PS Three-Dimensional Stratigraphic Complexity Within Mixed Eolian-Fluvial Successions: Implications for Reservoir Connectivity*

Oliver Wakefield[1], Nigel Mountney[2], Ed Hough[1], and Jo Thompson[1,3]

Search and Discovery Article #41668 (2015)**
Posted August 24, 2015

*Adapted from poster presentation given at AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015

[1]British Geological Survey, Nottingham, Keyworth, United Kingdom (oliverw@bgs.ac.uk)
[2]Fluvial & Eolian Research Group, University of Leeds, Leeds, United Kingdom
[3]Department of Environment, Earth and Ecosystems, Faculty of Science, The Open University, Milton Keynes, United Kingdom

Abstract

On-going exploration of conventional hydrocarbon plays is increasingly focused towards the development of geologically complex reservoirs for which stratigraphic heterogeneity is difficult to predict. Many such current reservoirs, and an increasing proportion of likely future ones, are characterized by sedimentary bodies that accumulated as mixed eolian-fluvial systems that competed and interacted synchronously. Well-known reservoir examples include the Permian Unayzah Formation of Saudi Arabia, the Permian Rotliegend Group of the North Sea, the Triassic Ormskirk Sandstone of the East Irish Sea, the Jurassic Norphlet Sandstone of the Gulf of Mexico, and the Cretaceous Agrio Formation, Argentina. These mixed depositional systems typically exhibit highly variable lateral and vertical facies configurations that preserve complex juxtapositions of architectural elements composed of stratal units with markedly variable reservoir properties. Such stratigraphic partitioning is intrinsically difficult to predict from limited subsurface data. As such, there exists a requirement for more sophisticated geological models to better account for reservoir architecture and connectivity. This work uses outcropping case-study examples of eolian-fluvial interactions from the Triassic Sherwood Sandstone Group of the UK and the Permo-Pennsylvanian Cutler Group of southeast Utah, USA, to develop a suite of predictive models that depict common styles of stratigraphic complexity within eolian-fluvial systems. Studied successions accumulated in response to a variety of system interactions, deposits of which are preserved at a range of spatial scales from 100–104 m: (i) short-lived and localized fluvial reworking of eolian dune deposits in response to flash flood events; (ii) eolian reworking of fluvial deposits via winnowing; (iii) the fluvial exploitation and possible damming of open interdune corridors; (iv) the flooding of isolated (spatially enclosed) interdune hollows in response to an elevated water table. Identified types of interactions are characterized within a spatial scheme whereby occurrences can be used as a predictor of relative position within the larger-scale zone of transition between coeval eolian dune-field and fluvial systems. Application of this spatial scheme allows for prediction of the type of eolian-fluvial interactions expected for a range of paleogeographic settings, thereby serving as a tool for ranking exploration targets within larger prospect areas.

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

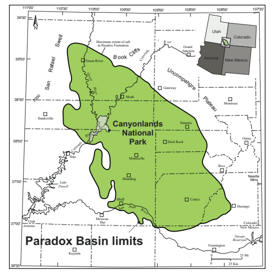
Three-Dimensional Stratigraphic Complexity Within Mixed Eolian-Fluvial Successions: Implications for Reservoir Connectivity

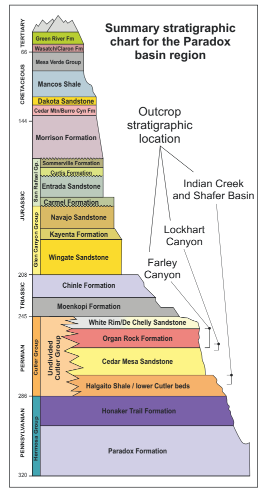
Oliver Wakefield[1], Nigel Mountney[2], Ed Hough[1], Jo Thompson[1,3]
1 - British Geological Survey, Keyworth, Nottingam, NG12 5GG, UK.
2 - Fluvial & Eolian Research Group, School of Earth & Environment, University of Leeds, LS2 9JT, UK.
3 - Department of Environment, Earth and Ecosystems, Faculty of Science, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.
The Open University
UNIVERSITY OF LEEDS
ERG FRG

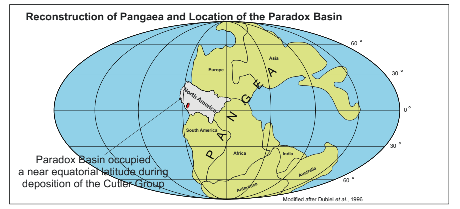
Introduction

Overview

The Cutler exposed in the Paradox Basin SE Utah, is comprised of sedimentary rocks of eolian, fluvial and shallow marine affinity. The arrangement and relationship of these depositional systems is responsible for a myriad of sedimentary expressions. Whilst reference is made to various parts of the group the lower Cutler beds form the main focus of this poster.

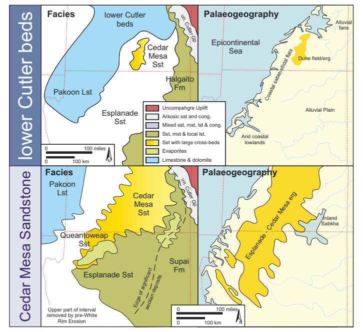


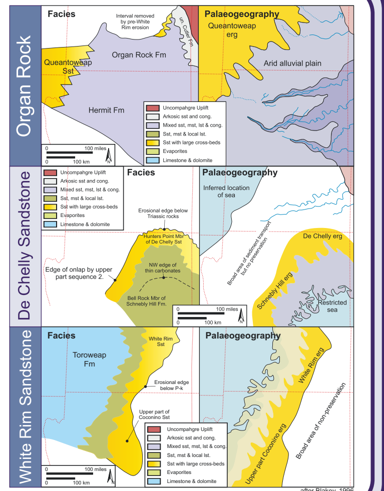




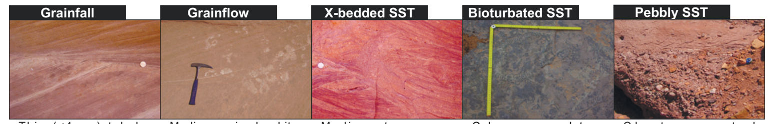
Palaeogeography

The Permian Cutler Group experienced sedimentation by eolian, fluvial and shallow marine processes. The arrangement and interaction between these systems results from external (allogenic) forces and those generated within the system (autogenic). The following palaeogeographical reconstructions from Blakey (1996) detail the broad depositional geographies of each formation within the Cutler Group.





Facies



Grainfall – Thin (<4 mm) tabular packages of very well sorted yellow-white fine sands.

Grainflow – Medium-grained, white-yellow homogenous sands, in steeply inclined packages (18°-25°) up to 3 cm thick.

X-bedded SST – Medium- to coarse-grained, moderate- to well-sorted dark-red SST arranged in planar and tough crossbedded sets.

Bioturbated SST – Calcareous sandstone with original sedimentary structures removed as a result of extensive bioturbation.

Pebbly SST – Clast-supported comglomerates with medium- to coarse-grained sandstone matrix.

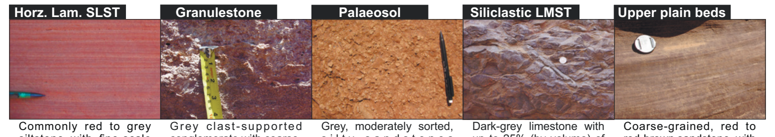
Rippled SST – Very fine- to fine-grained, moderately sorted. Shrinkage cracks and bioturbation are common in this facies.

Convoluted SST – Fine- to medium-grained, dark-red to red-brown sandstones with wavy and or convolute lamination.

Massive SST – Red-brown to red, fine- to coarse-grained structureless sandstones.

Bioclastic LMST – Grey to dark-grey bioclastic limestone with abundant *brachiopod, bivalve, bryozoan, crinoid* and coral fragments.

Translatent Strata – Eolian strata with cross-lamination not evident due to homogeneity in compositional material. Has a horizontally laminated structure.



Horz. Lam. SLST – Commonly red to grey siltstone with fine-scale horizontal lamination. Often occurs interbedded with very fine sandstone, as seen above.

Granulestone – Grey clast-supported conglomerate with coarse-grained sandstone to gritstone matrix. Contains broken fragments of shelly fauna.

Palaeosol – Grey, moderately sorted, silty-sandstones containing abundant calcrete material and rooting.

Siliclastic LMST – Dark-grey limestone with up to 25% (by volume) of siliciclastic material. Commonly contains shelly fragments.

Upper plain beds – Coarse-grained, red to red-brown sandstone, with horizontal bedding and primary current lineation.

Facies & Architectural Elements

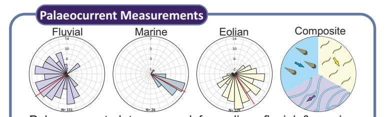
Facies

Fifteen different lithofacies types have been identified within the lower Cutler beds succession. Each is briefly described in the facies section; accompanying representative photographic examples are shown.

