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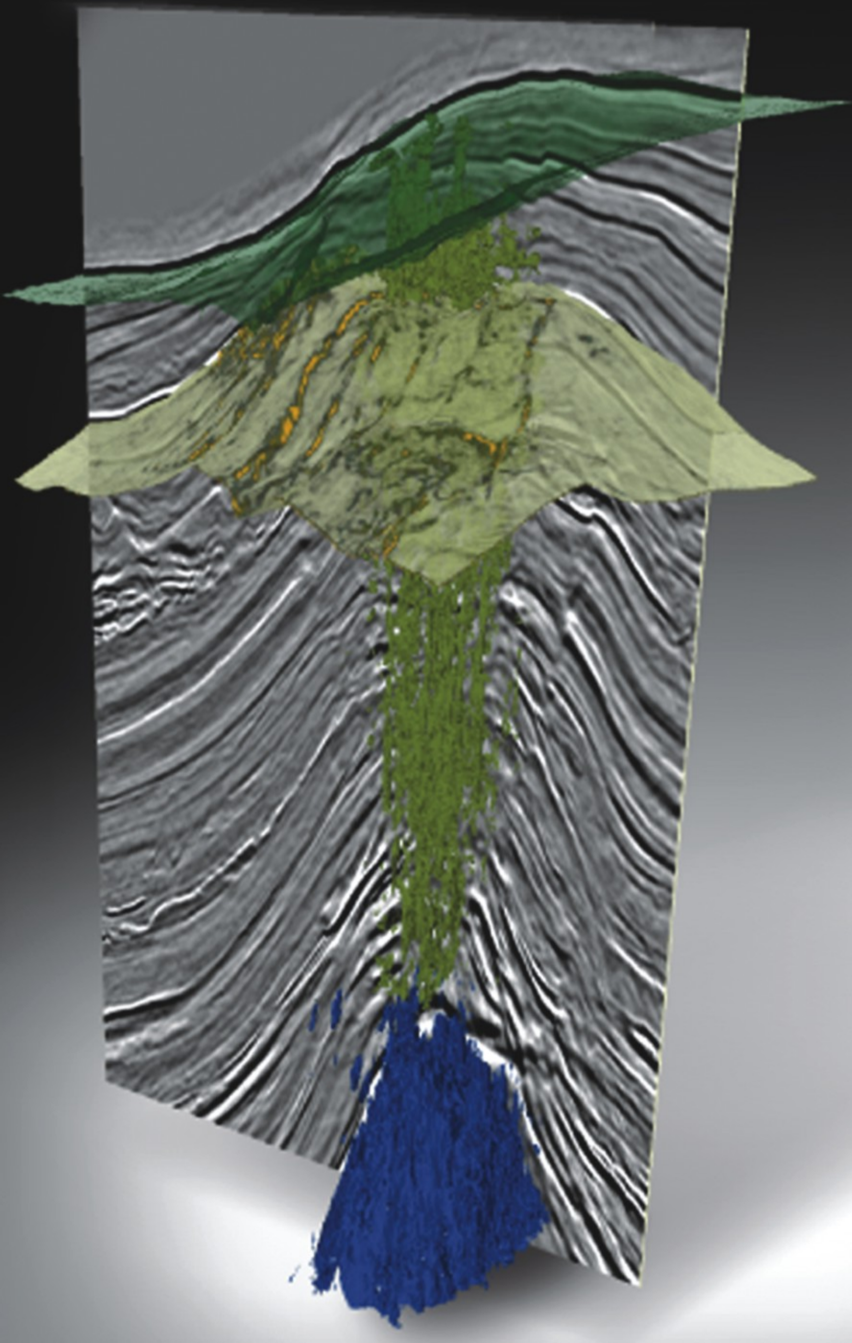
Advanced seismic interpretation techniques in OpendTect



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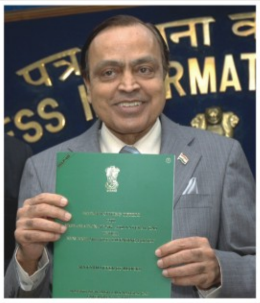

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Advanced seismic interpretation techniques in OpendTect

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Summary

OpendTect supports a range of advanced seismic interpretation techniques to improve the interpretability of the data and/or to gain new geologic insights. Which technique to apply depends on many factors including but not limited to: type and quality of available data, geologic setting and study objectives, available budget and time constraints. In this article we present a number of techniques that are routinely applied by dGB in proprietary service projects. We explain the methods and show examples of attributes, filters, object detection, pattern recognition, and sequence stratigraphic studies.

