The horizon cube: A step change in seismic interpretation!

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Conventional interpretation workflows require a limited number of key horizons to be mapped. These are used to construct a generalized geologic model on the basis of which economic decisions are made. In the process, gigabytes of data are reduced to just a few kilobytes of interpreted data, during which potentially valuable information is often lost.

In this paper, we propose that a step-change improvement in interpretation can be achieved by greatly increasing the number of mapped horizons through semiautomated techniques (Figure 1), thus maximizing the potential of high-resolution seismic in reservoir characterization, reducing risk, and improving the chances of commercial success.

In the near future, high-density sets of mapped horizons ("horizon cubes") will be the norm in interpretation workflows delivering a wide range of benefits including (1) improved quantitative rock property estimation (2) improved definition of stratigraphic traps, and (3) more accurate, robust geological models.

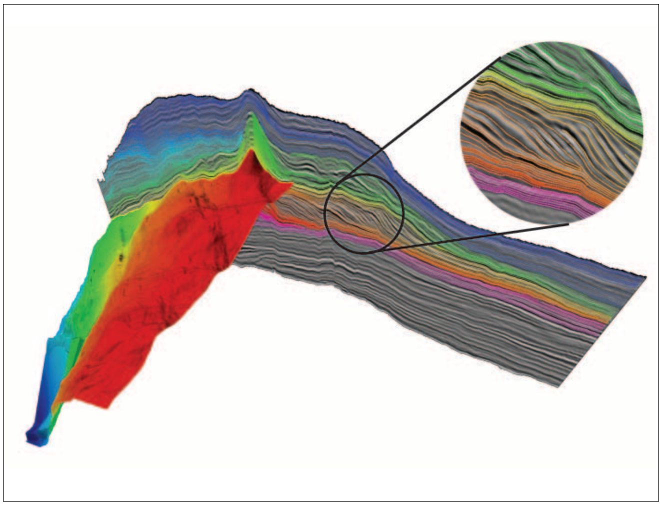

Figure 1. Example of a horizon cube, containing a dense set of autotracked horizons, which in this case are 4 ms apart on average.

