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The impact of spatial heterogeneity on mixing and reactions in coastal aquifers

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Abstract

The fresh-saltwater transition zone is a critical region for enhanced chemical reactions arising from chemical disequilibrium and variable density flow. We investigate the impact of heterogeneity on the chemical reaction of fast calcite dissolution in coastal aquifers. While previous studies have addressed calcite dissolution in idealized homogeneous coastal aquifers, none have comprehensively investigated the role of heterogeneity for the same hydrogeochemical problem. Here, we consider three different types of heterogeneity (multi-Gaussian, connected and disconnected fields) for weak ($\sigma^2_{lnK} = 1$) and strongly heterogeneous ($\sigma^2_{lnK} = 3$) media. We find that heterogeneity not only influences the characteristics of the saltwater wedge (length of the toe, width of the mixing zone and mixing area), but also strongly impacts the local and global response of mixing and reaction rates across the salt-freshwater mixing zone. As expected, we find that heterogeneity increases the width of the mixing zone. On the other hand, although the considered heterogeneous fields have identical spatial statistics, the effective hydraulic conductivity for connected and disconnected fields is altered, which significantly impacts on the length of the toe leading to an advance and recession of the wedge, respectively. We also find that reaction rates (i.e. spatial dissolution patterns) in heterogeneous media yield unique features that strongly differ from that of the homogeneous case due to increased fluid segregation and subsequently velocity variations. Numerical results also provide evidence that although connected heterogeneous fields have the lowest dissolution potential per unit area, they have the highest local reactions rates which better address the potential for karst formation. We also compare the global reaction rates to their equivalent homogeneous counterparts and we find that for weakly heterogeneous media the global behavior can be captured fairly well. Under stronger heterogeneities, however, the effective behavior tends towards the global mixing rate. We demonstrate that heterogeneity plays a key role in the formation of more realistic dissolution patterns and reaction networks observed in actual karst systems.

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