Stratigraphical models for aeolian-marine margins: implications for subsurface CO_2 migration and trapping.

Keele University in collaboration with the University of Oslo, the British Geological Survey, University of Texas and the Utah 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 wealth of exposure with which to study aeolian-marine interactions

Transgression and regression at a basin margin produce surfaces of chronostratigraphical significance (including unconformities), and translate sedimentary systems such that the sediments they deposit are spatially linked to those surfaces. In temperate settings, sequence-stratigraphical models for this are well developed, and they provide a framework of surfaces that can be recognised, from offshore to onshore, by the strata that bound them. However, aeolian systems behave differently to changes in base level, and the barren nature of aeolian successions makes tracing a framework of chronostratigraphical surfaces up-dip from the marine realm problematical. While we may have a good understanding at the facies scale, the stratigraphical scale remains poorly constrained. *How do periods of transgression and regression at the margin manifest themselves in the sediments of the aeolian system? How do key chronostratigraphical surfaces develop, and how might both be recognised?*

This work will use spectral gamma ray & magnetic susceptibility data, combined with sedimentary logs & photogrammetry to generate 'ground-truthed' geophysical datasets from aeolian-marine margins. Combined with dating control from the marine sections, these datasets will be used for cyclostratigraphical analysis of the aeolian sections to correlate in time, based upon astrochronological signals preserved in the strata. The degree to which these signals are preserved, the temporal & spatial scales over which they may be correlated, the stratal surfaces they correlate with, and nature of the strata that bound those surfaces, can all be examined. Consequently, the work will develop a framework of chronostratigraphical surfaces within the aeolian margin.

Rationale

The potential for Carbon Capture and Storage (CCS) using depleted hydrocarbon fields has been demonstrated as a viable proposition from a scientific perspective, but the potential sizes 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). While a few of these targets offer traditional 'hydrocarbon type' closure, almost all saline-aquifer targets are basin scale in extent and are termed 'open' because they do not provide clearly defined structural or geometric closure to the reservoir (Bentham et al., 2014). At this scale, CCS reservoir character and trap integrity are likely to be constrained by a complex regional 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.

The value of models that correlate strata based upon a framework of surfaces with some chronstratigraphical significance (sequence stratigraphy) is well recognised. This approach has been adopted by some of the most recent CCS-focused geological research internationally, and by some of the project supervisors on this current project. However, current models do not address arid-marine margins adequately, despite the fact that sediments of arid settings provide some of the most attractive saline aquifer targets for CCS in the UK and internationally. The current foci of the UK (BGS) for CCS are the saline aquifer successions of the Bunter Sandstone (Sherwood Sandstone Group). Field-scale CCS targets have also been proposed within the Permian successions of the Southern North Sea. In both

successions, transgressive and regressive relationships at an arid margin effect the proposed CCS reservoir stratigraphy at a variety of scales.

Project Details:

The proposed project will examine in detail the sedimentary succession and relationships of the margin of the Curtis Basin on the Colorado Plateau, Utah, USA, and combine those data with subsidiary studies from the late Jurassic strata of the Paradox Basin. The interval of interest in the Curtis Basin is encompassed by the Entrada, Curtis & Summerville formations of SE Utah, and represents a transgressive-regressive cycle in which a well-developed aeolian system is transgressed by a shallow sea. Previous work by the present authors has examined the marine margin and produced an evolutionary model for that section (Zuchuat et al., 2019a), and highlighted stratigraphical complexities not recognised by standard sequence-stratigraphical models (Zuchuat et al., 2019b). Preliminary investigations supervised by the present authors (Cross et al., 2021) have demonstrated cyclostratigraphical signals in gamma-ray data from both the aeolian and marine sections, but the significance and correlative nature of these signals remain equivocal. The section has the added advantage of three-dimensional exposure, and of affording the opportunity for geophysical logging of complete successions covering a full transgressive-regressive cycle, thus providing an idea dataset for cyclostratigraphical analysis.

Fieldwork in the Curtis basin will be augmented by focused studies of the Carmel interval (and time equivalents) from the Jurassic section of the Paradox Basin. Primary data from both these studies will be supplemented by data from ongoing work within the research group (Whitworth) on the aeolian marine margin of the Henry Basin (Utah), and compared with the Cretaceous Iberian Desert System (IDS), northern Spain (Rodriguez-Lopez, 2012 & existing data of the group). The aeolian-marine margins to be examined in the proposed work have been carefully chosen because their geological settings provide comparative and contrasting factors with these two ancillary studies, within the broad definition of an 'aeolian-marine' margin. Consequently, generic models can be developed from comparisons of all datasets.

