F026

Improving Seismic Inversion through Detailed Low Frequency Model Building

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SUMMARY

This paper describes a comparison between two absolute acoustic impedance inversion runs. The only difference between the two runs is the low frequency model that is supplied as input to the inversion algorithm to constrain the solution. Both models are constructed using three out of four available wells. In run No. 1 the model is constructed in the conventional manner: only two mapped seismic horizons are used to guide the interpolation of acoustic impedance well logs. In run No. 2 nineteen additional horizons are used to guide the interpolation algorithm in the construction of the low frequency model. The additional horizons are auto-tracked from a steering-cube , i.e. local seismic dip- and azimuth information. The inverted acoustic impedance results obtained in run No. 2 (21 horizons) follow the seismic events much more closely than the inverted results obtained in run No. 1 (2 horizons). Also quantitatively run No. 2 correctly retrieves the trend whereas run No. 1 under-predicts by 4%. In general it is hypothesized that in many geologic settings the following statement is true: "the higher the number of horizons used to construct the low frequency model, the higher the accuracy of the inverted results."

Introduction

Seismic inversion is the process of estimating an impedance model of the subsurface from seismic data. Due to the band-limited nature of the input, seismic inversion is inherently a non-unique process: there can be a large number of alternative models that match the measurements and the constraints given. Over the years many different inversion algorithms were developed to optimally estimate the earth's acoustic and elastic properties. Initially research focused on defining and solving the objective function. Sparse spikes and model driven inversion are examples of algorithms developed more than twenty years ago that are still used routinely today. Next came pre-stack inversion with products like elastic impedance, and Vp, Vs and Density volumes. Thereafter, stochastic inversion was introduced. Instead of one output volume, a stochastic inversion generates many realizations that are post-processed to gain a better insight in the uncertainties of the inversion process. The current focus of inversion R&D is to develop algorithms that invert the full waveform.

What is striking in this brief history is that inversion R&D seems to be driven solely by geophysical motives. The geologic input to all methods routinely applied in current inversion schemes has not changed since impedance inversion was introduced in the nineteen-eighties. Nevertheless, it can be argued that the largest error in any (absolute) impedance result is directly related to the geologic constraints given to the inversion scheme. Especially the "missing" low-frequency part of the seismic spectrum is crucial in this context as this part contains the information concerning the absolute values of the impedance. Without low frequency information the inversion scheme can only estimate relative impedance changes. The missing low frequencies are usually given in the form of a smooth interpolation of the well impedance values, constrained stratigraphically by mapped seismic horizons (Francis, 2006a and 2006b).

Low Frequency Model Building

A low frequency model typically contains frequencies in the 0 – 15Hz range. The model is constructed by interpolating available well logs: sonic, density and optionally shear-sonic. Inverse distance and Kriging are typical examples of interpolation algorithms used for this purpose. The main geologic input in the model building is supplied in the form of a few key seismic horizons to guide the interpolation algorithm. Most inversion packages support three forms of stratigraphic guidance: stratal (proportional) slicing, parallel to upper, and parallel to lower. All models are built from ratios expressing the relative position (height) in the wells (Fig. 1).

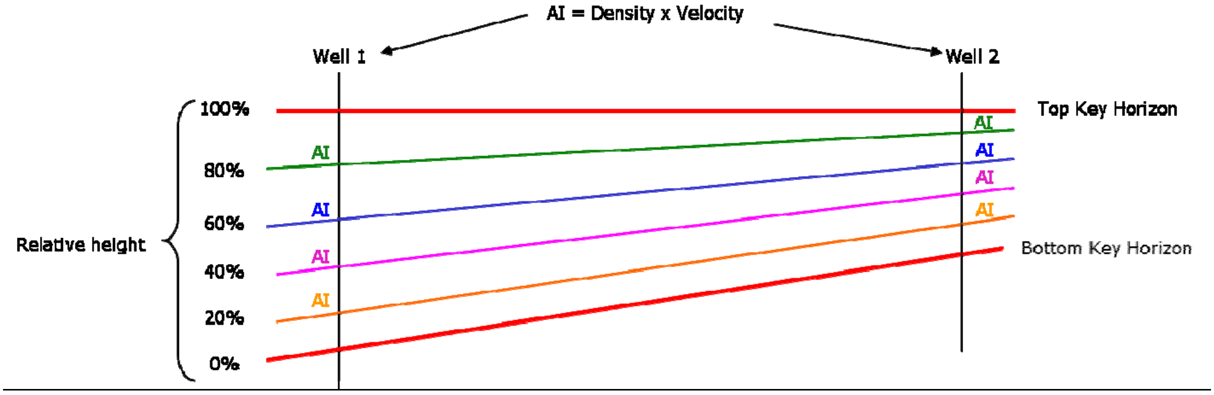

Figure 1 *Schematic representation of stratal slicing. Well data is interpolated along the coloured lines that represent surfaces of equal relative height ratio.*