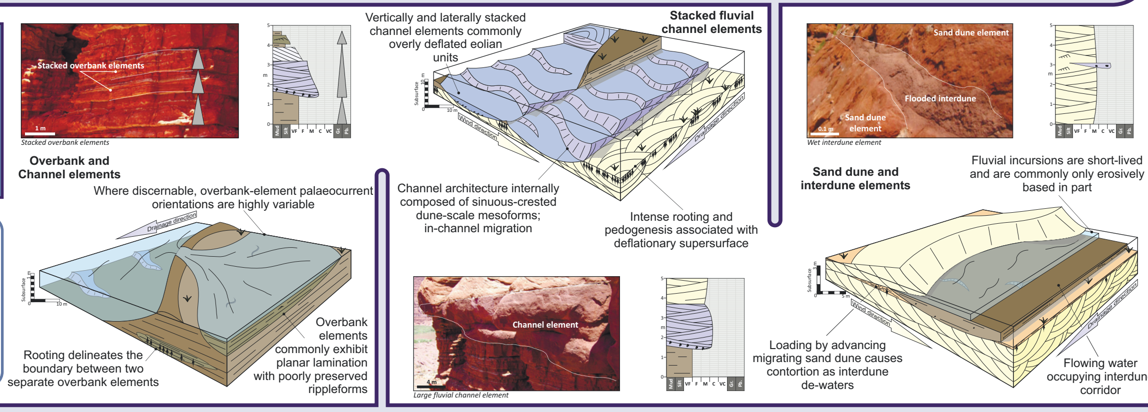
Architectural elements

Six different architectural elements are recognised within the lower Cutler beds (eolian dune, interdune, fluvial channel, overbank, marine granulestone barform & limestone sheet). Common styles of interaction and relationships between elements are depicted in five block models.

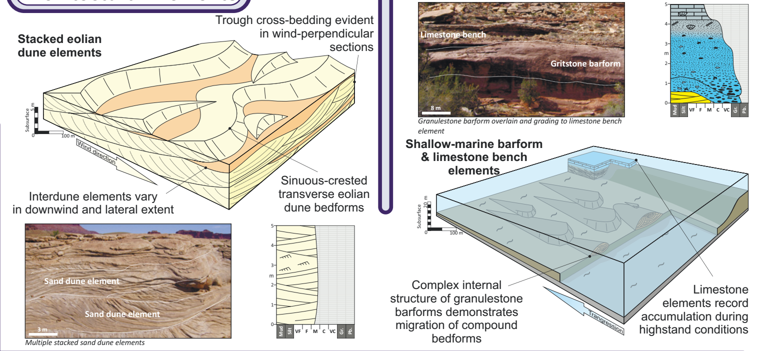
Palaeocurrent Measurements



Palaeocurrent data grouped for eolian, fluvial & marine systems. Fluvial readings taken from primarily x-bedded SST facies; eolian readings taken from grainflow and grainfall facies. Shallow-marine readings taken from granulestone lithofacies.



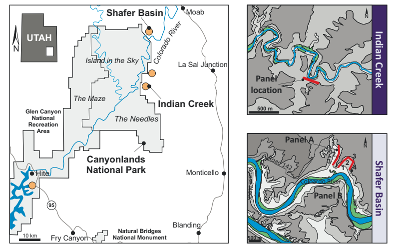
Architectural Elements

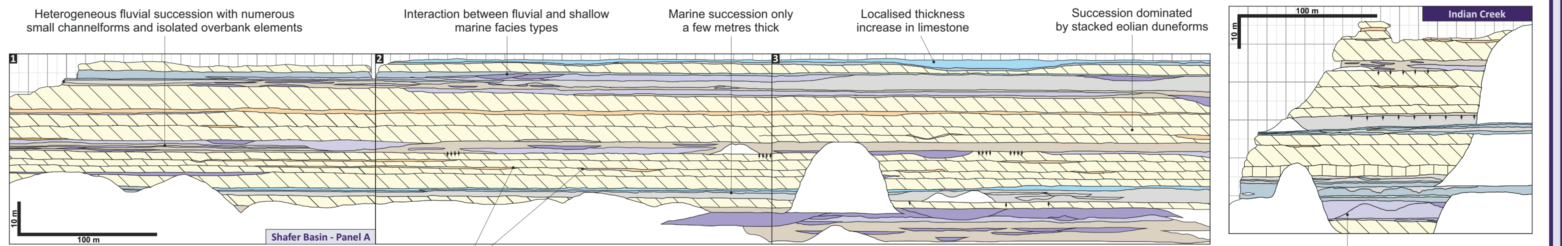


Architectural Panels

Panel legend

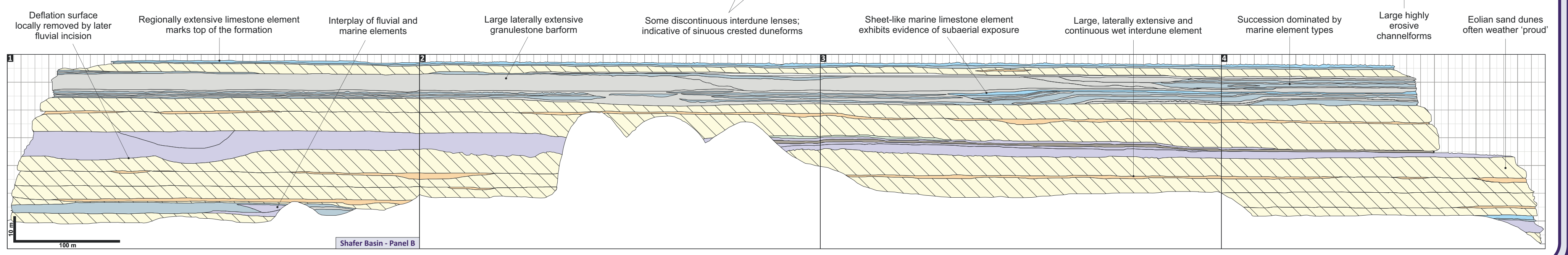
Limestone (sheet-like)	Palaeosol
Granulestone barform	Fluvial overbank
Marine (other)	Eolian sandsheet
Amalgamated fluvial channels	Eolian dune
Fluvial Channel	Eolian interdune
Conglomeratic fluvial channels	Rhizolith





lower Cutler beds

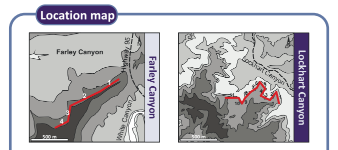
The lower Cutler beds are the lowest stratigraphical unit of the Cutler Group; being a tripartite mix of eolian, fluvial and shallow marine facies types in almost equal volumes. The arrangement of the different depositional system facies types records the formation and establishment of a series of time-independent incised valley systems. The creation and subsequent fill of these incised valleys occurred in response to linked climatic and relative sea-level forcing. This linkage generated dry periods concordant with periods of relative sea-level lowstand. During such periods, the absence of atmospheric moisture and the exposure of upwind coastal sediment generated periods of eolian dominance and in contrast during humid highstands prevented dunefield construction.



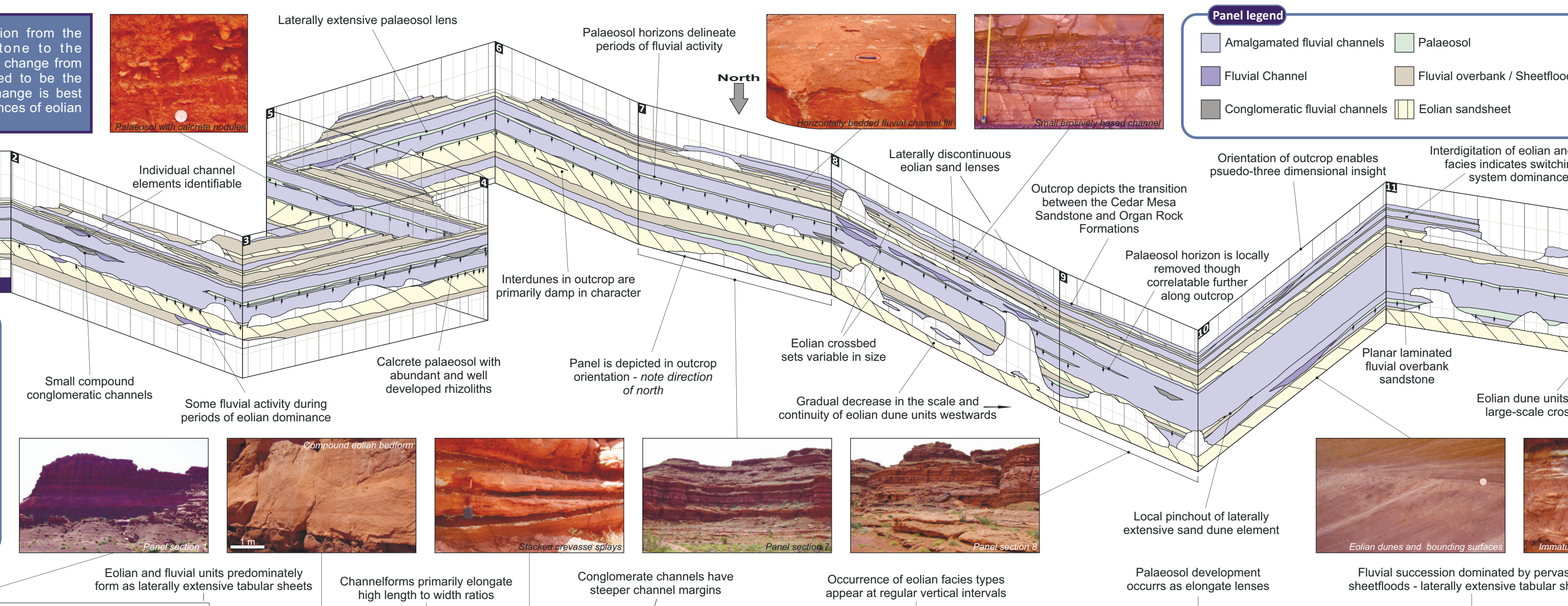
Architectural Panels 2

Lockhart Canyon

The Lockhart Canyon panel details the transition from the predominately eolian Cedar Mesa Sandstone to the predominately fluvial Organ Rock Formation. The change from one system dominance to another is considered to be the response to prevailing climatic variation. This change is best illustrated by the reduction in the size and occurrences of eolian facies types upwards in all of the panel sections.

