Maximizing the value of seismic data through increased horizon mapping: applications in the Middle East and Canada

Friso Brouwer,[1] Paul de Groot[1*] and Michael Kumpus[2] show how a dense set of horizons enables seismic interpreters to extract more information from seismic data, using example from the Middle East and the Canadian oil sands.

Having access to a dense set of seismic horizons opens new seismic interpretation possibilities. In this article, we will first discuss how to create a HorizonCube - a volume containing a dense set of 3D correlated stratigraphic surfaces. Then, we will discuss two examples of HorizonCube applications. The first example is from the Middle East where a significant improvement is achieved in modelling the architecture of a producing Rudist Reef complex belonging to the Middle Cretaceous Mishrif Formation. The second example is from Canada, where the dense sets of horizons are used to help characterize heterogeneous oil sands of the Lower Cretaceous McMurray Formation.

In typical seismic interpretation projects we end up with a couple of mapped horizons and an over-simplified geologic model. In the process we reduce terrabytes of useful seismic information to a few megabytes of interpreted data.

With automated horizon tracking tools, it is possible to extract much more geology from the seismic data (de Groot et al., 2010). With a dense set of auto-tracked horizons we can see more geology by slicing through the data in a geologically sound way. We can use these horizons to guide well correlations; to flatten data (Wheeler transformations); obtain a better insight into the depositional environment; interpret systems tracts; and increase our chance of finding stratigraphic traps.

However, the biggest benefit of having a dense set of horizons is in geologic model building and related low frequency model building to improve seismic inversions. By interpolating well data along the dense set of horizons, we can now generate detailed geologic models that are consistent with seismic measurements. Better models will lead to improved reservoir management and better economic decisions.

The first tools to auto-track hundreds of horizons are coming to the market. The examples shown in this article are generated with a dip-steered auto-tracker. The dense set of auto-tracked correlated 3D stratigraphic surfaces, created by the auto-tracker, is called a HorizonCube. Each horizon in the HorizonCube represents a (relative) geologic time line.

Creating a HorizonCube

The software to create a HorizonCube requires three basic inputs: 1) mapped horizons, 2) mapped fault planes, and 3) the dip/azimuth field. The input horizons form a framework that is to be filled in with more horizons to create a dense set of horizons. The infilling is done per sequence bounded by mapped top and bottom horizons. HorizonCube horizons are created either in a model-driven way (stratal/proportional slicing, parallel to upper/lower), or in a data-driven way via a dip-steered auto-tracker.

Framework horizons are either mapped with a conventional amplitude/similarity auto-tracker, or with the dip-steered auto-tracker. The advantages of the dip-steered tracker above a conventional tracker are the speed and the tracker's greater awareness of faults.

By automatically stopping against mapped fault planes, horizons with watertight intersections at the faults are generated. Watertight intersections are a prerequisite for creating sharp fault throws in the HorizonCube. For conventionally mapped horizons, a utility can optionally be applied to the horizons to make them watertight. The utility blanks a user-specified zone around the fault plane and then uses the dip-steered tracker to re-track the blanked out zone into the fault plane.

The other key input is the dip/azimuth field. A (dip) Steering Cube is generated which calculates local dip azimuth values of coherent features within the seismic. Dips can be calculated in many ways. The software used here supports algorithms based on Fourier-Radon transforms and algorithms that compute dips from the gradient of the instantaneous phase.

The auto-tracker tracks the dip/azimuth field from the Steering Cube to generate horizons that are typically separated by one sample at the starting position. The first advantage of this workflow is that it enables the dip-azimuth field to be filtered. Noise can be removed from the dip-fields to enable the user to control the detail that needs to be captured by the horizon tracker. Typically a three-dimensional median filter is used to smooth the Steering Cube.

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Another advantage is that (smoothed) dip fields are more continuous than amplitude fields. Conventional auto-trackers that pick amplitudes and/or trace similarities stop when the constraints are no longer satisfied. This leads to a set of patchy horizons rather than continuous, chronologically consistent horizons as needed for Horizon Cube applications.

Example 1: Mapping of a producing Rudist complex

The field subject of this study is located offshore Abu Dhabi. The field is producing from a complex reefal and shoal limestone build-up, where only discrete zones yield high production rates. The producing reservoir is the Middle Cretaceous Mishrif Formation (Bellah et al., 2010). The reservoir is characterized as a typical thick bottom water drive reservoir. The relatively thin dry oil interval is sited above a huge transition zone. Six depositional cycles (R0 to R5) have been recognized relating to progradation, aggradation, and retrogradation of reef complex sediments deposited as a result of base level fluctuations.

