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Comparison between deterministic and statistical wavelet estimation methods through predictive deconvolution: Seismic to well tie example from the North Sea

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A B S T R A C T

Wavelet estimation as well as seismic-to-well tie procedures are at the core of every seismic interpretation workflow. In this paper we perform a comparative study of wavelet estimation methods for seismic-to-well tie. Two approaches to wavelet estimation are discussed: a deterministic estimation, based on both seismic and well log data, and a statistical estimation, based on predictive deconvolution and the classical assumptions of the convolutional model, which provides a minimum-phase wavelet. Our algorithms, for both wavelet estimation methods introduce a semi-automatic approach to determine the optimum parameters of deterministic wavelet estimation and statistical wavelet estimation and, further, to estimate the optimum seismic wavelets by searching for the highest correlation coefficient between the recorded trace and the synthetic trace, when the time–depth relationship is accurate. Tests with numerical data show some qualitative conclusions, which are probably useful for seismic inversion and interpretation of field data, by comparing deterministic wavelet estimation and statistical wavelet estimation in detail, especially for field data example. The feasibility of this approach is verified on real seismic and well data from Viking Graben field, North Sea, Norway. Our results also show the influence of the washout zones on well log data on the quality of the well to seismic tie.

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1. Introduction

The earth's subsurface is composed of rock layers with different lithology and physical properties. From the seismic point of view, these layers manifest as density and velocity contrasts as seismic waves propagate through them. The product of density and velocity generates the seismic impedance. The impedance contrast between the adjacent rock layers causes the reflections that are recorded along a surface profile. These signals are what we will refer to as real seismic data. The recorded seismogram can also be modeled by the convolution of the earth's reflectivity, using well log data, with the seismic wavelet. The result of the modeled seismogram is the synthetic seismic trace. The process of seismic-to-well tie involved mostly the comparison between the real seismic trace and the synthetic trace (Rob Simm, 2014).

Seismic-to-well tie is a useful tool used to relate recorded seismic waveforms to the lithology, stratigraphy and rock properties of the subsurface (White et al., 1998). Accurate seismic-to-well tie is pertinent to a successful seismic lithological interpretation (White, 2003). As long as the geology in the vicinity of the well is not unduly complex, the main factors controlling accuracy of seismic-to-well tie are the quality of the seismic processing as well as the accurate replication of the earth model from well logs. The link between a primary reflection signal and the reflectivity constructed from a well log is the seismic wavelet. In general, most studies of this subject agree that methods to estimate the seismic wavelet are divided in two categories: deterministic methods and statistical methods. Deterministic methods require direct measurements of the source wavefield or the use of the well log data (Oldenburg et al., 1981; Yilmaz, 2000). Statistical methods estimate the wavelet from the seismic trace itself and require some assumptions about the characteristics of the wavelet (Buland and Omre, 2003; Edgar and Der Baan, 2011; Lundsgaard et al., 2015). The latter, is based on mathematical tools to solve

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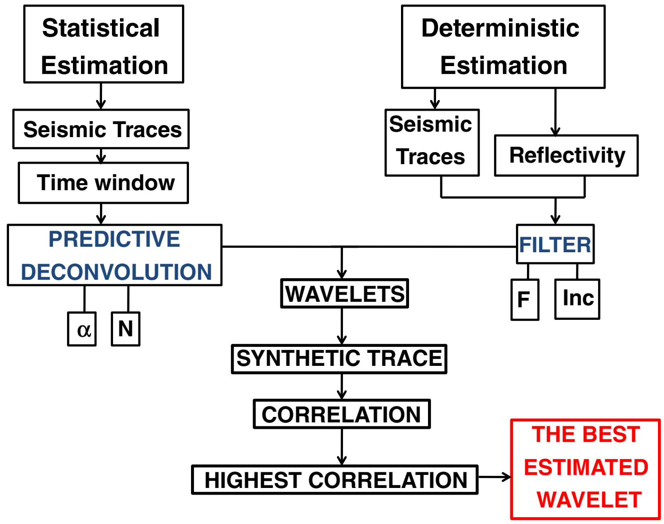

Fig. 1. A schematic illustration of the algorithm for the estimation of the wavelet that produces the best well to seismic tie.

the problem of wavelet estimation. Beyond these, there are other methods based on intelligent optimization algorithms used to estimate the seismic wavelet (Yuan et al., 2009) and the seismic phase wavelet (Wang et al., 2015), with a fixed filter length. Both works are based on swarm intelligence inversion methods.

