[PS]Sedimentary and Stratigraphic Expression of Fluvial-Aeolian Interactions: Examples from the Skeleton Coast of Namibia and the Triassic Helsby Sandstone Formation, UK, With Implications for Reservoir Heterogeneity*

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Search and Discovery Article #51188 (2015)**
Posted October 19, 2015

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

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Abstract

Fluvial drainage networks are common at the margins of desert basins. Some penetrate 101–102 km into the inner parts of eolian dune fields; others are dammed and ponded at outer margins. Some systems occupy long-lived fluvial corridors that partition dune fields; others occupy transient interdune corridors that open and close as desert dunes migrate. Thus, a range of styles of fluvial-eolian interaction arise. Results from two case studies are presented here: the presently active Skeleton Coast Erg, Namibia and the Triassic Helsby Sandstone Formation, UK. This study documents the effects of temporal and spatial variability on preserved stratigraphic architecture of mixed fluvial-eolian systems arising from: (i) changes in the dune and interdune morphology; (ii) variability in sediment transport processes across desert basins for both settings; (iii) variability in the preservation mechanism for sediments of mixed systems. Fluvial incursions into desert basins are controlled by precipitation-event frequency and magnitude, fluvial runoff distance from catchment to receiving basin, sediment yield, changes to regional water-table level in response to flood events, paleotopography of the accumulation surface, and long-term climate change. These factors conspire to determine fluvial discharge to the receiving basin in the form of confined floods within channelized networks or as widespread unconfined sheet flows in dune-field margins. Presently active system interactions include: (i) the establishment of long-lived major through-going open interdune corridors along which well-established rivers pass; (ii) the damming of river courses by active eolian dunes that form barriers to flow, thereby resulting in the ponding of flood waters and the development of large, slowly draining flood basins; (iii) the passage of flood waters as sheet flows into the outer margins of eolian dune fields. The preserved stratigraphic expression of ancient fluvial-eolian interactions include: (i) relationships indicative of systematic temporal change from an eolian dune field characterized by small, isolated dry interdunes to one in which interdunes were large and interconnected such that they acted as conduits for fluvial flow whereby fluvial channels were able to penetrate into dune-field center settings; (ii) evidence for fluvial reworking of eolian dune deposits by erosive flows that resulted in temporary cessation in dune migration in the immediate aftermath of flood events.

Sedimentary and Stratigraphic Expression of Fluvial-Aeolian Interactions

Types of Present-Day Interaction Between Fluvial & Aeolian Systems: Skeleton Coast Erg, Northern Namib Desert

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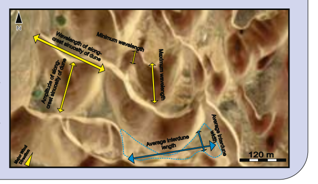
Introduction

A 6 to 22 km-wide, north-northwest trending dune field (erg) of the Skeleton Coast, northern Namibia, forms a 2000 km^2 region of active aeolian construction and accumulation, within which bed-forms of various morphological types are present and attain heights up to 50 m. This coastal erg has developed because the regional climate is strongly influenced by the northward-flowing Benguela Current and its associated cold-water up welling system offshore Namibia, which has resulted in anomalously low humidity and strong southerly, coast-parallel winds. The erg acts as a major obstacle to a series of fluvial systems that drain west-southwest-ward towards the coast. These fluvial systems are subject to ephemeral or intermittent flow but undergo marked changes in discharge in response to seasonal monsoonal rainfall events in their continental-interior catchments. Evidence for interaction between competing fluvial versus aeolian processes is present where the rivers intersect the erg. Significant and regionally extensive flood events have been recorded in 1934, 1982, 1984, 1988, 1995, 1997 and 2000. Analysis of a time-series of aerial photographs and satellite imagery reveals the history of a series of fluvial floods into the aeolian dune-field system.

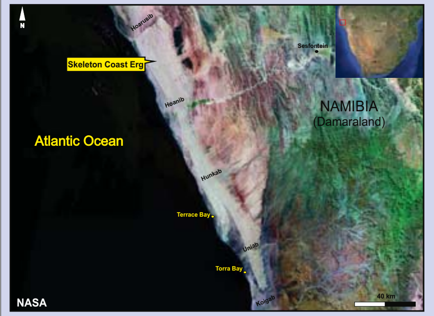
During major flood events, rapid rises to peak discharge result in channel breaching and widespread flooding into adjacent interdune depressions at the erg margin. Ponded flood water within interdunes rapidly evaporates and infiltrates to leave deposits of thin beds of cohesive mud that tend to resist aeolian reworking and accumulate progressively over multiple floods. The northern rivers that pass into the main part of the erg system (e.g. Hoanib and Hoarusib) are fed by large catchments and are characterized by relatively high-discharges. Along the eastern erg margin, episodic damming of fluvial systems results in the development of an extensive flood basin ponded behind a dune wall. Once the water level within the basin attains a critical level it floods into the erg interior via so-called dune break-through at points where dune cols are overtopped. This process guides the northern rivers into the dune-field centre. The southern rivers (e.g. Koigab, Uniab and Hunkab) interact with the erg system in a different manner; they are characterized by short-time-scale rises to peak discharge in the aftermath of floods emanating from catchments of restricted area. Discharge is rarely sufficiently high to result in dune break-through; instead, transient lake systems develop in the immediate aftermath of floods.

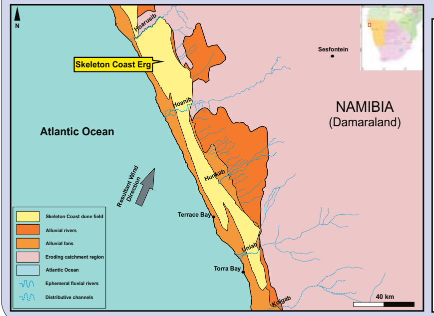
Data & Methods

Data from 3 rivers studied along the Skeleton Coast Erg document spatial changes in the morphology of aeolian dunes and interdunes that are present in close proximity to the rivers. The Hoanib, Hunkab and Uniab each pass from the eastern to the western erg-margin. Geomorphological relationships have been examined through analysis of high-resolution satellite imagery data from Google Earth Pro software. Each individual image has a resolution of 4800 x 2717 pixels and 2-3 m diameter objects such as shrubs can be resolved. A variety of quantitative data relating to the geometry of 1400 dunes and 800 interdunes have been collected, including: mean dune spacing, minimum, mean and maximum dune wavelength, plan-form wavelength and amplitude of along-crest sinuosity of dunes with sinuous crestlines, interdune length and width, and dune and interdune orientation. Data reveal predictable changes in dune and interdune size, spacing, orientation and morphology with increasing proximity to the major river courses.

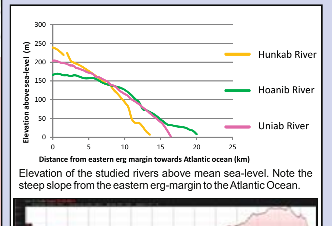


Location





The Skeleton Coast is located in northwest Namibia between latitude 19°05' S to 20°35' S and longitude 12°30' E to 13°30' E. The coastal region spans ~300 km of the Atlantic coastline of NW Namibia, across which several ephemeral rivers drain. Several of these rivers drain through the ~2000 km^2 Skeleton Coast dune field (erg), a large accumulation of aeolian dune forms, the eastern margin of which is orientated perpendicular to the preferred flow directions of the rivers; as such, the dune field represents a major obstacle to fluvial flow. The climate of the Skeleton Coast erg is hyper-arid with less than 50 mm average annual rainfall. Dunes of the Skeleton Coast erg are composed mainly of large isolated barchan forms and chains of transverse, compound crescentic and barchanoid forms, most of which are actively migrating northwards. The river systems examined in this study are characterized by networks of shallow ephemeral braided channels with longitudinal sand bars. During flood events, at points where these rivers intersect the dune field, they flood interdune areas adjacent to the main river courses, leaving deposits of gravel, sand and silt, which are draped by clay-prone mud layers up to 15 cm in thickness and which represent waning-stage flood deposits. A variety of fluvial-aeolian interactions characterize these regions.

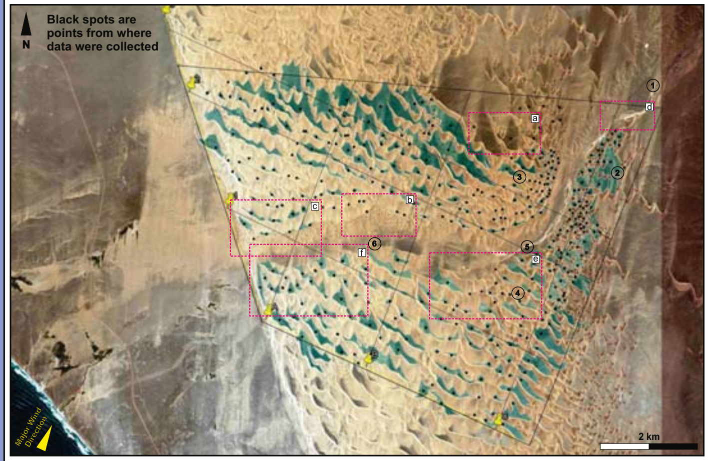


Elevation of the studied rivers above mean sea-level. Note the steep slope from the eastern erg-margin to the Atlantic Ocean.