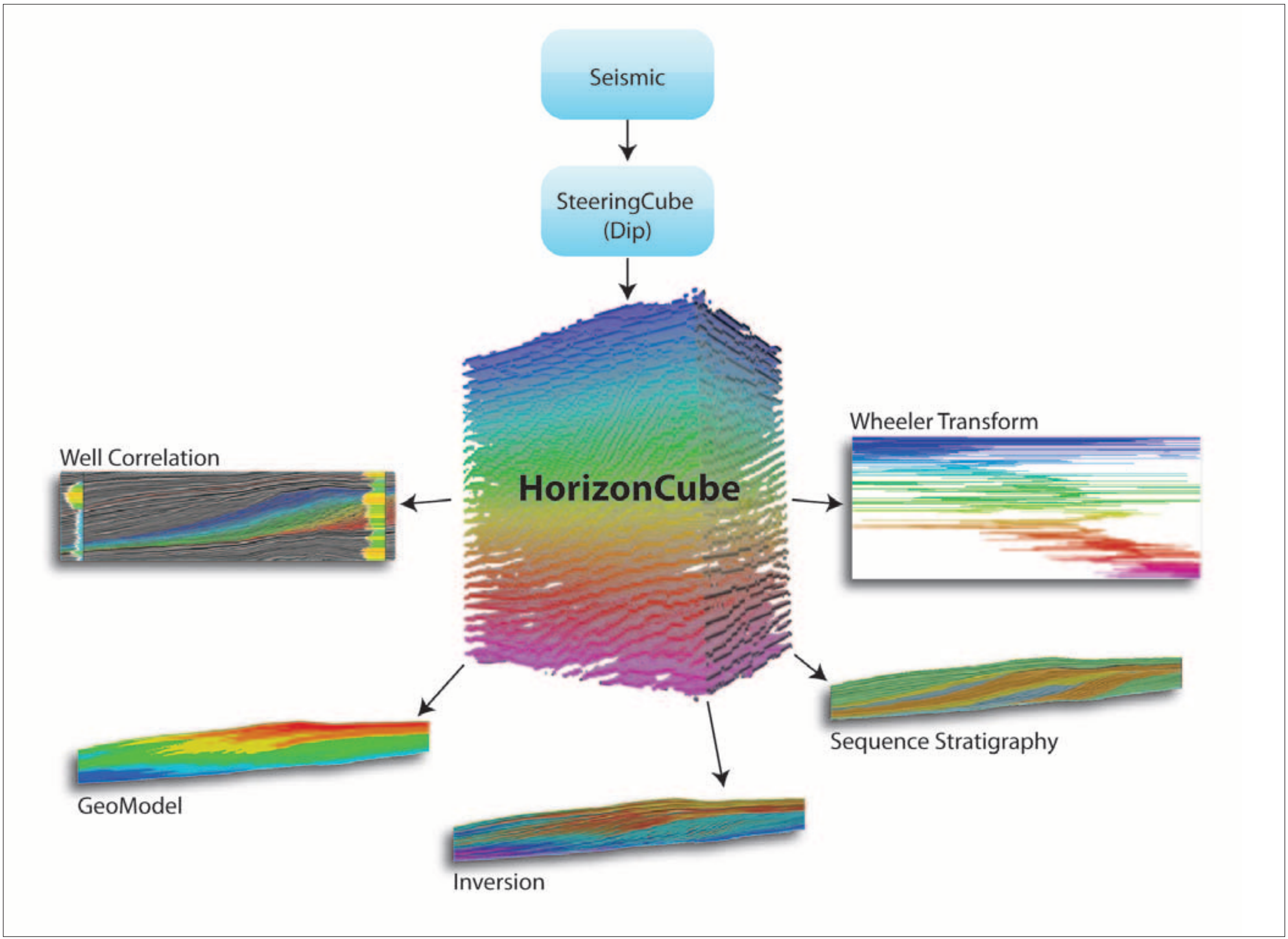

Figure 2. Diagram showing the creation of a horizon cube from a steering cube. The 3D chronostratigraphic horizons in a horizon cube are used, amongst others, for well correlations, in sequence stratigraphic interpretations and to build detailed geologic models.

