2D Imaging with Electromagnetic Logging-While-Drilling Measurements

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Electromagnetic (EM) measurements have been widely used for oil and gas exploration to determine the reservoir conductivity from the well-bore, and to infer the water saturation and hydrocarbon content. The new generation of directional EM tools are primarily used to steer horizontal wells to avoid drilling hazards and optimally place the well. These tools use multiple antennas, combination of axially wound, tilted and/or saddle coils, spaced up to 50 m apart along the drill string, operating at multiple frequencies in the kHz to MHz range. The EM measurements typically react to the conductivity distribution up to the maximal tool spacing (distance between transmitter and receiver) away from the wellbore, depending on conductivity as well as formation complexity. The tools typically send up to 100 different responses to the surface while drilling for real-time interpretation. The measurement complexity and number of responses make a direct interpretation impossible. Instead, an inversion process is used to infer the local conductivity profile in real-time to identify the reservoir boundaries and fluid contacts. This information is utilized to stay in the reservoir and steer the well to the sweet spot of the reservoir to maximize hydrocarbon production.

The currently used real-time inversion assumes that the formation structure is locally 1D, using semi-analytical fast 1D forward modeling in the inversion loop to reconstruct the measurements. This approach is adequate if the formation is layered and slowly varying laterally. However, in complex reservoir scenarios with locally 2D or 3D structures or where the formation changes abruptly, the 1D approximation used in real-time may not be the most accurate solution.

We present an imaging inversion for EM logging-while-drilling measurements to accurately map complex 2D anisotropic conductivity distributions in the vicinity of the wellbore. The imaging domain is discretized using a non-uniform pixel distribution, based on EM measurement spatial sensitivities, leading to a discretization domain of 10,000 to 30,000 unknowns (pixel horizontal conductivity and anisotropy). An efficient 2.5D EM solver is used to model the tool responses and to match them to the acquired measurements using the Gauss-Newton algorithm, estimating the 2D conductivity distribution in the process. An additional adaptive regularization term on the pixel conductivity differences in the Gauss-Newton algorithm ensures that the most plausible conductivity distribution with the least conductivity variation is found. The algorithm is parallelized to run on a cluster so inversion can be carried out in near real-time.

The new inversion is validated on several realistic 2D synthetic models, such as faults, demonstrating its ability to accurately image complex scenarios where standard 1D inversions are not able to provide an adequate answer. The derived conductivity maps provide additional insight about the reservoir structure while drilling, used to make steering decision as well as to better characterize the reservoir and refine the geological models in order to optimize the production.