Mineralization in variably saturated porous media and its consequential changes on effective diffusivity

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Mineral precipitation in partially saturated porous media plays an important role in various processes, ranging from degradation of monuments, threats to agriculture, to subsurface exploitation for future energy needs. For example, in certain nuclear waste repository concepts, partial saturation of the host rock may persist for hundreds of years, while the presence of gas could enhance mineralization at the interfaces between the engineered system and the host rock. This process may lead to porosity clogging, resulting in localized pressure buildup due to gas production from organic waste degradation and corrosion processes, potentially causing fracturing and the formation of preferential flow paths possibly compromising the long-term containment of radioactive waste. Consequently, developing experiment integrated theoretical models that describe the changes in transport properties of a partially saturated porous media undergoing mineralization is necessary for optimizing these systems.
In recent decades, significant efforts have been made to develop process-based models to describe diffusion in a fully saturated chemically evolving porous media (Lönartz et al., 2024). These studies have demonstrated that classical empirical relationships, such as Archie's law, fail to accurately describe changes in diffusive transport caused by mineral precipitation, highlighting the need for an extended law informed by experimental observations.
In this study, we developed a column experiment, monitored using micro-computed tomography (micro-CT), to investigate mineralization in partially saturated porous media. Four experiments, each with an initially different level of partial saturation, were conducted to examine the evolution of mineral precipitation patterns over time. Micro-CT enabled the visualization of precipitation patterns within the porous media, including the initial nucleation at the gas-water interface. Pore-scale modeling, based on Yang et al. (2024), was performed on the 3D images to determine the effective diffusivity of the chemically evolving porous media. These experiments aim to integrate new pore-scale insights to develop constitutive equations describing the interplay between transport (diffusion) and precipitation processes in partially saturated porous media.

Lönartz, Mara I., et al. (2023) Capturing the dynamic processes of porosity clogging. *Water resources research* 59(11).

Yang, Yuankai, et al. (2024). Pore-Scale Modeling of Water and Ion Diffusion in Partially Saturated Clays. *Water Resources Research* 60(1).