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Iterative Multiscale Deep-Resistivity Imaging

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Abstract

Accurate interpretation of the modern array resistivity log data is critical to drilling, formation evaluation, and reservoir characterization. Multidimensional inversion-based array data interpretation methods are often used for this purpose. These methods commonly employ a single formation model for the entire interpretation process. Here we present an inversion method that utilizes log-resolution-dependent multiscale formation models. The method works as follows. First, we estimate shallow (near-borehole) resistivity structure. Then, we generate an image on a coarse spatial grid inverting the logs with the lowest resolution. After that, we perform iterative image refining using multiscale formation models and logs of a higher resolution as input. The resulting model generated at each step is used as a starting model for the subsequent step of the method.

We present the test results using synthetic and field galvanic array lateral logs. Synthetic data was simulated by means of benchmark models containing thin layers of different resistivities. Field data was acquired in an offshore Mediterranean well. In both synthetic and field cases we demonstrate that our method is an efficient log data interpretation instrument allowing picturing fine formation features clearly and quantitatively.

Introduction

Multiscale methods have revolutionized digital signal processing and biomedical imaging. These methods are now widely used for seismic imaging[1, 2]. Despite the remarkable advantages of array resistivity log data acquisition systems, conventional inversion-based interpretation methods use a single formation model[3-6]. Such an approach does not allow to fully extract information from the recorded array logs and may lead to unstable and erroneous results. Therefore, there is a great need for new methods which would make use of the rich information content of array data to accurately determine reservoir structure and its resistivity image.

Some multiscale data-adaptive algorithms have been proposed in[7, 8]. In this paper, we will be further evaluating an iterative multiscale deep-resistivity imaging method[7] on model and field data. This method is based on sequential inversions of array logs of a different spatial resolution. It is applicable to both induction and galvanic array logs but we will be testing the method using only galvanic array lateral log data simulated and measured in conductive boreholes.

The paper has the following structure. The next section shows the modeling work results illustrating the sensitivity of the array lateral logs to spatial variations of formation resistivity. The following two sections detail inversion-based multiscale formation imaging method and its testing on synthetic models. The last section presents the case study and evaluates the practical capabilities of the method.

The Spatial Sensitivity of Array Measurements

Array lateral log tool measures voltage potentials (V) and first differences (FD) along a 19-electrode array. Additionally, first-difference data are combined to compute second differences (SD)[6]. Potential voltage logs have the deepest depth of investigation, particularly the long subarrays, but relatively low vertical resolution. The first and especially second potential difference data are much less affected by adjacent resistivities. It makes these logs very useful in estimating resistivity of local anomalies (Fig. 1) and fine beds traversed by a borehole.

Let us perform sensitivity analysis of array lateral logs simulating the effect of a layer of contrasting resistivity away from, but not intersecting, the wellbore (Fig. 2)[5]. In the model presented in Fig. 2, the constant parameters are: the resistivity of the bottom layer R_{t2}=1.5 Ohm-m; the wellbore diameter Cal=8 inch, and the wellbore resistivity R_m=0.1 Ohm-m. The distance L from the wellbore to the bottom of the overlying top layer varied from 0 to 20 ft and the resistivity of the top layer was set to three values of R_{t1}=0.5, 5, and 50 Ohm-m.

Modeling results are presented as normalized V, FD, and SD (Fig. 3-5). They are normalized with respect to a