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Implications of HorizonCubes in Shallow Geohazards Interpretation

3D Seismic Data in Geohazard Analysis

Recent research and surveys have recognized the applicability of using conventional 3D seismic for pre-drilling shallow hazard analysis. Recently, in Selvage *et al* (2012), for example, BG Group 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 and the improved reliability of post- and pre-stack amplitudes, 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 time lines, thereby facilitating the recognition of depositional features and potential shallow hazards.

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 time line. 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).

By greatly increasing the number of mapped horizons through semi-automated techniques and through the creation of fully interpreted seismic volumes, interpreters can maximize the potential of high resolution seismic in reservoir characterization.

Generating a HorizonCube and Its Applications in Geohazard Analysis

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 captured by the horizon tracker.

HorizonCubes have key applications for shallow hazard analysis prior to the drilling of new wells. In a typical shallow hazard application *(see Figure 1)*, 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) centered on the intended drilling site. The focus is on the shallow section up to 2,000 meters below the water bottom. A dense set of horizons are mapped through a data-driven approach by tracking dip and azimuth information

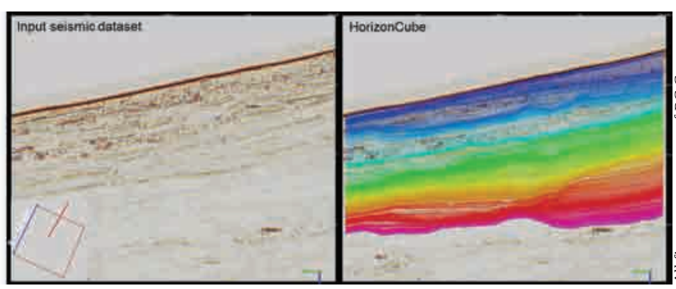

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Figure 1: Left – the input seismic data set for generating a HorizonCube. The volume is extracted from the larger 3D exploration seismic volume centerd on the proposed drilling location. Right – the HorizonCube creates a pseudo-stratigraphic framework for flattening any attribute that may help assess the risk associated with identified shallow hazards.

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.

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 2* shows a HorizonCube example which adopts both approaches.

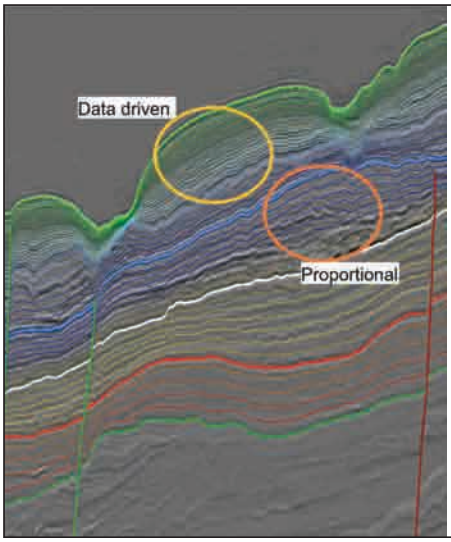

Figure 2: An example seismic section showing an overlay of HorizonCube horizons. Both data-driven and model-driven approaches were utilized to produce a continuous set of dense horizons.

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. 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 analyze 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 stratigraphy studies. As long as the events are locally following geologic time lines, 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 a 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 deepwater 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 characterized 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 this deepwater area seabed and immediately 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 3*) with bright amplitudes being associated with fluid fill or lithology.

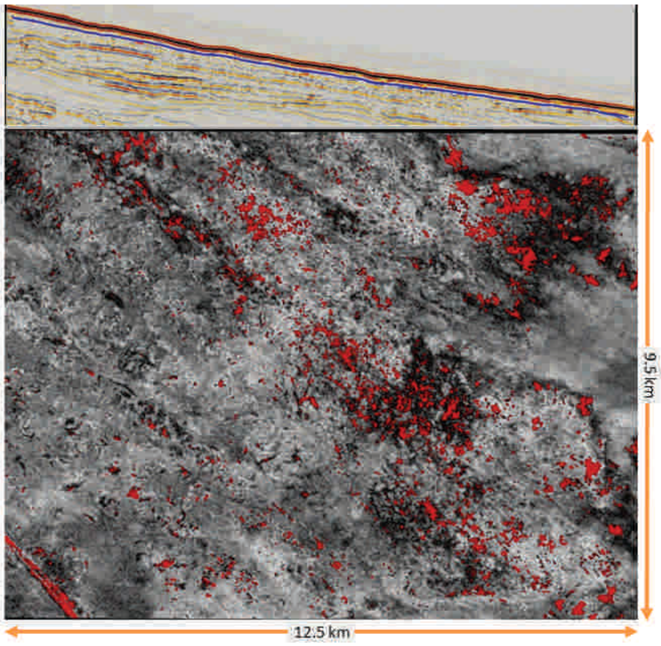

Figure 3: Chaotic seismic reflectors are seen just below the seabed in this deepwater location (top). The red amplitude overlay shows extreme RMS amplitudes. In the context of shallow geohazards these may be shallow gas accummulations.

In *Figure 3*, 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 onto the pseudo-stratigraphic slice shows that features trend perpendicular to TWT contours. The TWT times can be used to search for whether the bright amplitudes are structurally 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 risk such features further. Similar analysis is shown for anomalously bright amplitudes in *Figure 4*.

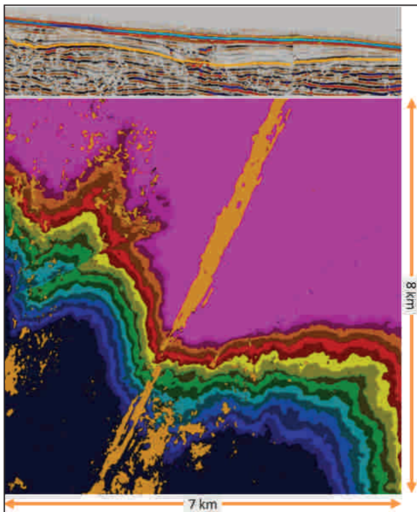

Figure 4: A high amplitude feature is observed in a synclinal feature on the pseudo-stratigraphic slice extracted from the HorizonCube (top). The TWT values are extracted onto the slice with bright amplitudes rendered in orange (bottom). The bright linear feature is interpreted to be a shallow channel. The color 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.

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. The result was 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 article 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 a 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 focussing their efforts on assessing identified geohazards rather than manually searching for them.

Acknowledgements

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