In 2000, a sedimentological study was undertaken to understand the depositional context of the Mishrif formation and its sequence stratigraphic architecture. Core description data, wireline logs, thin sections, carbon isotopes data, and sequence stratigraphic principles were used to identify the six cycles, to correlate between wells, and to understand the controls on facies association distribution.

To arrive at more robust geological and simulation models, a seismic reservoir characterization study was performed in 2009. One of the main challenges in the seismic study was the poor quality of the 3D data. Automated tracking of chronostratigraphic unit boundaries is not possible on the 3D seismic volume using conventional tracking methods. Amplitude and phase responses were too indistinct for the tracker to trace for any distance in a consistent manner.

It proved feasible, however, to track the dip-field and thus to create a dense set of auto-tracked horizons (Fig. 1). These were used to produce a suite of seismic-based maps of depositional cycles and system tracts reflecting the reef build-up accretion.

The results provided a clear image of reservoir geometries and facies distribution within the reef core body and its associated progradation packages. The study had a significant impact on the accuracy of the geologic model of the field, on the basis of which economic field development decisions are made. Fig. 2 shows thickness maps of the depositional sequences of the field model before and after the seismic study. Fig. 3 shows cross-sections through the field before and after the seismic study.

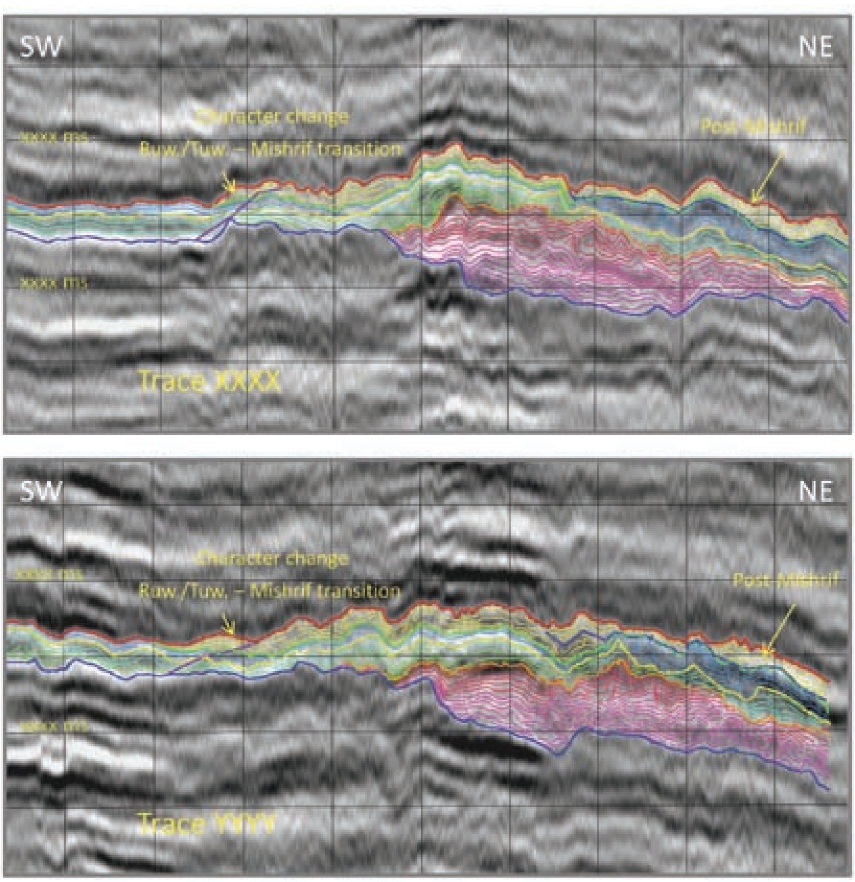

***Figure 1** Seismic section showing auto-tracked (chronostratigraphic) horizons from the HorizonCube. Illustration by kind permission of Sameer Bellah, Zakum Development Company (ZADCO).*