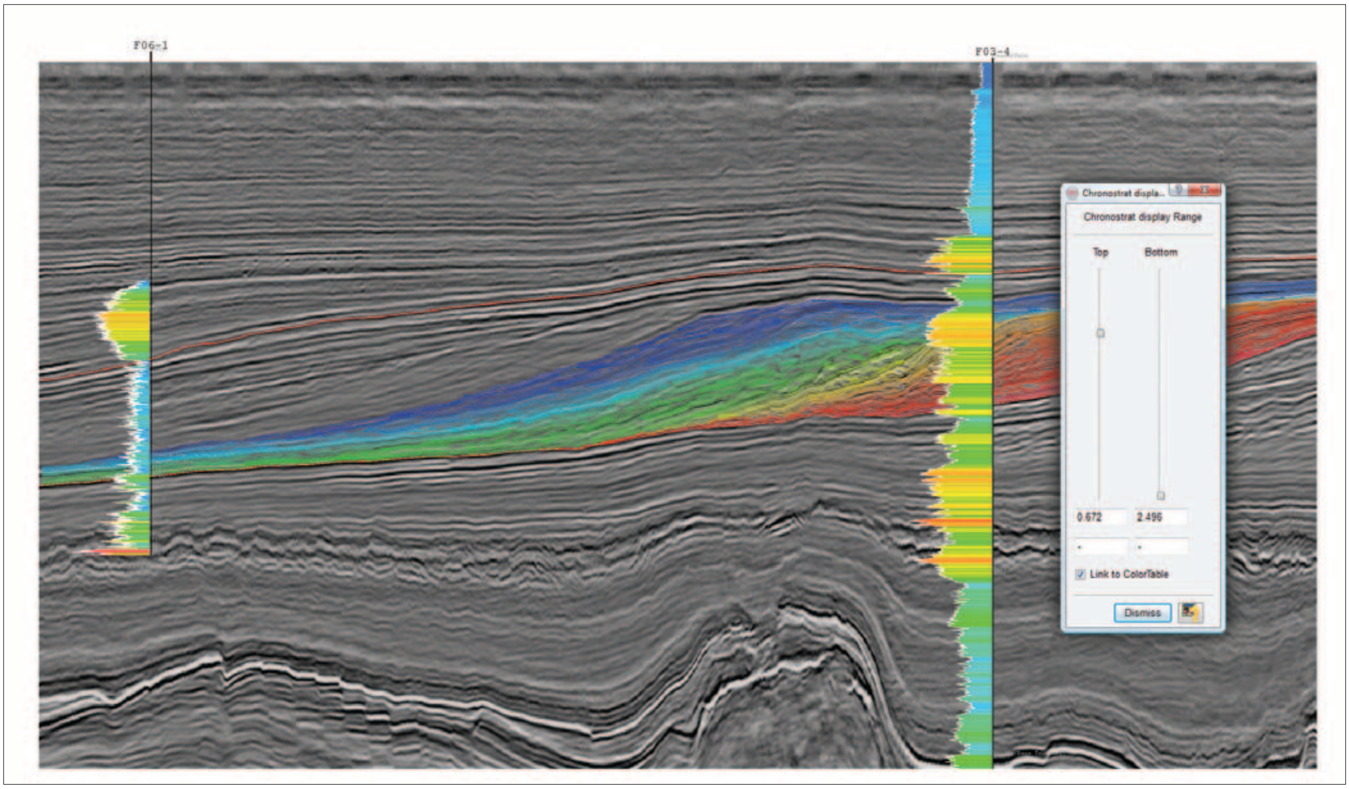

Figure 3. *A random line through two wells showing gamma-ray logs and densely tracked chronostratigraphic horizons. The color-coding indicates relative geologic age. The chronostrat slider on the right is used to interactively correlate chronostratigraphic sequences of interest.*

Horizon cube

The approach currently being adopted for generating the horizon cube involves two main steps. First, a (dip) "steering cube" is generated which calculates local dip azimuth values of coherent features within the seismic. The steering cube is subsequently used to generate the horizon cube. A special autotracker tracks the dip/azimuth field 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 smoothed. Smoothing reduces the impact of random noise and enables 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. Another advantage is that (smoothed) dip fields are more continuous than amplitude fields. Conventional autotrackers 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 a set of continuous, chronologically consistent horizons as needed for horizon cube applications. Figure 2 schematically depicts the workflow and some applications.

Data set

The 3D data set used in the following examples is from the F3 Block in the Dutch sector of the North Sea. Clastic sediments of Miocene through Pleistocene age comprise the upper 1200 ms of this data set. The large-scale sigmoidal bedding that can be clearly seen was generated by a major fluviodeltaic system that drained extensive parts of the Baltic Sea region. The deltaic package consists of sand and shale, with an overall high porosity (20–33%). Some carbonate-cemented streaks are present. A number of interesting features can be observed in this package. The most striking feature is the large-scale sigmoidal bedding, with textbook quality downlap, toplap, onlap, and truncation structures. Bright spots associated with biogenic gas pockets, not uncommon in this part of the North Sea, are also clearly visible. Several seismic facies can be distinguished: transparent, chaotic, linear, shingles. Well logs show the transparent facies to consist of a rather uniform lithology, which can be either sand or

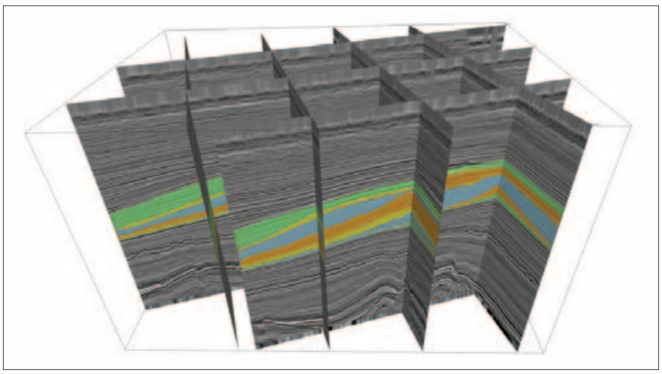

Figure 4. *Systems tracts interpretation. The user subdivides a sequence into packages with similar depositional characteristics revealed by the densely tracked horizons. Boundaries are classified with the aid of the chronostrat slider tool. Classification is based on external knowledge and/or the direction of horizon stacking patterns: marineward (progradational), landward (transgressive), upward (aggradation, etc.).*