Elevation from the northern to the southern margin of the erg along a transect through the central part of the erg.

Uniab River

The 110-km-long Uniab River, which drains a 4,500 km^2 catchment area within which only 2.3% of the area receives average annual rainfall of >100 mm, intersects the northern part of the southern dune field. The dunes are composed of chains of barchanoid ridges up to 30 m high but saddles, cols and interdune flats between the individual bedforms mean that the river has been able to establish and maintain a course through the 7-km-wide dune field, reworking aeolian sand over its course. Successive flood events repeatedly flush aeolian sand from the channel, thereby maintaining the fluvial course.

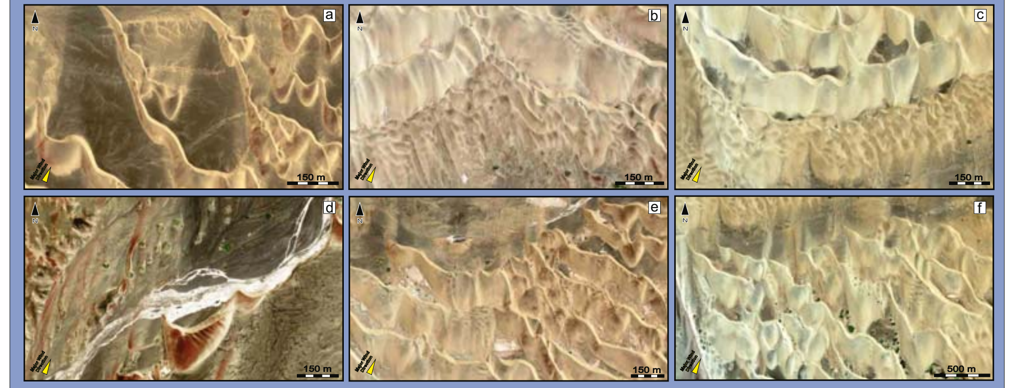


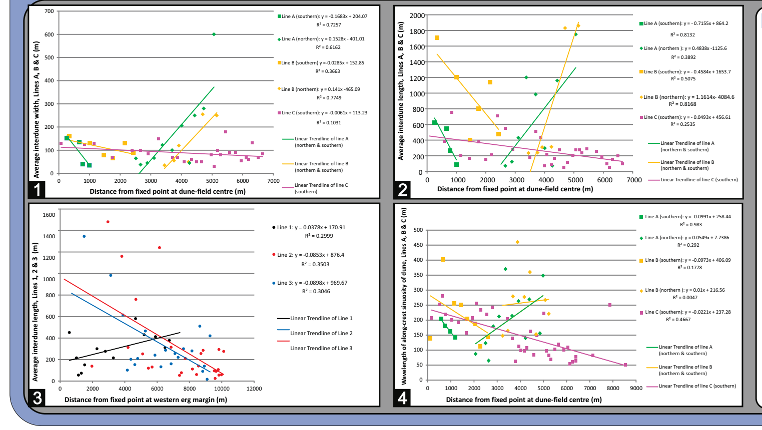
Key Observations

1. Active channel of the Uniab
2. Small barchanoid dune ridges with broad dune spacing & interdune flats
3. Barchanoid dunes with narrow dune-spacing & lacking interdune flats
4. Mud-rich interdune flood pond (dry in image)
5. Main channel dammed & diverted by dunes
6. Transmission losses due to evaporation & infiltration: flood terminus

Interpretation

During floods, the present-day Uniab River penetrates into the Skeleton Coast dune field, 25 km east of the coastline. Flood waters pass through the dune field along a long-lived break-through corridor, before entering the coastal plain about 6.5 km east of the Atlantic coastline. The dune field at the western margin forms large crescentic dunes, many of which are compound and up to 30 m high. In contrast, barchanoid dunes at the eastern dune-field margin decrease in height to an average of less than 15 m.



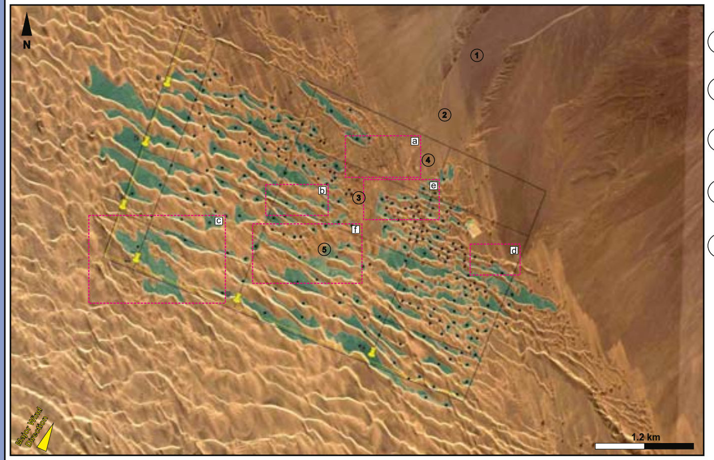


Key Observations

Examples of data displaying the results of the intimate relation between aeolian dunes and interdunes in present time from six cross-sections: lines A, B & C are parallel to the prevailing dune migration direction; 1, 2 & 3 are perpendicular to the prevailing dune migration direction. (1) average interdune width along lines A, B & C decreases towards NNE to the south of the river and increases to the north of the river for line A & B due to decreasing dune size and increasing dune spacing. (2) average interdune length for lines A, B & C decreases towards the river in the southern part of the study area and increases for lines A & B away from the river in the northern part. (3) average interdune length of line 1 increases as dune spacing increases. Line 2 & 3 show decrease in the length when dune spacing decreases and the amplitude along-crest sinuosity of the dunes increases. (4) Decrease in the average wavelength of the along-crest sinuosity of the dunes in lines A, B & C with increasing proximity to the river in the southern part of the study area and corresponding increase away from the river in the northern part of the study area (for lines A and B).

Hunkab River

The 90-km-long Hunkab River is the shortest major river to intersect the northern part of the Skeleton Coast dune field and has a small catchment (~700 km^2) that receives mean annual rainfall below 100 mm. This river has broken through the Skeleton Coast dune field only twice in recent decades: April 1995 and March 2000. The 1995 flood bore passed successfully through the entire dune field following the build-up of flood water and its subsequent break-through of a natural dune dam that was composed of large compound crescentic dunes ranging from 30-50 m in height. A natural col between the dunes acted as the point of break-through.

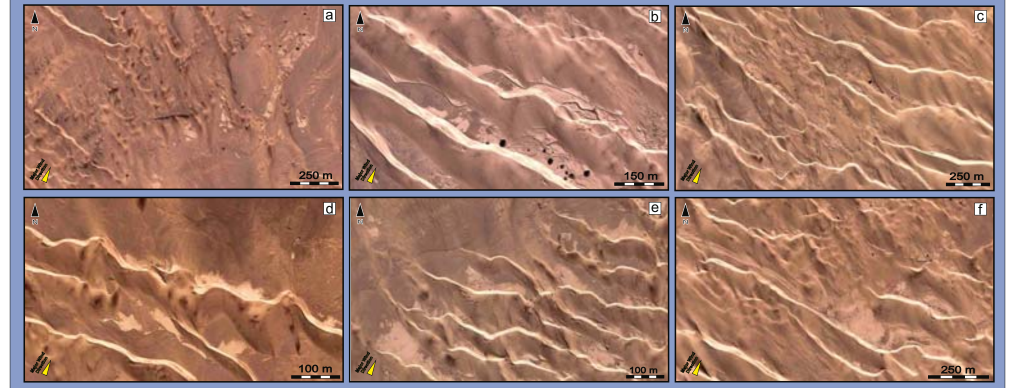


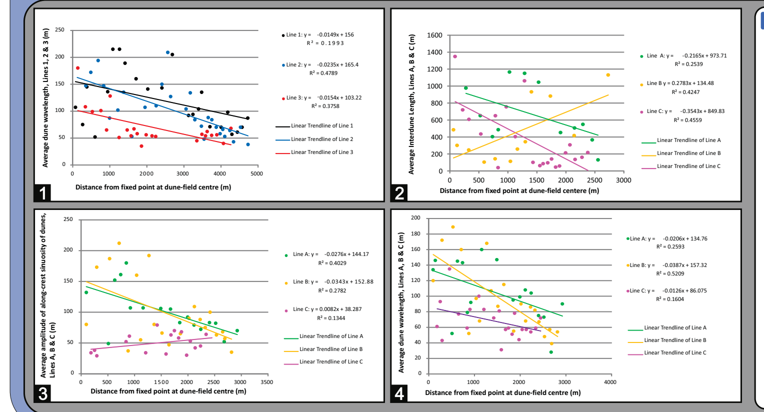
Key Observations

1. Passage of Hunkab River through its main catchment
2. Braid-like fluvial barform architecture with vegetation
3. Site of limited break-through into the dune field; river forms a series of ponds and distributary channels between dunes
4. Path of former successful break-through: fluvial course passes through dune field toward the Atlantic Ocean
5. Course of former floods obscured by aeolian dunes that have migrated over former channels; no evident course for fluvial systems to cross dune field

Interpretation

Since 1995, the Hunkab River has been dammed by the dunes at the leading edge of the 15-km-wide dune field. No significant flood-basin lake has developed to the east of the dune field. This detailed image reveals no long-lived fluvial corridor through the dune field. The river channel is re-occupied rapidly by aeolian bed-forms in the aftermath of floods in response to aeolian sand migration following flood break-through events.