Experiment

The F3 data comes from the Dutch sector of the North Sea. The target interval is the upper 1200 ms that consist of reflectors belonging to the Miocene, Pliocene, and Pleistocene (Fig. 2a). The large-scale sigmoidal bedding in this interval consists of deposits of a large fluvio-deltaic system which drained large parts of the Baltic Sea region (Sørensen et al, 1997; Overeem et al, 2001). In this study the 3D volume is inverted to absolute acoustic impedance using the industry-standard “Strata” software by Hampson-Russell. The model-driven inversion is performed twice with different low frequency models. Both models are constructed by stratal slicing and using three out of four available wells. Model 1 represents the accepted standard way: the model is constructed with only two horizons: the mapped top and bottom of the target interval (Fig. 2b). In run 2 the low frequency model is constructed using 21 horizons to guide the interpolation algorithm: top and bottom horizons + 19 additional stratigraphic horizons.

The additional stratigraphic horizons are auto-tracked by a 3D auto-tracker that tracks hundreds of surfaces simultaneously in a pre-calculated steering cube. The steering cube is a volume that stores the local dip and azimuth of the seismic events. In this case the steering cube is calculated with a 3D FFT algorithm. The resulting cube is subsequently smoothed with a 3D median filter. The auto-tracker follows the smoothed dip-field in three dimensions and repeats this exercise to arrive at a dense set of horizons that are approx. 4ms separated in two-way time. For practical reasons the low frequency model is in this study constructed from a sub-set of 19 horizons that are selected from the dense set of auto-tracked horizons.

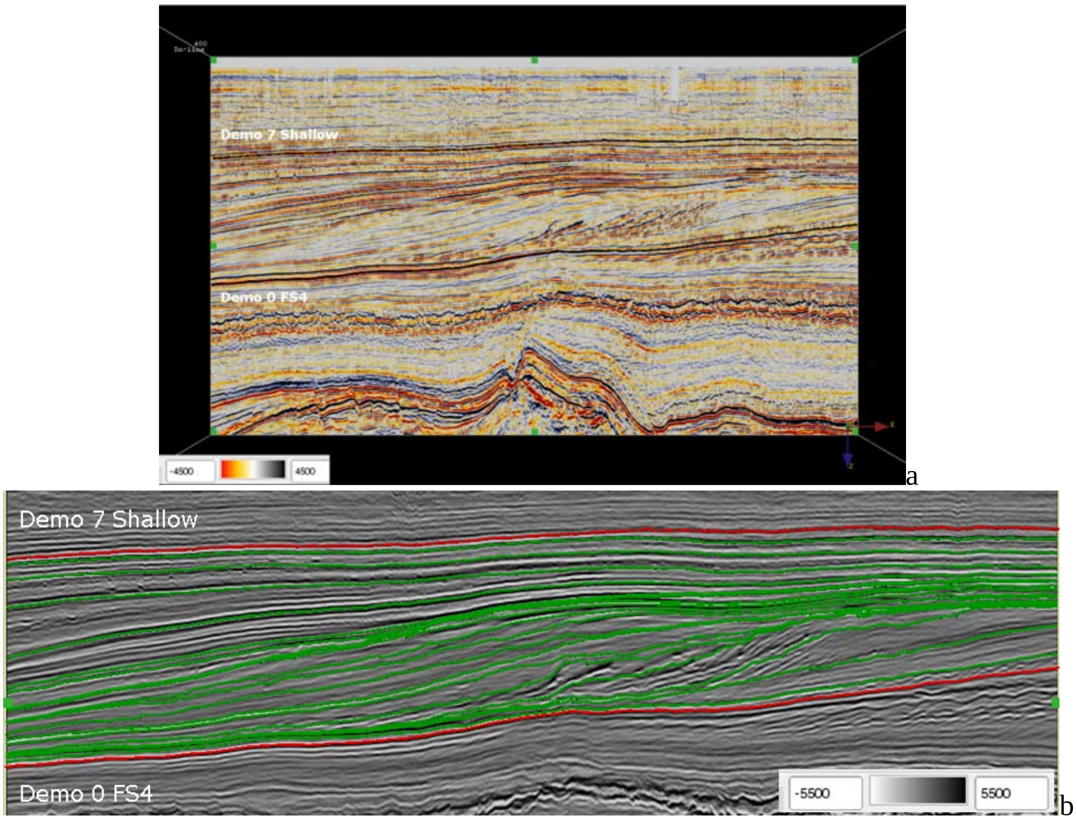

Figure 2 *a) Inline 442. b) Same inline showing the target interval for the inversion. In Run 1 the low frequency model is constructed by stratal slicing guided only by top and bottom mapped horizons (red surfaces). In run 2 the low frequency model is also constructed by stratal slicing but now the interpolation is guided by two mapped horizons (red) and 19 additional horizons (green) that were auto-tracked in 3D using a dip-steered auto-tracker.*

