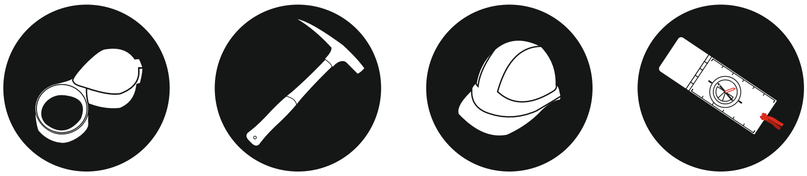
AEOLIAN-FLUVIAL DRYLAND SYSTEMS

BSRG Core Workshop

20th December 2015



BSRG Sedimentary Research

Imperial College London

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Aeolian-fluvial drylands systems

British Sedimentological Research Group (BSRG)
AGM Core Workshop

Course Leaders:

Steven G. Banham
Imperial College London
s.banham@imperial.ac.uk

Oliver J.W. Wakefield
British Geological Survey
oliverw@bgs.ac.uk

AGM Convenor (Keele University):

Hazel Beaumont[1,2]
1 - Keele University
h.beaumont@keele.ac.uk
2 - University of Birmingham
h.beaumont@bham.ac.uk

Keele University

The course leaders would like to the thank Nigel Mountney and Gary Hampson for their insightful comments that greatly helped in the production of this workshop.

We also like to the acknowledge the Fluvial Research Group and Eolian Research Group and its members for a providing some of the material included in this handout.

FRG ERG

Contents

Introduction

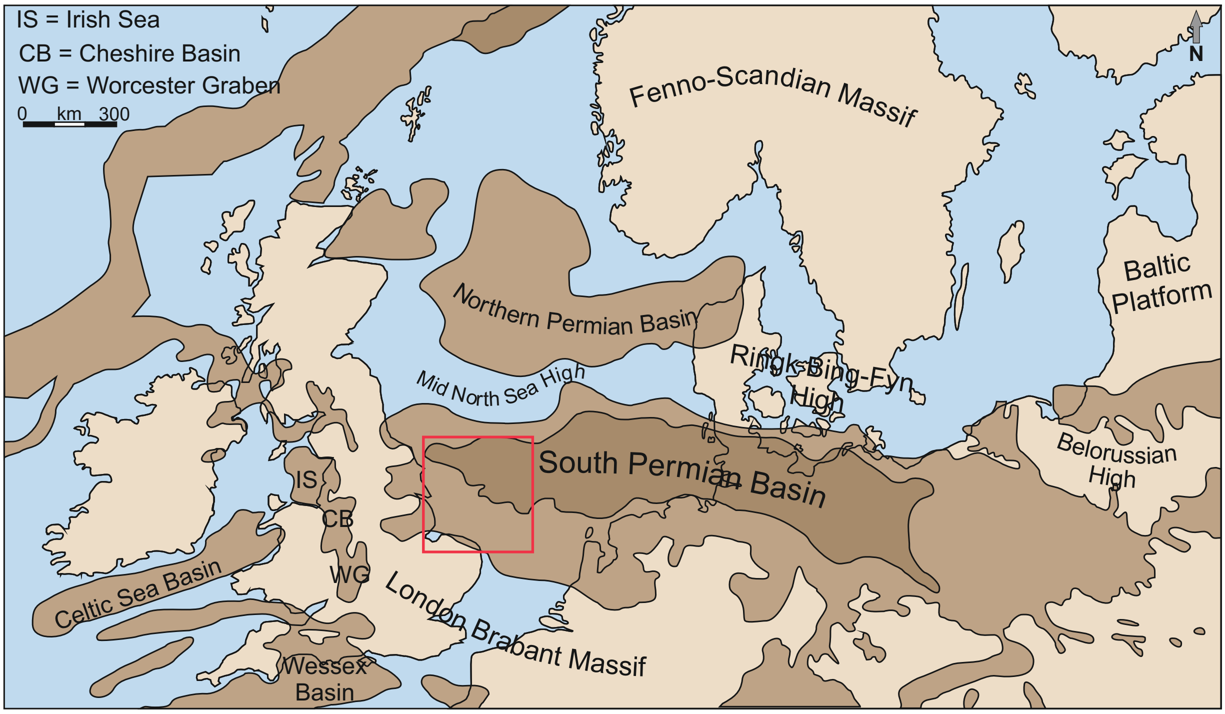
Interpretation of core material can be a complicated process, in part due to the one dimensional nature of the sample, and the limited spatial availability of core; caused by both the limited spatial sampling frequency (distribution of wells with core intersecting the interval of interest) and limited temporal sampling (limited number of core runs recovering material from the interval of interest). To interpret core effectively requires a good understanding of both spatial and temporal variations that can occur within a depositional environment, but also requires the interpreter to know limitations and pitfalls with observing and interpreting the core.

