Chaotic seismic reflectors are seen just below the seabed in this deepwater location (top). The red amplitude overlay shows extreme RMS amplitudes. In the context of shallow geohazards these may be shallow gas accummulations. These anomalous amplitude features trend perpendicular to the horizon slice time contours (middle). 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 (bottom). To emphasise this the colour bar has been squeezed.*

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.

In this deep-water area seabed and immediate sub-seabed, sediments were expected to be very-soft-to-soft deepwater muds with occasional sands. These intervals are often channelized and contain sandy intervals with higher porosity. Such intervals can have a chaotic amplitude character (Figure 8) with bright amplitudes being associated with fluid fill or lithology.

In Figure 8, 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. Comparing the RMS amplitudes extracted with TWT extraction on to the pseudo-stratigraphic slice shows that the features trend perpendicular to TWT contours. The TWT times can be used to search for whether the bright amplitudes are structurally

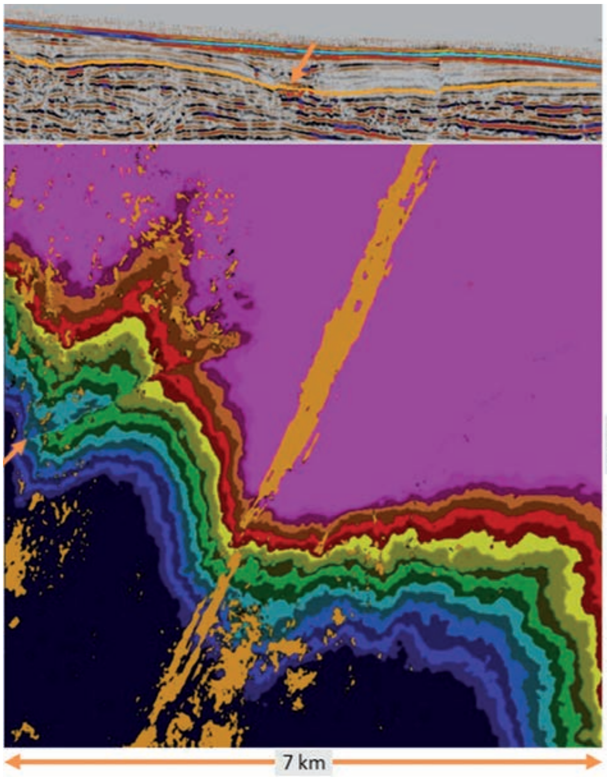

Figure 9 *A high amplitude feature is observed (orange arrow top) in a synclinal feature on the pseudo-stratigraphic slice extracted from the HorizonCube (top). The TWT values are extracted onto the slice with bright amplitudes rendered in orange (bottom). The bright linear feature is interpreted to be a shallow channel. The colour bar on the TWT has been squeezed to evaluate whether any bright amplitudes coincide with closure against the shallow fault observed on the pseudo-stratigraphic slice (orange arrow bottom).*

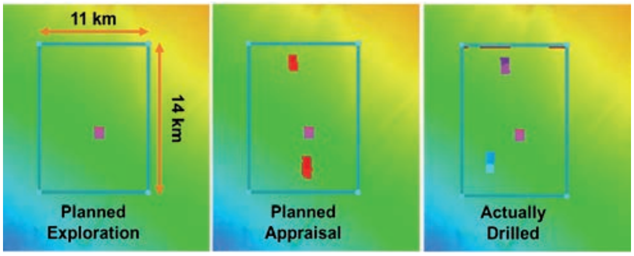

***Figure 10** Example of planned exploration and appraisal drilling locations. The HorizonCube area of 11 km by 14 km was chosen to cover an exploration well (left) and two possible appraisal (middle) locations. One of the actually drilled locations differed from the planned appraisal location (right). Such flexibility is possible because the HorizonCube is generated over a larger area than is typical in shallow hazard studies.*

conformable, which may increase the likelihood that they are associated with shallow gas. If structural conformance were observed, a Vp/Vs ratio attribute may help to risk such features further. Similar analysis is shown for anomalously bright amplitudes in Figure 9.

The efficiency of the HorizonCube methodology means that a suite of pseudo-stratigraphic slices can be generated over a large area when compared to typical shallow hazard studies. Figure 10 shows a HorizonCube created over an 11 km by 14 km area designed to cover one planned exploration well and two likely appraisal well locations, should the exploration well be successful. One of the appraisal wells was subsequently drilled in a different location, demonstrating the flexibility that the HorizonCube brings.

Conclusion

What this has demonstrated are the significant benefits that the HorizonCube brings to shallow hazard analysis and, through analogy, seismic interpretation in general. The HorizonCube is a global interpretation tool that enables any attribute of interest to be flattened to perform a more complete analysis of shallow hazards. The stratigraphy of an entire shallow section is followed in considerable detail. Not only does this lead to a more holistic understanding of shallow hazards, but it also provides greater flexibility in the choice of well location.

The process of generating an HorizonCube is semi-automated and it is expected that further developments in global interpretation methodologies will improve both the automation and robustness of the results. This will achieve our overarching objective that specialists in shallow hazard interpretation should be focusing their efforts on assessing identified geohazards rather than manually searching for them.

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References

De Groot, P., Huck, A., de Bruin, G., Hemstra, N. and Bedford, J., 2010, The horizon cube: A step change in seismic interpretation. *The Leading Edge*, **29**, 1048–1055.

Hoyes J., Cheret T. 2011. A review of “global” interpretation methods for automated 3D horizon picking. *The Leading Edge,* **30** (1), 38-47.

Selvage, J., Jones C. and Edgar J., [2012] Maximizing the value of 3D seismic data for shallow geohazard identification. *First Break*, **30** (8), 73-64.

Stark T., Zeng H., Jackson A. [2013] An introduction to this special section: Chronostratigraphy. *The Leading Edge*, **32** (2), 132-138.

Wheeler, H.E., 1958, Time stratigraphy. *AAPG Bulletin*, **42**, 1047–1063.