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Multi-scale Evaluation of Leduc and Ireton Formations for Geological CO_2 Sequestration

A. Younis, M. Shabani, A. Ghanizadeh, C.R. Clarkson, M. Parvazdavani, Af. Ghanizadeh
Department of Earth, Energy, and Environment (EEE), University of Calgary

Summary

Geological CO_2 sequestration (GCS) in deep saline aquifers and depleted oil and gas reservoirs has been identified as a key strategy to reduce CO_2 emissions (Bachu and Bennion 2008, Bachu et al. 2014, Chalaturnyk 2022). The Upper Devonian Leduc Formation in Alberta, with the overlying Ireton caprock, is an attractive target for GCS (Lyster et al. 2024). Widespread lateral distribution, significant thickness (up to 260 m; Downing and Cooke 1955), high permeability (up to thousands of md), large pore volumes (cm-sized vuggy pores), and the presence of an overlying effective seal underscore its potential for GCS.

Although the Leduc Formation has been extensively explored for oil and gas extraction, few studies (e.g., Stacy 2024) have evaluated its petrophysical properties for GCS applications. The majority of the core analysis studies were conducted between the 1950s and the 1970s for hydrocarbon exploration, using older core and instruments with limited technological advancements. Hence, these historical datasets often lack accuracy and do not meet the rigorous standards required for modern numerical simulation models, such as measurements taken under reservoir conditions (e.g., stress). Additionally, the Leduc Formation is highly heterogeneous, exhibiting a range of permeability and pore sizes due to depositional processes inherent to shallow-water reef systems (Amthor et al. 1994) and post-depositional processes such as dolomitization (Stacy 2024). This small-scale heterogeneity, characterized by variable pore sizes (nm to cm) and diverse pore types (intracrystalline, melodic, vuggy, and fractures), and core sampling biases (full diameter to small core plugs), make it challenging to determine representative permeability using conventional methods.

In this study, a multi-scale experimental workflow was developed to characterize the Leduc and Ireton formations for GCS evaluation. To capture the geological variability of the Leduc Formation across Alberta, three cores from northwestern, central and southern Alberta were selected for this study. A variety of routine and special core analysis methods were conducted on slabbed cores and selected core plugs. The primary focus was to identify lithofacies within the Leduc Formation, evaluate caprock sealing efficiency, and understand the controls on CO_2 storage and flow properties.

A high-resolution (cm-scale) screening core analysis dataset was collected for selected slabbed core intervals including elemental composition (X-ray fluorescence), profile gas (N_2) permeability and mechanical hardness, to characterize vertical heterogeneity and flow units (Becerra et al. 2024). Lateral heterogeneity was also characterized by combining high-resolution cm grid screening with CT scanning for selected core pieces.

Based on screening results, core plugs were drilled from different lithofacies and stress-dependent gas permeability and dynamic geomechanical properties were measured under reservoir conditions. Subsequently, brine permeability and CO_2-brine relative permeability were measured for selected core plugs to evaluate the relative permeability displacement characteristics of CO_2-brine systems in the Leduc Formation. These experimental results will be valuable for numerical simulation models for GCS in heterogeneous carbonate formations.

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