Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35485

The Impact of Chemical Interactions on Deformation in Mica Minerals Assessed with In-Situ Nanoindentation

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Layered materials, such as muscovite mica, exhibit complex deformation behaviors under mechanical stress, significantly influenced by environmental conditions. Understanding these interactions is crucial for subsurface engineering applications like carbon storage and nuclear waste containment. This work develops a mechanistic framework to differentiate and quantify deformation mechanisms in muscovite under varied chemical stressors using nanoindentation. Discrete displacement bursts (pop-ins) in load-displacement data serve as proxies for deformation events such as delamination, kink band formation, and fracture.

In-situ liquid nanoindentation demonstrated significant chemomechanical weakening of muscovite in aqueous solutions. In the presence of hydroxyl ions (OH^-), Si-O-Si bonds undergo more frequent hydrolysis, resulting in a decrease in hardness and reduced modulus by over 40% in a pH 12 0.1M NaCl solution [1]. Analysis of over 9,000 displacement bursts revealed that NaCl solutions decreased the minimum plastic zone volume required to initiate a burst by an order of magnitude compared to dry conditions. Importantly, the statistics of these bursts follow scale-independent avalanche scaling theory, indicating that environmental conditions tune the system's proximity to a critical failure point [2]. This research provides a new framework for linking chemical reactions to small-scale deformation events, and further to the large-scale mechanical behavior of layered minerals.

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