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CO_2 migration and sequestration by combined capillary and solubility trapping: theory, experiments, and capacity estimates at the basin scale

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The large-scale injection and storage of carbon dioxide (CO_2) into deep saline aquifers is a promising tool for reducing atmospheric CO_2 emissions to mitigate climate change. Success of geologic sequestration relies on trapping the buoyant CO_2, to minimize the risk of leakage into shallower formations through pre- existing wells, fractures or faults. However, traditional reservoir-simulation tools are currently unable to resolve the impact of small-scale trapping processes on fluid flow at the scale of a geologic basin. Here, we formulate a sharp-interface mathematical model for the post-injection migration of a CO_2 plume driven by groundwater flow in a sloping aquifer, subject to both capillary trapping and CO_2 dissolution by convective mixing. We develop semi-analytical solutions that elucidate the nontrivial interplay between the two trapping mechanisms, and how their synergetic action controls plume migration. We validate the theory by means of laboratory experiments with analogue fluids to study how convective mixing arrests the buoyant current. We use our findings to estimate the dimensionless rate of solubility trapping for several large saline aquifers in the United States, and assess the importance of solubility trapping in practice.