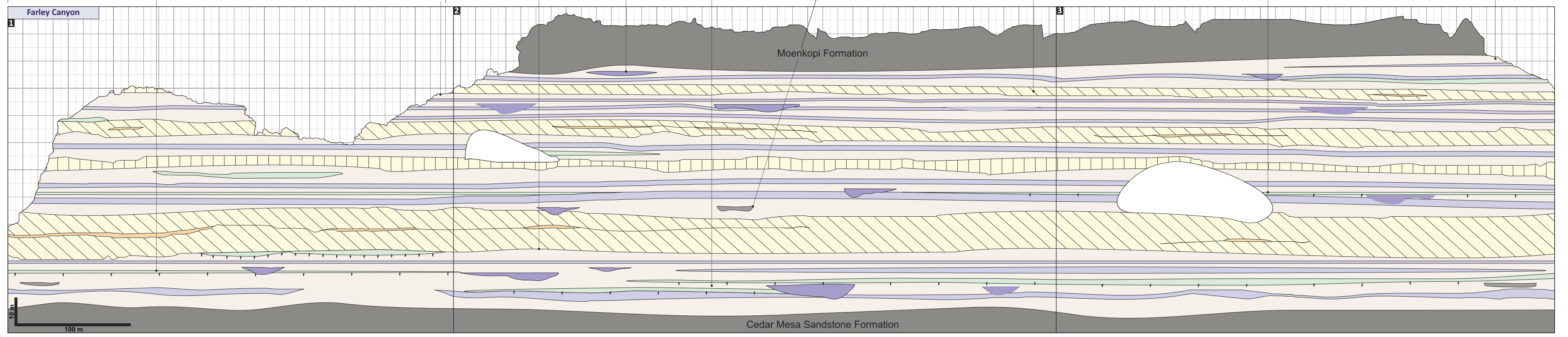


Diagrammatic location maps for Farley Canyon and Lockhart Canyon. Darker areas indicator higher terrain. Red line indicates architectural panel location, number pertain to individual sections of the panel.



Panel legend

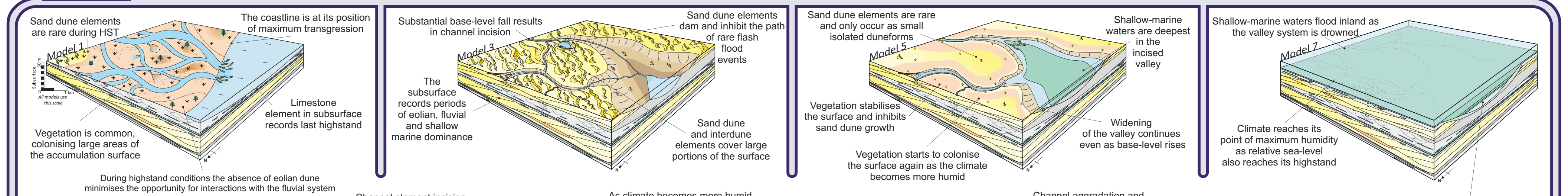
Amalgamated fluvial channels	Palaeosol	Eolian dune
Fluvial Channel	Fluvial overbank / Sheetflood	Eolian interdune
Conglomeratic fluvial channels	Eolian sandsheet	Rhizolith



Farley Canyon

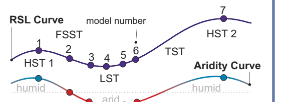
The Organ Rock Formation is exposed at Farley Canyon and has been interpreted as a distal member of a distributive fluvial system (Cain & Mountney, 2009). As such, there is a reduction in the size and frequency of channelised fluvial bodies in favour of laterally extensive pervasive sheetflood deposits. Some of these sheetfloods show instances of crude pedogensis indicating generally quiescent conditions with minimal sedimentation taking place.

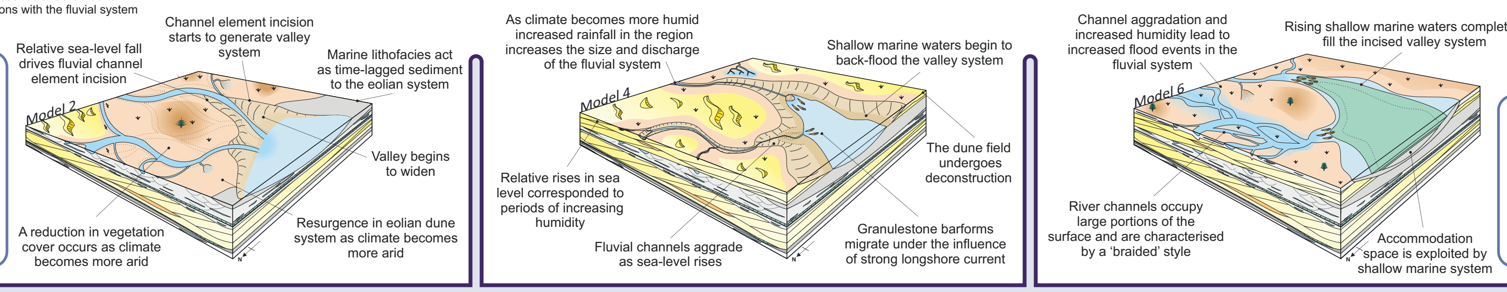
Conclusion



Depositional Models

From the data sets on the lower Cutler beds *(Indian Creek and Shafer Basin)* a suite of seven models have been developed to depict the palaeogeography from a single highstand to highstand cycle. The position of the models within the cycle are depicted below.





Conclusion

The configuration of the eolian, fluvial and marine facies of the lower Cutler beds is controlled by allogenic linked climate and relative sea-level forcing, with episodes of greater aridity linked with periods of lowstand conditions and conversely periods of greater humidity with highstand conditions. At least twelve cycles of linked climate and relative sea-level fluctuations are recognised.

The following groups are thanked for their sponsorship of the Fluvial & Eolian Research Group
AREVA bhpbilliton ConocoPhillips MURPHY OIL CORPORATION nexen Saudi Aramco Shell TULLOW woodside YPF

oliverw@bgs.ac.uk
http://www.bgs.ac.uk
+44 (0) 115 936 3169

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Three-Dimensional Stratigraphic Complexity Within Mixed Eolian-Fluvial Successions: Implications for Reservoir Connectivity

Oliver Wakefield[1], Nigel Mountney[2], Ed Hough[1], Jo Thompson[1,3]
1 - British Geological Survey, Keyworth, Nottingam, NG12 5GG, UK.
2 - Fluvial & Eolian Research Group, School of Earth & Environment, University of Leeds, LS2 9JT, UK.
3 - Department of Environment, Earth and Ecosystems, Faculty of Science, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.

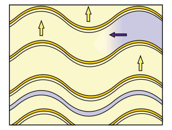
The Open University
UNIVERSITY OF LEEDS
ERG FRG

Introduction

Overview

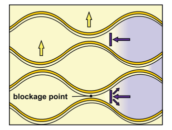
The preserved sedimentary expression within dryland environments was traditionally thought of as the product of either extensive ephemeral fluvial sedimentation or by eolian sedimentation in the form of varying styles of migrating duneforms. However, within the last couple of decades increasing evidence has shown that few dryland environments remain solely within the remit of either eolian or fluvial completely, commonly exhibiting a mix of both. This study details the four types of eolian-fluvial interaction.

Dunefield arrangement



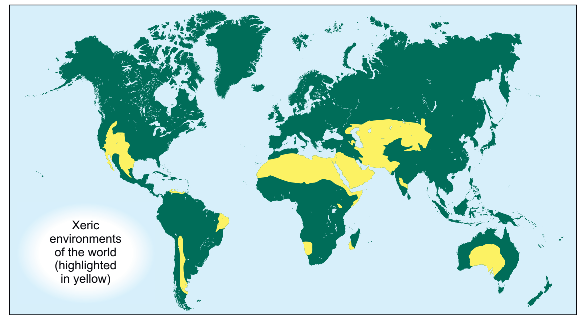
In-phase duneform trains
Sinuous duneforms that maintain equidistant spacing between bedforms in the train. As such, the interdune space is often open and continuous along its length.

