Effect of Sub-seismic Reservoir Heterogeneity on CO_2 Plume Migration, Onshore Gulf of Mexico

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The University of Texas at Austin, 2024

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This study examines the impact of sub-seismic faults and channels on CO_2 plume behavior in the Lower Miocene formation in an onshore area of the Texas Gulf of Mexico. This geological formation is characterized by heterogeneous reservoirs with an important amount of unconsolidated fluvial sandstones, where sub-seismic faults and channels are challenging to identify using conventional seismic methods. The research focuses on potential unintended lateral migration of CO_2 and changes to the area of review (AoR) size beyond the leasing area in carbon capture and storage (CCS) projects.

A methodology was developed to characterize sub-seismic faults and channels by integrating seismic data, literature correlations, and well log analysis. Fault seal capacity was estimated using a combination of shale gouge ratio (SGR) and transmissibility multiplier approaches, yielding fault transmissibility values higher than 0.1 as a realistic value for sub-seismic faults. Additionally, a workflow for generating capillary pressure and relative permeability curves was established, integrating literature data and well-known correlations. This workflow enables reservoir engineers to include these curves in the simulation even in data-scarce regions.

Experimental static models were built using available geological information, including 2D/3D seismic amplitude extractions, well log correlations, and core data integration. These were followed by dynamic simulations incorporating these sub-seismic features in synthetic, single-unit, and full-field models. Sensitivity analyses on geological uncertainties and sub-seismic fault characteristics revealed that sub-seismic faults with transmissibility values higher than 0.1 have minimal impact on the AoR size and shape. CO_2 migration was confined to high-permeability injection zones, while pressure dissipation occurred throughout the model, with low-permeability zones acting as pressure buffers.

The full-field models validated these findings under realistic operational constraints, demonstrating that sub-seismic features do not significantly influence unintended CO_2 migration or pressure buildup in most scenarios. Additionally, low-permeability zones were found to act as barriers to CO_2 flow and as pressure dissipation reservoir units, reducing AoR size and shape.

These findings suggest that operators should prioritize seismic-scale feature characterization and consider heterogeneous geological settings without the need of regional seals for CO_2 injection. Proper boundary definitions are critical for optimizing AoR size, minimizing costs, and enabling CCS projects in areas previously considered as unsuitable. - This study highlights the potential of composite confinement systems concept in enabling effective CO_2 storage in complex geological environments.