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Research paper

Reservoir lithology classification based on seismic inversion results by Hidden Markov Models: Applying prior geological information

Runhai Feng[a,*], Stefan M. Luthi[a], Dries Gisolf[b], Erika Angerer[c]

[a] Department of Geoscience and Engineering, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, The Netherlands
[b] Department of Physics, Delft University of Technology, Lorentzweg 1, 2628 CJ, Delft, The Netherlands
[c] OMV Exploration & Production, Trabrennstraße 6-8, 1020, Vienna, Austria

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ABSTRACT

Hidden Markov Models (HMMs) have been applied to predict reservoir lithologies using seismic inversion results as inputs. This approach takes into account the conditional probabilities between different lithologies, i.e. the vertical transitions in sedimentary sequences. These properties are used as prior geological information. In order to relate the seismic inversion results to the true well-log data, HMMs need to be trained based on the Expectation-Maximization theory. Application of the resulting model on a synthetic example from the Book Cliffs (Utah, USA) showed that most lithologies are classified correctly, even for some thin layers. A comparison with point-wise methods in which data samples are treated independently from each other, such as *k*-means and fuzzy logic classifiers, leads to the conclusion that the spatial correlation in HMMs allows better lithological predictions because the prior information accounts for the geological depositional processes. A real case study with data from the Vienna Basin (Austria) is performed, in which lithologies in a 3D cube are obtained based on properties from seismic inversions, via trained HMMs. While the vertical sequences are shown to be reasonably well predicted, the horizontal continuities are not. This indicates that the future research should focus on the lateral geological relationships.

1. Introduction

Lithology classification is one of the most important aspects in reservoir characterization, because it is the key to the translation of rock-properties to relevant reservoir parameters (Mahgoub et al., 2017). The distribution of reservoir lithologies, therefore, is needed to understand and predict a reservoir's production performance through reservoir modeling and simulation (Jennette et al., 2003). In order to separate lithologies into different classes, data obtained from cores and well-logs are usually used, which have a high vertical resolution. While these provide sufficient information on subsurface lithologies in a one-dimensional direction (depth), they provide little information about their lateral distribution. Additionally, in most cases, the density of boreholes is relatively sparse compared with the total reservoir volume. Seismic data, on the other hand, can provide two-dimensional or three-dimensional information over an area typically covering the extent of the target reservoir. It can, therefore, help to obtain three-dimensional models of the relevant reservoir properties. Here we present the results from an effort to extract reservoir lithologies, from the properties provided by full-elastic wave-equation based inversion of seismic data.

In general, full-waveform inversion, or FWI, is a challenging data-fitting procedure based on full-wavefield modeling to extract quantitative information from seismograms (Tarantola, 1984; Virieux and Operto, 2009; Morgan et al., 2013, 2016; Warner et al., 2013). The information from different types of waves including refractions and diving waves, which used to be considered as noises in normal seismic data processing, are utilized in this optimization procedure.

FWI became only feasible after a significant increase in computing power and longer offset seismic acquisition methods became available, because it is computationally intensive and sensitive to the structure of the intermediate/long wavelengths that could be obtained from long-offset data (Mora, 1987). Pratt et al. (1996) used wide-angle seismic data to reconstruct a higher-resolution two-dimensional velocity model compared with pre-stack migration and traveltime tomography. Shipp and Singh (2002) used a two-dimensional elastic wave equation to generate all possible waves, including converted ones, in order to simulate a complex seismic wavefield in a marine environment. Plessix (2009) implemented a three-dimensional frequency-domain full-waveform inversion in which a multiscale approach with an iterative solver is adopted.

* Corresponding author.
E-mail address: r.feng@tudelft.nl (R. Feng).

