Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.29576

Synchrotron-based Dual Imaging and Diffraction for in situ analysis of fluid-rock interactions in geological samples

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The Dual Imaging and Diffraction (DIAD) beamline at the Diamond Light Source facilitates simultaneous X-ray imaging and diffraction at a fixed sample location, enabling the real-time investigation of dynamic fluid-rock interactions relevant to subsurface energy storage. In this study, DIAD is applied to two geoscience case studies: barite precipitation in sandstone and carbonate dissolution in mudstone. For the mineral precipitation experiment, the injection of barium chloride and sodium sulfate solutions induces barite formation within a sandstone matrix. Three-dimensional reconstructed volumes reveal the coexistence of tabular and fibrous barite morphologies with the width of 5-10 µm, while X-ray diffraction (XRD) analysis identifies preferential growth along the (021) and (121) crystallographic planes. These observations are critical for understanding mineral scaling, as growth along specific planes may result in localised clogging of pore throats and fractures, thereby altering reservoir porosity and permeability. In the carbonate dissolution experiment, acid injection into mudstone predominantly induces mineral dissolution near the injection site. XRD patterns indicate that Mg-rich calcite is the primary mineral affected by the acid. The heterogeneity of the mudstone plays a significant role in governing fluid flow and reactive transport in geological formations, which is reflected by spatial variations in mineral and fluid concentrations in sample. Integrating in situ imaging with XRD analysis provides a comprehensive view of the crystallographic and mineralogical evolution during fluid-rock interactions. The insights gained from these experiments are instrumental for refining reactive transport models and optimising subsurface energy storage processes, including carbon capture and storage, hydrogen storage and geothermal energy systems.