Key Observations

Examples of data displaying the results of the intimate relation between aeolian dunes and interdunes in present time. Lines A, B & C are parallel to the prevailing dune migration direction; 1, 2 & 3 are perpendicular to the prevailing dune migration direction. (1) Decrease in average dune wavelength towards the eastern erg-margin where the amplitude of along-crest sinuosity of dunes increases. (2) Average interdune length of line A & C decreases towards NNE due variations in dune size and dune-spacing, whereas line B increases due to variation in dune-size and spacing. (3) Average amplitude of along-crest sinuosity of dunes of line A & B decreases towards NNE where the dune size decreases towards the eastern erg margin. (4) Decrease in the average wavelength of the along-crest sinuosity of dunes in lines A, B & C. Trends reveal systematic changes in dune size and morphology with increasing proximity to the fluvial channel course demonstrating the effects of flooding on aeolian sand supply and its availability for transport to sites of aeolian construction.

Hoanib River

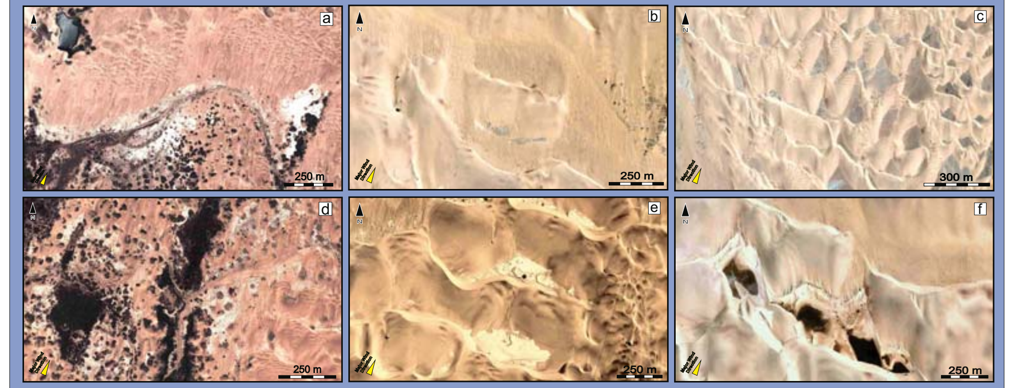
The 270-km-long Hoanib River drains a catchment of 17,200 km^2, of which 72% receives average rainfall of 100-300 mm/a and 12% >300 mm/a. The river historically flowed between trains of dunes in the northern part of the dune field. However, compound aeolian bedforms up to 50 m high have recently migrated to block the river course. Since 1984 the Hoanib River has broken through the dune field to reach the Atlantic Ocean only three times (1984, 1995, 1997). Most recorded floods terminate in a transient lake body (8 x 4 km): the Gui-uin flood basin. This vegetated basin lies directly upstream of a dune-dam at leading dune-field edge.

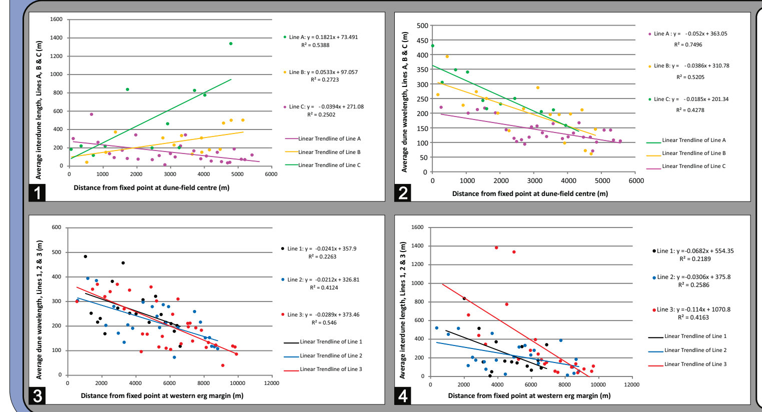
Key Observations

1. Passage of Hoanib River through its main catchment
2. Braid-like fluvial barform architecture with vegetation
3. Site of limited break-through into the dune field; river forms a series of ponds and distributive secondary channels between dunes
4. Path of former successful break-through; fluvial course passes through dune field toward the Atlantic Ocean
6. Migrating dunes accumulate aeolian sand in dry channels
5. Fluvial fan developed at point of emergence of river from dune field

Interpretation

During high-discharge flood events, a lake forms behind the dune barrier for several days or weeks; the water level within the flood basin reaches the dune low-points (cols) enabling passage into the dune field. The morphology of the transverse dunes and their intervening interdunes guides the flood waters through the dune field. Multiple smaller flood-basins form in blind interdune depressions.

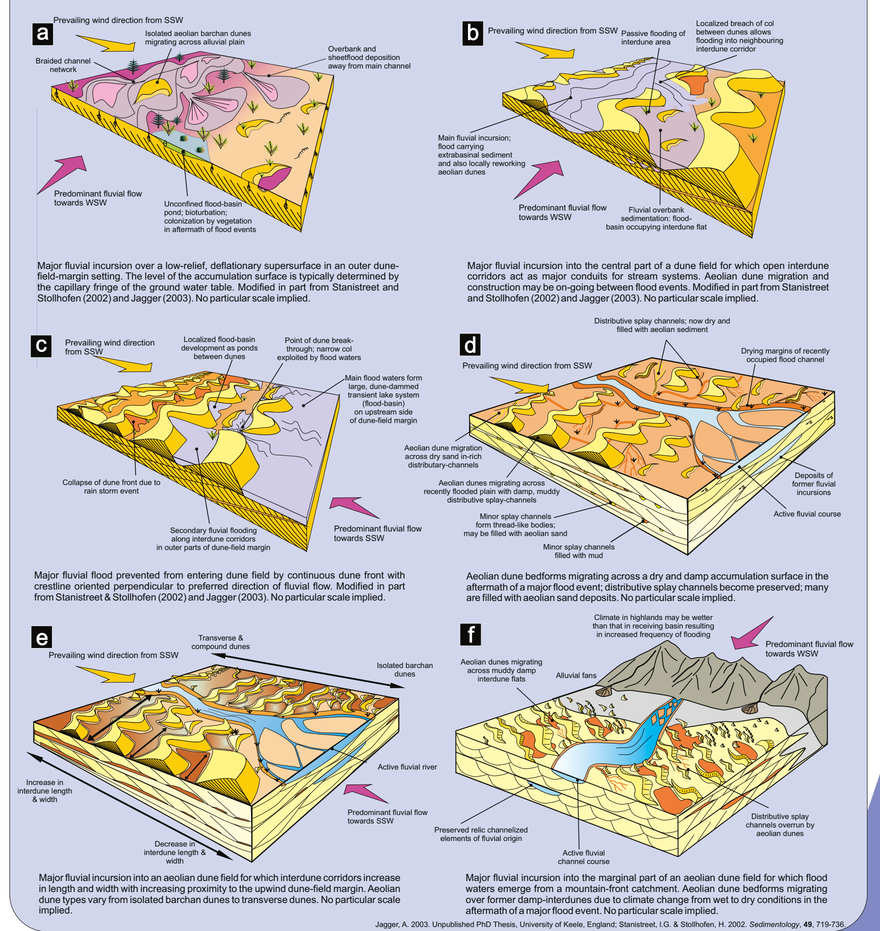




Key Observations

Examples of data displaying the results of the intimate relation between aeolian dunes and interdunes in present time. Lines A, B & C are parallel to the prevailing dune migration direction; 1, 2 & 3 are perpendicular to the prevailing dune migration direction. (1) Average interdune length of lines A & B increases towards the NNE due to an associated increase in dune spacing to the north of the river, whereas line C decreases due to an increase in the size of the flood-basin ponds at the eastern erg-margin. (2) The average dune wavelength of lines A, B & C decreases towards the NNE where the areal extent of flood-basin ponds increases; dunes migrate over the pond deposits during dry intervals. (3) Lines 1, 2 & 3 reveal a decrease in the average dune wavelength towards the eastern erg-margin where the ponds and vegetation are larger and more amalgamated. (4) The average interdune length along lines 1, 2 & 3 decreases towards the eastern erg-margin. Trends reveal systematic changes in dune size and morphology with increasing proximity to the fluvial channel course demonstrating the effects of flooding on aeolian sand supply and its availability for transport.