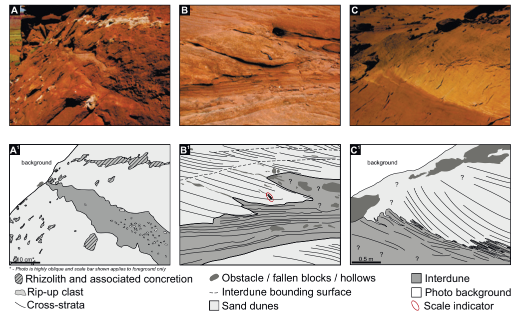
In this idealised example, in-phase configuration of the sinuous transverse dunes allows fluvial incursions, as either a pervasive or channelised flow, to occupy and flow along interdune corridors.



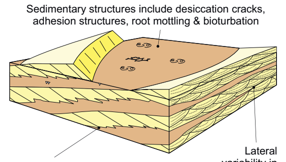
Out-of-phase duneform trains
Sinuous crested bedforms with an out-of-phase configuration. The configuration generates areas in the dune train where interdunes narrow, *and dependant upon the dune wavelengths*, become pinched. This relationship creates natural bottle-necks to incursive fluvial flow.

The idealised example here depicts the complete barring of fluvial flow where two duneforms meet.





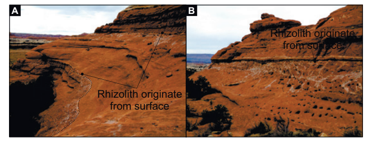
Examples of coeval dune- interdunes with diagrammatic illustrations. Feathering denotes coeval nature, most notable in 'B' & 'C'. Conceptual model below indicates relationship.



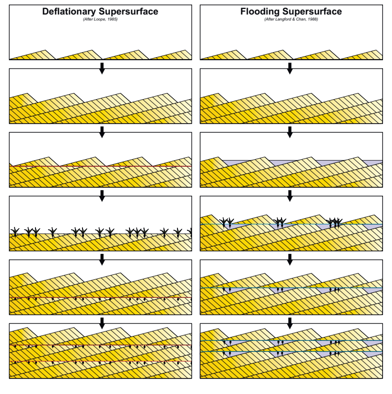
Eolian surface generation

Deflationary Supersurfaces
Generated from periods of sediment supply restriction and/or increase wind carrying capacity. Resulting in a net loss of sediment from the dunefield with duneforms migrating at zero angles of climb (bypass).

Flooding Supersurfaces
Fluvial incursions result in the raising of the activation energy of sediment to wind entrainment - effectively reducing the sediment supply. Duneforms begin to bypass.



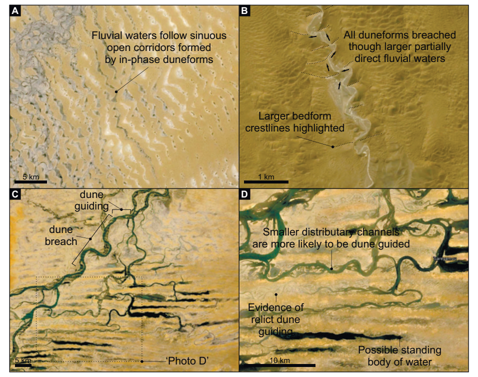
Examples of regional correlatable eolian supersurfaces. In both of the above examples rhizoliths eminate from the supersurface and denote an unconformity; i.e. the time required for colonisation by vegetation.



Interdune Guiding

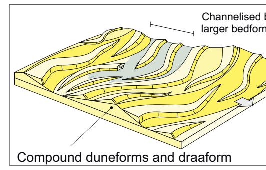
Overview

Interdune guiding results from the incursion of the eolian dunefield by fluvial waters along open interdune corridors. The size of the interdune and dune wavelengths can either limit the incursion into small highly guided corridors or allow more freedom within relatively larger interdune expanses. Interdune guiding as depicted in the modern examples (*situated to the right of this text*) force the fluvial system to flow perpendicular to the prevailing eolian migration direction. As such, instances whereby the fluvial drainage direction and wind direction are near perpendicular to each other facilitates this interaction type. Dune guiding also commonly occurs with close association to examples of eolian dune breach.



Google Earth images of dune/interdune control on fluvial waters (dune guiding). A) Northwest of Lake Chad, Chad, B) Southwest Taklimakan Desert, China, C & D) Central Tombouctou Region, Mali. Note that dune guiding occurs with intermittent examples of dune breach.

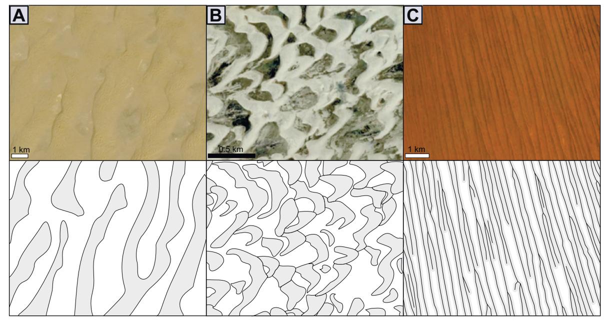
Conceptual model below details the dune guiding effect that larger eolian duneforms or draaforms may exert upon fluvial waters in instances where smaller bedforms are breached and reworked.



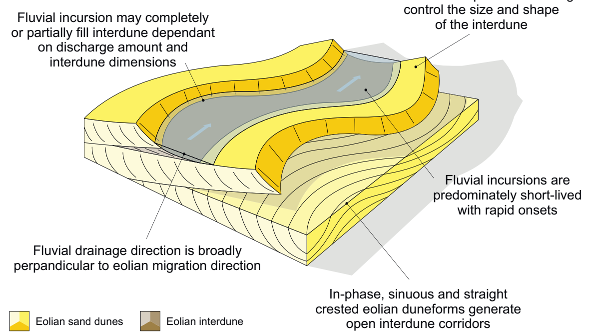
Dunefield arrangement

Modern examples of eolian dunefield configuration. Each example is accompanied by a diagramatic representation of the dune and interdune morphologies. Note barchan dunes of 'B' and their arrangement generate no continuous interdune corridors, as such, preventing this interaction type.

A) Sinuous-crested highly variable dunes, Taklamakan Desert, China, B) Barchan dunes, Lençóis Maranhenses, Brazil, C) Regular spaced linear dunes, Simpson Desert, Australia.



Conceptual model of eolian dune guiding



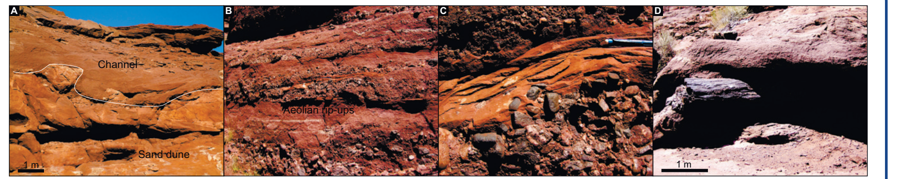
Eolian Dune Breach

Overview

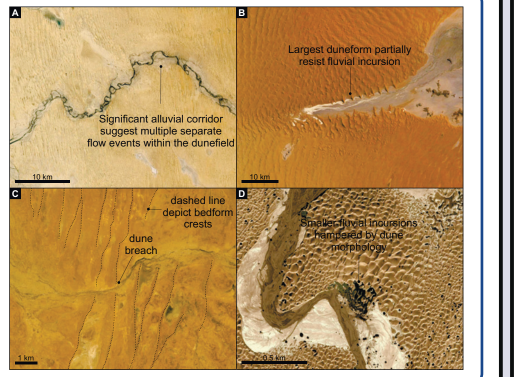
Interdune breach results from the cutting of eolian dunes by fluvial incursions. Such instances usually involve relatively large flood events, whereby the fluvial incursion has the energy to erode and remove barrier dunes. This interaction is best facilitated where competing system flow directions are opposed (180°).

Examples of eolian dune breach by fluvial channel elements. Fluvial channel penetration into the dunefield is restricted to the most energetic channel elements, as a result they often contain features not normally observed in other smaller channel-forms.

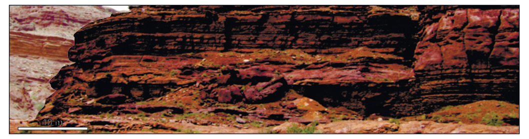
Photos: A) Large channel element with highly irregular erosive base cutting into underlying sand dune element, B) Large channel fill succession with cyclic pulses in energy regime denoted by coarser bands, note eolian sand inclusions, C) Close-up example taken from photo 'B', D) Energetic fluvial channel fluvial that includes large tree trunks.



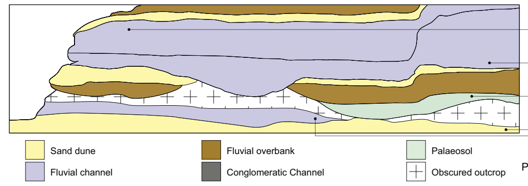
Examples of eolian dune breach as a result of fluvial channel penetration. A) North Lake Eyre, South Australia B) Namib Desert, Namibia, C) Lake Harry, South Australia, D) South Taklimakan Desert, China.