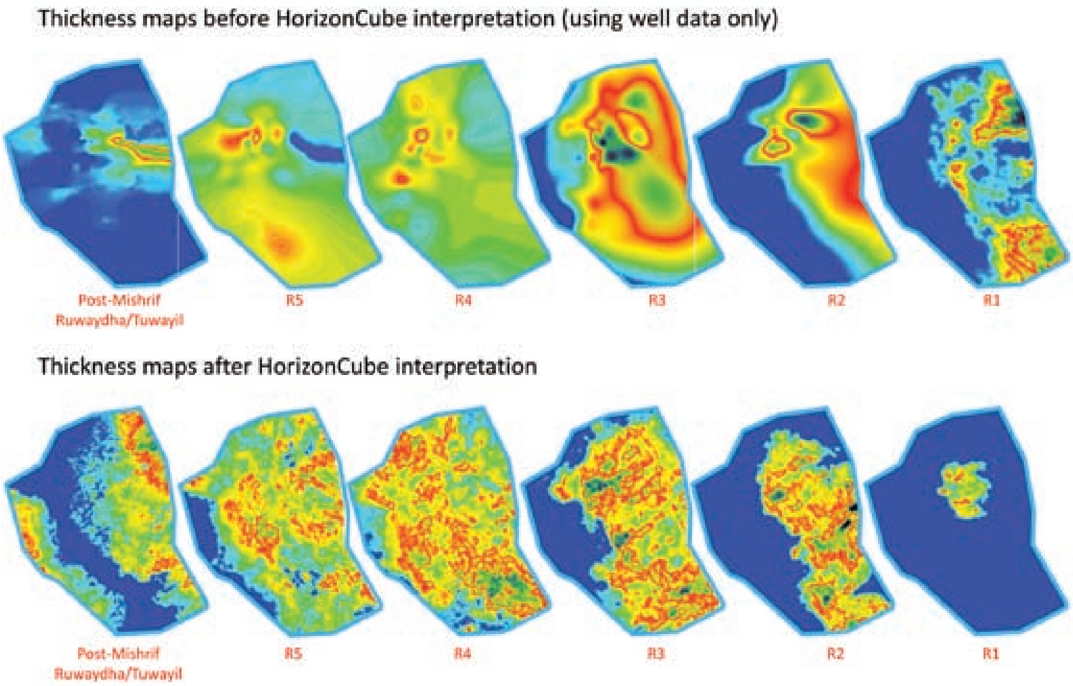

***Figure 2** Thickness maps of depositional sequences before and after application of the HorizonCube. Illustration by kind permission of Sameer Bellah, Zakum Development Company (ZADCO).*

