The controls upon aeolian cyclicity: implications for reservoir-scale heterogeneity.

Keele University in collaboration with the University of Texas and Georgia Southern University

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Cyclicity in aeolian strata exists at a variety of scales and strongly controls fluid flow in the subsurface. Example from Zion National Park, Utah.

Aeolian strata are some of the best hosts of geofluids in the subsurface, and they have excellent potential as prospective targets for CO_2 storage, but maximising their capacity in this regard requires detailed characterisation and regional correlation. It has long been recognised that sedimentary 'cycles' exist in aeolian strata, and correlations based upon such cycles provide a means of predicting reservoir character away from the well bore. Both sedimentary and geophysical data suggest the cyclicity may be allogenically controlled, but the precise nature of the controls upon deposition and preservation of the cycles remain under investigated and very poorly constrained. We recognise the cycles, but we do not fully understand why they occur, despite their consequent value for correlating and for predicting spatial distributions of sediments within aeolian strata.

This work will use a strong combination of sedimentary and geophysical outcrop studies combined with forward numerical stratigraphical modelling to investigate the controls upon the cyclicity that is developed and, crucially, preserved in aeolian strata. The outcrop studies will focus upon the sediments of well characterised aeolian systems that developed under the influence of distinctly different allo-controls and consequently preserve cycles influenced by those controls. Numerical modelling techniques will be used to forward model to solutions that match the preserved cycles. The work will produce a set of models that define how allo-controls influence cyclicity, and geometry of aeolian systems. The models will be applied to regional scale potential UKCS CCS targets.

Rationale

For the timescales over which fluids migrate naturally, the detailed intricacies of aeolian reservoir heterogeneity are of lesser importance than many other factors. But for Carbon Capture and Storage (CCS) applications operating on human timescales, reservoir heterogeneity is of utmost importance for maximising fluid storage. The potential for CCS using depleted hydrocarbon fields has been demonstrated as a viable proposition from a scientific perspective, but the potential size of such schemes, in terms of CO_2 volumes that can be stored, are limited to the field scale. Consequently, the British Geological Survey (among others) has proposed 'sandstone saline aquifers' as alternative potential targets because they offer a much greater storage capacity. For the UK, sandstone saline aquifer storage provides most of the CCS potential (Bentham et al., 2014). However, understanding reservoir heterogeneities at this 'stratigraphical scale' requires correlation, and correlation is difficult within aeolian successions given their generally barren nature. Consequently, investigation of the controlling factors upon aeolian cyclicity provides a means of interpreting CCS saline-aquifer reservoir heterogeneity and a means of correlating strata across aeolian systems. The current foci of the UK (BGS) for CCS are the saline aquifer successions of the Bunter Sandstone (Sherwood Sandstone Group), and some field-scale targets within the Leman Sandstone of the Southern North Sea.

Project Details:

In aeolian systems, stratal cyclicity is typically explained in terms of cyclic climate which controls environment, sediment production, sediment transport processes and sediment supply. However, accumulation of sediment and its potential for preservation are largely independent. Significant volumes of sand may be deposited but not necessarily preserved, and controls upon preservation are different to those that govern accumulation. Furthermore, the timing of accumulation within a climatic cycle may be different and independent from the timing of preservation.

The field sites for this project have been selected to address these questions. The studies concentrate on the Navajo, Entrada and Page sandstones, and aeolian sections from the Cutler Group, of Utah and Arizona, USA. The Page and

Navajo sandstones are both dry aeolian systems; the Entrada Sandstone and aeolian sections of the Cutler Group are typically wet systems. The Page and Entrada sediments were deposited under conditions of low accommodation, but the sediments of the Navajo and Cutler were deposited under conditions of high accommodation. The strata are well known for their exceptional three-dimensional outcrop and they have been well studied for various aspects of their sedimentology by various past workers, including the current authors. The existing body of literature on these strata is an important aspect in the proposed work, since the tectonic and structural controls upon the systems, as well as their sedimentology, are well characterised. Consequently, the proposed project will concentrate upon the differences in sedimentology, geometry and cyclicity that result from differences in climate and accommodation-space in their depositional systems, rather than upon the sedimentary interpretation of the systems per se. Key sections will be logged and undergo photogrammetric analysis to establish a sedimentological framework to define the composition of a cycle in each case. This will provide a basis for integrating published sedimentological studies, but the bulk of field studies will concentrate upon the collection of gamma-ray data from sections, in order to explore aspects cyclicity. From gamma data, preserved aeolian cycles can be identified within the log, along with the general log motif for each accommodation and climatic condition, for comparison with the sedimentological analysis. Time-series analysis can be used in conjunction with forward modelling techniques (Swanson *et al.,* 2020) to understand their geological significance. Integration of these results with photogrammetric analyses provides a means of examining spatial correlation.