The Permian Leman Sandstone is the preserved expression of a mixed fluvial – aeolian succession, deposited by a fluvial system which terminated in a desert basin. The fluvial system which originated from the London-Brabant Massif, and flowed NNE into the south western edge of the South Permian Basin, which was occupied by an aeolian erg field along the southern margin and sabkahas and playa lakes toward the basin centre. The interactions between the fluvial system and the dune field lead to the deposition of a hybrid stratigraphy, where episodic fluvial activity would rework and entrain material from aeolian deposits, before later being reworked themselves by ongoing aeolian processes.

This workshop aims to familiarise participants with the expression of fluvial and aeolian strata in core, and to understand the potential pitfalls and limitations with these interpretations.

Key aims of this core workshop are to:

- Familiarise the participants with identifying key aeolian and fluvial facies in core.
- Identifying the processes which formed these faces.
- Using facies associations and successions to build depositional models.
- Understand pitfalls and limitations with interpretation of core materials.

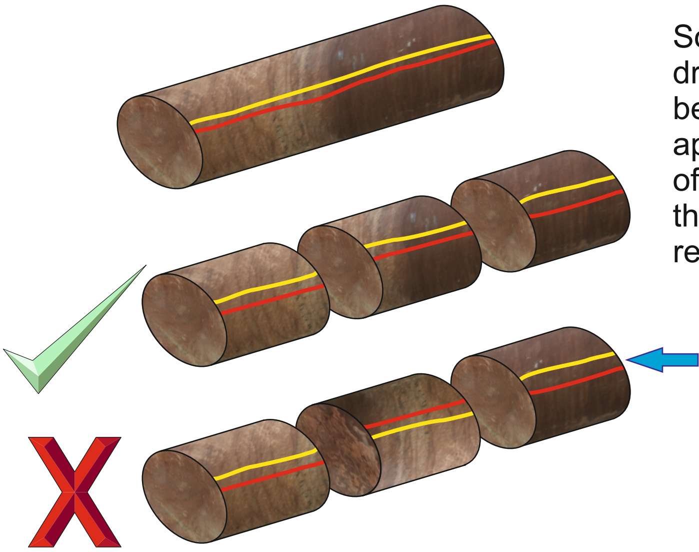


Permian (Rotiegend Group) palaeogeography of NW Europe showing distribution of major non-marine sedimentary basins. AOI in red. Modified after Ziegler (1990).

Handling the core

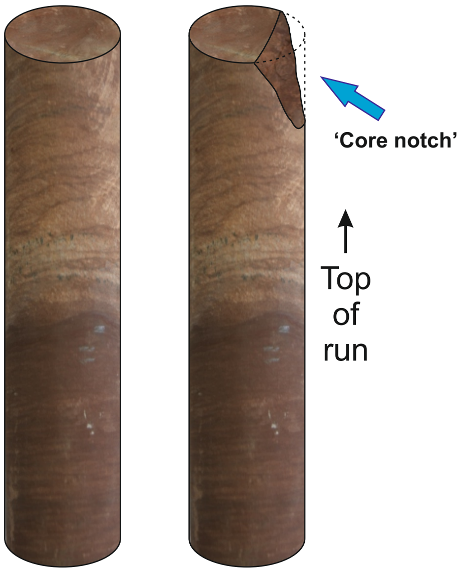
Please ensure that any core removed from its box is replaced in the correct position with the correct orientation.

Please also handle the core with care to avoid accidental injury to yourselves, or more importantly to avoid damage to the core material!



Some core will have coloured lines draw along its length. These lines can be of variable colour and are usually applied soon after drilling. The addition of the lines is used to prevent pieces of the core being put upside-down in relation to the rest of the core.

