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Reactive flow and homogenization in anisotropic media

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Dissolution by reactive fluid flow is a fundamental process in geological systems. It controls diagenesis and karst evolution and has broad implications for groundwater hydrology. Specifically, reactive flow controls the evolution of the void-space structure via the feedback between the reaction and transport. In some instances, advective transport rate is high compared to that of geochemical reactions (low Damköhler number, Da), such that the reactive fluid penetrates the system before its reactivity is exhausted, resulting in a relatively spatially-uniform dissolution. Despite the importance of low Da conditions, the emerging transformations in the medium structure, flow field, and its bulk properties are not well understood. Likewise, our ability to decipher diagenetic history and preexisting structure is lacking.

Here, using a network model, we investigate the evolution of heterogeneous and anisotropic medium during dissolution at low Da conditions. The numerical simulations show that the medium progressively becomes more homogeneous as well as isotropic, which consequently makes the flow field more uniform. Homogenization is particularly notable for anisotropic media, in which the transverse channels are wide relative to the channels parallel to the main flow direction. In this case, flow is initially focused within a few highly tortuous pathways, hence emphasizing the effect of dissolution on flow heterogeneity and tortuosity. The homogenization process is further enhanced when the surface reaction is transport-controlled—that is, when diffusion of dissolved ions away from the mineral surface to the bulk fluid is slow, reducing the reactivity adjacent to the surface: At first, since diffusive transport is more effective in narrow channels, they undergo faster dissolution, which selectively enlarges them leading to an initial steep rise in permeability. Later, however, as dissolution proceeds and the channels broaden, the overall dissolution rate drops, diminishing the growth rate of permeability. Our findings provide fundamental insights into reactive transport and hydrogeological processes in fractured and porous media.