

A glimpse of the solid-water interface: An ion-exchange case study showing how geo-electrical measurements can help us to understand (bio)geochemical reaction dynamics

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Processes at the solid-water interface (nm- to μm -scale) govern the fate, transport and thus distribution of carbon, nutrients and redox-sensitive elements at larger m- to km-scales. The (bio)geochemical reactions that modulate subsurface turnover, however, are ‘hidden’ by the natural complexity of soils, sediments and aquifers. Traditional biogeochemical characterization methods, while highly accurate, are invasive and thus suffer from limited spatiotemporal resolution, stalling improvements in the mechanistic understanding of coupled biogeochemical reactions and their impact on reactive transport. Here, we present a powerful alternative approach that uses geophysics, specifically the method spectral induced polarization (SIP), to non-invasively acquire information about reactive processes at the solid-water interface in real time. We performed a series of flow-through experiments using natural aquifer sediment from a calcareous floodplain aquifer high in NOM derived from peat to investigate the ability of SIP to monitor ion-exchange and microbially-mediated reactions. The result showed changes in SIP signals that captured the timing of Na^+ and $\text{Ca}^{2+}/\text{Mg}^{2+}$ ion-exchange during an abiotic tracer experiment. Our findings highlight the sensitivity of SIP to the geochemical makeup of the electrical double layer (EDL) at charged surfaces. Moreover, the presence of NOM yielded polarization phenomena that deviate from the classical mineral-only polarization model highlighting the need to better understand the role of organic matter in modulating electrical polarization signals. Nevertheless, our findings showcase the ability of SIP to monitor ion-exchange reactions. The analysis of an additional dataset acquired during a nitrate biostimulation flow phase highlights an approach to decouple abiotic signal contributions from those of microbial activity during denitrification. Because of its ease-of-use, the approach lends itself to a variety of applications in (bio)geochemistry, monitoring reactions in real time by relying on electrical signal changes as their proxy. Based on our findings, we lay out a *how-to-guide* for its application.