The models and outcomes developed from fieldwork will be applied to case studies from the UKCS (Bunter Sandstone in particular) using well logs and cores from suitable intervals to build reservoir models guided by fieldwork. The core and well data required for this aspect of the work are held by BGS and are readily accessible through their core store at their headquarters in Keyworth.

Work Package 1: Scientific familiarisation and exploration of ideas and concepts

This WP will examine the existing science and ideas (literature review) of marginal aeolian systems and their preservation as strata, along with aspects of aeolian cyclicity and cyclostratigraphy. In the context of these investigations, the package will examine, process, and interpret pilot-study datasets collected previously by the supervisory team from the Curtis Basin and IDS.

Work Package 2: The cyclostratigraphical nature of aeolian-marine marginal strata

This WP will explore the cyclostratigraphical nature of aeolian marine strata to determine what it is that constitutes the cycles from a sedimentological perspective, and what scales of cycles can be correlated across the margin. Objective statistical and mathematical techniques for examining cyclicity will be used to develop a first-pass spatial framework based upon sedimentology.

Work Package 3: Astrochronology to provide a time framework

This work package will process the geophysical datasets for cyclicity and astrochronology to determine the relative astrochronological ages of the marine transgressions studied, along with the associated spatio-temporal distribution of marine deposits. The WP will develop a time-constrained and time-correlated model for each margin.

Work Package 4: Integration, application and reporting

The final work package will integrate results from the primary field studies for this work with those of published and ongoing studies by members of the research group to produce generic and statistical interpretations. The outcomes will be applied to an analysis of core from case studies from the UKCS (Leman and Bunter sandstones) to build preliminary reservoir models. Methods such as those of Enge et al. (2007), whereby surfaces based upon the cyclicity derived from field based study, and stratigraphical correlations, will be used to grid analogous reservoir models to which petrophysical properties can be assigned.

Work Plan:

- **Year 1 (2022/23):** Extensive literature review into aeolian sedimentology/stratigraphy/cyclicity and for the field sites (WP 1); preliminary investigations into existing ideas of cyclicity and astrochronology to provide a basis for field data collection (WP 1); introduction to existing datasets of the research group, along with initial processing and interpretations of cyclicity (WP 1); initial fieldwork for sedimentology, photogrammetry, magnetic susceptibility and spectral gamma ray of key sections from the Entrada and Curtis successions (WP 1 & 2); preliminary interpretation of the field data (sedimentology & photogrammetry) to build first-pass spatial framework (WP 2). University progression & year 1 review, including presentation to collaborators; CDT training and annual conference.

- **Year 2 (2023/24):** Sedimentary and stratigraphical interpretation using existing sedimentary, photogrammetric, magnetic susceptibility and gamma ray data from the IDS (WP 2); determination of cyclicity in the aeolian-marine marine of the Entrada-Curtis through cyclostratigraphic analysis and improved sedimentological analysis of these settings (WP 2); develop and refine field data collection techniques and practice; principal field season on Curtis-Entrada and Carmel successions based upon best-practice developed on existing IDS data (WP 2 & 3); Initial correlations and development of spatial framework models (WP 2 & 3); international conference presentation; Paper 1 – "How do stratigraphic-scale sedimentary cycles manifest themselves in the strata of aeolian marine margins?" (WP 2 & 4); University progression and end year 2 review, including presentations to collaborators; CDT training and annual conference.

- **Year 3 (2024/25):** Astrochronology of field data, to constrain timing for key stratigraphic surfaces (WP 3); development of conceptual sequence models for transgressive marine-aeolian margins (WP 3); international conference presentation; Paper 2 – "Spatio-temporal interactions of aeolian marine margins: Sequence stratigraphic models" (WP 3); University progression and end year 3 review, including presentations to collaborators; optional CDT training courses; CDT annual conference.

- **Year 4 (2025/26)** Development of generic and statistical models of cyclic components within aeolian strata (WP 4); time analysis of the Curtis and IDS transgressive margins to determine diachroneity and time-transgression rate components, and to build a surface model (WP 4); Application to examples from UKCS (WP4). Thesis production and completion (WP 4); final presentation to collaborators; Potential for Paper 3 – "The diachroneity and stratigraphy of aeolian marine margins" (WP 4); CDT annual conference.

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.

The proposed project is supported and underpinned by the current interests of the Basin Dynamics Research group. Recently completed studies by members of the group have examined aeolian systems (Cousins, 2019) and aeolian marine margins, including the Curtis succession (Cross, 2021). Ongoing studies of the group focus on sedimentology of arid-marine margins (Whitworth) and 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 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 sedimentology and sequence stratigraphy 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/*

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