Introduction

In the value chain of seismic data from acquisition to processing and interpretation the objective of each process is to increase the value of the data. We try to maximize the geologic information that can be extracted from the data in order to reach more informed economic decisions. In our service work at dGB we routinely apply a range of different techniques. We make a distinction between qualitative interpretation methods, here loosely defined as methods without well data and quantitative methods, which are defined as methods including well information.

In quantitative methods the aim is to predict a quantifiable variable from the seismic measurements. An example is the prediction of rock properties like porosity or water saturation. Given our definition of using well information this group of methods includes seismic inversion and forward modeling techniques. Because we have to integrate seismic with well data the geoscientist requires a good understanding of at least four disciplines: geology, geophysics, petro-physics and rock-physics. In general quantitative studies are more time-consuming and are executed by specialists. Quantitative techniques are beyond the scope of the current

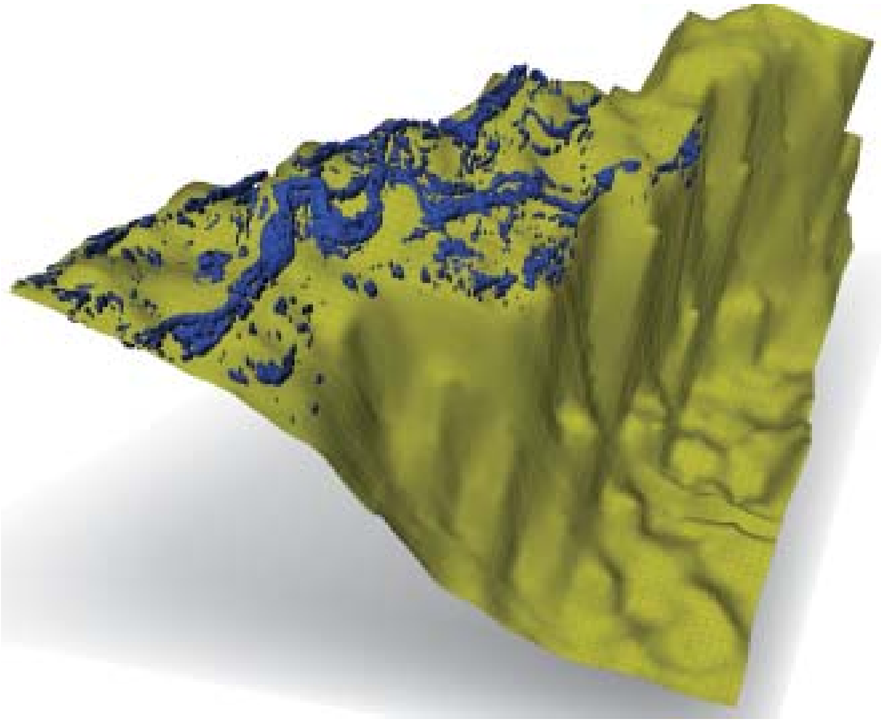

Fig. 1. Channel visualized with the Energy attribute (amplitude squared summed over a time-window).

paper. Here, we will restrict ourselves to examples of qualitative interpretation techniques.

In qualitative methods the general objective is to enhance the visibility of seismic features of interest to generate new ideas and/or to facilitate the interpretation. Amongst others this group includes seismic filters, attributes, pattern recognition techniques and data transformations. The examples presented in this paper are generated with OpendTect + plugins. As in our definition of qualitative methods no well information is used, these methods are in general fast and relatively easy to apply.

