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# Editorial: Developments in reservoir characterization for carbon dioxide sequestration

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Editorial on the Research Topic
Developments in reservoir characterization for carbon dioxide sequestration

To restore the climate back to its natural trend, the National Academy of Sciences (NAS) and Intergovernmental Panel on Climate Change (IPCC) posit that up to 10 Gt of Carbon Dioxide ($CO_2$) may be needed to be removed annually from the atmosphere by 2050. Even if $CO_2$ is removed from the atmosphere through Direct Air Capture (DAC), or other mechanisms, the biggest question is where to store such large volumes of gas. The subsurface presents a vast array of sedimentary reservoirs in the form of depleted oil and gas and saline formations that can hold $CO_2$ in a supercritical state for geological periods of time. Naturally, sequestering $CO_2$ in the subsurface is viewed as one of the most promising ways of addressing the issue of climate change. The process is, however, not without its own set of risks or challenges. Faults and fractures, weak caprock, and proximity to naturally unstable crust are among the many factors that may lead to leakage of the injected $CO_2$ from the reservoir. This issue of Frontiers is dedicated to identifying and characterizing subsurface formations for sequestering $CO_2$ safely over geological periods of time.

The article by Wei et al. discusses a framework for assessing $CO_2$ storage capacity for subsurface reservoirs. The article takes a broad view of the characterization process and divides the assessment criteria into nine categories to account for several geological and non-geological variables. These include geological heterogeneity, trapping mechanism, data resolution, algorithmic efficacy, data evaluation, and integration strategies, storage efficiency and capacity in the framework of the intended storage period, as well as economics and regulatory protocols. The article further highlights the role of data resolution and algorithmic efficacy in assessing the $CO_2$ storage capacity of a formation and argues that a repeated evaluation of error bars posted on the storage capacity numbers is necessary through the integration of new data. The authors in fact emphasize uncertainty re-evaluation as an integral part of $CO_2$ storage endeavors. The article illustrates the proposed hierarchical classification using the example of sedimentary basins from mainland China.

Cao et al. present a case study focusing on a potential $CO_2$ storage unit, the redbeds of Hazlehurst, in the Coastal Plain area in the states of Georgia and South Carolina (United States). The storage unit is a saline reservoir that includes a sedimentary sequence with a maximum thickness of 450 m. The study focuses on an integrated workflow based on stratigraphic modeling, well-log analysis, and petrophysical studies to assess the storage capacity at the regional scale. The main trapping mechanism is associated with capillarity and solubility. The study also investigates sealing properties.

The article by Romdhane et al. presents a workflow for screening, monitoring, and remediation of legacy wells in the context of $CO_2$ storage in saline aquifers. The article uses the example of the Horda platform, North Sea, as a strong candidate for offshore large-scale CO2 storage due to factors such as proven storage capacity, caprock integrity, existing infrastructure, and public acceptance, but cautions that the legacy wells tend to pose the biggest risk. The article argues that evaluating well integrity is the key to opening up depleted reservoirs for $CO_2$ storage and using real data examples from the Norwegian Continental Shelf (NCS) demonstrates the workflow which consists of 1) screening and evaluating all legacy wells in the given area, 2) building a numerical model for the chosen legacy wells based on plugging and abandonment reports, 3) modeling electromagnetic response of the well to identify monitoring capabilities, 4) proposing possible remediation approaches using an electrochemical enhanced mineral deposition.

Almutairi et al. use seismic impedance inversion to identify potential $CO_2$sequestration targets in the Cretaceous section of the South Georgia Embayment offshore the southeastern United States. Using legacy industry seismic data and additional data from exploratory wells in the area, they perform a joint inversion of seismic and log data to determine porosity everywhere within the seismic dataset. A correlation between porosity and permeability from the COST GE-1 well is then used to estimate permeability from the inverted porosity values. They identify two potential sequestration targets at depths of ~1,646–1,700 m (5,400–5,580 ft) and ~1,743–1,814 m (5,720–5,950 ft). The deeper target is predicted to have higher porosity (19–30.1%) than the shallower (17–23%), while both are predicted to have permeabilities ranging from mD to hundreds of mD. Both targets are interpreted to be capped by low-permeability shales, which could form potential capillary seals. This paper demonstrates the utility of legacy seismic data in identifying $CO_2$sequestration targets and suggests that further work should be performed to delineate the $CO_2$sequestration potential of the southeastern U.S. offshore region.

The article by Ansari et al. evaluates the effect of $CO_2$, and low- and high- Total Dissolved Solids (TDS) injection on overpressure in the caprock, reservoir, and its hydraulically connected crystalline basement. The research is motivated by the induced seismicity patterns observed in Kansas in the last decade. The article observes that while $CO_2$ injection pressures the caprock, high TDS brine injection increases pressure in the basement. Although the results may broadly reflect intuition given the buoyant nature of $CO_2$ compared to high and low TDS fluids, the paper shows the crucial role of permeability in determining the rate at which pressure propagates through the system.

The article by Dawuda and Srinivasan looks into quantifying geological heterogeneity in fluvial reservoirs. The focus of the paper is point bars, which is a common architecture for siliciclastic reservoirs being considered for storage of $CO_2$ worldwide. The first part of the paper is dedicated to modeling the architecture itself using curvilinear grids to best account for the structural contours. The second part is the calibration step using historic data where the point-bar model is updated using the Ensemble-Kalman filter first for structure and then for permeability. The workflow is demonstrated on the Cranfield point-bar reservoir, Mississippi, United States.

The paper from Bowersox et al. presents an overview of the properties of the Rose Run sandstone formation, Central Appalachian Basin, Northeast Kentucky, and assesses the formation's capabilities to store $CO_2$. For this important aquifer in the Appalachian basin, two existing studies based on Batelle 1 and Ohio 1 wells concluded that the Rose Run formation was not suitable for $CO_2$ storage. The authors underlined the key differences with the northeastern Kentucky location and demonstrate that reservoir properties, storage capacity, and sealing properties are sufficient for the storage of supercritical $CO_2$, as part of a stacked-storage reservoir. They especially emphasize that average porosity and net reservoir thickness are sufficient and that the overburden property is satisfactory with careful monitoring of injection pressures.

The most important lesson learned from articles in this special section is that although saline aquifers and depleted oil and gas formations are abundant, not every unit is suitable for $CO_2$ injection and storage. Based on the collective findings, seal integrity and formation permeability emerge as the two most critical factors that determine the long-term storage feasibility. The injected $CO_2$ migrates away from the wellbore and rises towards the top of the formation (due to buoyancy), eventually getting accumulated below the sealing caprock. Intermittent sealing units, depending on their thickness and location, can also trap a portion of the injected $CO_2$. However, as intuitively expected, thin, weak or structurally deformed seals may not be able to hold a sizable continuous $CO_2$ column for long periods of time. Although the papers here provide a generic sense of $CO_2$ dynamics within a fully-connected porous medium, future studies are needed to understand how the same system will behave when the permeability structure and capillary forces are time-varying, e.g. due to chemical trapping (reaction between $CO_2$ and reservoir minerals).

## Author contributions

PJ organized the special issue. All authors contributed to the article and approved the submitted version.

## Conflict of interest

BD was employed by the SINTEF.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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