Large-scale Carbon Capture and Storage solutions: The CCS potential of arid-marine sediments.

Keele University in collaboration with the University of Oslo, the Utah Geological Survey, Wolverine Oil and Gas, and the British Geological Survey.

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The Jurassic strata of the Colorado Plateau form some of the most spectacular landscapes in Utah and provide a weather of exposure with which to study aeolian-marine interactions

Of the myriad of Carbon Capture and Storage (CCS) techniques that have been proposed, CO_2 storage within subsurface geological formations – typically termed 'geo-sequestration' – is a method that has been demonstrated as highly feasible by using depleted hydrocarbon fields as subsurface targets (Chadwick *et al.,* 2010; Bennion & Bachu, 2008). Hydrocarbon fields are attractive because their local geology and context are well-characterised from extensive geological studies conducted for the production of hydrocarbons, the reservoirs are known to be able to store gas and fluids for millions of years, and boreholes down to the target (along with the infrastructure to support them) are already in place. Equally, the processes of CO_2 injection, along with the compound's mobility and trapping in the subsurface, are well known from modern Enhanced Oil Recovery (EOR) techniques, as well as the CO_2 storage operation at Sleipner in the Norwegian North Sea (Chadwick *et al.,* 2010).

That said, the locations of declining hydrocarbon fields are typically non-ideal with respect to the locations of major industrial producers of CO_2, and the physical sizes of the traps (in terms of the volumes of CO_2 they could store) are small compared to CO_2 volumes that need to be captured and stored (Blunt, 2010). *Deep saline aquifers* have been proposed as alternatives to depleted hydrocarbon fields for geo-sequestration, and potentially they offer solutions to these challenges. Saline aquifers offer large volumes of rock for CO_2 storage but, on this scale, CCS reservoir character and trap integrity are likely to be constrained by a complex regional (rather than local) interplay between CO_2-permeable and impermeable sediments – an interplay that strongly reflects the evolution of the basin and the inter-dependence of depositional environments through geological time.

One palaeo-depositional setting recognised as generating rocks that may be particularly favourable for saline-aquifer geo-sequestration is the arid-marine margin. Desert systems generate and preserve large, laterally extensive volumes of sandstone with a highly porous and permeable matrix that make excellent potential reservoirs. Sediments deposited in the coeval marine and littoral environments potentially make good seals on a regional scale. The physical characteristics of these rocks have separately been well studied because of their potential value in hydrocarbon exploration, but the complex spatial regional-scale interplay between these deposit types, and their temporal and spatial responses to basin evolution, have not been adequately examined to date. If saline-aquifer geo-sequestration is to become a feasible proposition, significant research must be undertaken into such sedimentary interdependence at a regional scale, and into the allo-controls upon such deposits.

The Temple Cap Formation that crops out on the Colorado Plateau of the Western USA represents sediments deposited in such a marine/aeolian interplay. The sediments of the formation were deposited along the arid palaeo-shoreline of a basin with varied relief that was subject to repeated marine transgression and regression through time, and a degree of tectonic influence. Recent work by the Utah Geological Survey (UGS) has produced a new, more robust, correlation of the strata (Doelling *et al.,* 2013; Sprinkel *et al*., 2011). These new insights provide an excellent framework into which detailed sedimentological studies could be set, in order to understand the complex relationships between the preserved strata of the coeval and competing environments, their relationships to basin geometry, and the influence of sea-level variation and tectonics upon them.

This project will examine in detail the sedimentology, stratigraphy, geometry and evolution of the Temple Cap Formation at a regional scale across southern Utah, in order to provide an analogue for arid margins of this nature. The work will characterise the aeolian sediments, along with the influence of the marine system upon their distribution, architecture and preservation, spatially and temporally, in order to build generic models for CCS reservoir quality. Following on from that baseline, the work will characterise the marine and coastal sediments, their spatial relationships to the aeolian sediments, and their evolution in response to allo-controls through time, in order to provide insight into their ability to seal the reservoir and provide trap integrity. The models will provide a basis for interpreting large-scale relationships between reservoir and seal rocks in potential subsurface geo-sequestration scenarios involving sediments deposited in similar settings.