OpendTect software

OpendTect is a seismic interpretation software system in an open source environment. The base system enables processing, visualization and interpretation of multi-volume seismic data using attributes and modern visualization techniques such as stereo viewing and volume rendering. Because the base system is open source and is developed with plugin architecture the system serves two functions: seismic interpretation platform and R&D environment. Plugins build in the R&D environment are added to the base system at run-time. Commercial plugins are available to support several unique work flows. In this paper we show examples involving the base system only and examples involving three commercial plugins: Dip-steering, Neural Networks and Sequence Stratigraphic Interpretation System.

Attribute Analysis (OpendTect Base)

Multi-volume, interactive attribute analysis is what distinguishes OpendTect base system from other seismic interpretation systems (de Groot, 2006a). The user zooms in on the area of interest and on-the-fly calculates attributes from the data for immediate visual inspection. Attribute parameters are inspected in a movie-style fashion and it is possible to calculate attributes from attributes and to create attributes by math and logic. This style of working enables the user to visualize the data in an infinite number of ways in a fraction of the time needed by other attribute systems. In this way geologic features are picked up that may otherwise remain obscured in the data. For example, in Figure 1 a channel is highlighted by calculating the Energy just above a mapped horizon.

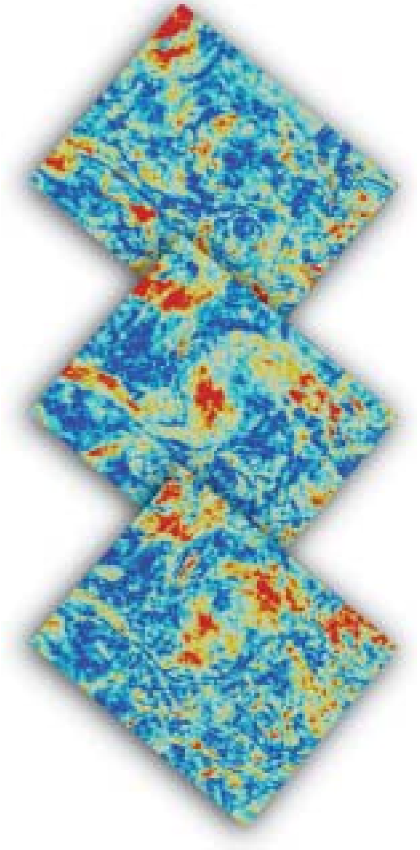

Fig. 2. Spectral Decomposition of a channel complex. Top 75Hz, Middle 45 Hz, Bottom 15 Hz.

In the example shown in Figure 2 we use Spectral Decomposition to analyze a channel complex at sub-seismic resolution. A continuous wavelet transformation (OpendTect also supports FFT transforms) was used to decompose the target interval around a mapped horizon. We show the results at three wavelet scales (roughly equivalent to 3 frequencies). If a layer thickness falls in the tuning range the amplitude increases at the corresponding wavelet scale. The observed amplitude variations in the slices can thus be interpreted as thickness variations of the internal features that compose the channel complex.

Seismic filters (dip-steering plugin)

The dip-steering plugin enables the creation and application of "steering cubes". A steering cube contains at every sample position the local dip and azimuth of the seismic events.

The cube is used for:

a) Structurally oriented filtering.
b) Improving multi-trace attributes by extracting attribute inputs along reflectors
c) Calculating Curvature attributes.

Figure 3 shows the principle of "dip-steering". Basically we create a virtual horizon at each position by following the dip-azimuth information from the steering cube from trace-to-trace. The dip-steered data

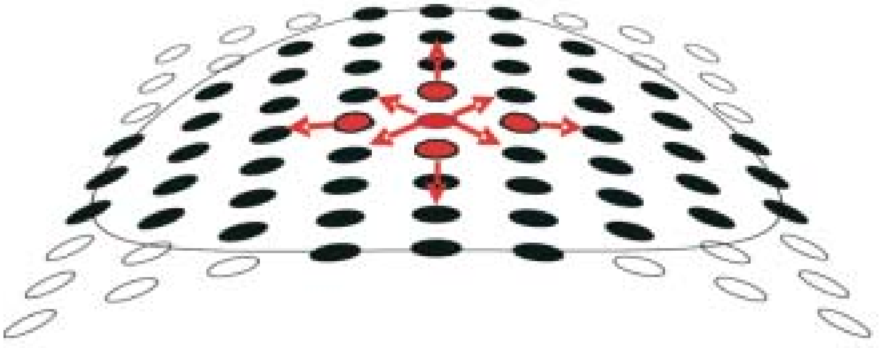

Fig. 3. Dip-steering: from the central position we follow the same seismic event by tracking the dip-azimuth information from the steering cube.