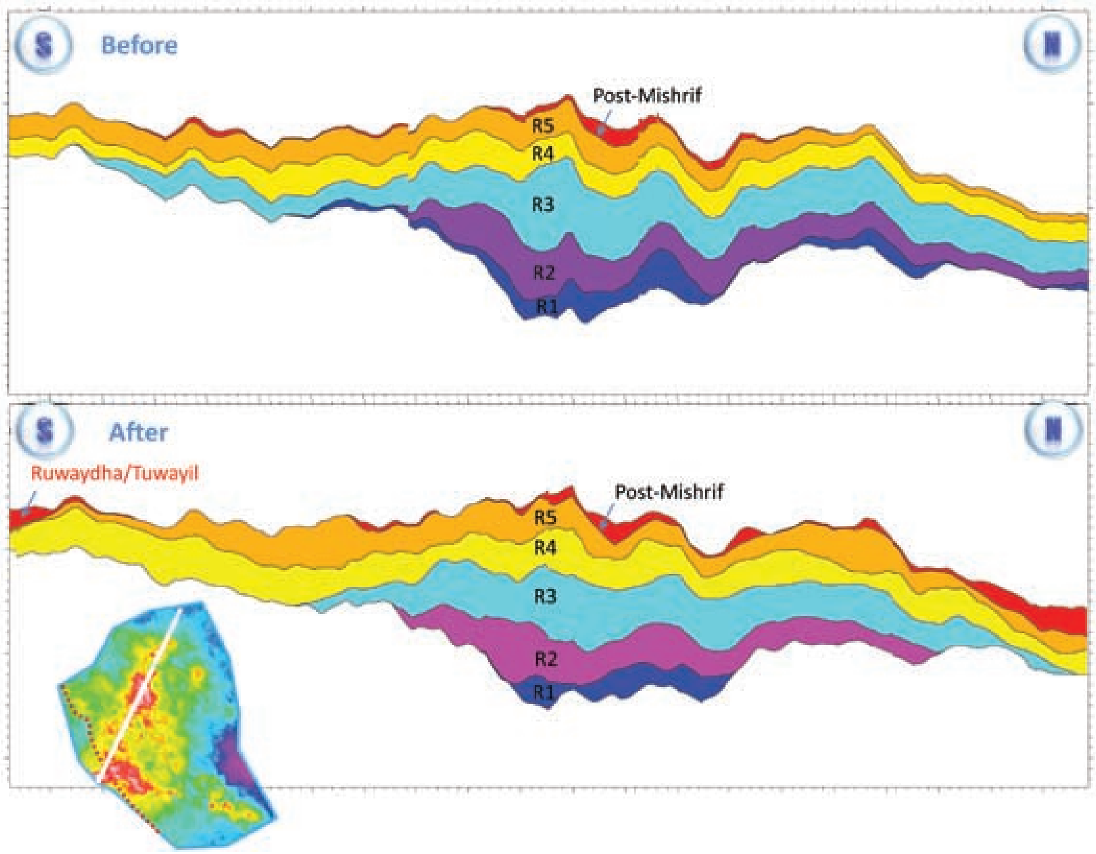

***Figure 3** Cross-sections through the field model before and after application of the HorizonCube. Illustration by kind permission of Sameer Bellah, Zakum Development Company (ZADCO).*

Example 2: Mapping heterogeneities of Canadian oil sands

The McMurray Formation represents a fluvial estuarine depositional system, hosting rich bitumen and water-sand reservoirs. The unconsolidated sands of the McMurray Formation in the study area are at depths of about 450 m, with a pay thickness of up to 40 m and porosity between 27% and 30% (Tonn, 2010). The sands are inter-bedded to varying degrees with muds. Depending on the depositional environment, the muds can be localized or extended over large regions.

Oil is produced by steam assisted gravity drainage (SAGD), which uses horizontal well pairs to extract the bitumen. The upper horizontal well is for steam injection and the lower well for oil drainage. SAGD can only be operated efficiently if the subsurface geoscientist team is able to image, model, and predict the subsurface with high accuracy. Knowledge of the depositional facies, geometry of the reservoir (including top and base of the SAGD pay interval and thickness), and distribution and lateral continuity of potential mud baffles and barriers are critical for a successful SAGD operation. The key for successful placement of the SAGD injector-producer pairs is understanding reservoir heterogeneity.

To reduce risk associated with the reservoir, we aim to extract information about the reservoir structure and facies from the seismic data. One of the geophysical challenges is to create a reliable chronostratigraphic framework within the reservoir. While the top and bottom reservoir reflectors are relatively continuous, high reflectivity interfaces that are easier to map, the channelized low contrast reservoir sands in the reservoir provide a challenge. This is exacerbated by the patchy character of the amplitudes due to the discrete nature of the sedimentary bodies and tuning effects and the varying bed thickness. This makes it very difficult to confidently interpret intra-reservoir horizons by the conventional method of manually tracking seismic amplitudes. With the HorizonCube, which auto-tracks the horizons from a pre-calculated continuous dip field, instead of discrete amplitude patches, it is possible to fill the reservoir interval with a dense grid of high confidence horizons.

The processing of the HorizonCube in this dataset consisted of two steps. Firstly, the removal of residual noise from the seismic data is required as coherent noise events can cause misaligned reflectors. The noise removal is illustrated in Fig. 4. The original seismic is shown in Fig. 4 (left side), demonstrating an undue rapid lateral variation in amplitude and TWT (two way time) of the reflectors. Applying a structurally oriented filter resolves this problem. The filtered data is shown in Fig. 4 (centre).

When not obscured, several sedimentary features can be straightforward to recognize, such as the incised channel (in the lower left of the image) with channel fill and possible levee structure to the right of the channel fill. To confirm that the filter does not remove any geological meaningful signal, the filter residual is displayed in Fig. 4 (right side). This primarily shows high dip coherent events that do not relate to any geology, confirming that only noise is removed. This shows that with the application of structurally oriented filters, the HorizonCube workflow can also be applied to seismic data with low signal to noise ratio.

