Contribution ID: **200** Type: **Poster Presentation**

Role of Surface Roughness and Fracture Aperture in Enhancing CO_2 Mineralization in Synthetic Olivine Fractures

Wednesday, 21 May 2025 10:05 (1h 30m)

In-situ mineralization provides a promising pathway for permanent carbon storage, but achieving efficient subsurface mineralization requires sufficient permeability in the host rock formation, a significant challenge for scaling up these processes. This work investigates the effects of fracture characteristics (i.e., surface roughness and fracture aperture) on CO_2 mineralization reaction by reacting saw-cut dead-end fractures in forsteritic olivine. Synthetic fractures with controlled apertures (0.5–1.6 mm) and varying surface roughness were subjected to high-pressure (13.7 MPa) and high-temperature (185℃) CO_2 batch experiments for two weeks. Post-reaction characterization techniques, including Raman spectroscopy, X-ray diffraction (XRD), and optical microscopy, were used to assess the extent of mineralization, identify secondary minerals, and determine their relative abundance.

In small fractures (0.5–0.6 mm), results from optical microscopy and Raman spectroscopy showed that the co-precipitation of magnesite ($MgCO_3$) and maghemite (Fe_2O_3) occurred primarily on rough surfaces, while smooth surfaces exhibited lower carbonation rates and minimal iron oxide precipitation. We also observed the diminishing effect of surface roughness on mineralization in large fractures (1–1.6 mm), as they exhibited more uniform magnesite and maghemite precipitation across both rough and smooth surfaces. This uniformity can be attributed to the formation of a Fe-Si-rich coating on the olivine surface. This coating masks the surface characteristics of the olivine, reducing the influence of surface roughness on carbonation rates. In smaller fractures, fewer ferrous oxides precipitate, leaving more olivine exposed to aqueous fluids. This exposure allows surface roughness to play a more significant role in influencing carbonation in smaller fractures. This study provides fundamental insights into the effect of fracture characteristics on CO_2 mineralization. Understanding this relationship is essential for optimizing subsurface mineralization processes and scaling up operations to achieve meaningful contributions to carbon storage efforts.

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References

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Session Classification: Poster

Track Classification: (MS25) Advances in Carbon Mineralization: Unveiling Multiscale Geo-processes and Coupled Mechanisms