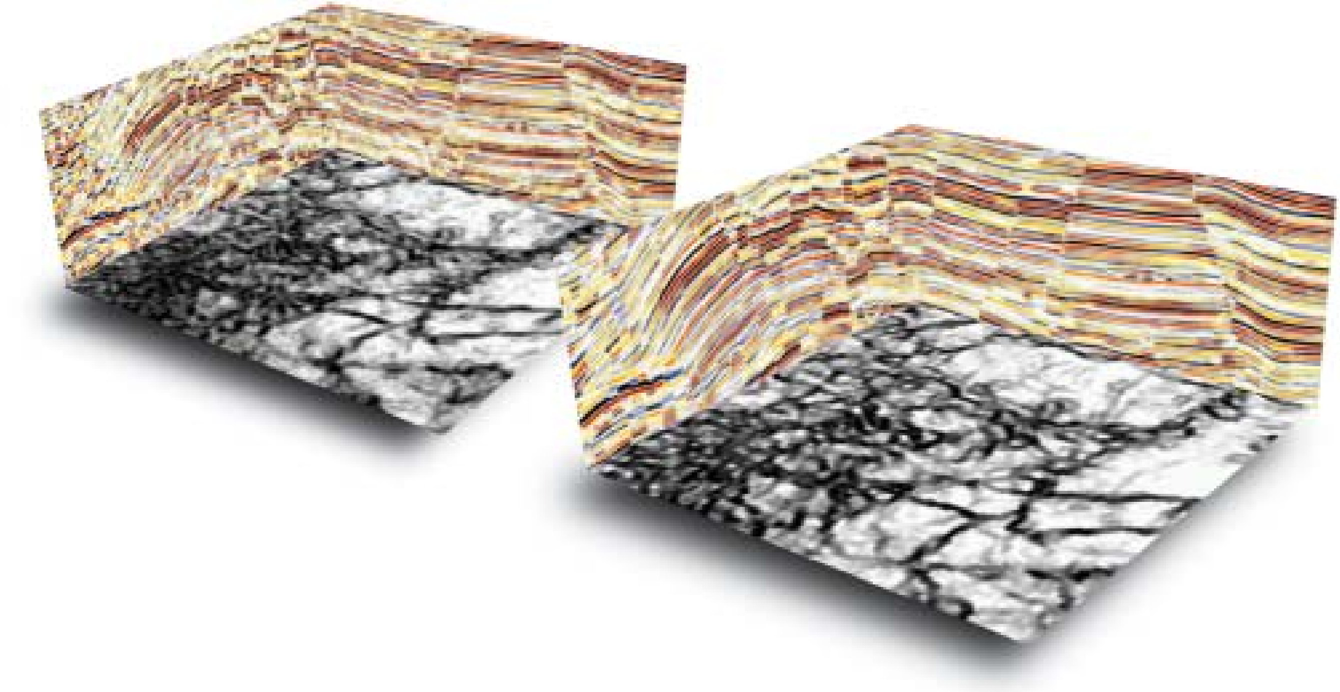

Fig. 4. Left: original seismic with similarity time-slice. Right: dip-steered median / diffusion filtered data with similarity time-slice calculated from the filtered data.

is then used as input to a filter, or to calculate the attribute response.

