Contribution ID: **489** Type: **Oral Presentation**

Direct observations of solute dispersion in rocks with distinct degree of sub-micron porosity

Monday, 19 May 2025 14:05 (15 minutes)

The transport of chemical species in subsurface rocks is influenced by their structural heterogeneity, resulting in a wide range of local solute concentrations. In the context of CO_2 storage, understanding chemical transport is crucial for processes such as the convective dissolution of CO_2-rich brine in saline aquifers and the precipitation or dissolution of $CaCO_3$ in carbonate reservoirs - processes driven by mixing between miscible fluids. To accurately quantify these spatial mixing behaviors, advanced methodologies are required for detailed characterization of both the rock's spatial heterogeneity and the resulting solute concentration distributions within the fluids.

In this study, we demonstrate the application of asynchronous multimodal imaging using X-ray computed tomography (XCT) and positron emission tomography (PET) to investigate passive tracer experiments in laboratory rock cores with varying degrees of subcore-scale heterogeneity and microporosity [1]. The four-dimensional concentration maps generated by PET reveal distinct signatures of the transport process, which we quantify using concentration probability density functions and fundamental measures of mixing and spreading. We observe that solute spreading strongly correlates with the degree of subcore-scale porosity heterogeneity measured by XCT. However, the extent of spreading is significantly moderated by the presence of sub-micron porosity, which enhances dilution and ultimately contributes to the so-called "anomalous transport" observed in breakthrough curves.

The PET imaging approach is capable of distinguishing between spreading and mixing in heterogeneous media. By complementing it with XCT, this distinctive behavior can be directly correlated to the strength and structure of subcore-scale heterogeneity. The proposed workflow bears important implications because classical breakthrough curve analysis cannot be used to unequivocally separate the effects of spreading and mixing. The dataset generated in this study [2] provides a foundation for developing realistic digital rock models and benchmarking transport simulations that incorporate rock property heterogeneity in a deterministic manner.

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References

[1] Kurotori, T., Zahasky, C., Benson, S., and Pini, R. (2024). Direct observations of solute dispersion in rocks with distinct degree of sub-micron porosity. Authorea. https://doi.org/10.22541/au.172426895.50891936/v1.
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Session Classification: MS26

Track Classification: (MS26) Mechanisms Across Scales in Subsurface CO2 storage: A Special Session in Honor of Sally Benson