Note that the middle piece is orientated incorrectly to the other pieces (indicated by the coloured lines).

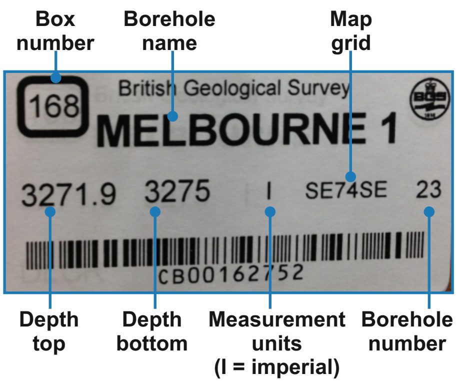


The coring process can sometimes lead to the upper parts of a core-run having a 'notch' at the top. The damage occurs when the drill is replaced in the hole after the subsequent core has been retrieved. As such, the identification of this damage can sometimes be used to orientate the top of individual core runs in the absence of other information.

All boreholes are catalogued in the National Geological Repository using a barcode system. This includes lables on the borehole boxes. This commonly indicates the depth range for the core box (top and bottom), but may also include information on:

- The top of the core.
- Whether the measurements are in imperial or metric (dennoted by a 'm' or 'I').

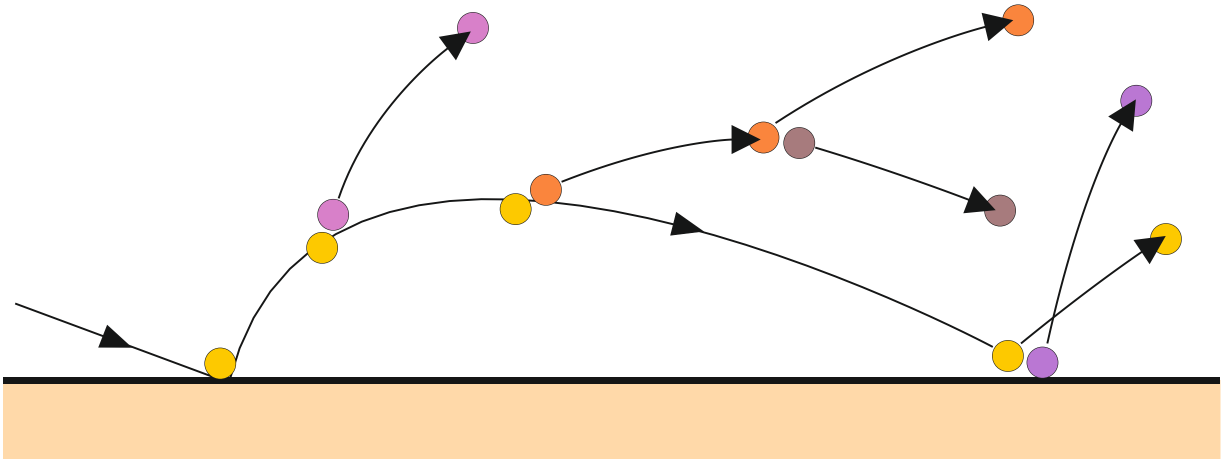
Additional depth information is sometimes written on the insides of the core box.



Terminology: processes

Saltation

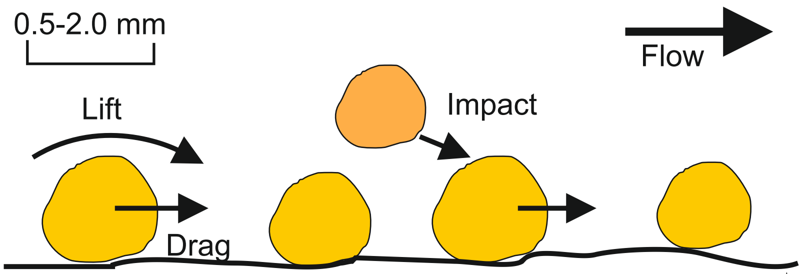
A transport process whereby particles are transported by a series of small leaps within a fluid (air or water) parallel to the prevailing current. This process is an intermediate between traction (where the particles are in constant contact with the underlying substrate) and suspension (where the particle is suspended completely within the fluid). Intergranular collisions while the grains are travelling within the flow are important for altering the trajectory of individual grains and keeping sediment aloft. In aeolian environments sediments transported by this processes are dominated by a narrow grainsize range, typically between 0.15 mm and 0.3 mm in diameter (Bagnold, 1941).