In Figure 4 we show an example of dip-steered filtering for improving fault detection. We use a combination of two dip-steered filters: median and diffusion. A median filter is a powerful tool for removing random noise. In principle a median filter is edge-preserving, which means that a break in the data is preserved; no filter-tails are generated and the faults remain sharp. A diffusion filter is an even better filter for sharpening faults. The filter evaluates the quality of the seismic response, e.g. by looking at the similarity at every location in a dip-steered radius. It then replaces the seismic amplitude at the evaluation position with the amplitude where the quality is considered best (highest similarity). In the vicinity of a fault the result is that good quality seismic is moved from the sides towards the fault plane. A drawback of the diffusion filter is that it does not do as well in areas where the seismic quality is already good. We therefore combine the strengths of both filters: if the quality is good we apply the dip-steered median filter and if the quality is poor (near faults) we use the dip-steered diffusion filter (Figure 4, right). If we now calculate (dip-steered) similarity on the original seismic data and on the filtered data we clearly see that the faults are considerably sharper, hence easier to interpret (Figure 4 time-slices).

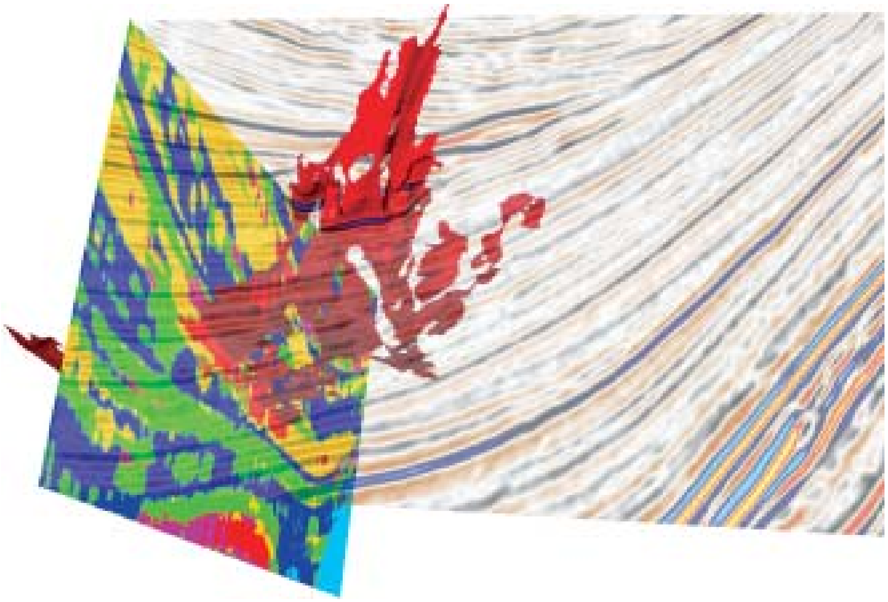

Fig. 5. Example of seismic facies clustering by an unsupervised neural network (colored section). One of the clusters is volume rendered (red object) to study its spatial distribution and to see the intersection with the seismic section in the front.

Pattern recognition (neural networks plugin)

Nowadays seismic interpreters work with multiple seismic volumes simultaneously. Moreover, an infinite number of attributes can be calculated from the data and several routinely are. Each new volume presents a different view of the data. The interpreter must decide: which view do I believe and is this the optimal view for this feature? At dGB we solve these problems by using neural networks to combine multiple attributes (and/or volumes) into "meta-attributes". In the neural networks plugin two types of neural networks are supported: supervised and unsupervised. The main application of unsupervised networks is clustering of attributes and/or waveforms for seismic facies analysis. An example of 3D clustering is shown in Figure 5. The supervised approach is used for more advanced seismic facies analysis and to create object "probability" cubes such as TheChimneyCube® and TheFaultCube® (de Groot, 2006a). For optimal results neural networks are usually fed with dip-steered attributes.

In Figure 6 two neural networks are used to visualize different elements of a petroleum system. Salt dome and seismic chimneys are object "probability" volumes generated by a supervised neural network. The interpreter manually picks examples representing "object" and "non-object". At the picked locations a range of attributes is extracted to train a fully-connected Multi-Layer-Perceptron type of neural network. The trained network is applied to the entire volume. At each location the network returns the "probability" of belonging to the "object" class. Also visualized in Figure 5 are faults (dip-steered similarity) at a mapped horizon above a seismic anomaly (not visible in this image). The alignment of faults and chimneys reveals that the faults above the target are leaking. dGB classifies this particular chimney configuration as a "fault leak trap". Previous studies show that 3 out of 4 fault leak traps are dry and the study thus downgraded the prospect.