In this paper we compare the quality of seismic-to-well tie based on two different wavelet estimation methods. The first method is the traditional deterministic method, which selects a segment of the reflectivity sequence and a segment of the seismic data. The best wavelet estimated is the one that leads to the best match between the seismic trace and the synthetic trace. The second method is based on classical predictive deconvolution assumptions about the convolutional model of the earth, which infers a minimum-phase wavelet and a random process reflectivity. We introduce a semi-automatic approach to determine the optimum parameters in deterministic and statistical wavelet estimation, and further obtain the optimum wavelets by searching for the best seismic-to-well tie. Tests with numerical data using our semi-automatic algorithm show the estimation of the seismic wavelet with a reasonable degree of accuracy for both cases. The feasibility of the algorithms is verified on the real seismic and well data from Viking Graben field, North Sea, Norway. Our results also show the influence of washout zones on the quality of the seismic-to-well tie.

2. Seismic-to-well tie

Seismic-to-well tie is an important part of a seismic interpreter's trade once they have the following prerequisites of 1) correctly identifying horizons to pick and 2) estimating the wavelet for inverting seismic data to impedance (White and Simm, 2013). It is a basic tool to estimate the connection of subsurface geology and seismic. Borehole measurements such as sonic and density logs are recorded in depth while seismic measurements are in time. To convert the borehole measurements from depth to time, a time–depth relationship need to be established. This time–depth relationship is usually acquired as checksots at the borehole location. In general, the seismic-to-well tie workflow include the following steps:

(1) Edit the sonic and density logs.
(2) Generate a reflectivity series.
(3) Apply a time–depth relationship.
(4) Convolve the reflectivity series with a wavelet.
(5) Compare the output of the convolution with the real seismic data.

The first step is necessary in order to avoid the introduction of noise or spikes to the generated reflectivity series. Both the sonic and density curves may have some spikes and null values that needs to be dealt with. The reflectivity series is generated by changes of impedance $I = \rho V_p$ within the earth. The reflectivity ($r(i)$) on the depth axis can be calculated from the sonic and bulk density logs,

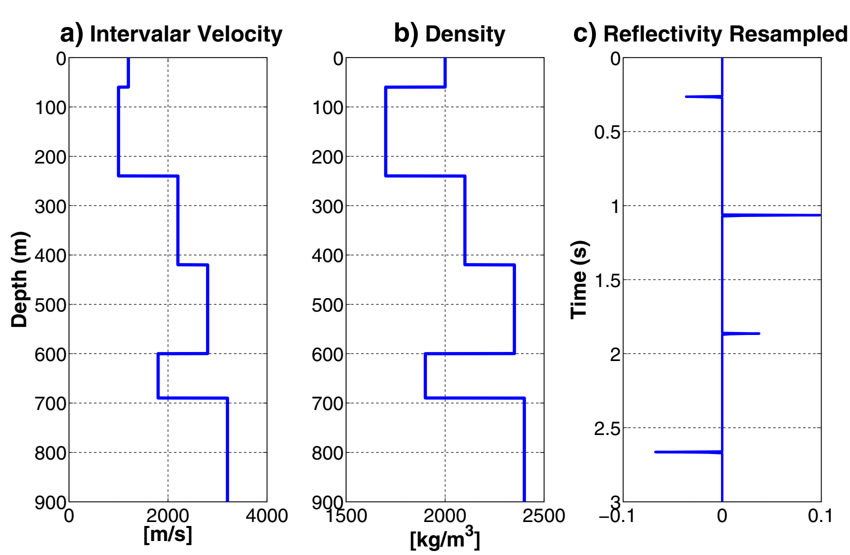

Fig. 2. a) P-wave log related to a synthetic model. b) Density log related to a synthetic model with 6 layers. c) Calculated reflectivity resampled to fit the time axis.

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