A dip-volume and HorizonCube is processed from the filtered seismic data. Fig. 5 shows a set of horizons from the 3D 'cube' of horizons. The image illustrates the 3D nature of the HorizonCube that can be used in downstream applications such as stratigraphically consistent inversions, building stratigraphically consistent reservoir models, and the accurate geo-slicing of seismic attributes for seismic interpretation at any arbitrary geological level in the reservoir.

Next, we show an example of the 3D seismic sequence stratigraphic analysis enabled with the 3D HorizonCube. From an extensive well-based study of the McMurray Formation (Ranger and Pemberton, 1997) the generalized stratigraphy can be summarized as an overall aggrading system with multiple parasequences of rapidly prograding fluvial systems, followed by erosion and channel incisions during episodes of base level fall.

The incised channels are then filled with mainly estuary sands during the subsequent base level rise. Elements that fit the episodes in these parasequences can conveniently be extracted in 3D with the HorizonCube.

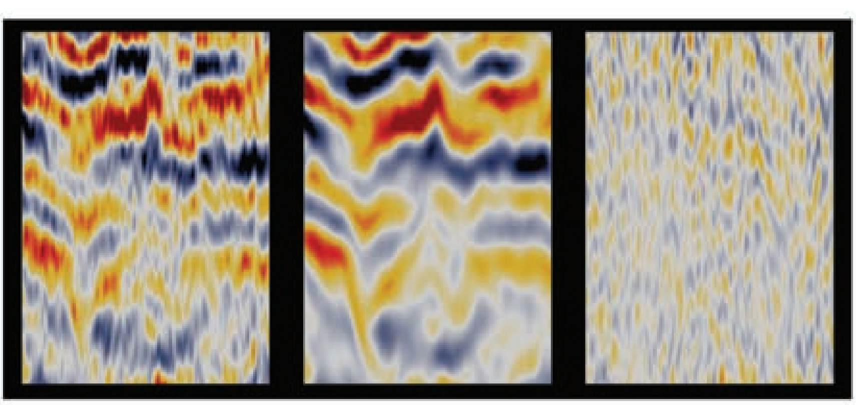

***Figure 4** Data quality improvements necessary before applying the HorizonCube to low signal to noise ratio seismic data. Figure on left shows the original seismic data, centre the filtered seismic data, and right the filter residual.*

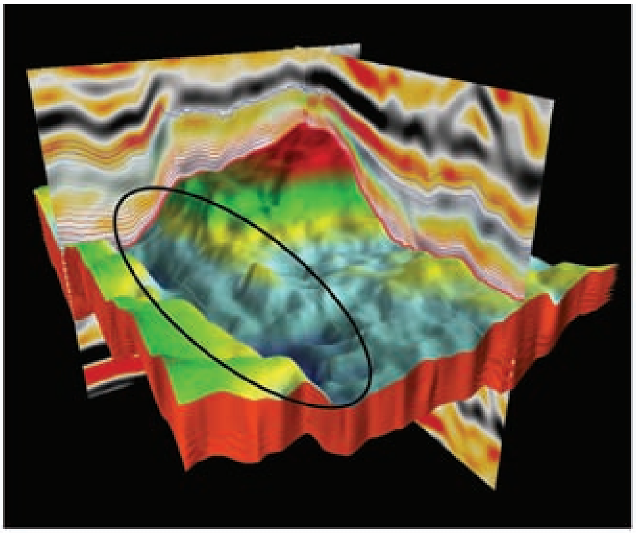

Figure 5 *3D impression of the HorizonCube showing a subset of the horizons. The black circle indicates the deep incised channel that is the focus of our interpretation.*

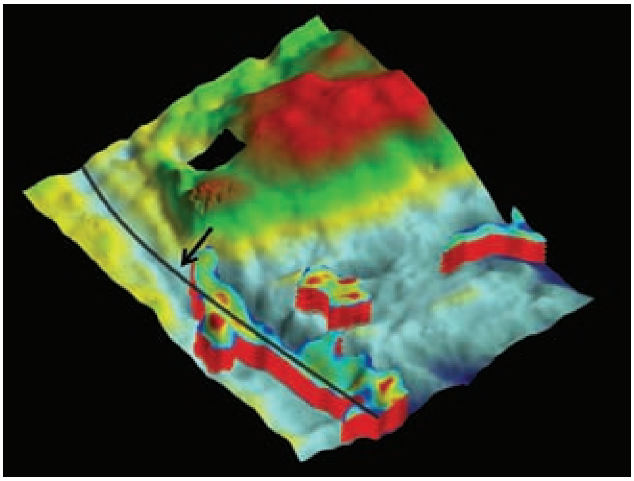

Figure 6 *Using a threshold for the isopach we cut out and identify the 3D extend of the secondary channel fill bodies. The transparent black line indicates the direction of the random line shown in Figure 7. The arrow shows the position of the knickpoint, which separates older and younger transgressive channel fills.*

