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Impact of heterogeneity and its alteration by erosion on solute transport in unsaturated media

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Solute transport in unsaturated media exhibits a complex, nonmonotonic dependence on fluid saturation and flow rates. Adding to the intricate dependence of multiphase flow and solute transport on the heterogeneity across scales is their coupling: the sensitivity of the concentration fields to the spatial distribution of the fluid phases and their velocity fields.

Here, we study solute transport following partial displacement of one fluid by the other, where the fluids are immiscible and hence solute transport occurs only in one fluid and the fluid-fluid interface acts as barrier for transport.
We combine pore-scale simulations (using openfoam) with microfluidic experiments to examine the role of the pore-scale heterogeneity structure (in terms of its spatial correlation) and its evolution with chemical and mechanical erosion.
We find that increasing the correlation length in particle size increases fluid connectivity, and thus the solute spreading by reducing the number of advection-dominated regions. Decreasing saturation of carrier fluid (in which dissolved solutes are transported) is found to promote dead-ends (slow flow regions), and thus of diffusion.

We compare two simple forms of erosion in granular media: mechanical where the smallest particles are washed away, vs. chemical where all particles are shrunk by uniform dissolution. We find that mechanical erosion, unlike chemical erosion, alters the pore space morphology toward a multi-modal variation in pore sizes, which shifts transport towards a more non-Fickian spreading. For saturated media, erosion induces a non-monotonic effect on solute spreading, promoting spreading at the diffusion-dominated (low Peclet) regime while suppressing it at higher rates (high Peclet). Under unsaturated conditions, erosion decreases spreading by reducing local velocities through widening available pathways, and enhances mixing by minimizing dead-ends which enhances the relative strength of advection.

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References

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