The field studies will provide the well-constrained dataset that characterises preservation of aeolian cyclicity under different climatic conditions and with different accommodation-space scenarios. Numerical forward modelling will be used to attempt to recreate the cyclicity observed from first principles. From these analyses, the key controls, and their relative influences, upon sediment deposition and preservation can be elucidated.

Work Package 1 – Scientific familiarisation and exploration of ideas and concepts.
This WP will examine the existing science and ideas (literature review) of aeolian systems and their preservation as strata. Preliminary data on the proposed stratigraphy of study will be examined, interpreted and processed to test ideas and to examine best-practice approaches to the proposed work.

Work Package 2 – The influence of climate on preserved cyclicity in aeolian strata.
This WP will examine the differences in preserved sedimentology that result exclusively from differences in climatic setting at the time of deposition. Comparisons will be drawn between interactions of preserved sedimentary cycles in wet and dry aeolian systems and compared to forward models based upon these allo-controls.

Work Package 3 – The influence of accommodation space on preserved cyclicity in aeolian strata.
This WP will examine the differences in preserved sedimentology that result exclusively from differences in accommodation at the time of deposition. Comparisons will be drawn between interpretations of preserved sedimentary cycles in low and high accommodation systems and compared to forward models based upon these allo-controls.

Work Package 4 – Integration of results and reporting
The WP will integrate the results from WP 2 & 3 to provide an interpretation of 'what matters' in terms of allo-controls for the preservation of aeolian cycles, their variability and their correlation over distance. The WP will develop generic models of likely stratal heterogeneity and geometry developed under climatic and accommodation scenarios, along with summaries of probable scales of correlation. The models will be applied to down-hole geophysical and core data from the UKCS (leman Sandstone) as a means of correlating in the subsurface.

Work Plan:

- **Year 1 (2022/23):** Extensive literature review into aeolian sedimentology/stratigraphy/cyclicity and for the field sites (WP 1); introduction to existing datasets along with initial processing and interpretations to test ideas and approaches in preparation for fieldwork; initial fieldwork in key sites beginning with the high accommodation settings that, in theory, preserve the greatest resolution - sedimentology, geometry and spectral gamma ray data collection from the Navajo Sandstone and Cutler aeolian systems (WP1 & 2); initial interpretations of the field data from the Navajo and Cutler (WP1 & 2); University progression & year 1 review, including presentation to collaborators; CDT training and annual conference.

- **Year 2 (2023/24):** Examination and interpretation of cyclicity in the high accommodation settings, along with development of generic sedimentological models (WP2); gamma data processing and interpretation relative to sedimentology of high accommodation settings (WP2); principal field season to include tidying up the first seasons data of high accommodation settings and collecting sedimentological and spectral gamma data from low accommodation settings (WP2 & 3); international conference presentation; Paper 1 - "How do climatic variations manifest themselves in aeolian strata?" (WP2 & 4); University progression and end year 2 review, including presentations to collaborators; CDT training and annual conference.
- **Year 3 (2024/25):** Sedimentological and gamma ray interpretation of low accommodation settings (WP 3); forward modelling of cyclic variations using climate and subsidence fluctuations (WP3 & 4); development of summary generic models based upon key allo-controls (WP4); build statistical models of cyclic components within aeolian strata (WP4); major international conference presentation; Paper 2 "How does accommodation space creation alter aeolian cycles?" (WP3). University progression and end year 3 review, including presentations to collaborators; CDT optional training and annual conference.
- **Year 4 (2025/26)** Application of statistical models of cyclicity to core and down-hole goephsycial data from the UKCS subsurface analogue such as Leman/Rotliegend to determine cyclic components and correlate across basins. How does this improve on our current models? (WP4); Thesis production and completion (WP4); final presentation to sponsors; potential for Paper 3 "Improving our understanding of aeolian correlations" (WP4); CDT annual conference.

The project provides many opportunities for the student to work closely with the collaborators and their institutions. 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.

The proposed project is supported and underpinned by the current interests of members of the Basin Dynamics Research group. Recently completed studies by members of the group have examined aeolian systems (Cousins, 2019). Ongoing studies focus on aspects of astrochronology and cyclicity in aeolian successions (Mitten), as well as arid continental sedimentology in general. Although the proposed project is self-contained research, and successful completion of it does not depend upon the other work of the group, it does benefit greatly from these existing research themes, and it integrates fully with them.

Funding

This project is offered for competitive studentship 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 2022

Application

This position would suit an applicant with a 2:1 or higher bachelor's degree (or equivalent) in geology, geoscience or a related discipline, and a keen interest in sedimentology. An enjoyment of fieldwork is important. Some existing experience or background in aeolian 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/*

Cited references (members of the supervisory team in bold):

Bentham. M., Mallows, T., Loundes, J. & Green, A. 2014. CO2 STORage Evaluation Database (CO2 Stored). The UK's online storage atlas. Energy Procedia 63 5103 – 5113.

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Mitten, A. The signature of climate change preserved in aeolian strata. PDRA research: Expected completion 2022.