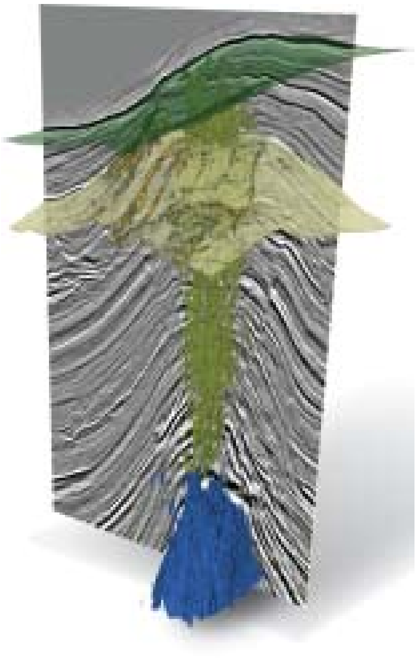

Fig. 6. Neural network enhanced seismic features: Salt dome (blue) and seismic chimneys (green) are detected by supervised neural networks; Alignment of chimneys and faults (dip-steered similarity) at a mapped horizon just above the drilling target show us that faults directly above the structure are leaking hence there is a high risk of drilling a breached trap (Heggland, 2002).

A third neural network application supported by the software that is worth mentioning is the use of supervised networks for rock property predictions (de Groot, 2006a). For this application the learning set is constructed from examples extracted along available well tracks. The input typically comes from impedance volumes (acoustic and/or elastic) while the target values come from well logs (porosity, Vshale, Sw etc.).

Sequence stratigraphic interpretation (SSIS plugin)

The Sequence Stratigraphic Interpretation System was the subject of an article in the DEW issue of Sep. 2006 (de Groot, 2006b). The plugin allows seismic data to be studied in the chronostratigraphic domain. All chronostratigraphic events (horizons) are auto detected by the system and placed into stratigraphic order. This enables:

1. Visualization of the depositional history on inlines and crosslines
2. Automated construction of chronostratigraphic diagrams and flattened volumes (Wheeler transform).
3. Full systems tracts interpretations and annotations.

Figure 7 gives an example of a sequence stratigraphic analysis on a 2D section.

In structural settings stratigraphic features are better visible along horizons than on time-slices. This is the main reason why