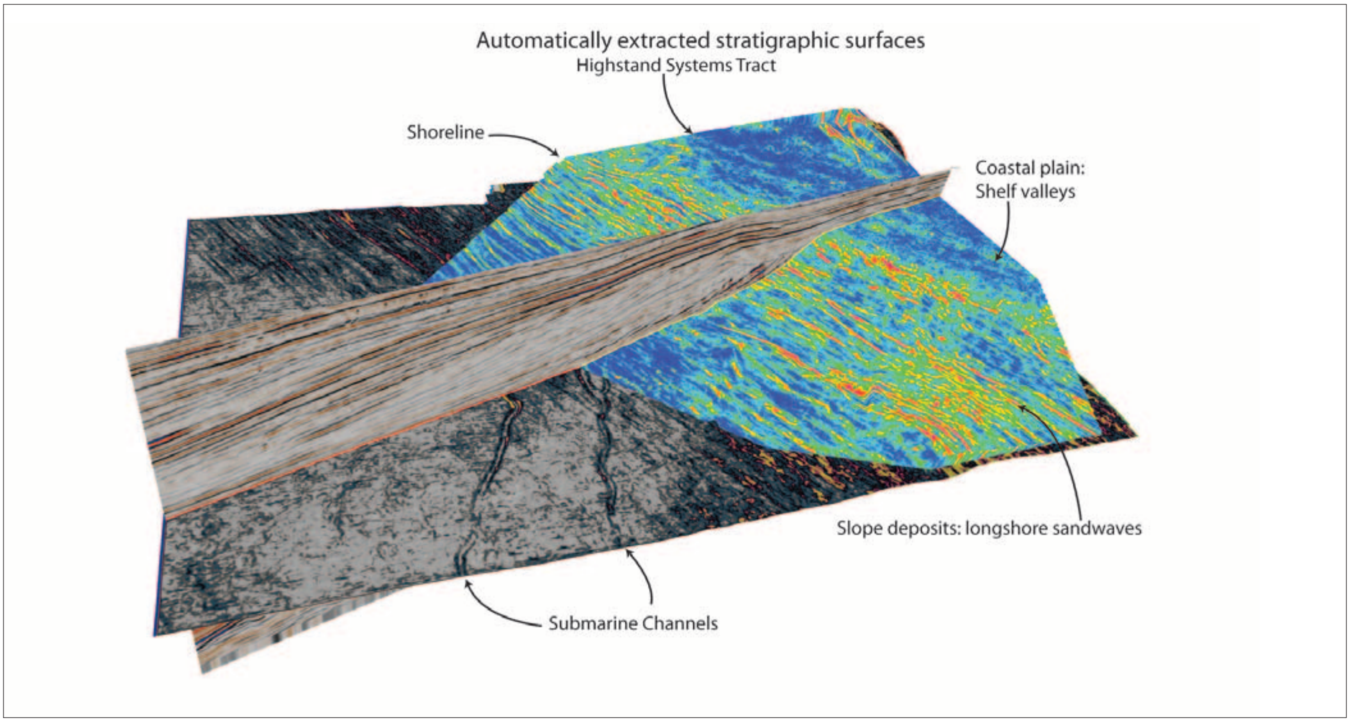

Figure 5. *Autotracked horizons from the horizon cube and stratigraphic surfaces based on systems tracts interpretation slice through the seismic volume in geologically meaningful ways. Attribute analyses applied on such surfaces reveal paleo-geomorphological features and increase insight into the 3D facies distribution.*

