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Reaction-driven mineral expansion and its impact on fluid flow

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Addressing climate change necessitates shifting from fossil fuels to renewables and implementing carbon capture and storage (CCS). Storing CO_2 in mafic and ultramafic rocks is appealing due to the potential for mineral conversion. Recent pilot studies showed the feasibility of mineral CO_2 storage in basalts. However, combating climate change requires increasing injection volumes by several orders of magnitude. Discussion continues on whether mineralization processes will still be as efficient at larger scales. One foreseen issue is the potential pore clogging due to mineral precipitation, eventually impeding the reaction. While reactive transport models based on dissolution-precipitation mechanism predict pore clogging and thus the limited extent of reaction, there is clear field evidence for complete reactions in natural analog systems. Besides, developing new injection sites requires pre-injection feasibility studies based on numerical simulations. These simulations aim to provide an initial evaluation of the potential success and challenges associated with the proposed CO_2 injection project. They require large-scale, high-resolution simulations, which are challenging for commercially available codes. Recent success in using GPUs for scientific computing combined with matrix-free numerical methods stimulates the development of new numerical models and the revisiting of underlying theoretical approaches. CCS in depleted reservoirs, especially with old plugged-and-abandoned wells, also presents challenges. CO_2 interacting with old cement compositions may compromise well integrity, leading to potential CO_2 leakage along wellbores. Chemical reactions, fluid flow, and deformation are intricately coupled processes. Studies highlight the dependence of reaction progress both on assumed kinetics and constitutive hydro-mechano-chemical models. While conventional knowledge suggests transport-dominated reactions leading to pore clogging, recent observations challenge this, indicating that reaction-induced alterations occur in the solid phase without changing pore volume. A novel model addressing reaction-driven mineral expansion is presented, preserving porosity while allowing solid volume change. Examining fluid-rock interaction at the pore scale, we derive effective rheology for reacting porous media. The micromechanical model assumes rocks or cement as assemblies of solid reactive grains, accommodating externally applied and reaction-induced stresses through elastic, viscous, and plastic deformation mechanisms. Depending on the level of reaction-induced stresses, the model predicts either pore clogging or porosity-preserving solid volume increase as dominant mechanisms, with the latter facilitating complete reactions. Macroscopic stress-strain constitute laws account for chemical alteration and viscoelastic deformation, elucidating the dependence of mechanical rock properties on fluid chemistry [1]. We use a two-phase continuum medium approach and local equilibrium thermodynamic models [2]

to investigate the coupling between reaction, deformation, and fluid flow on a larger scale. We consider two simple examples of the carbonation of portlandite and the hydration of mantle rocks. Both reactions are associated with a change in solid volume. We show how reaction-driven mineral expansion affects the porosity evolution and reaction progress.

References:

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