Summary Facies Models



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Conclusions

- Damming of fluvial courses by aeolian landforms occurs at a range of scales along the eastern margin of the Skeleton Coast dune field.
- Trains of aeolian bedforms with crestlines aligned perpendicular to the path of fluvial streams tend to result in the damming of the fluvial course, leading to the development of large flood basins on the immediate upstream side of the dune-field margin.
- Trains of aeolian bedforms with crestlines aligned parallel to the path of fluvial streams tend to promote fluvial incursion into the margins of aeolian dune fields.
- The distance of penetration of fluvial courses into dune fields is in part a function of the interconnectedness of interdune corridors along which flood waters pass: open interdune corridors promote incursion, whereas closed interdune depressions restrict incursions.
- Recurring flooding with frequent repeat intervals encourages the development of through-going fluvial corridors that remain open due to repeated flushing of aeolian sand from the fluvial fairway.
- This work has applied significance because it serves as the basis for a series of predictive models based on empirical relationships that can be used to predict likely preserved stratigraphic style in aeolian dune-field margins that are subject to repeated fluvial incursions.
- The empirical relationships documented here can be used to determine the likely thickness, lateral extent and continuity of reservoir-quality sands of aeolian-dune origin for preserved desert successions in which fluvial-aeolian interactions are known to occur.
- An outcome of this work is the construction of a series of predictive models that can be used to assess likely subsurface reservoir prospectivity in mixed fluvial-aeolian successions that range from aeolian dominated inner erg-margin settings to fluvial dominated outer erg-margin settings.
- The data collected from the Skeleton Coast for this study form part of a larger database of fluvial and aeolian sedimentary architectural styles that has been developed by the Fluvial & Eolian Research Group (FRG-ERG) at the University of Leeds.

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FRG ERG

Sedimentary and Stratigraphic Expression of Fluvial-Aeolian Interactions

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Preserved Sedimentary Record of Fluvial-Aeolian Interaction: Triassic Helsby Sandstone Formation, Cheshire Basin, UK

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Introduction

Fluvial-aeolian interactions are common at the margins of desert regions where drainage networks may penetrate tens to hundreds of kilometres into the inner parts of aeolian dune fields. Elsewhere fluvial systems may be dammed and ponded at outer dune-field margins. Some fluvial systems occupy long-lived fluvial corridors that partition dune fields; others temporarily exploit transient interdune corridors that open and close as aeolian-dunes migrate. This study documents the effects of temporal and spatial variability on preserved stratigraphic architecture of mixed fluvial-aeolian systems arising from: (i) morphological changes in aeolian dune and interdune configuration; (ii) variability in processes of sediment transport across desert basins for both fluvial and aeolian systems; (iii) variability in the mechanism of sediment preservation. Controls on fluvial incursions into dune fields include temporal and spatial changes in the frequency and magnitude of precipitation events, fluvial runoff distance from catchment to receiving basin, sediment yield, changes to regional water-table level in response to flood events, subtle variations in palaeotopography of the accumulation surface. These factors conspire to determine whether floods are confined within channelized networks or occur as non-confined sheet flows that inundate large areas of dune-field margins.

Outcrop analysis of the Helsby Sandstone Formation (Cheshire Basin, UK) reveals the preserved stratigraphic expression of several types of ancient fluvial-aeolian interactions: (i) relationships indicative of systematic temporal change from an aeolian dune field characterized by small, isolated dry interdunes to one in which interdunes were large and interconnected such that they acted as conduits for fluvial flow whereby fluvial channels were able to penetrate into dune-field centre settings; (ii) evidence for fluvial reworking of aeolian dune deposits by erosive flows that resulted in temporary cessation in dune migration in the immediate aftermath of flood events.

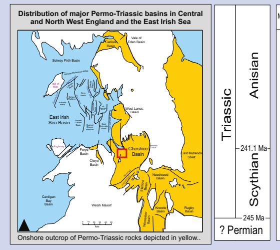
Aim and Objectives

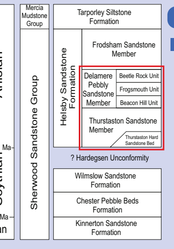
The aim of this study is to examine a series of well-exposed successions of aeolian and fluvial origin in the upper Thrustaston Member and lower to middle Delamere Member of the Helsby Sandstone Formation of the Cheshire Basin to document preserved examples of fluvial-aeolian utilizing outcrop data from well-exposed outcrop localities at Beacon Hill and Dunsdale Hollow.

Specific objectives of this study are as follows: 1) to describe and interpret the sedimentary facies of ancient fluvial and aeolian deposits present in an ancient preserved erg-margin succession; 2) to describe the nature of the interaction between aeolian, fluvial and floodplain sub-environments within the study area; 3) to integrate field-based observations made as part of this study with observations from earlier discussions and publications by others to further develop an understanding of the distribution of occurrence and lateral extent of lithofacies and their spatial and temporal variations in a fluvial-influenced erg margin depositional system.

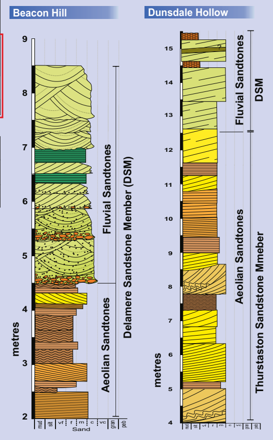
A specific outcome of this work is to demonstrate how careful field examination can be used to document detailed stratigraphic architectural relationships that can be used as the basis for the development of high-resolution, three-dimensional facies models that account for the style and mechanism of preservation of fluvial and aeolian deposits. A further outcome is to develop a discussion that considers the principal factors that influence sedimentation in erg-margin settings, including an examination of the role of water-table level, sediment supply, and sediment availability. Such models have valuable predictive potential.

Location and Geological Setting





Examples of Measured Sections



The Cheshire Basin is one of a series of Permo-Triassic basins present in NW England; it is faulted-bounded rift half-graben, the eastern margin of which has a NE-SW trend. The basin was initiated at the end of the Variscan (late Carboniferous) period. The Cheshire Basin represents one part of a complex N-S trending major rift system, which extends for more than 400 km, from the English Channel Basin in the south to the East Irish Sea Basin in the north.

In early to mid-Triassic times, the NW England region occupied an arid climatic region in the northern part of the Pangea supercontinent (Laurasia) where the climate was arid to semi-arid. Within the fill of the Cheshire Basin, the Sherwood Sandstones Group (SSG) represents a lower, predominantly arenaceous, part of the Triassic basin fill (Anisian). This is overlain conformably by the Merica Mudstone Group (MMG) that comprises an upper, predominantly argillaceous red-bed sequence. Based on seismic data, the total thickness of the preserved Permo-Triassic (SSG and MMG) and Lower Jurassic sediments within the Cheshire basin is typically more than 4000 m. The combined SSG and Permian arenaceous sediments are 2600-2800 m thick and overlying MMG is 1400-1500 m thick in the south of the Cheshire Basin.

The SSG is characterized by red, yellow and brown continental sandstones that accumulated mainly in a range of fluvial and aeolian environments. The Helsby Sandstone Formation (HSF), which is the focus of this study, is divided into three members: the basal Thrustaston Soft Sandstone Member (mostly aeolian), the middle Delamere Pebbly Sandstone Member (mized fluvial-aeolian), and the upper Frodsham Soft Sandstone Member (mostly aeolian). The HSF lies unconformably on Wilmslow Sandstone Formation (WSF), also of largely aeolian origin.

Facies Code

Code	Facies
A/DGFW	Aeolian Dune: Grainflow Strata
A/DWR	Aeolian Dune: Wind-Ripple Strata
A/DDW	Aeolian Dune: Convoluted Laminated Strata
A/IPL	Aeolian Interdune: Planar Laminated Sandstone
A/IWL	Aeolian Interdune: Wavy/ Crinkly Laminated Sandstone
F/EFM	Fluvial Extraformational Pebbly Sandstone
F/IFM	Fluvial Intraformational Pebbly Sandstone
F/LTX	Fluvial Low-angle Trough Cross-bedded Sandstone
F/HTX	Fluvial High-angle Trough Cross-bedded Sandstone
F/HL	Fluvial Horizontally Laminated Sandstone
F/CR	Fluvial Current-rippled Laminated Sandstone
F/DC	Fluvial Deformed (De-watered) Sandstone
F/LS	Fluvial Horizontally Laminated Sandy Siltstone
F/LM	Fluvial Horizontally Laminated Mudstone

Data and Methods

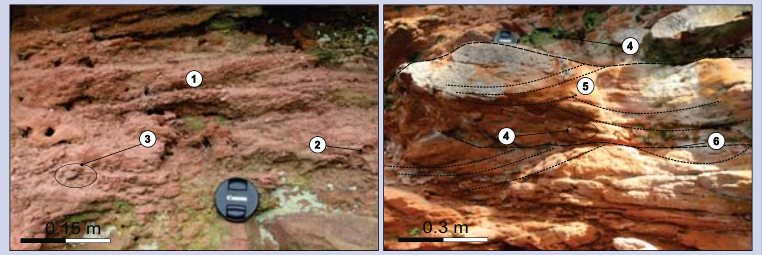
Outcrop data have been collected from a series of outcrops near to the town of Frodsham in northwest of England: Beacon Hill, Dunsdale Hollow, Runcorn Expressway road-cut, and Helsby Hill and Quarry. A series of vertical-logs and two-dimensional stratigraphic panels have been constructed to record the stratigaphic architecture in detail. Architectural panels and vertical logs from the Beacon Hill locality record a series of types of aeolian and fluvial interaction present in the DSM of the Helsby Sandstone Formation, whereas data from the Dunsdale Hollow locality record types of types of aeolian and fluvial interaction present in the lowermost part of DSM and uppermost part of TSM. The description of the two-dimensional panels shown here reveals variability in the lateral and vertical facies distribution of both fluvial and aeolian strata, the geometric relationships between aeolian-dune and -interdune facies, and the styles of interaction between competing fluvial and aeolian palaeoenvironments. More than 200 palaeocurrent measurements have been collected from both aeolian and fluvial sandstones at Beacon Hill and Dunsdale Hollow outcrops to show the prevailing wind and flow directions.