The project will utilise extensive sedimentary logging and sampling, along with terrestrial and drone-based photogrammetry, to acquire large three-dimensional datasets from outcrop. Appropriate field localities across south-western Utah will be identified in the early stages of research in collaboration with the Utah Geological Survey. Three-dimensional data visualisation and analysis techniques will be used to interpret fieldwork data to provide spatially constrained 3D geometric interpretations of units of different facies types, separated by the surfaces that bound them.

Extensive sampling of the facies observed in outcrop will take place during fieldwork in order to provide a baseline dataset of textural and petrophysical properties comparable with down-hole datasets and provide a means of correlating and comparing outcrop data with existing extensive subsurface datasets available to the project from petroleum exploration.

Models that characterise the regional sedimentology of the Temple Cap Formation and its development through geological time will be developed from interpretations of the new field data. These models will form the basis of generic geobody models that will be statistically and stochastically defined to describe the internal properties, geometry and distribution of different sediments occurring on aeolian-marine margins.

The developed models of geobody distribution, coupled with analysis of the sediment properties contained within them, the bounding surfaces that bound them, and their cyclicity (if apparent), will provide methods for predicting geobody presence, distribution, interactions and properties in the subsurface. Comparisons will be drawn with other well-characterised examples of arid-marine margins (e.g. Zuchuat *et al*., 2019) to provide generic predictive models for assessing the likelihood of trap integrity in similar large-scale saline aquifers with CCS potential. The results are directly applicable to potential CCS targets from the North Sea and UKCS, such as the Leman and Sherwood sandstones.

Work Plan:

- **Year 1 (2020/21):** Extensive literature review of aeolian and relevant marine processes and products; extensive literature review of the Temple Cap Formation and associated stratigraphy of the Colorado Plateau; introduction to available subsurface datasets; initial examination and interpretation of subsurface material to provide guidance for fieldwork; initial fieldwork in identified key sites to examine the aeolian system; processing of fieldwork datasets to interpret and numerically quantify aeolian sediments in response to basin geometry and evolution; University progression and year 1 review, including presentations to sponsors.

- **Year 2 (2021/22):** Initial development of geometric models from fieldwork; development of evolutionary ideas; principal fieldwork period, including examination of the marine system; sampling; thin-section and sample analysis; development of wireline data and models for cyclicity; AAPG ACE 2021 presentation; Paper 1 - Evolutionary models for the Temple Cap; University progression and end year 2 review, including presentations to sponsors.

- **Year 3 (2022/23):** Development of geobody models and application to CCS in saline aquifers; development of models to predict reservoir character; minor fieldwork to resolve any remaining issues; AAPG ACE 2022 presentation;

- **Year 4 (2023/24)** Paper 2 – Geometry and preservation of aeolian margins; thesis production and completion; final presentation to sponsors.

The project provides many opportunities for the student to work closely with the collaborators and to work within the facilities of the Utah Geological Survey, the University of Oslo and the British Geological Survey for extended periods over the course of the project. Furthermore, the Basin Dynamics Research Group strongly encourages research students to undertake internships (where available) with their collaborators for up to six months over the course of their degree.

Funding

This project is offered for competitive scholarship funding through the CDT in 'Geoscience for the Energy Transition'. Funding covers UK/EU Home fees, student stipend to RCUK levels, and a 5k pa Research Travel and Subsistence Grant (RTSG) to support fieldwork, conference attendance and training.

Start Date: September 2020

Application

This position would suit an applicant with a 2:1 or higher first degree in geology, geoscience or a related discipline, and a keen interest in sedimentology & sequence stratigraphy. An enjoyment of fieldwork is important. Some existing experience or background in aeolian and/or shallow marine sedimentology is useful but not essential.

For further information on this project please feel free to contact the lead supervisor Dr Stuart Clarke at Keele University by email (s.m.clarke@keele.ac.uk) or by phone (+44 1782 733171).