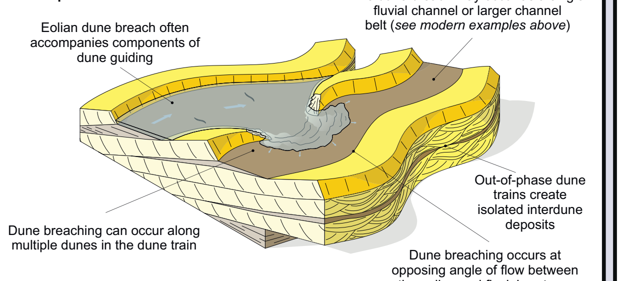
Rock record example



Example from the Undivided Cutler Group, Paradox Basin, SE Utah. In this example eolian sand dune elements are eroded to form two discrete separate lenses. Beyond the limits of the photo the upper and lower sand dune elements meet, suggestive of a coeval relationship.



Conceptual model of eolian dune breach



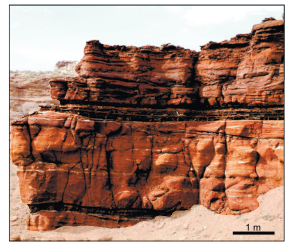
Interdune Damming

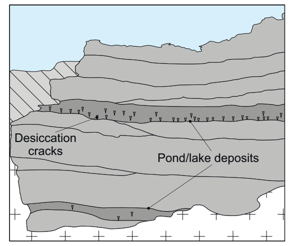
Overview

Interdune damming occurs where flood waters become blocked within the dunefield; a result of three-dimensional, out-of-phase duneform configurations. The damming of the fluvial waters may not be restricted to one interdune, but result from the destruction of some eolian dunes to form a wider dammed area depending on the strength of the fluvial incursion.

Rock record example

The photographic example and diagrammatic interpretation depicts two small sub-metre thick lacustrine deposits. Each shows variable waterlevel indicators through the presence of multiple desiccation cracks emanating from multiple horizons in each element.

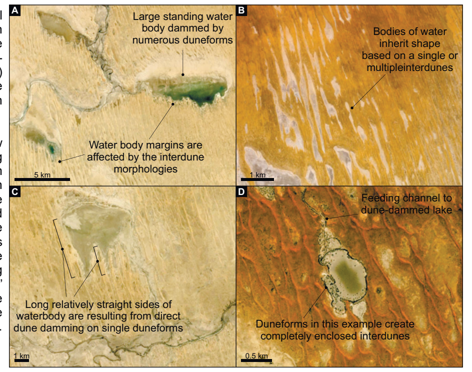


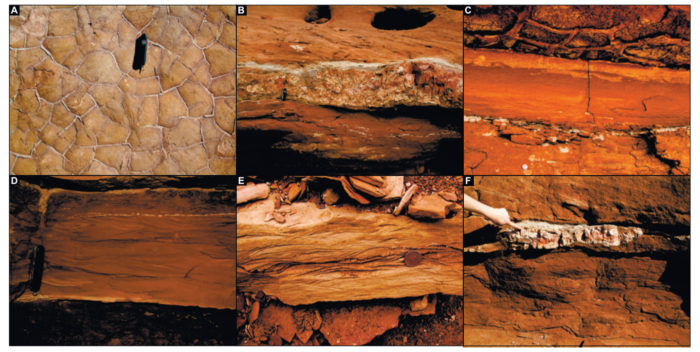


Modern Examples

Google earth images of dune damming of fluvial waters. A) Lake Eyre, South Australia, B) Simpson Desert Conservation Park, South Australia, C) Lake Pathraootara - South Australia, D) Northeast Lake Eyre, South Australia.

Note 'A' & 'C' show dune damming resulting from multiple eolian duneforms. Some of the dammed lake margins have straight edges resulting from the surrounding duneforms. 'D' depicts a single dam from one interdune element.

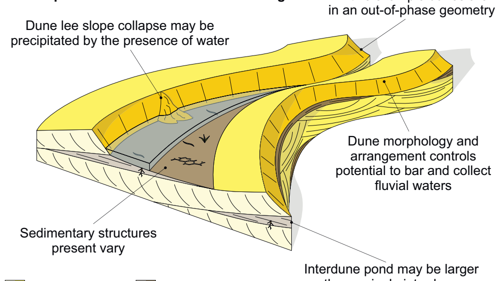




Photographical examples of the potential consistent facies types present within ponded interdune (dammed interdune).

A) Planform example of dessication cracks, highlighted well by finer, lighter sediment fill to the cracks, B) silcrete layers within an eolian interdune, C) Interdune deposit with small climbing ripples overlain by dessication cracks, D) Irregular shaped wave ripples, likely resulting from wind agitation, E) well-defined rippleforms, F) smaller thin example of silcrete lens.

Conceptual model of eolian dune damming

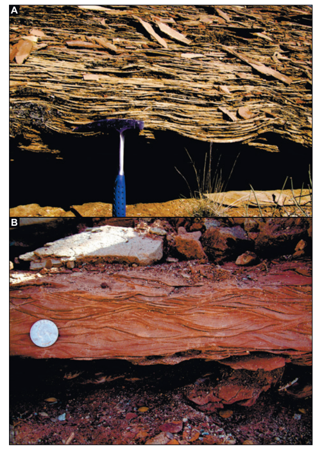


Accessory Flooding

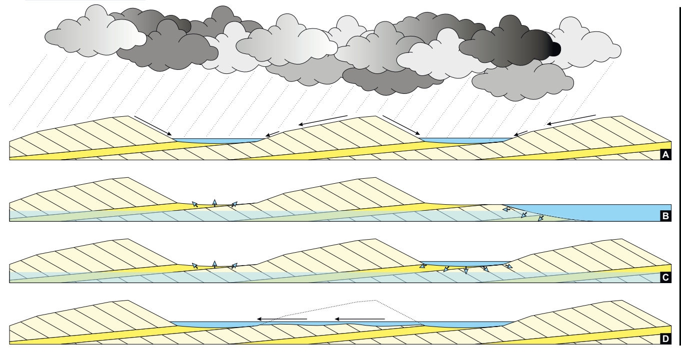
Overview

Accessory flooding, though very similar in expression to dune damming / ponding, is distinct in that it occurs isolated from the direct effects of fluvial incursions. Accessory flooding occurs where isolated interdune depressions fall below the level of the watertable; thus forming isolated ponds. The watertable rise required to form this interaction is not solely within the remit of fluvial incursions and could relate to from; i) fluvial incursions, ii) intra-system precipitation events, or, iii) proximity to larger permanent waterbodies. Importantly as the flooding of the interdune occurs from a watertable source, the deposits will be absent in fluvial facies types - a key diagnostic feature in discriminating between this interaction type and dune damming.

Example facies Photo captions; A & B) wave ripples - commonly resulting from wind agitation.



Dunefield arrangement



Accessory Flood types

The diagrammatic cross-sections detailed in this section compare three types of accessory flood and an example of dune breach. In each example the interdune flooding occurs in the interdune situated on the leftside of the diagram which is completely enclosed.

A) Precipitation event within the eolian system. Flood waters are gathered within the localised interdune depressions. Such examples are not frequent due to the general absence of precipitation in arid and semi-arid settings. Accessory flooding in such events would be short-lived.

B) Accessory flooding relating to the proximity to larger bodies of water. This type of accessory flooding is the most likely to generate relatively persistent high watertable.

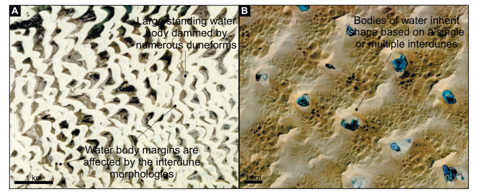
C) Accessory flooding relating to fluvial incursions. Such accessory flooding would be most prevalent adjacent to the flood incursion.

D) Example of dune breach for comparison. Note the removal of the barrier duneform and the chance to preserve fluvial facies types in the adjoining interdunes.

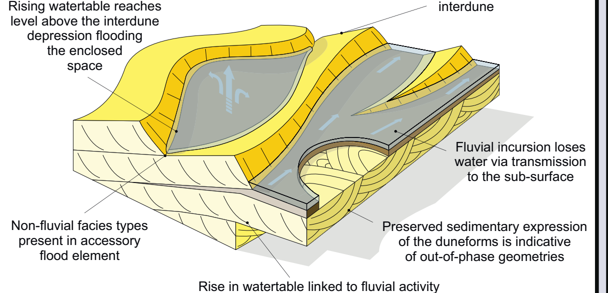
Modern Examples

Google Earth images of accessory flooding within dunefield as a result of watertable rise. A) Lençóis Maranhenses, Brazil, B) South Gobi Desert, Mongolia.

Note that the example from Lençóis Maranhenses experiences accessory flooding in relation to its proximity to the ocean.