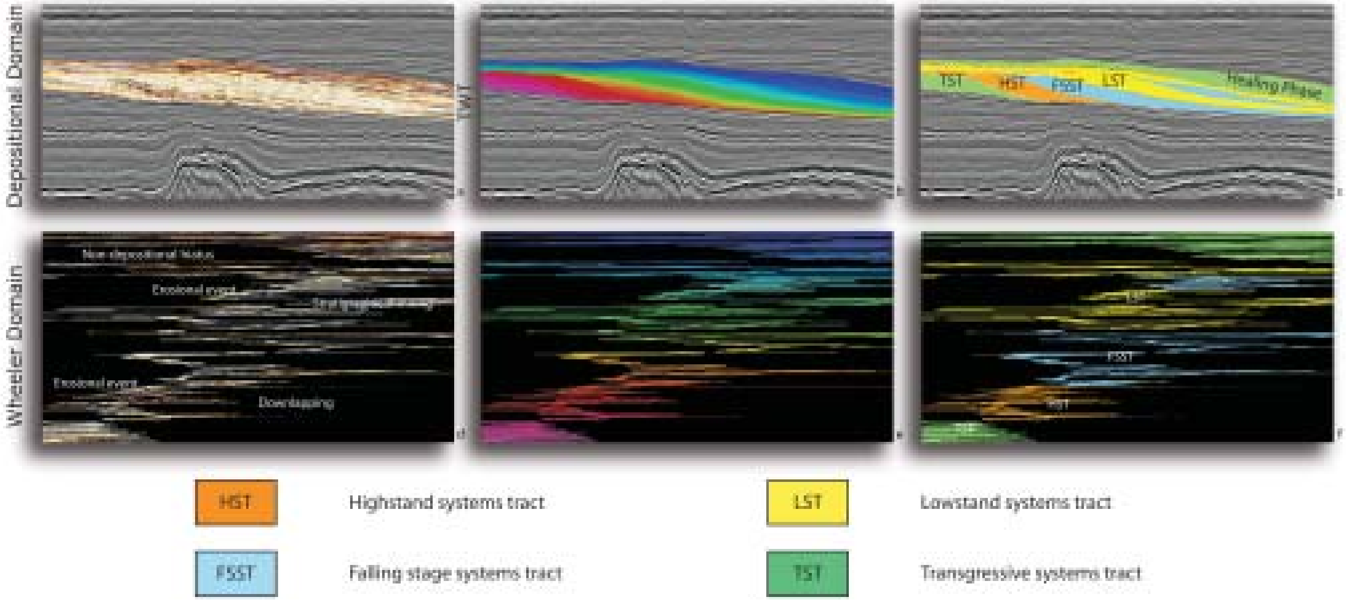

Fig 7. SSIS analysis. Top: data in the normal (structural) domain. Bottom: data in the Wheeler transformed (stratigraphic) domain. Left: seismic data. Middle: Chrono-stratigraphy (auto-tracked time lines). Right: systems tracts interpretation.

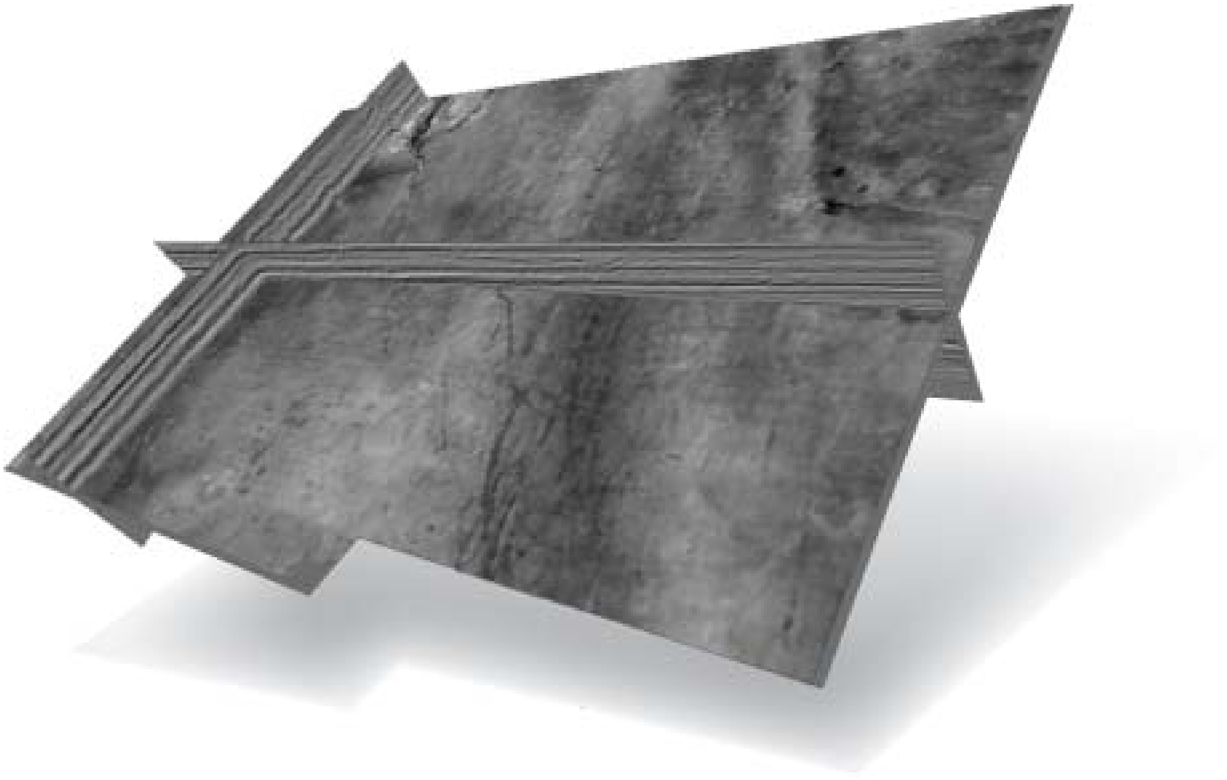

Fig. 8. A 3D Wheeler transformed volume. Time-slicing through such flattened volume reveals subtle stratigraphic features.