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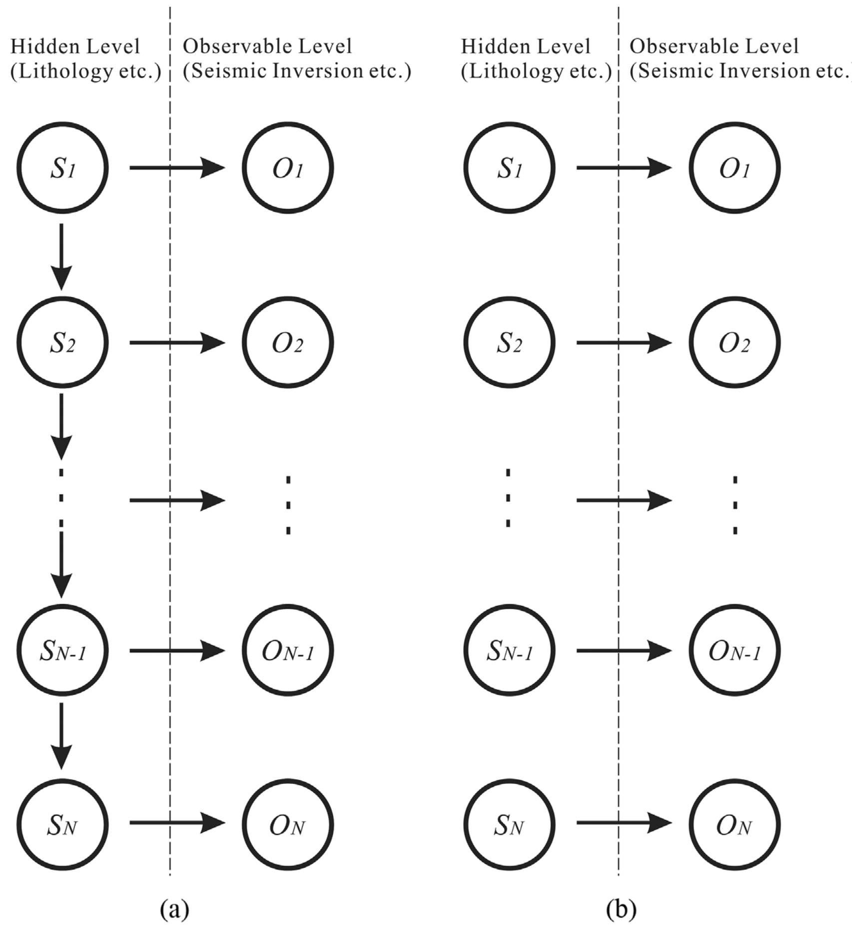

Fig. 1. Comparison between HMMs and other point-wise methods. a) With vertical coupling. b) Without vertical connection. S_1, S_2, $\cdots$, S_N are hidden states or variables while O_1, O_2, $\cdots$, O_N are observations (modified from Lindberg and Grana, 2015).

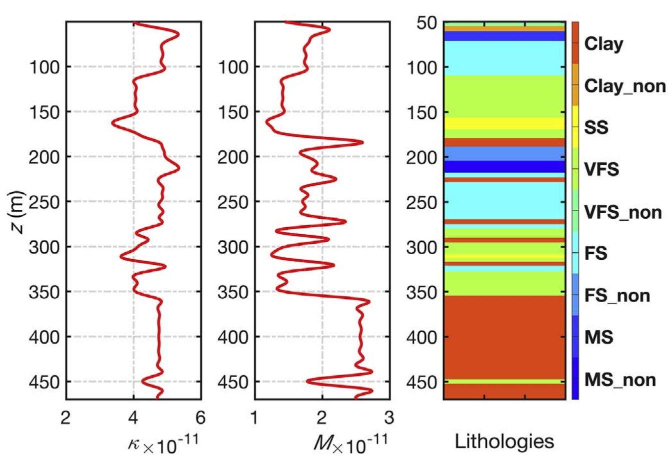

Fig. 2. Rock physical properties and lithologies at one single CMP. MS – Medium-grained sandstones; FS – Fine-grained sandstones; VFS – Very fine-grained sandstones; SS – Siltstones, and each lithology has been divided into two parts – marine and non-marine (designated by non).

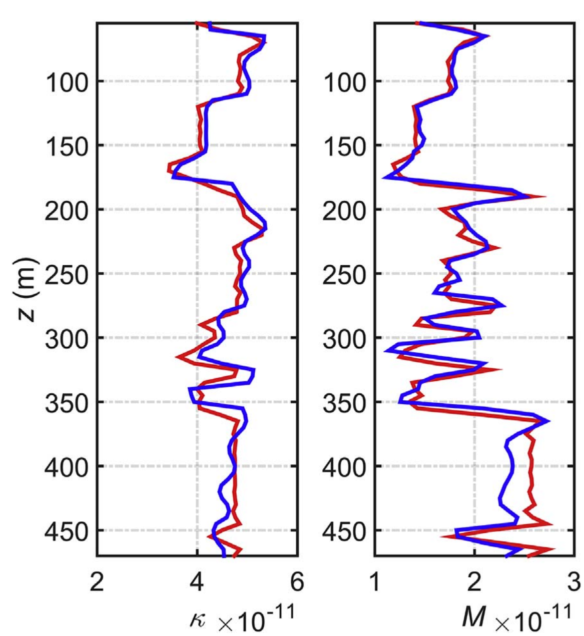

Fig. 3. Truth (red curves) and inversion (blue curves) at one CMP location of the synthetic example (Feng et al., 2017). Rock properties have been resampled to the seismic grid size. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

In contrast to the methods mentioned above, the scheme of wave-equation based inversion used here is based on the integral representation of the full-elastic wave equation. The orders of multiple scattering that are accounted for in the inversion are determined by the number of iterations. All internal transmission effects and internal multiple scattering/mode-conversions are considered, allowing the