For further information on the Basin Dynamics Research Group please see: *keele.ac.uk/bdrg/*

For further information on studying at Keele please see: *keele.ac.uk/pgresearch/howtoapply/*

Formal applications for the PhD study at Keele are handled centrally through Keele University's central admissions system: *keele.ac.uk/researchsubjects/geologygeoscience/*

Further information on the collaborators and sponsors:

The project integrates well into existing research by the Basin Dynamics Research Group at Keele, including projects that examine: the geometry and distribution of aeolian sediments in erg settings (Cousins *et al*., 2019); the variations in aeolian styles at marine and lacustrine margins (Cross; Regis); interactions between aeolian systems and erg-marginal continental and marine environments (Cousins; Priddy and Clarke, 2020; Pettigrew *et al*., 2019; Pettigrew *et al.,* 2020); reservoir modelling in continental settings (Mitten *et al.,* 2020; Priddy); climatic cyclicity in continental sediments (Pettigrew *et al.,* 2020; Regis); and allo-controls upon the evolution of basin fill (Mitten; Howell *et al.,* 2019).

The recent stratigraphical work by the Utah Geological Survey (Doelling *et al.,* 2013; Sprinkel *et al.,* 2011; Sprinkle *et al.,* 2009) provides a timely framework as well as ongoing research that this project will build upon and integrate with. The Utah Geological Survey (UGS) has an extensive interest in the Lower and Middle Jurassic formations of Utah, especially the aeolian deposits, because these formations form some of the most iconic landscapes in Utah, are proven petroleum reservoirs (Chidsey & Sprinkel, 2016; Chidsey & Sprinkel, 2014; Chidsey *et al.,* 2007; 2011; Sprinkel, 1982; Sprinkel & Waanders, 1984), are known to be significant aquifers, and are recognised more recently as potential targets for storage for CO_2 sequestration (Sprinkel *et al.,* 2011b; Doelling *et al.,* 2013). The UGS supports this work on the Temple Cap Formation and other Middle Jurassic formation for reasons above. The UGS maintains a Core Research Centre that contains core and cuttings of the Temple Cap Formation and other Middle Jurassic formations. This facility and its resources will be made available to researchers for this project. Doug Sprinkel is currently an emeritus geologist at the Utah Geological Survey. He provides an extensive dataset, experience, and knowledge of surface and subsurface sections of the Temple Cap Formation, and its regional distribution.

The Tectonostratigraphic Research Group at the University of Oslo are at the leading edge of CO_2-related research in Norway, as the University of Oslo is hosting part of the Norwegian Carbon Capture and Storage (NCCS) centre of excellence, together with Sintef (Sundal *et al.,* 2017, Skurtveit *et al.,* 2017).This proposed project dovetails neatly with ongoing work of the group (in collaboration with Basin Dynamics Research Group) which has examined a contrasting arid-marine margin (Zuchuat *et al*., 2019) to the Temple Cap Formation and so can provide a comparative example for the proposed project. The Tectonostratigraphic Research Group has extensive expertise in the basin evolution of the study area during the Jurassic Period (Zuchuat *et al.,* 2018; 2019; Skurtveit *et al.,* 2017) that it will share with the proposed study.

Wolverine Gas and Oil have commercial interests in this part of the Jurassic Stratigraphy of the Colorado Plateau (Chidsey *et al*., 2011; Chidsey *et al.,* 2007), and they bring a wealth of background geological knowledge and subsurface fluid flow expertise to the collaboration (Hartwick, 2010a;b). Their portfolio of subsurface data including well resistivity image logs and geophysical subsurface data will be made available to constrain models developed by the proposed project.

The British Geological Survey has a global reputation for expertise in geoscience disciplines essential to the understanding and characterising the subsurface for multiple uses, including carbon capture and storage. The British Geological Survey will grant access to facilities and regional datasets that may be relevant for this project, but also contribute considerable expertise based on providing objective and rigorous scientific assessments of basin systems, and utilising these assessments to support government, industry and academia. Considering that the British Geological Survey has recently launched a new strategy, with significant emphasis on decarbonisation and the Energy Transition, this project would provide an ideal synergy between Keele University and the British Geological Survey.

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Cross, S. The development of aeolian-marine margins: The Moab Member of the Entrada Formation, Utah, USA

Regis, A. The development of lake margins, their interactions with contemporaneous continental environments and the implications for their reservoir potential.

Howell, L. Structural, stratigraphical and geodynamic controls on the evolution of the Carboniferous succession of Northern England and Southern Scotland.

Priddy, C. Climatic cyclicity and environmental interactions in arid continental basins: The Leman Sandstone, Southern North Sea.