Geoscience for CO₂ storage: an introduction to the thematic collection

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During the first year of the global Covid-19 pandemic (2020), the Editors of Petroleum Geoscience decided to invite submissions under an open call for papers on the theme of CO₂ storage geoscience, in contrast to the historical practice of drawing thematic collections from inspiring conferences. The experiment was very successful, and the collection built steadily towards 12 research papers by the end of 2021, when the editors drew a line in the sand for this particular call. No doubt many more papers on this theme will continue to be published in this and other Journals, however this particular set provides a valuable snapshot of the state of play in 2020–2021.

It is clear that in the transition towards a carbon-neutral future, CO₂ storage will be a critical technology for decarbonization of society, particularly in those areas of industry and energy supply where renewable energy solutions are more difficult to apply, or where CO₂ is a by-product of the process (e.g., manufacture of cement or fertilizer). Successful geological storage of CO₂ requires careful consideration of many factors in geoscience and engineering, some of which have long been critical in petroleum exploration and production activities, while others are relatively new. It is therefore important to foster and disseminate the emerging geoscience skill set needed to mature and apply CO₂ storage technology.

We cannot review the entire fields of CO₂ capture and CO₂ storage in this short introduction and there are many such reviews found elsewhere. Readers unfamiliar with the underlying concepts may like to refer to MacDowell et al. (2010) on CO₂ capture technologies, Baines and Worden (2004) or Benson and Surles (2006) on CO₂ storage concepts and Ringrose (2020) on operational experience with CO₂ injection projects. The goal of this thematic collection is to bring together recent insights from current fields of research and current industry practice to illustrate recent progress and future directions – with a focus on the geoscience aspects. The suggested themes in the call for papers included regional screening studies, quantification of storage containment systems, predictive models of storage processes, storage site management, monitoring methods and long-term fate of CO₂ in the subsurface. The papers included in the collection covered most of these themes, although not necessarily with the breadth of content implied by the ‘wish list’. However, the papers do cover the span from regional mapping to site-specific case studies and can be grouped under the following themes:

- regional mapping for storage potential (2 papers)
- site screening studies (3 papers)
- assessment of trapping mechanisms (3 papers)
- assessing containment and leakage risks (4 papers)

Under the theme of regional mapping for storage potential, we have a significant national mapping study by Pereira et al. (2021) in which they assess and quantify the storage potential of Portugal for both onshore and offshore regions. The study builds on previous continental-scale resource mapping but matures the previous work significantly to quantify the resources for the nation of Portugal. They derive probabilistic ranges for CO₂ storage capacity in the many basins of western Iberia with a central (P50) estimate of 7.09 Gigatonnes (Gt) for the total storage potential in Portugal. They identify the Lusitanian Basin (West Iberian Margin) as the most suitable basin for storage, as it covers both onshore and offshore regions and offers significant storage capacity favourably located in relation to the main industrial CO₂ emitters. The second paper under this theme is an evaluation of the CO₂ storage potential via CO₂ enhanced oil recovery (EOR) projects in the petroleum basins of Colombia. Yáñez et al. (2022) explain how different screening approaches, deterministic and probabilistic, lead to different estimates for the volumes of CO₂ that could be stored via CO₂-EOR and associated geological storage. For example, five large oil fields could be used to store around 200 Mt of CO₂ while producing up to 690 million barrels of incremental oil. The underlying concept is that the additional oil produced can finance the CO₂ storage activity offering a pathway towards a decarbonized economy.

Moving on to the theme of site screening, Payton et al. (2021) take a more fundamental look at the pore-scale properties needed to provide sufficient permeability for storage projects. Focusing on sandstones from the UK Geoenergy Observatories (UKGeOS) site in Glasgow, they assess the suitability of sandstones from the Coal Measures Formation as compared with the Wilmslow Sandstone Formation in Cumbria, UK. The pore-scale analyses conducted showed that the Glasgow site material was unsuitable for CCS due to its very low porosity while the Wilmslow Sandstone...
demonstrated good porosity and permeability, thus emphasizing the importance of screening studies and reminding us that suitable storage formations may not always be found where you need them. In the study presented by Pourmalk et al. (2022) they start with potentially good storage sites in terms of pore-scale properties and go on to assess the impacts of larger-scale sedimentary heterogeneities for mixed siliciclastic–carbonate systems. Using detailed 3D models from three contrasting outcrop analogue field sites (the Grayburg Formation in the USA, the Lorca Basin outcrop in Spain, and the Bridport Sand Formation in the UK), they show how facies architecture affects fluid flow, storage capacity and security. The interplay between layering and fluid buoyancy forces is clearly shown to be important, affecting both storage efficiency and the fluid contact area between the injected CO₂ and brine, thereby promoting CO₂ dissolution. Overall, reservoir heterogeneities in these mixed carbonate–siliciclastic facies contribute to improving the safe and effective storage of CO₂. Proietti et al. (2022) estimate the potential storage capacity of four saline aquifers in the northern Adriatic Sea (Cornelia, Patrizia, Elga and Serena), using 3D petrophysical models in combination with standard capacity equations. Porosity values were obtained from sonic logs, and variograms were based on the sedimentary environments. CO₂ density was estimated from effective pressure and temperature. The analyses show the effect of varying the key input parameters to obtain a realistic estimate of capacity for each structure.

Leslie et al. (2021) take an in-depth look at CO₂ solubility in brine, a trapping mechanism providing an important component of long-term storage security. The current uncertainties on the rates and magnitudes of this process can be significantly reduced by comparing data from natural analogue sites with engineered CO₂ storage reservoirs. Their insightful review shows that solubility trapping can account for between 10 and 50% of the CO₂ stored. Timescales are important, and the data from natural analogue reservoirs indicates they are in dissolution equilibrium for most of the CO₂ residence time. Their plot of average dissolution rate v. CO₂ storage duration from multiple datasets (Leslie et al. 2021; Fig. 4) is likely to be a valuable resource for many years to come. Pearce et al. (2021) take us into a detailed evaluation of CO₂ mineral trapping mechanisms, using a case study from the Precipice Sandstone reservoir and overlying Evergreen Formation – an important reservoir-seal pair for prospective CO₂ storage in the Surat Basin, Australia. They show that while no significant CO₂ mineral trapping will occur in the quartz-rich Precipice Sandstone reservoir, some mineral trapping in the overlying Evergreen Formation could occur, depending on the amounts of more reactive feldspars, clays, calcite and siderite. As well as neatly demonstrating the analytical techniques used (e.g. SEM-EDS) and the kinetic geochemical models needed to quantify the reaction geochemistry, the study also illustrates how mineral trapping is likely to provide additional long-term security to the CO₂ storage process. Stewart (2022) proposes a novel variation on more conventional trapping mechanisms, whereby dissolution of CO₂ in the aqueous phase of the saline aquifer would lead to a denser fluid gradually sinking to the base of the formation. In contrast to buoyant fluids which are normally considered in hydrocarbon exploration and CO₂ storage, ‘spill’ from a high-level synform would be downward into the basin rather than up towards the surface or caprock. A potential benefit of this mechanism would be a significant increase in storage volumes available in synforms, potentially up to the size of the entire basin.

In summary, as well as offering valuable insights into current research in the field of CO₂ storage geoscience, this collection should also help new practitioners appreciate the many aspects of exploration, appraisal and development as applied to this ‘new use’ of the subsurface. While CO₂ storage geoscience has many overlaps with petroleum geoscience it also challenges us with new topics such as long-term forecasting of CO₂ and brine flow processes and migration of complex fluids along faults and into shallow aquifers.

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