Lithofacies recognised from exposed parts of the HSF within Cheshire Basin have been documented previously by several workers (e.g., Thompson, 1969; 1970a & b; Mountney and Thompson, 2002). However, no detailed studies have been published previously relating to the outcrops discussed herein. Within this study, 14 distinct lithofacies are identified representing both fluvial and aeolian environments.

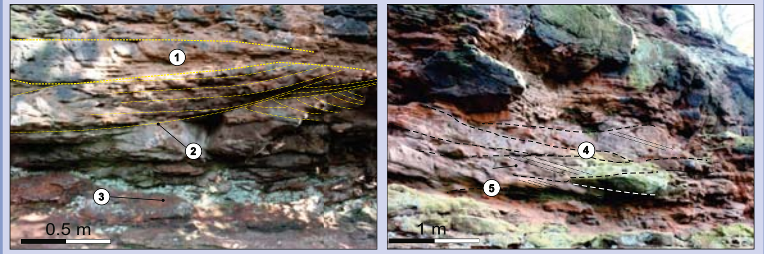
Fluvial Lithofacies

Facies F/PI Pebbly Sandstone with Extraformational Clasts

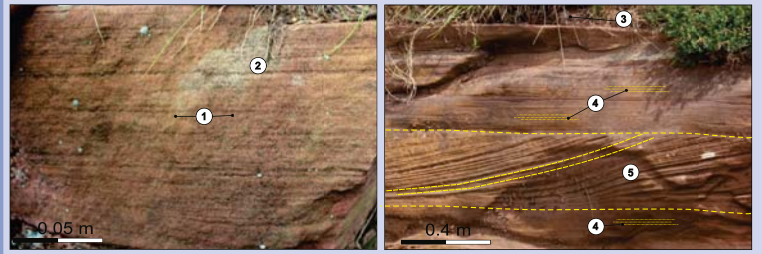
Facies F/PE Pebbly Sandstone with Intraformational Clasts



Facies F/HTX High-angle and F/LTX Low-angle Trough Cross-Bedded Sandstone



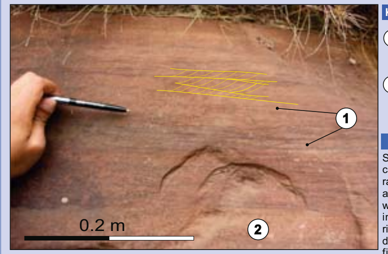
Facies F/HL: Horizontally Laminated Sandstone



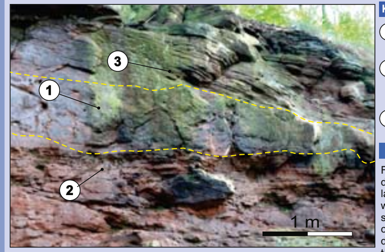
Interpretation

This facies represents deposits developed dominantly under upper-stage plane bed flows. Indicates suppressed turbulence within the flow; streaks of faster and slower moving water close to the bed. The fine-grained laminae may record deposition of the suspension load at the distal lee-side of bed waves. Common in late-stage channel filling.

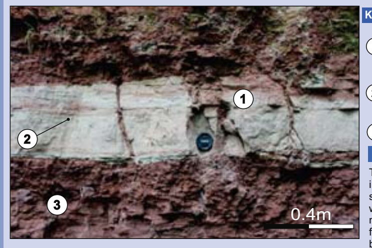
Facies F/CR Current-rippled Laminated Sandstone



Facies F/DC Deformed Sandstones



Facies F/LM Laminated Siltstone and Mudstone



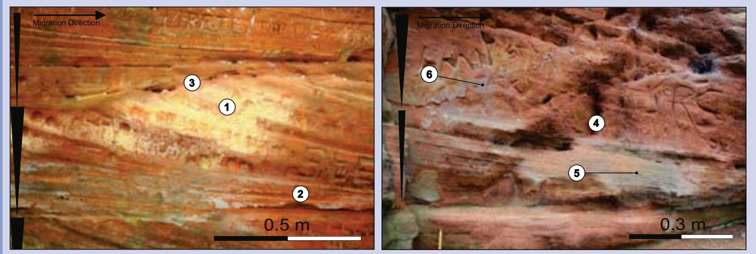
Facies Association: Non-confined Fluvial Sheets

Architectural Elements: F2, F3

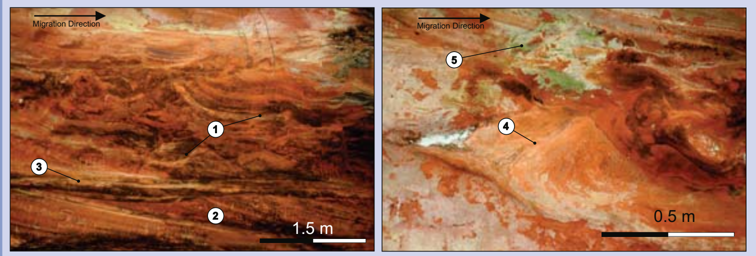
Aeolian Lithofacies

Facies A/DGFW Grainflow Strata

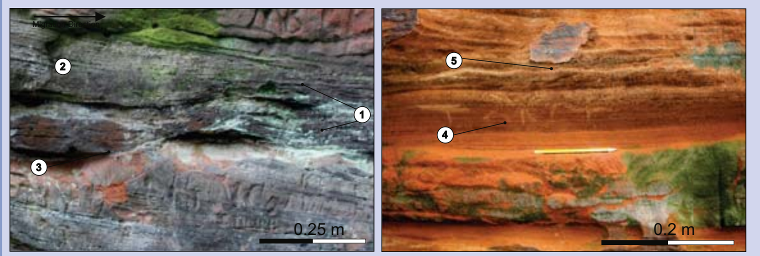
Facies A/DWR Wind-Ripple Strata



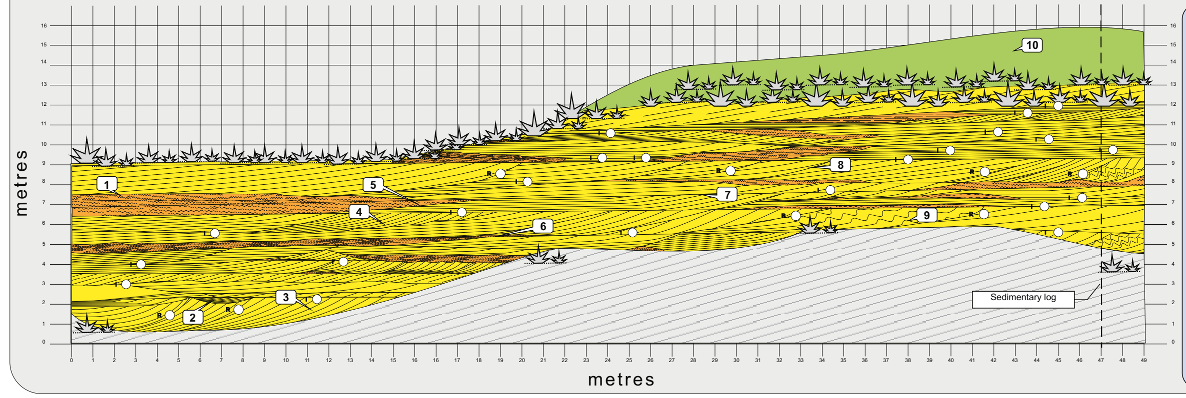
Facies A/DDW Convoluted Dominated Sandstone



