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Investigating Pore-Scale Geochemical and Structural Changes for Sustainable Lithium Extraction

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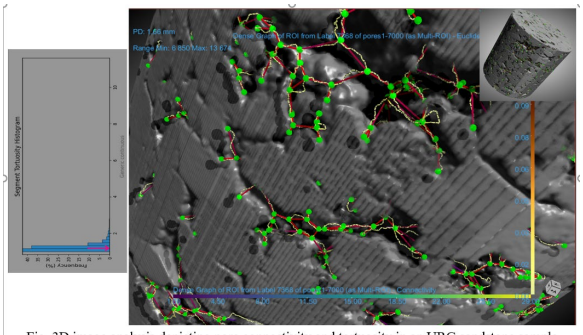

Fig. 3D image analysis depicting pore connectivity and tortuosity in an URG sandstone sample

Abstract

The global energy transition requires secure, sustainable, and responsibly sourced critical materials, with lithium playing a key role in battery technologies for renewable energy storage. The Upper Rhine Graben (URG), a crucial segment of the European Cenozoic Continental Rift System, hosts high-temperature hydrothermal brines with lithium concentrations up to 210 mg/L, making it a prime target for sustainable lithium extraction. However, the long-term viability of lithium recovery and geothermal reservoir management remains uncertain due to poorly understood pore-scale geochemical and structural changes. This study investigates the microscopic mechanisms governing fluid transport, mineral reactivity, and reservoir permeability evolution in URG sandstone formations.

We employ X-ray micro-computed tomography (micro-CT) to visualize three-dimensional pore network modifications before and after hydrothermal fluid exposure (2 molal NaCl at 200°C). Combined with deep learning-based image segmentation and Digital Volume Correlation (DVC), this approach provides unprecedented insights into porosity evolution, clay mineral transformations, and dissolution-precipitation dynamics. Additional analyses, including petrography, SEM-EDX, and ICP-MS tracking of lithium release, will further elucidate key fluid-rock interactions.

The results of this study will advance our understanding of reservoir-scale permeability evolution, directly informing strategies to optimize lithium extraction while maintaining long-term reservoir integrity. These insights are essential for enhancing the economic feasibility and sustainability of geothermal lithium production in the URG and similar georesource settings worldwide.

Keywords

Lithium- X-ray micro-computed Tomography- Sustainability- Upper Rhine Graben

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