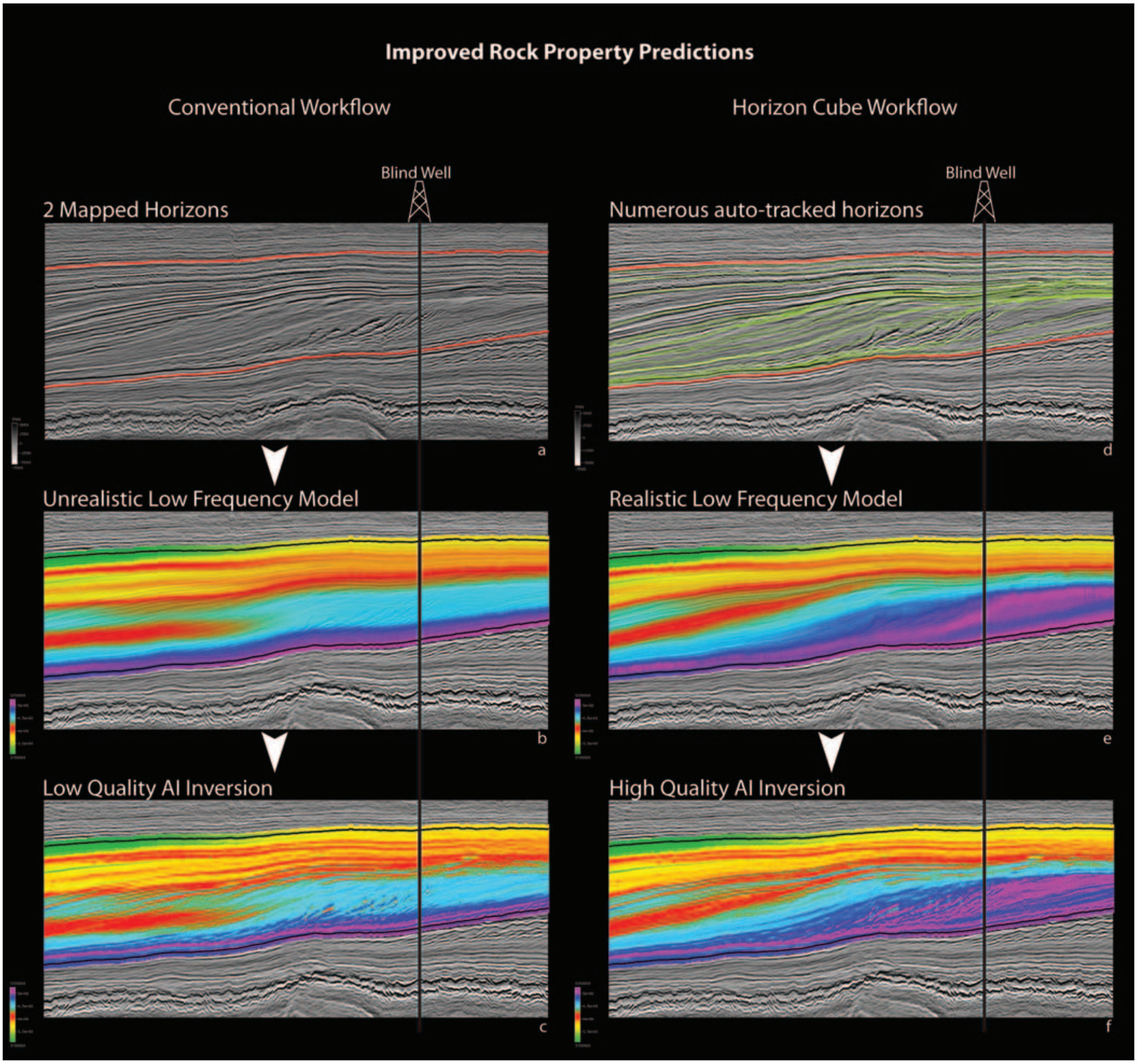

Figure 6. *AI inversion experiment with two different low-frequency model inputs. The simple model uses only top and bottom horizons to guide the well interpolations (a). The detailed model uses 19 additional horizons (d). The simple low-frequency model (b) does not fully honor the seismic while the detailed model does. The inverted results which are driven by the input models reflect these differences (c and f).*

shale. The chaotic facies likely represents slumped deposits, and the shingles at the base of the clino-forms have been shown to consist of sandy turbidites.

