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Borehole radar response of a mud-invaded oil-bearing layer

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In the process of oil drilling, mud filtrate penetrates into porous formations and alters their pore fluid properties. This, in turn, complicates the formation evaluation process based on conventional well logging. If adequately characterized, the mud-contaminated part of the formation does, however, also carry valuable information, notably with regard to its key hydraulic properties. To achieve this objective, we propose to use borehole radar logging to determine the mud invasion depth, which critically depends of the formation's porosity and permeability. A series of 3D numerical simulations has been carried out to assess the feasibility and potential of this approach. The underlying electromagnetic (EM) model is coupled with a multi-phase fluid flow model to simulate the responses of borehole radar to the mud-invaded formation. The EM model is constructed using gprMax, an open-source software package that employs the finite-difference time-domain method (FDTD) to numerically solve Maxwell's equations, while the fluid flow model is based on a numerical solution of the corresponding governing equations with an implicit pressure and explicit saturation (IMPES) method. The two models are coupled via electrical material property formulas based on petrophysical mixing models. Simulations of the time-lapse logging response is performed to extract the generally weak EM signals associated with the mud invasion. The corresponding results suggest that observable reflections arise from the invasion transition zones, which demonstrates the potential of borehole radar logging in oil exploration in the presence of water-based drilling muds of low salinity. The technical challenges reside in developing a radar logging tool that is able to support the antennas against the borehole wall, in order to focus the EM energy towards the formation.