Conceptual model of accessory flooding



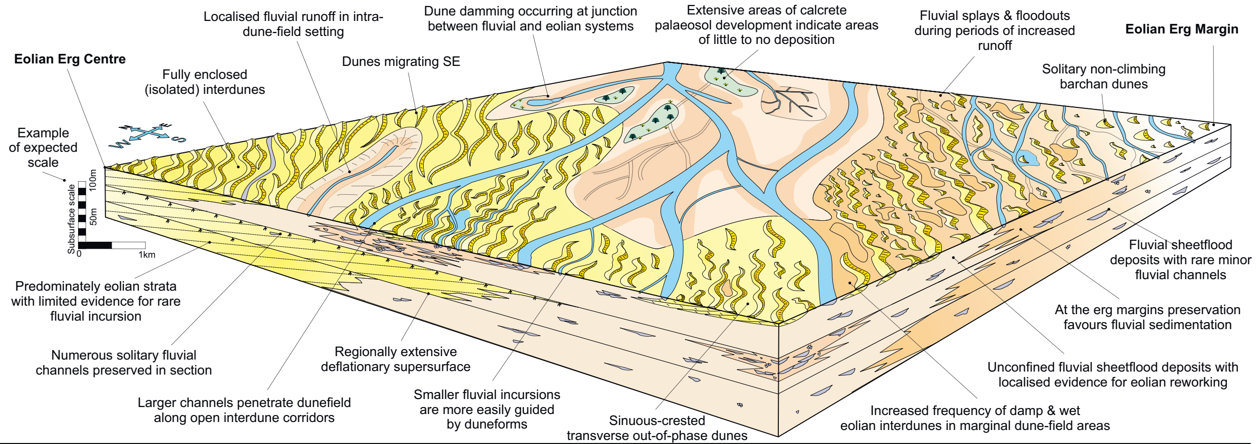
Conclusion

Overview

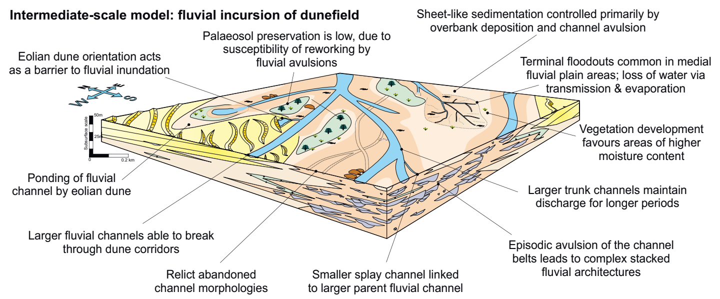
Conceptual model of an eolian dunefield from the erg centre to its margin.

The conceptual model depicts a dunefield subject to varying types of fluvial incursions. Notice the increasing duneform wavelengths, and subsequent interdune geometries, and variation in duneform morphology.

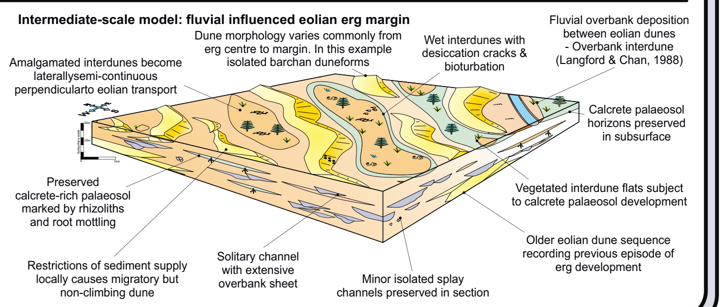
Two higher resolution intermediate-scale models below depict examples of the erg (right to left); i) fluvial incursion of dunefield, and, ii) fluvial influenced eolian erg margin.



Intermediate-scale model: fluvial incursion of dunefield



Intermediate-scale model: fluvial influenced eolian erg margin



Aerial photos taken from Google Earth™

The following groups are thanked for their sponsorship of the Fluvial & Eolian Research Group:
AREVA bhpbilliton ConocoPhillips MURPHY OIL CORPORATION nexen Saudi Aramco Shell TULLOW OIL woodside YPF

oliverw@bgs.ac.uk
http://www.bgs.ac.uk
+44 (0) 115 936 3169

Three-Dimensional Stratigraphic Complexity Within Mixed Eolian-Fluvial Successions: Implications for Reservoir Connectivity

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

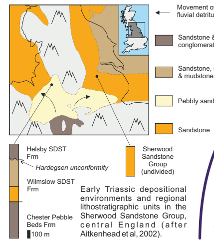
Oliver Wakefield[1], Nigel Mountney[2], Ed Hough[1], Jo Thompson[1,3]
1 - British Geological Survey, Keyworth, Nottingam, NG12 5GG, UK.
2 - Fluvial & Eolian Research Group, School of Earth & Environment, University of Leeds, LS2 9JT, UK.
3 - Department of Environment, Earth and Ecosystems, Faculty of Science, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK.

The Open University
UNIVERSITY OF LEEDS
ERG FRG

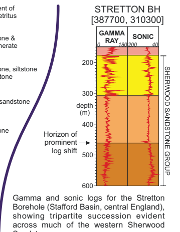
Introduction

Geological setting

The Sherwood Sandstone Group is late Permian to Mid-Triassic (Ladinian) in age. The Early Triassic in Britain was characterised by rifting and extension, related to the break-up of Pangea, with thick accumulations of arenaceous sediments developing in a series of actively subsiding linked half-graben which fringed the local palaeo-high of the Pennines. Locally, preserved sediments reach over 1000 m in some depocentres, with younger units overlapping inter-basinal highs. Regional-scale depositional models suggest a southerly source in the Variscan foldbelt some few hundreds of kilometres to the south, with northwards draining rivers bifurcated by the Pennine High, diverting sediment westwards towards the Cheshire Basin, Lancashire and Cumbria, and eastwards to the Needwood Bain and East-Midlands Shelf.



Early Triassic depositional environments and regional lithostratigraphic units in the Sherwood Sandstone Group, central England (after Aitkenhead et al, 2002).



Gamma and sonic logs for the Stretton Borehole (Stafford Basin, central England), showing tripartite succession evident across much of the western Sherwood Sandstone.

Context

The Sherwood Sandstone is a critical geological unit in Britain. It is the 2nd most important groundwater aquifer in England, and is a reservoir to hydrocarbon fields both onshore and offshore. Its close spatial relationship with the Coal Measures and proximity to major urban areas including Birmingham and Manchester has led to localised contamination. As such, an understanding of petrophysical properties of the group is relevant to many disciplines.

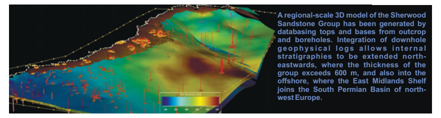
Lithostratigraphy Challenge

The classification of the Sherwood Sandstone is largely based on lithostratigraphy, due to an absence of age-diagnostic fossils. Historically, this succession has been split by using gross differences in composition and character (e.g. pebble content, degree of cementation). However, whilst this approach is successful in areas of lithological variability and good outcrop exposure, and can to some extent be confirmed by borehole cores and logs, it is difficult to apply where variations are more subtle, or outcrop and cores are not available.

The Sherwood Sandstone Group exhibits considerable facies variation to the west of the Pennines (Cheshire and East Irish Sea basins). In many areas, the group can be divided into a tripartite succession comprising a lower fluviatile unit, a middle unit that is predominantly eolian (becoming more so in distal areas), and an upper unit of mixed eolian and fluvial facies which have a complex spatial relationship. In this succession, major erosive bounding surfaces may represent significant time-gaps. Whilst this subdivision is possible across much of central and north-west England, correlations in the north-east (East Midlands Shelf and Cleveland Basin) are difficult to establish and the group remains undivided in the east.

East vs West

To the east of the Pennines, the apparent lack of local and regional-scale lithological variability in a sandstone-dominated succession that reaches over 600 m in thickness is difficult to explain given the obvious variability at the outcrop-scale, where a degree of emergence (overbank and the development of rare vertisols) is evident at outcrop. The relationship between basins to the east and west of the Pennines hinges on a key region between the Needwood Basin and East Midlands Shelf. Bedrock exposure is poor, and there is an absence of borehole core material to analyse, precluding a fuller understanding of this relationship.