Facies A/IWL Wavy Laminated and Facies A/IPL Planar Laminated



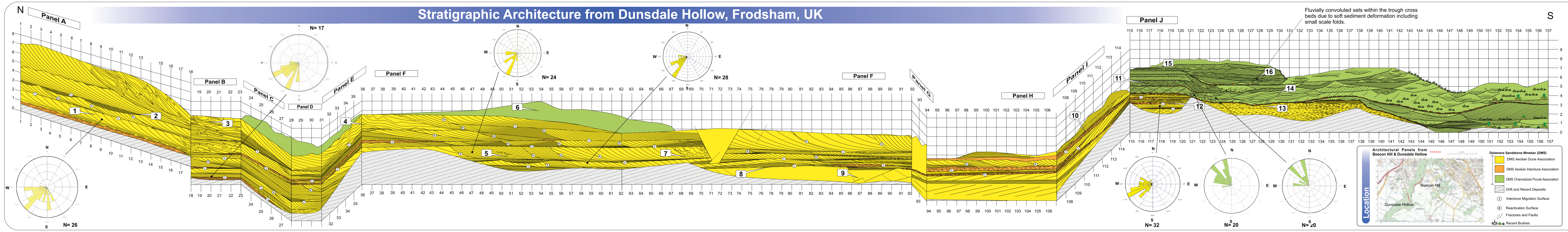
Stratigraphic Architecture from Dunsdale Hollow, Frodsham, UK



Features of Sedimentological Interest

1. Stacked beds of wet interdune origin dominated by wavy laminated, very fine-grained sandstones that extend laterally more than 13 m. Indicates cyclic deposition within interdune depressions.
2. Fine-grained sandstone dominated by planar and wind-ripple laminated sandstone; dry interdunes.
3. Aeolian grainflow strata characterized by high-angle stratified, medium-grained sandstone. Grainflow deposits are each up to 60 mm thick.
4. Erosive base of aeolian dune dominated by grainflow strata.
5. Lateral transitional facies change from wet interdune to wind-ripple strata indicative of dry interdune.
6. Lateral thinning-out of wet-interdune facies.
7. Stacked aeolian dune-strata separated by interdune surface.
8. Stacked aeolian dune-strata separated by interdune surface.
9. Deformed aeolian-dune sets (slumped) as a result of wetting of advancing-dune.
10. Fluvial succession cuts into older aeolian strata.

Stratigraphic Architecture from Dunsdale Hollow, Frodsham, UK



Features of Sedimentological Interest

1. Medium-grained sandstone characterized by high-angle aeolian grainflow strata. Grainflow deposits 50 mm thick.
2. Medium-grained sandstone dominated by planar and wind-ripple laminations of dry interdunes.
3. & 4. Thick convoluted aeolian-dune sets dominated by A/ADDW facies.
5. Medium-grained grainflow dominated sandstone with small-scale slump structures.
6. Channelized fluvial successions (CF1, CF2) cut into aeolian successions (SH2, AD1, AD2).
7. Medium- to coarse grained sandstone of thick convoluted aeolian-dune sets.
8. Lateral transitional facies change from wet-interdune to wind-ripple strata indicative of dry accumulation.
9. Faulted blocks due to regional tectonic movements.
10. Wet interdune dominated by wavy laminated, very fine-grained sandstones that extend laterally more than 20 m.
11. Small scale fluvial trough cross-beds associated with intraformational clasts.
12. Very fine-grained planar to wavy laminated sandstone of wet and dry interdune sets due to water table fluctuations.
13. Major fluvial incursion into an aeolian sandsheet succession that is dominated by wind-ripple strata. Extraformational and intraformational clasts associated with erosional base of fluvial channel.
14. Large-scale, wedge, shaped sets of trough cross-bedded, medium- to coarse-grained sandstone (3 m wide).
15. Fluvial horizontal laminated sets characterized by medium-grained channel-fill sediments.

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Sedimentary and Stratigraphic Expression of Fluvial-Aeolian Interactions

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Preserved Sedimentary Record of Fluvial-Aeolian Interaction: Triassic Helsby Sandstone Formation, Cheshire Basin, UK

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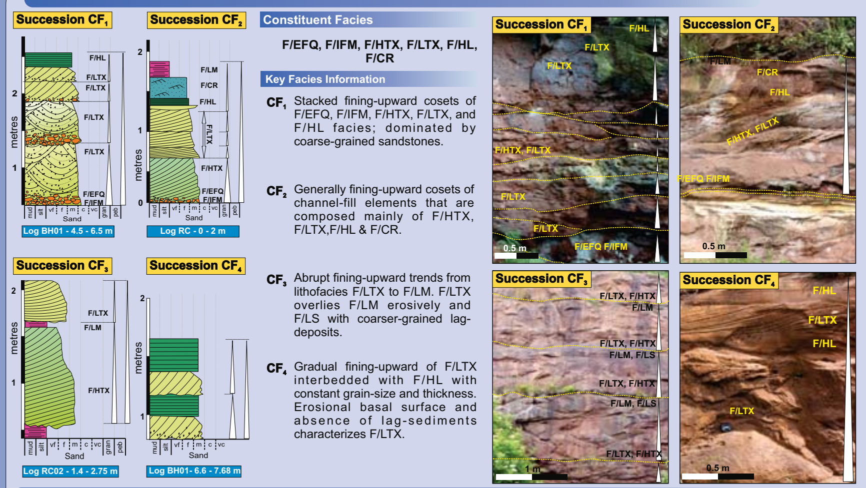
Facies Associations

CF - Channelized Fluvial Facies Association



Constituent Facies

F/EFQ, F/IFM, F/HTX, F/LTX, F/HL, F/CR

Key Facies Information

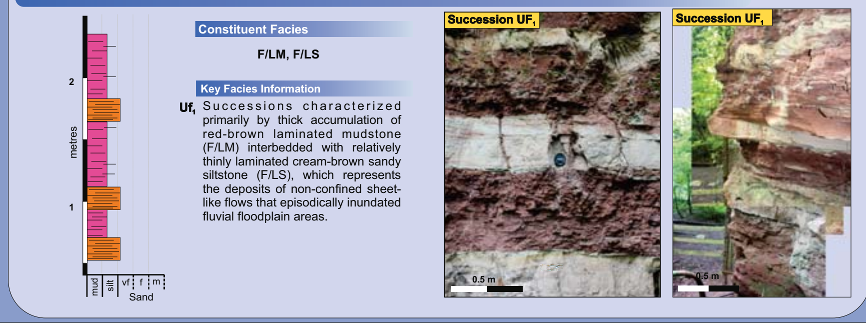
CF_1 Stacked fining-upward cosets of F/EFQ, F/IFM, F/HTX, F/LTX, and F/HL facies; dominated by coarse-grained sandstones.

CF_2 Generally fining-upward cosets of channel-fill elements that are composed mainly of F/HTX, F/LTX,F/HL & F/CR.

CF_3 Abrupt fining-upward trends from lithofacies F/LTX to F/LM. F/LTX overlies F/LM erosively and F/LS with coarser-grained lag-deposits.

CF_4 Gradual fining-upward of F/LTX interbedded with F/HL with constant grain-size and thickness. Erosional basal surface and absence of lag-sediments characterizes F/LTX.

UF - Non-confined Fluvial Sheet Facies Association



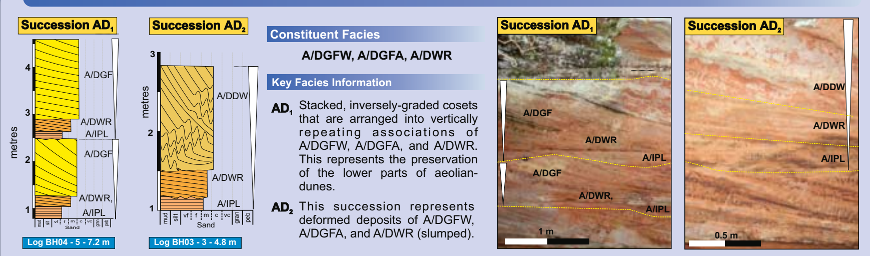
Constituent Facies

F/LM, F/LS

Key Facies Information

Uf_1 Successions characterized primarily by thick accumulation of red-brown laminated mudstone (F/LM) interbedded with relatively thinly laminated cream-brown sandy siltstone (F/LS), which represents the deposits of non-confined sheet-like flows that episodically inundated fluvial floodplain areas.

AD - Aeolian Dune Facies Association



Constituent Facies

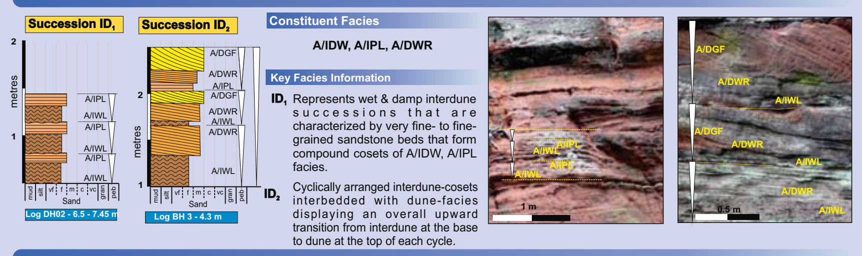
A/DGFW, A/DGFA, A/DWR

Key Facies Information

AD_1 Stacked, inversely-graded cosets that are arranged into vertically repeating associations of A/DGFW, A/DGFA, and A/DWR. This represents the preservation of the lower parts of aeolian-dunes.