To analyze the sedimentation between, we slide through the HorizonCube and select stratigraphically meaningful sets of horizons, i.e., all horizons in the set belong to the same depositional event. For each set, we created cut-outs of the HorizonCube based on the isopach value of the horizon set. Where sets of horizons have low isopach values, indicating slow sedimentation, we make the horizon set transparent. Where the horizon set has large isopach values, the horizons remain opaque. For each set of horizons this method shows the HorizonCube at the paleo-depocentres only. We have applied this analysis to the main sequences found in the deep incised channel indicated in Fig. 4. The workflow is illustrated in Fig. 6. In this figure a paleo-knickpoint is indicated that is identified on several horizons within the HorizonCube. This knickpoint is an indication of an erosional phase separating two transgressive events filling the channel. Then a set of horizons associated with the younger transgressive event filling the incised channel above and downstream of the knickpoint has been selected from the HorizonCube. Within this set we are showing the thickest of the sediments that are found in the deepest part of the incised channels, using the before mentioned method.

From this 3D analysis using the HorizonCube we can deduce the following likely order of events: 1) the incision of a deep channel in older fluvial sediments, 2) a first transgressive channel fill that is subsequently partly eroded again; and 3) a second transgressive channel fill. A section with an interpretation layer created from the HorizonCube is shown in Figure 7, illustrating the order of events.

The first advantage of the HorizonCube is to be able to isolate genetically different depositional elements at any point in the 3D volume as readily demonstrated by the examples presented. As depositional geometries (progradation, incision, etc) are visible in section view, it is easy to interpret the sedimentary element correctly. In addition, units can be correlated with well logs to create a seismic to well correlation for the rock properties.

From the HorizonCube, the 3D depo-centre for each depositional event can easily be determined using the variations in deposition rate implicitly registered in the HorizonCube. Using this information, together with the information about the sedimentary environment, one can estimate where the most favourable rock properties for reservoir, seal, or source rock may occur. In addition, stratigraphic traps or permeability baffles, associated with pinch-outs or lateral facies change, may be identified.

More applications lie downstream in the geophysical workflow where the HorizonCube and any information

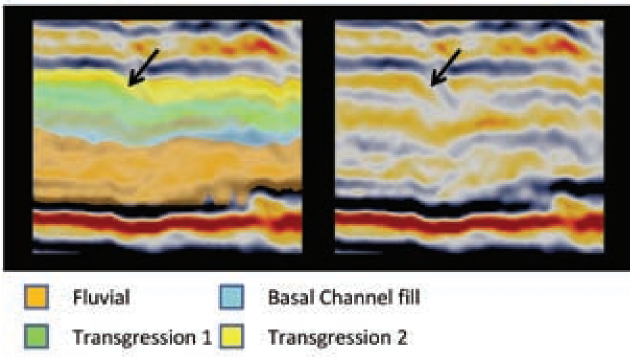

Figure 7 *Left image shows the interpretation overlain on the random line. Orange represents the older fluvial section, of which the upper part is eroded. The other colours represent infill of the erosional incisions. Blue represents basal channel fill, green the first channel fill, yellow the secondary channel fill. Note the knickpoint indicated by the arrow, showing the extent of the erosion in the first channel fill. Right image shows the same line without interpretation for comparison.*

derived from the HorizonCube interpretation is used to build background models for acoustic inversion, and geological models for rock property inversion, and reservoir modelling and simulation. Though not tested at the time of writing, these geophysical applications have great promise for the additional reduction of risk on the placement of SAGD injector-producer pairs.

Conclusions

The two examples discussed in this paper show that a dense set of horizons enables us to extract more geologic information from the seismic data. Both studies led to more accurate models and consequently more informed economic decisions. In the case study from the Middle East, the dip-steered auto-tracker enabled detailed mapping of the complex rudist reef reservoir units. In the Canadian example the dense set helped to characterize the heterogeneity of the oil sands - a key input parameter in (horizontal) well planning.

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