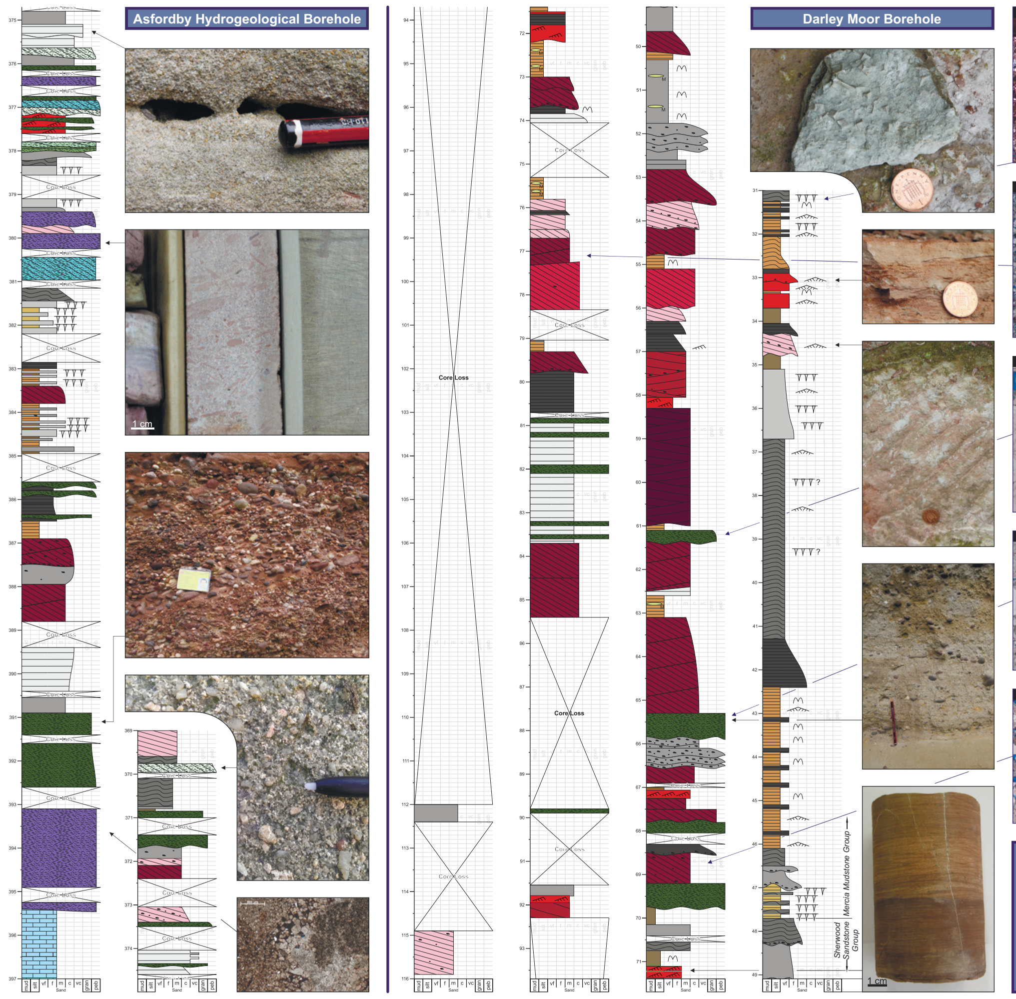
A regional-scale 3D model of the Sherwood Sandstone Group has been generated by databasing tops and bases from outcrop and boreholes. Integration of downhole geophysical logs allows internal stratigraphies to be extended north-eastwards, where the thickness of the group exceeds 600 m, and also into the offshore, where the East Midlands Shelf joins the South Permian Basin of north-west Europe.

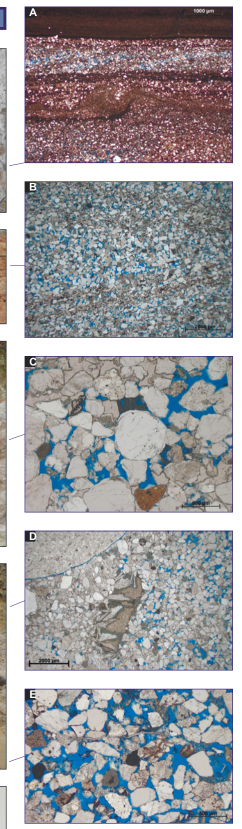
Adding detail to models

Analysis of outcrop sections from the East Midlands Shelf show a variable facies and element constituent at the sub-seismic (up to ~5 m) scale. This is not observed on down-hole or traditional lithological logs, and facies analysis is much improved by integrating borehole descriptions with log. One important marker horizon that can be identified from geophysical logs to the west of the Pennines is a prominent log shift within the lower part of the Sherwood Sandstone. This is characterised by an upward decrease in both sonic and gamma responses, and although identified regionally and offshore into the East Irish Sea Basin (e.g., Colter & Barr, 1975), the interval has not been described from cores onshore. However, it is likely that the interval represents an upward-drying event, with facies becoming less clay-prone.

Asfordby Hydrogeological Borehole

Darley Moor Borehole

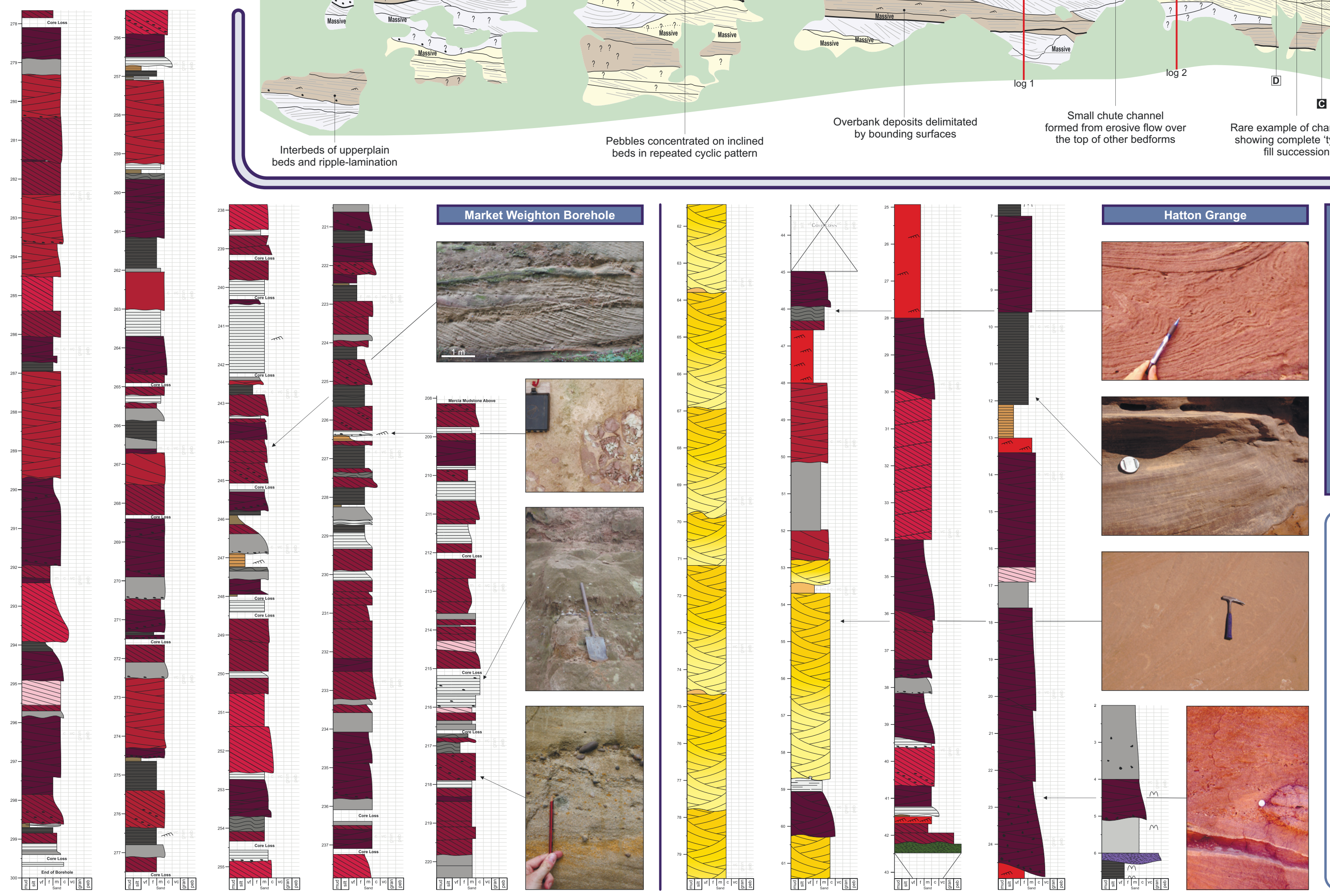




Thinsection captions: A) Cross beds, mud laminations and soft sediment deformation. Differential compaction. B) Cross beds, framework grain dissolution. C) Rare eolian grain with quartz overgrowth, framework grain dissolution and patchy fluorite cement. D) Baryte replacement of carbonate, framework grain dissolution. E) Deformed muscovite, framework grain dissolution.

Market Weighton Borehole

Hatton Grange



The boreholes detailed here show the general bulk facies assemblages of the Sherwood Sandstone Group. Note the absence of eolian facies types from the boreholes taken from central and eastern England (see map in intro section).

Whilst prevailing climatic conditions were conducive to eolian dunefield development across both the east and west of England during the early Triassic the lack of any observed instances in the east is suggestive of a sediment supply or carrying capacity limitation to the wind conditions.