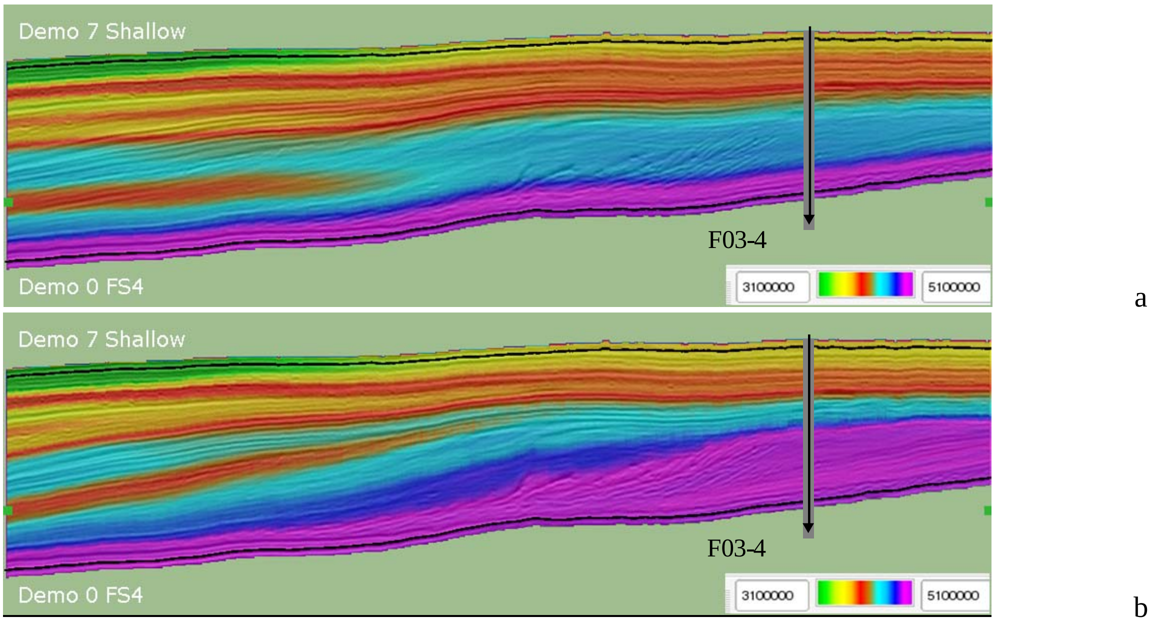

Figure 3 *Low frequency models overlying the seismic data at inline 442. a) Model 1 (2 horizons) and b) Model 2 (21 horizons). As expected the model with 21 horizons much better follows the seismic events. Compare e.g. the red streak on the left-hand side and the purple and blue packages around blind well F03-04.*

Results

Figure 4 shows the results after acoustic impedance inversion.

