Project summary: CO_2 seal bypass – a multidisciplinary approach to CO_2 migration and storage

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Abstract

A multi-disciplinary research project with a scope of increasing the understanding of CO_2 seal-bypass systems through studies of natural analogues in southwestern Utah is summarized.

The Navajo Sandstone – Page Sandstone – Carmel Formation – Entrada Sandstone – Curtis Formation – Summerville Formation succession is a largely siliciclastic-dominated succession, which is naturally fed by mantle-derived CO_2-rich fluids. Visually striking red rocks stained by Fe-oxides are bleached pale yellow/white by chemical reduction and dissolution into migrating reservoir fluids, creating visible traces of relict plumes and striations through strata. These now exhumed, stained units represent readily identifiable paleo-reservoirs and migration conduits for fluids, respectively. Typical field expressions are sandstone-dominated reservoir rocks that once were filled with reactive fluids (i.e. CH4 and/or CO_2 in groundwater), fed from below by fracture corridors in low-permeability rocks such as marls and mudstones representing the main migration pathways through reservoirs and seals (exceptions exist for both types).

Accessible cliff sections and drilled subsurface Jurassic strata in Utah represent an outstanding field laboratory to target fundamental understanding of natural CO_2 plumbing systems and how they are analogue to prospective storage of CO_2 elsewhere. The project covers aspects such as temporal impact of fluid flow and model forecasting capability, rock strength and geomechanical modeling of deformation. This will facilitate sensitivity studies on parameters affecting reservoir quality, integrity and responses, thus providing a tool for forecasting suitability of a given site for CO_2 storage. The work has included: (i) High-resolution field studies, (ii) assessment of scaling from mm-cm scale outcrop observations to high-resolution, representative element volume reservoir models, (iii) analyses of diagenetic effects, (iv) investigation of geomechanical properties of fault rocks and tight

caprocks, (v) investigation around how reservoir pressure and time-dependent diagenetic impacts caused by CO_2 migration affect geomechanical properties, and (vi) education.

The project integrates observations from actively leaking and former, exhumed reservoir-seal systems employing field, laboratory and reservoir modeling studies. The aim is to implement observed flow and leakage patterns combined with observed diagenetic status and rock strength assessments in 3D simulation models. The outcome will be valuable for CO_2 storage site assessment by aiding containment planning, leakage prevention and mitigation.

Key challenges that have been addressed:

- What are the detailed CO_2 flow paths in specific sedimentary architectures and along fault and fractures?
- How will diagenetic changes by exposure to CO_2 over time impact flow paths and thereby the storage efficiency of CO_2 sinks?
- What are the critical loads (stresses) for fracturing caprocks and reactivating faults, and can this data be upscaled and implemented in reservoir models?
- Could diagenetic removal of load-carrying minerals in CO_2-filled reservoir successions trigger reservoir collapse?
- Is it possible to design an integrated reservoir model including fault grids (Fault Facies) and sedimentary architecture that can reproduce case-true observations in flow modeling?
- Can advanced reservoir models calibrated on detailed field-based observations and lab experiments be implemented and thereby improve confidence in North Sea CO_2 reservoirs?

The project is currently in its final phases, and in a position to build on a platform of previously existing data as well as information generated by the teams involved. The onset of the project included extensive efforts to improve the geologic framework in question in order to understand all new data in a correct context. Detailed studies of faults and fracture patterns through the target succession have revealed details that prove critical to how subsurface fluids migrated through the strata. Furthermore, a significantly improved sedimentological model highlights how sediment transport and dispersal at the time of deposition carries significant constraints on reservoir distribution, size, and connectivity after burial. Preferred migration pathways and subsequent juxtapositioning of sedimentary strata by faulting proves to be a substantial factor from a physical perspective. The timing and nature of deformation also has implications for the resultant groundwater chemistry and thereby its consequent diagenetic products and effect on reservoir properties, seals, and migration pathways.

Key outcomes from the combined efforts of teams led by the authors combine the structural and geomechanical response to geochemical alteration of heterolithic sedimentary rocks by storage and/or flow of CO_2-charged groundwater. This is coupled with improved models for how the initial reservoir conditions were established as a result of deposition in specific sedimentary environments. The linked transfer of conditions from deposition, via burial, to structural and mechanical modification, to geochemical and further geochemical alteration is considered crucial in developing an understanding of the full spectrum of factors that affect safe CO_2 storage.