Log legend

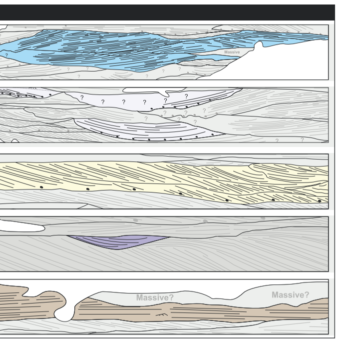
Fluvial facies types:
- Trough xbedded SDST
- Planar xbedded SDST
- Ripple laminated SDST
- Low-angle planar SDST
- SDST - massive
- Horizontal-laminated SDST
- Upper plain beds (SDST)
- Clast-supported congl.
- Clast-supported xbedded (planar) congl.
- Matrix-supported congl.
- Matrix-supported xbedded (planar) congl.
- Matrix-supported xbedded (trough) congl.
- Horizontal-laminated fines
- Fines - massive

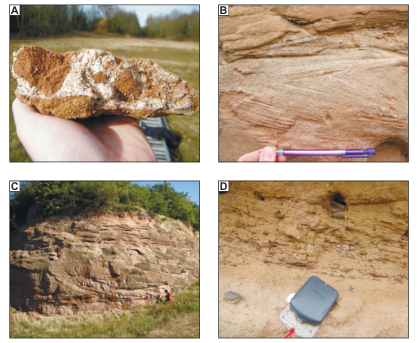
Eolian:
- Sand dune
- Interdune

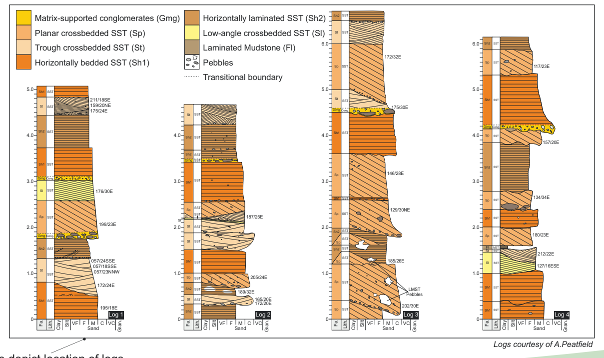
Architectural Panel

Code	Lithology	Sedimentary structure	Interpretation
Spb	Sand, medium- to coarse grained, with abundant pebbles (>20% by vol.)	Normally graded - sometimes weakly (A)	Channel lag deposits
Sp	Sand, medium- to coarse grained, sometimes pebbly	Planar crossbeds arranged in single or multiple sets (B)	Migration of single / multiple 2D bedforms
St	Sand, medium- to coarse grained, sometimes pebbly	Trough crossbeds arranged in single or multiple sets (B)	Migration of single / multiple 3D bedforms
Sl	Sand, fine - to coarse-grained, isolated pebbles	Low-angle crossbedding = <15° (C)	Migration of humpback duneforms (cf. Kostaschuk and Villard, 1996)
Sh1	Sand, medium- to coarse-grained, isolated pebbles	Horizontal bedding/lamination, parting lineation (D)	Upper plane beds (upper flow regime)
Sh2	Sand, very-fine- to fine-medium-grained	Horizontal lamination, rare instance of cm scale bedding (E)	Settling from suspension
Sr	Sand, fine- to medium-grained	Ripple cross-lamination (G)	Migration of rippleforms
Sm	Sand, fine- to coarse-grained, isolated pebbles	Structureless - Massive (F)	Gravity flow deposit
Fl	Silty sand (very fine) rare instances of mud	Fine lamination, often contains crude rippleforms (H)	Non-channelised flow and settling from suspension

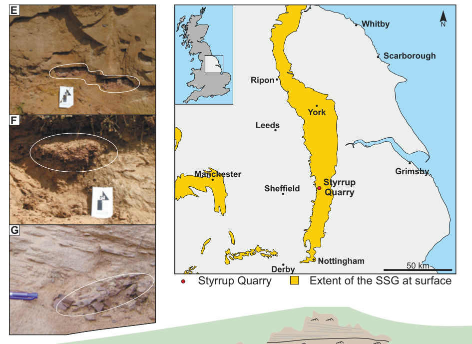
Name	Description
Lateral accretion element	Lensoidal shaped with a lateral extent of 10-18m and thicknesses 1 - 2 m.
Channel	Erosively based 'u' shaped element. Lateral extents of up to 20 m and thicknesses up to 3 m.
Downstream accreting element	Lensoidal shaped, <2.6 m thick with lateral extents up to 40 m.
Chute channel	Smaller erosively based channel feature; 1.2 - 2.6 m wide with a thickness ~0.5 m.
Sandy floodplain	Discontinuous tabular shape, thicknesses up to 3 m and lateral extents of up to 20 m.

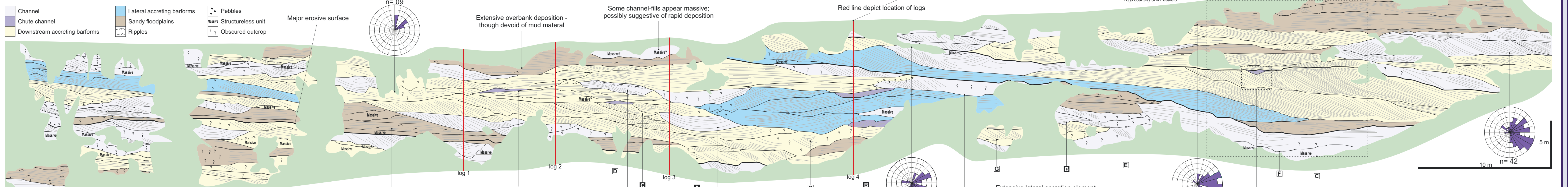


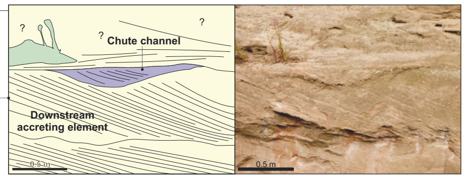




Logs courtesy of A.Peatfield







Zoomed architectural panel of well preserved chute channel

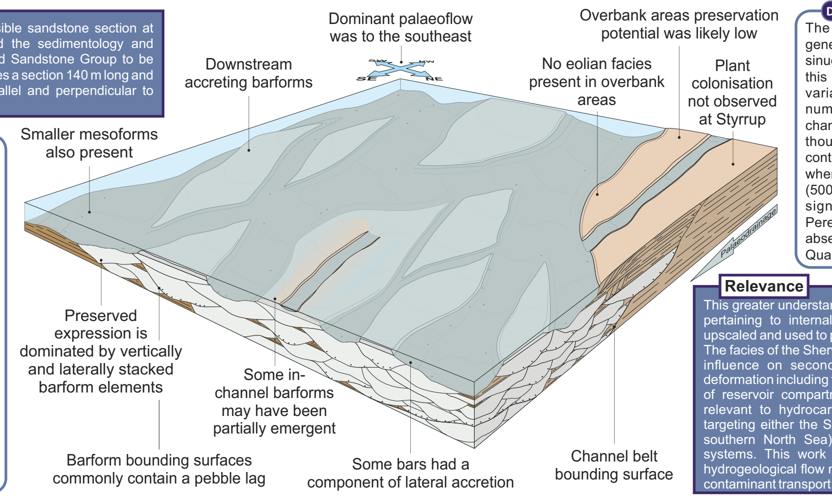
Three dimensional depiction of the architectural panel. *Note orientation of north.*

Conclusion

Analysis of one particularly well-exposed and accessible sandstone section at Styrrup Quarry (north Nottinghamshire) has allowed the sedimentology and internal geometries of the lower part of the Sherwood Sandstone Group to be placed in a modern context. The quarry section comprises a section 140 m long and up to 8 m high, allowing elements both broadly parallel and perpendicular to depositional flow to be examined.

Description

The sandstone at Styrrup Quarry preserves four main fluvial pulses comprising five discrete facies elements. Downstream accreting barforms comprise the majority of the section, and are up to at least 40 m wide, with a preserved thickness of up to 2.6 m. The relationship of surfaces within the downstream elements suggests smaller parasitic bedforms infront of, or on, the larger bedforms. Lateral accretion bedforms may be associated with some downstream influence, or be related to deposition in the falling stage, triggering lateral bedform development. Channel elements are also preserved, with horizontal lamination indicating upper flow regime conditions in some examples. A notable feature at Styrrup Quarry is a preserved, low-sinuosity chute channel, cut into a major downstream accretion element. Such features have not been identified previously. Preserved overbank deposits are common, but are sand, rather than mud-prone. Lateral extents vary up to 20 m, with thicknesses up to 3 m. Preserved mud in the system is restricted to mudstone intraclasts, which range up to cobble size.



Depositional Model

The facies elements support the previous general interpretations of a low-to moderate-sinuosity braided fluvial system. It is likely that this system did not reach equilibrium, and a variable rate of discharge is indicated by numerous reactivation surfaces and chute channel development, although variability is thought to have been limited, allowing for continuous river flow. This point is interesting when considering the distance from source (500 - 600 km to the south), suggesting a significant input of water into the basin. Perennial conditions are also supported by the absence of eolian deposits preserved at Styrrup Quarry.

Relevance

This greater understanding provides data at the sub-seismic scale pertaining to internal sandbody heterogeneities which can be upscaled and used to parameterise fluid flow and transport models. The facies of the Sherwood Sandstone are known to exert a strong influence on secondary diagenetic processes (cementation, deformation including fractures), that may result in the development of reservoir compartmentilisation. These improved models are relevant to hydrocarbon exploration and production activities targeting either the Sherwood Sandstone (e.g. Morecombe Bay, southern North Sea), or traps associated with dryland fluvial systems. This work is also important to the development of hydrogeological flow models for water resource management and contaminant transport studies in redbed fluvial systems.

The following groups are thanked for their sponsorship of the Fluvial & Eolian Research Group

AREVA bhpbilliton ConocoPhillips MURPHY OIL CORPORATION nexen Saudi Aramco Shell TULLOW woodside YPF

oliverw@bgs.ac.uk
http://www.bgs.ac.uk
+44 (0) 115 936 3169