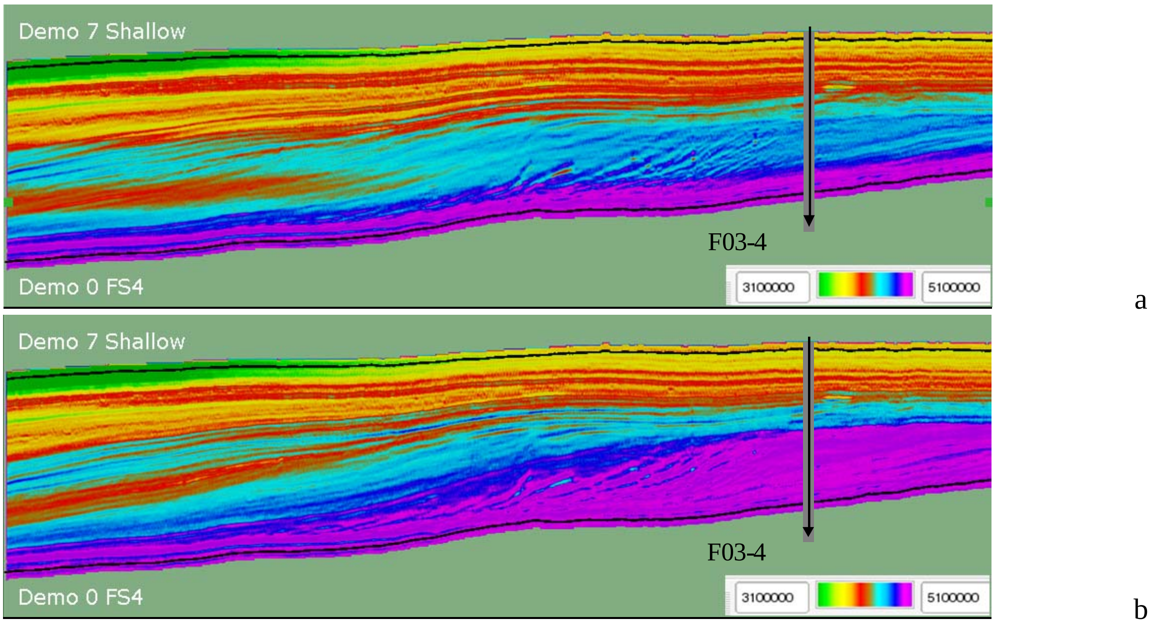

Figure 4 *Acoustic impedance inversion results at inline 442. a) Run 1 (2 horizons) and b) Run 2 (21 horizons). Acoustic impedances of run 2 much better follow the seismic events. Compare e.g. the red streak on the left-hand side and the purple and blue packages around blind well F03-04.*

A cross-plot of the inverted acoustic impedance versus the well log acoustic impedance at the blind well location is given in Figure 5. It shows that run 1 (2 horizons) under-predicts the actual impedances by approx. 4%. In run 2 the correct trend is predicted.

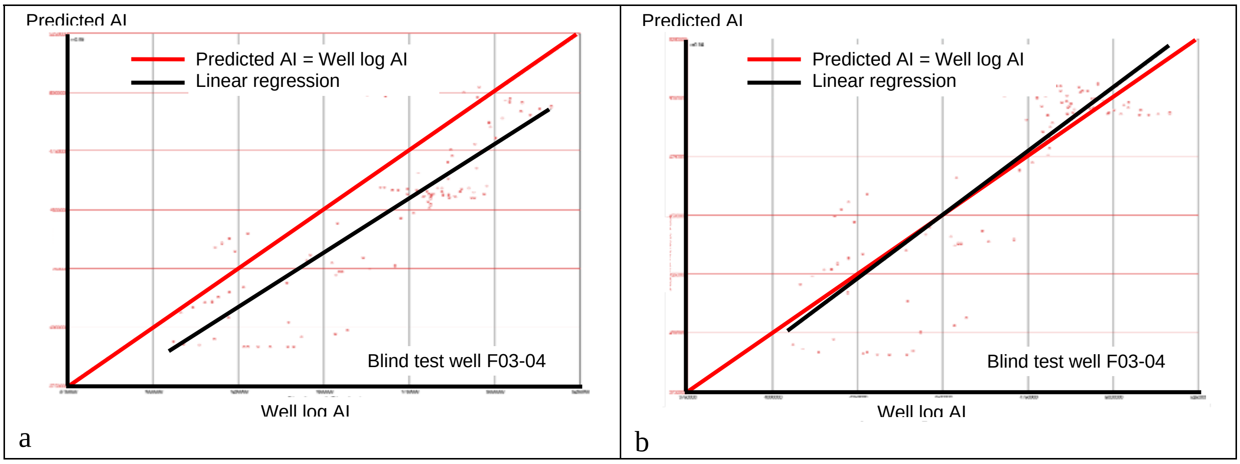

Figure 5 *Cross-plots of inverted Acoustic Impedance vs. upscaled well log (4ms) Acoustic Impedance. The red line is the correct answer. The black line is the linear regression through the predicted values. a) Run 1 (2 horizons) and b) Run 2 (21 horizons).*

Conclusions

The experiment described in this paper clearly demonstrates the impact of the low frequency model on the final outcome of an absolute seismic inversion result. The inversion result obtained with a detailed low frequency model is clearly more accurate than the result obtained with the coarser input model.

It is hypothesized that in many geologic settings absolute seismic impedance inversion results can be improved by incorporating more stratigraphic horizons to constrain the low frequency model. This statement can be further generalized to geologic model building: in many geologic settings incorporating more seismic horizons leads to more accurate geologic models.

These statements are the driving force behind our current R&D efforts: we strive to improve the accuracy of the dense 3D auto-tracker and to develop work flows that allow detailed geologic model building with minimal human interaction.

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