flattening of seismic data (or attributes volumes) is such a powerful visualization tool. The problem with flattening is that in settings with non-parallel layering the flattening is only correct at the horizon used to flatten the data. The further we move away from the horizon the more we deviate from the stratigraphic slicing we are aiming for. This is where the 3D Wheeler transform comes in as the ultimate flattening tool. A 3D Wheeler transformed data volume is a flattened volume in which time-gaps due to erosion or non-deposition are preserved. Because the Wheeler transform is based on tracking numerous horizons there is no distortion due to the distance from a mapped horizon as in conventional flattening. The key question is whether we are capable of tracking all chrono-stratigraphic horizons correctly in 3D. In a data-driven mode this is not always possible due to noise and faults that cannot be crossed without creating artifacts. In SSIS we therefore support a second mode for creating chrono-stratigraphic horizons. The model-driven mode generates chrono-stratigraphic horizons in between two mapped horizons by interpolation (a.k.a. stratal slicing), or creating horizons parallel to the upper horizon (onlap situations) or parallel to the lower horizon (truncations). To transform an entire volume the user maps the major bounding surfaces (unconformities) and then chooses per interval between data-driven mode and one of the model-driven modes to generate the chrono-stratigraphic horizons needed for the flattening process.

Figure 8 shows an example of a 3D Wheeler transformation of an interval that was flattened using 3 mapped horizons. The top interval was flattened by interpolation while the parallel to upper mode was used for the lower interval.

Conclusions

We have shown several examples of advanced seismic interpretation techniques supported in OpendTect + plugins. We focused on qualitative techniques (no well data) that can be executed quickly by non-specialists. In general, application of these techniques increases our geologic insight and facilitates the interpretability of the data.

Several examples of advanced seismic interpretation techniques supported in OpendTect + plugins are projected with focus on qualitative techniques (no well data) that can be executed quickly by non-specialists. In general, application of these techniques increases geologic insight and facilitates the interpretability of the data.

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ABOUT THE AUTHORS

Paul de Groot is managing director of dGB. He worked ten years for Shell where he served in various technical and management positions. Paul subsequently worked four years as a senior research geophysicist for TNO Institute of Applied Geosciences before co-founding dGB in 1995. He has authored many papers covering a wide range of geophysical topics and co-authored a patent on seismic object detection. Paul holds MSc and PhD degrees in geophysics from Delft University of Technology.

Fred Aminzadeh is president and CEO of dGB-USA and Global Business Development and Technology Alliance Director for dGB Group. He worked 17 years for Unocal in technical and management positions. Fred has authored many books, patents and articles on different aspects of geophysical technology, including modelling, seismic attributes, seismic processing, AVO and reservoir characterization. Fred earned his PhD from the University of Southern California. He is the current President of the Society of Exploration Geophysicists (SEG).

Nanne Hemstra is CEO of dGB India and a senior geo-scientific software engineer. He can be considered as one of the founders of OpendTect, and he has been involved in almost all OpendTect developments since he started working for dGB in 2001. He is responsible for many innovations and he is currently developing sequence stratigraphic functionalities for OpendTect. Nanne studied geophysics at Utrecht University where he specialized in exploration geophysics.

Geert de Bruin is a Geoscientist, working for dGB since 2004. He is the project leader of the second phase of the SSIS (Sequence Stratigraphic Interpretation System) development project. He is conducting sequence stratigraphic studies and is the (co-) author of numerous sequence stratigraphic articles. Furthermore, he is involved in seismic object detection and interpretation studies. Geert holds a MSc in sedimentary Geology from the Free University of Amsterdam, where he specialized in carbonate geology.