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The borehole-fluid effect in electrical resistivity imaging

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Fluid that fills boreholes in crosswell electrical-resistivity investigations provides the necessary electrical contact between the electrodes and the rock formation, but it is also the source of image artifacts in standard inversions that do not account for the effects of the boreholes. The image distortions can be severe for large resistivity contrasts between the rock formation and borehole fluid and for large borehole diameters. We have carried out 3-D finite-element modeling using an unstructured-grid approach to quantify the magnitude of borehole effects for different resistivity contrasts, borehole diameters, and electrode configurations. Relatively common resistivity contrasts of 100 : 1 and borehole diameters of 10 and 20 cm yielded, for a bipole length 5 m, underestimates of apparent resistivity by $\sim$12% and $\sim$32% when using AB-MN configurations and overestimates of apparent resistivity by $\sim$24% and $\sim$95% when using AM-BN configurations. Effects are generally more severe at shorter bipole spacings. We report here the results obtained by either including or ignoring the boreholes in inversions of 3D field data from a test site in Switzerland, where $\sim$10,000 crosswell resistivity tomography measurements were made across 6 acquisition planes between 4 boreholes. Inversions of raw data that ignored the boreholes filled with low resistivity fluid paradoxically produced high resistivity artifacts around the boreholes. Including correction factors based on the modeling results for a 1-D model with and without the boreholes did not markedly improve the images. The only satisfactory approach was to use a 3-D inversion code that explicitly incorporated the boreholes in the actual inversion. This new approach yielded an electrical resistivity image that was devoid of artifacts around the boreholes and that correlated well with co-incident crosswell radar images.