AD_2 This succession represents deformed deposits of A/DGFW, A/DGFA, and A/DWR (slumped).

ID - Aeolian Interdune Facies Association



Constituent Facies

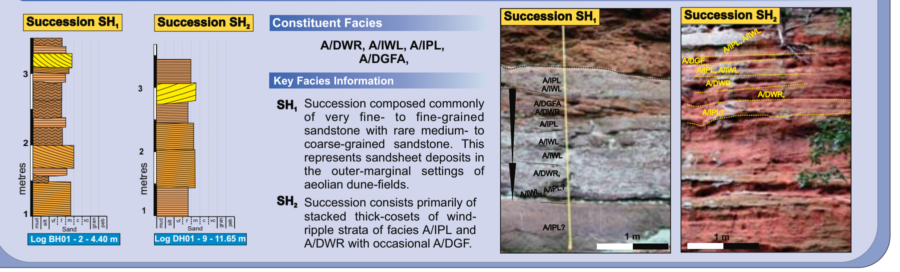
A/IDW, A/IPL, A/DWR

Key Facies Information

ID_1 Represents wet & damp interdune successions that are characterized by very fine- to fine-grained sandstone beds that form compound cosets of A/IDW, A/IPL facies.

ID_2 Cyclically arranged interdune-cosets interbedded with dune-facies displaying an overall upward transition from interdune at the base to dune at the top of each cycle.

SH - Aeolian Sandsheet Facies Association



Constituent Facies

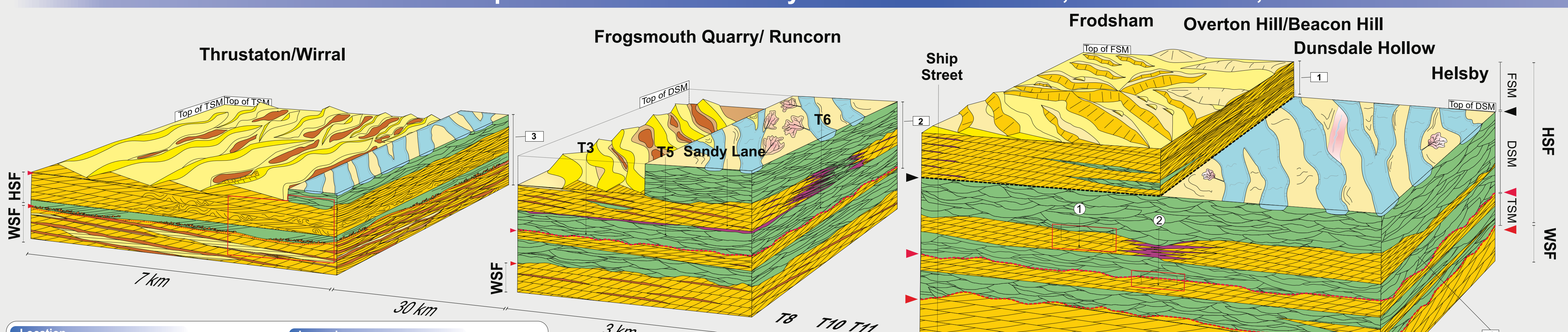
A/DWR, A/IWL, A/IPL, A/DGFA,

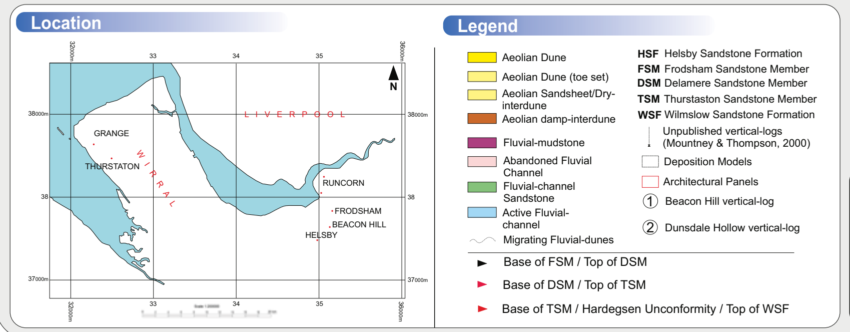
Key Facies Information

SH_1 Succession composed commonly of very fine- to fine-grained sandstone with rare medium- to coarse-grained sandstone. This represents sandsheet deposits in the outer-marginal settings of aeolian dune-fields.

SH_2 Succession consists primarily of stacked thick-cosets of wind-ripple strata of facies A/IPL and A/DWR with occasional A/DGF.

Depostional Model of Helsby Sandstone Formation, Cheshire Basin, UK





Key Features

Architectural panels from the Helsby Sandstone Formation (HSF) document the detailed stratigraphy in orientations both parallel and perpendicular to aeolian transport direction, enabling a quantitative 3D reconstruction of genetically related aeolian dune, interdune and fluvial channel and non-channelized sheet-like elements. Sets of aeolian dune strata are composed of grainflow and translatent wind-ripple strata and are divided by a hierarchy of bounding surfaces originating from oblique migration of superimposed dunes over slipfaceless, sinuous-crested parent bedforms, together with lee-slope reactivation under non-equilibrium flow conditions. Silty-mudstone and sandstone interdune units are characterized by wind-ripple-, wavy- and subaqueous wave-ripple-laminae, desiccation cracks, mud flakes, raindrop imprints, load casts, flutes, intraformational rip-up clasts, and vertebrate and invertebrate footprint impressions and trackways. These units result from accumulation on a substrate that varied from dry-, through damp- to wet-surface conditions. Interdune ponds were flooded either by fluvial incursions or rises in groundwater table and were periodically subject to gradual desiccation and re-flooding. Red silty-mudstone beds of subaqueous origin pass laterally into horizontally laminated wind-ripple beds indicating a progressive transition from wet-, through damp- to dry-surface conditions single interdune elements.

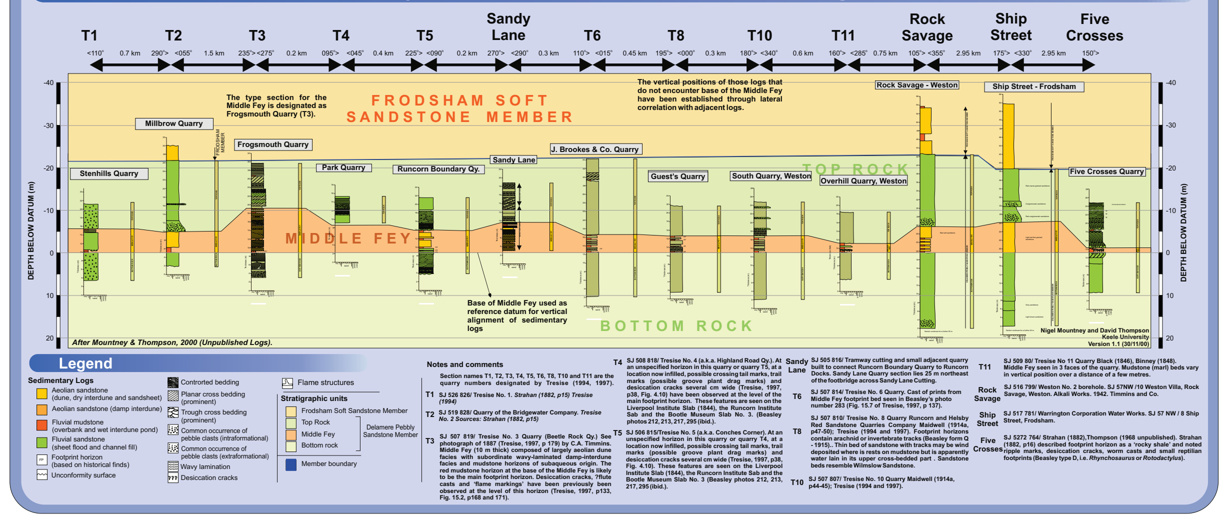
Key Features

1. The Frodsham Sandstone Member (FSM) is an aeolian succession that represents the preserved deposits of large dome-shaped aeolian dunes (Thompson, 1969), deposits of which are well-exposed in a railway cutting near Frodsham town, UK. Aeolian sets are up to 20 m thick and preserve convex-up foresets that dip in a variety of orientations. The FSM records the development of an extensive aeolian dune field in the central Cheshire Basin.
2. Mountney and Thompson (2002) described a series of two-dimensional stratigraphic panels of the DSM of the HSF in old sandstone quarries (Runcorn Hill). This work recognized significant lithological changes between fluvial and aeolian sedimentation. The aeolian unit is characterized by small aeolian dune sets with a variety of intervening wet, damp and dry interdune units; fluvial units are composed of channelized elements, many with mudstone intraclasts and water escape structures.
3. The Thurstaston Sandstone Member (TSM) is exposed is a dominantly aeolian unit at its type section, a 300-m-long, 5-10 m high road-cutting at Thurstaston. This section exposes the uppermost part of the WSF and the aeolian TSM of the HSF. The two formations are separated by The Hardegsen Unconformity. The base of the TSM is characterized locally by a prominent fluvial channel element (Mountney, 2006; Thompson, 1970a).
4. The Helsby Hill area is the type section for the HSF and the the 3 members are all well exposed. Thompson (1970) and Mountney & Thompson (2000) identified complex interactions between aeolian and fluvial units using extensive outcrop data from measured sections at Helsby Hill Main Cliff and Helsby Old Quarries.