Well correlation example. The example shown in Figure 3 demonstrates the power of high-density horizon tracking for chronostratigraphic correlation and rock property prediction away from the wellbore. In this case, the lateral facies changes of the sedimentary succession makes chronostratigraphic correlation between the wells practically impossible without seismic guidance. To facilitate correlation, a random line through the wells is created from the 3D volume, and a dense set of horizons is autotracked. All tracked events are assigned a relative geological age displayed with a corresponding color. An interactive slider is used to add or remove these chronostratigraphic events. This enables the interpreter to reveal the spatial evolution of the sedimentary succession by visually moving forward and backward in geological time. The process highlights in detail how events are correlated between the wells and aids in the understanding of how rock properties vary laterally. For example, the sandy shelf-edge facies observed in the right well correlates with a shaly, toe-of-slope facies in the well on the left.

Sequence stratigraphy example. Sequence stratigraphy, the study of rock relationships within a chronostratigraphic framework, is an established approach for the prediction of facies and lithology distribution. It is an established tool for predicting stratigraphic traps. However, its potential has not been fully realized largely due to the lack of effective inter-

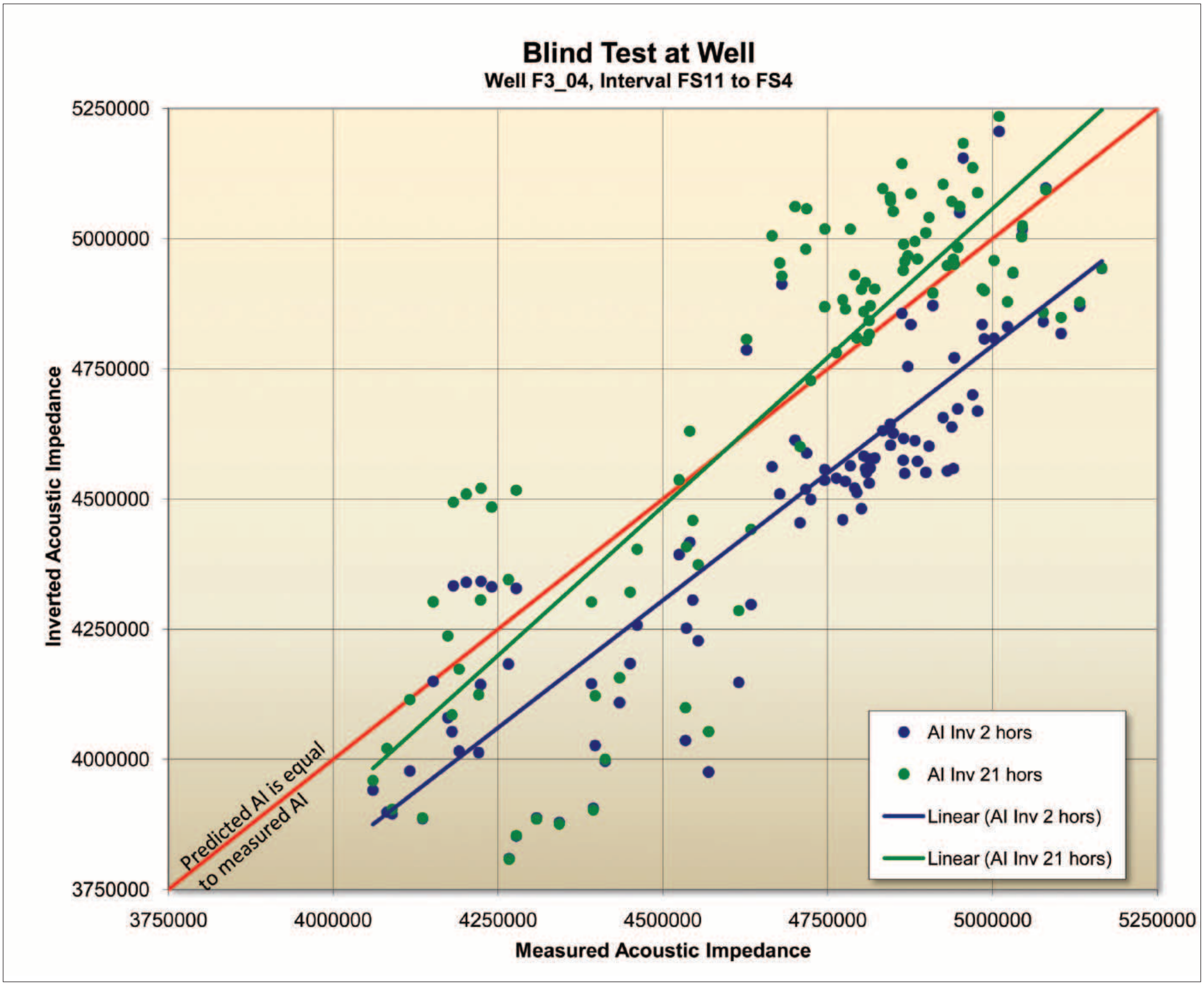

Figure 7. *At the F3-04 blind well location, the inverted result with the simple model (blue) underpredicts the well-log impedance by 4%, while the detailed model results (green) match the well data.*

pretation tools. The following examples illustrate how this is changing with the emergence of utilities centered on high-density horizon tracking.

In the first example, we discuss a workflow that can be applied to quickly analyze 2D and 3D data sets. Here it is applied to 3D. First, a 2D grid of random lines is extracted from the 3D volume. The line grid is oriented in the preferred direction of analysis. Next a dip steering cube is created for the random line grid to drive the horizon cube. The resulting dense set of horizons is grouped by the interpreter into genetically related units or systems tracts (Figure 4). The interpreter is aided by interactive visualization tools such as the chronostrat slider (explained above) and displays in the Wheeler domain (also known as a flattened or chronostratigraphic domain). The systems tracts interpretation facilitates the identification of favorable reservoir facies on sections. Next, stratigraphic surfaces (sequence boundaries, maximum flooding surfaces, etc.) are automatically inserted in between interpreted systems tracks. The workflow is continued in 3D by interpolating the mapped horizons followed by attribute analysis.

