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How to Best Model Multiscale Capillary Heterogeneity for Geologic CO2 Storage

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Objectives and Scope
The impact of capillary heterogeneity on CO2 multiphase flow behavior has been increasingly recognized in the past decade. Ranging from millimeter to kilometer scale, capillary barriers are prevalent in the subsurface. They can be formed wherever geologic heterogeneity exists, from slight variation in the sand grain sizes, to an extensive sequence of interbedded sand and shale. Because capillary heterogeneity is multiscale, its influence on CO2 flow and trapping also carries across scales. Therefore, it is important for practitioners to better understand and model capillary heterogeneity for CO2 storage.

Methods, Procedures, Process
We conducted a review on pertinent literatures and elaborated key observations from the core to field scales. For example, experimental studies have shown that millimeter-decimeter scale capillary heterogeneity can cause above-residual capillary trapping known as capillary heterogeneity trapping. Capillary heterogeneity at this scale can also lead to complex upscaled constitutive relationships under capillary-dominated flow regimes, such as flow-rate dependent and anisotropic relative permeability as well as non-conventional initial-residual saturation relationships. Furthermore, under gravity-dominated flow regimes, centimeter-meter scale capillary heterogeneity can entrap a significant amount of CO2 not just after imbibition, but also during drainage. The presence of capillary heterogeneity can even completely arrest the vertical movement of CO2 plume, hence not only greatly reducing leakage risks, but also demonstrating the feasibility of an alternative confining system to traditional continuous seal/cap rocks.

Results, Observations, Conclusions
To accurately model the influence of capillary heterogeneity on CO2 plume migration and retention at the field scale, a geologically realistic earth model is needed to ensure the proper representation of capillary heterogeneity across various scales, especially the larger-scale heterogeneity. At smaller scales, capillary effects should also be emphasized so that constitutive multiphase flow relationships affected by small-scale capillary heterogeneity can be properly upscaled.

Significance/Novelty
In this work, we present our best theoretical recommendation for a step-by-step workflow on how to preserve capillary heterogeneity across scales in order to increase accuracy when modeling CO2 plume migration and trapping in storage aquifers based on the literature reviewed.

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References

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