References

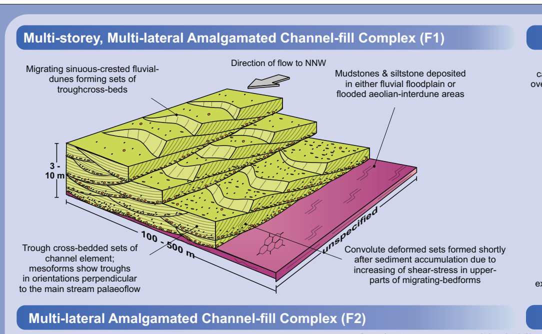
- **Mountney & Thompson, 2000**. Unpublished vertical logs.
- **Mountney, N.P. (2006)** Eolian Facies Models. In: *Facies Models Revisited* (Eds H. Posamentier and R.G. Walker). SEPM Mem., **84**, 19–83.
- **Mountney, N.P., Thompson, D.B., (2002)**. Stratigraphic evolution and preservation of aeolian dune and damp/wet interdune strata: an example from the Triassic Helsby Sandstone Formation, Cheshire Basin, UK. *Sedimentology*, **49**, 805–834.
- **Thompson, D.B. (1969)** Dome shaped aeolian dunes in the Frodsham Member of the so-called 'Keuper' Sandstone Formation [Scythian - ?Anisan: Triassic] at Frodsham, Cheshire (England). *Sed. Geol.*, **3**, 263-289.
- **Thompson, D.B. (1970a)** Sedimentation of the Triassic (Scythian) red pebbly sandstones in the Cheshire Basin and its margins. *Geol. J.*, **7**, 183-216.
- **Thompson, D.B. (1970b)** The stratigraphy of the so-called Keuper Sandstone Formation (Scythian-?Anisian) in the Permo-Triassic Cheshire Basin. *Q. J. Geol. Soc. Lond.*, **126**, 151-181.

Correlation of the Delamere Pebbly Sandstone Member in the Runcorn Region of the Cheshire Basin

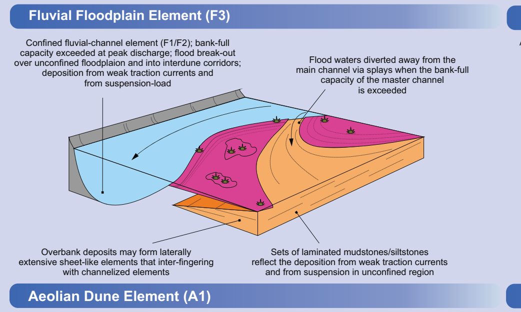


Facies Elements

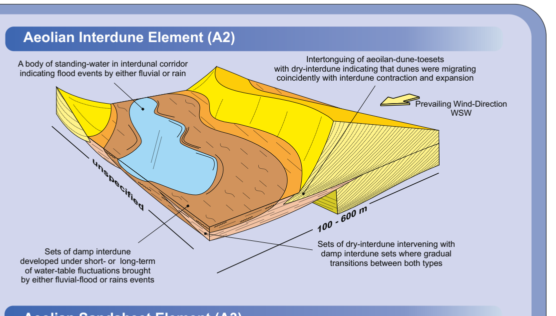
Multi-storey, Multi-lateral Amalgamated Channel-fill Complex (F1)



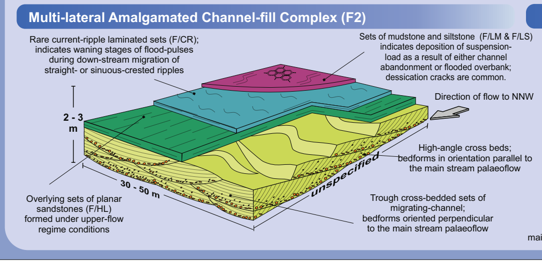
Fluvial Floodplain Element (F3)



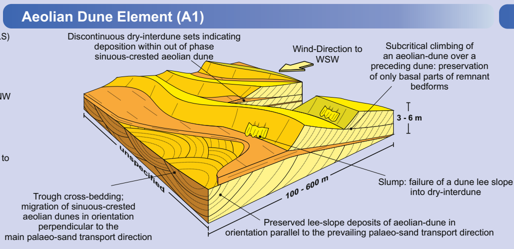
Aeolian Interdune Element (A2)



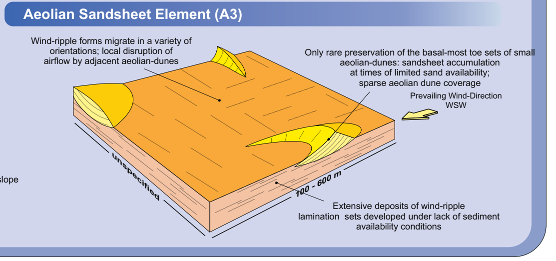
Multi-lateral Amalgamated Channel-fill Complex (F2)



Aeolian Dune Element (A1)

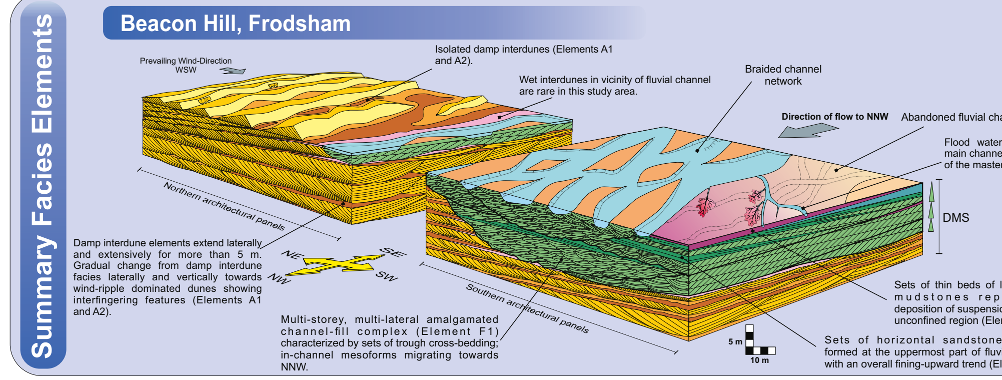


Aeolian Sandsheet Element (A3)

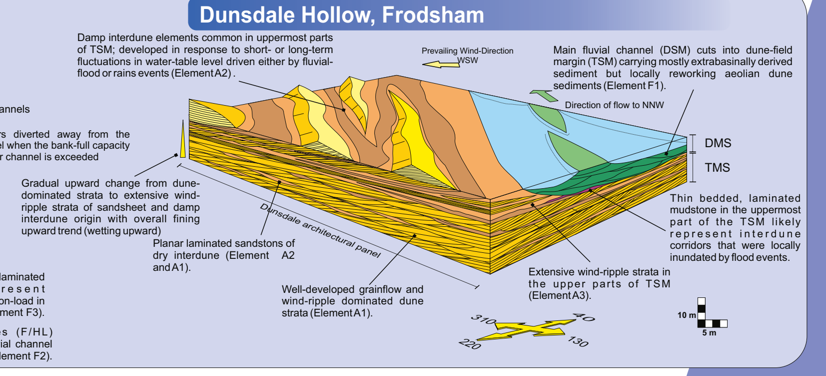


Summary Facies Elements

Beacon Hill, Frodsham



Dunsdale Hollow, Frodsham



Conclusion

- This study documents the effects of temporal and spatial variability on preserved stratigraphic architecture of mixed fluvial-aeolian systems arising from: (i) morphological changes in aeolian dunes and interdune configuration; (ii) variability in processes of sediment transport across desert basins for both fluvial and aeolian systems; (iii) variability in the mechanism of sediment preservation.
- Controls on fluvial incursions into dune-fields include temporal and spatial changes in the frequency and magnitude of precipitation events, fluvial runoff distance from catchment to receiving basin, sediment yield, changes to regional water-table level in response to flood events, subtle variations in palaeotopography of the accumulation surface. These factors conspire to determine whether floods are confined within channelized networks or occur as unconfined sheet flows that inundate large areas of dune-field margins.
- A specific outcome of this work is to demonstrate how careful field examination can be used to document detailed stratigraphic architectural relationships that can be used as the basis for the development of high-resolution, three-dimensional facies models that account for the style and mechanism of preservation of fluvial and aeolian deposits.
- A further outcome is to develop a discussion that considers the principal factors that influence sedimentation in erg-margin settings, including an examination of the role of water-table level, sediment supply, and sediment availability. Such models have valuable predictive potential.
- This study also attempts to outline the connection between hydrocarbon accumulation and both fluvial and aeolian facies within the equivalent subsurface reservoirs of Helsby Sandstone Formation that is strongly controlled by depositional facies.

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