The second example is a true 3D example. The autotracked surfaces from the horizon cube in Figure 5 slice through the seismic volume in geologically meaningful ways. Attribute analysis applied to these surfaces reveal paleo-geomorphological features and increase insight into the 3D facies distribution. To study the evolution of such features through geologic time, the interpreter transforms an attribute volume to the Wheeler domain and slices though the flattened volume in the z (relative geologic time) direction.

Example of inversion/geologic model building. Full-bandwidth acoustic impedance (AI) and elastic impedance (EI) inversion for quantitative rock property estimation form a crucial stage in modern reservoir characterization workflows and resulting drilling success. Accurate results are obtained only when missing low-frequency information is incorporated. This is typically constructed from log data interpolated between wells by relatively few coarse seismic correlations.

In many geologic settings, however, simple input models are inadequate and more detailed models constructed from high-density correlations are necessary to deliver robust and accurate results. This statement equally holds true for the general process of geologic model building. The potential improvement is illustrated by the example in Figures 6 and 7. Two low-frequency models are built, one in the conventional manner with coarsely correlated values, and the other with well-log values interpolated by a dense set of correlations (Figure 6 left and right, respectively). The AI inversions show that significant improvement is achieved in results generated with the high-resolution model which more faithfully honors the seismic. The degree of improvement is further illustrated and quantified in a blind test by comparing results directly with well-log data not used in the model building (Figure 7).

Conclusions

Densely tracked horizon mapping enables seismic interpreters to extract more information from their increasingly high-resolution data. The potential benefits for improved well correlation, detailed facies mapping, and rock property estimation have been illustrated by the examples in this paper.

The low-frequency model building case study illustrates how high-density horizon mapping is likely to impact future geological model building where the approach will deliver the greatest benefit. TLE

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Acknowledgments: The examples shown in this paper are generated in OpendTect using two commercial plug-ins: Dip-Steering and SSIS (Sequence Stratigraphic Interpretation System). OpendTect is an open source seismic interpretation system that is available from www.opendtect.org *under a triple licensing policy (open source, commercial and academic). The data set used in the examples are available without charge via bit-torrent technology from the Open Seismic Repository (*http://www.opendtect.org/osr*). We are grateful to all past/present sponsors of the OpendTect SSIS consortium who enable us to continue developing innovative seismic interpretation tools. For more information on the consortium, visit* http://www.dgbes.com/ssis3.

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