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Monitoring iron mineral dissolution in aquifer sand using the non-invasive geophysical method spectral induced polarization (SIP)

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Mineral dissolution plays a key role in subsurface geochemical dynamics particularly through the behavior of iron-bearing minerals. These minerals facilitate reactions involving the transfer of electrons, induce acidity at legacy waste sites, and regulate the mobility of contaminants such as arsenic and chromium. Real-time monitoring of mineral precipitation and dissolution is essential for e.g. evaluating an aquifer's electron-donating capacity, identifying environmental risks, guiding remediation strategies, and assessing sorption site availability in soils. The non-invasive geophysical technique spectral induced polarization (SIP) can measure charge storage at charged mineral, colloid and / or organic surfaces in porous media, in the presence of an external electrical field. This "induced polarization" effect is linked to the changing charging properties of porous media and can thus provide a powerful means for investigating processes such as mineral dissolution in real time. Here, we present results from a flow-through column experiment where we stimulated the dissolution of reduced iron(-sulfide) mineral phases in aquifer sand collected from the Fuhrberger Feld Aquifer (Hannover, Germany) via the infiltration of an acid-containing solution (0.01 M HCl). Our goal was to mimic mineral dissolution in a controlled setting to ascertain the ability of SIP to capture the timing of the dissolution front and the extent of dissolution. We coupled our geochemical experiment and spatially and temporally resolved geophysical measurements with a reactive transport model fitted to our measured pH and Fe(II)/(III) breakthrough curves. During the acid pulse, our SIP responses revealed a spatially staggered shift in polarization and conduction, with a distinct stepwise behavior, which was also evident in the pH measured at the outlet. The inclusion of (1) mineral dissolution as well as (2) protonation of the remaining mineral surface at the lower pH in our reactive transport model has thus far yielded promising results. The latter helps to link our SIP signals with the timing and location of the dissolution front. Our findings highlight the usefulness of non-invasive approaches with wide-ranging implications for geochemical monitoring.