In-flow collisions of saltating grains maintains momentum keeping grains aloft. Ground impacts induce new grains to saltate.

Surface Creep

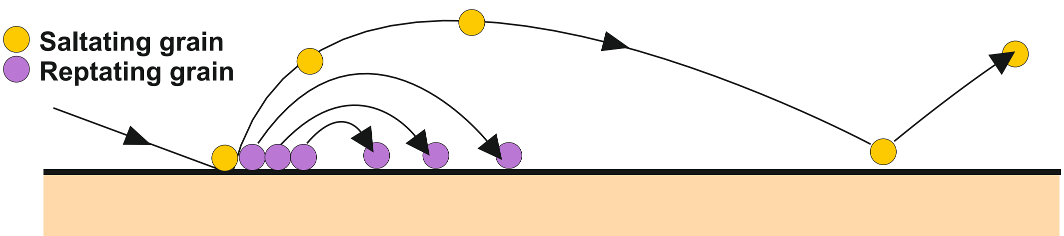
Transport process whereby larger particles incapable of saltation are moved by collision of saltating grains. This processes allows transport of coarser grained materials within an aeolian succession.



Process that act to induce motion by surface creep.

Reptition

Reptition is an intermediate step between surface creep and saltation. Saltating grains collide with surface particles providing sufficient energy to exceed the force of inertia, causing them to move with a singe bounce in a down current direction.



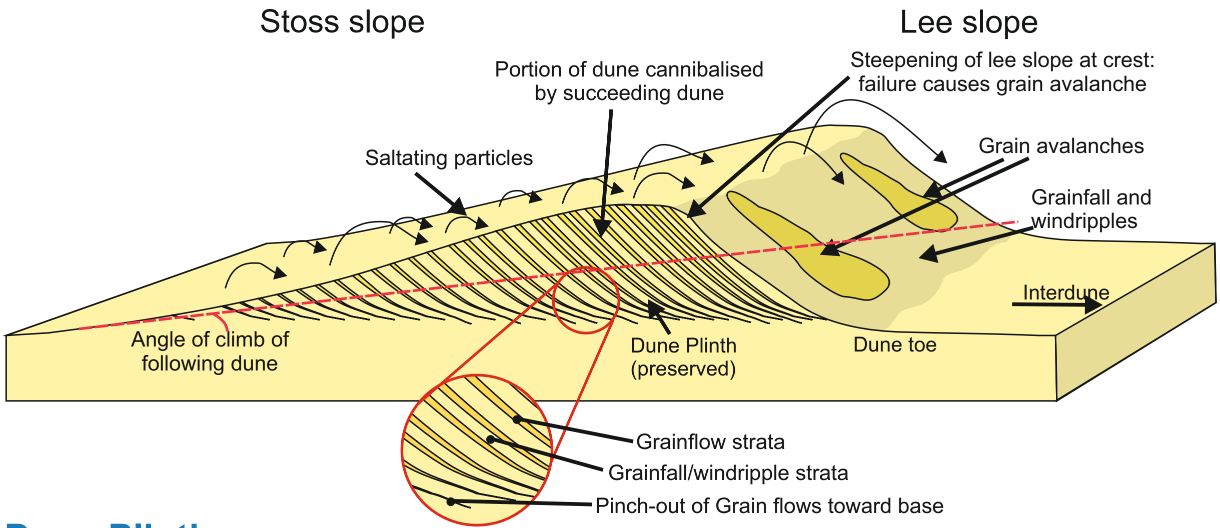
Terminology: dune morphology

Stoss slope

Shallow upwind side of the dune or ripple. Preservation of this slope is typically rare in climbing-ripple strata, and virtually non-existent in dune-scale bedforms.

Lee slope (slipface)

The steeper downwind side of the dune. Sediment is transported up the stoss side of the dune by creep and saltation, before cascading down the lee side of the dune either by saltation and/or avalanching. Avalanching is generated when the lee slope is over-steepened by sediments accumulating at the crest. Lee slope angles are limited by the maximum angle of repose in dry sediments, which is typically ~33° (Mountney, 2006).



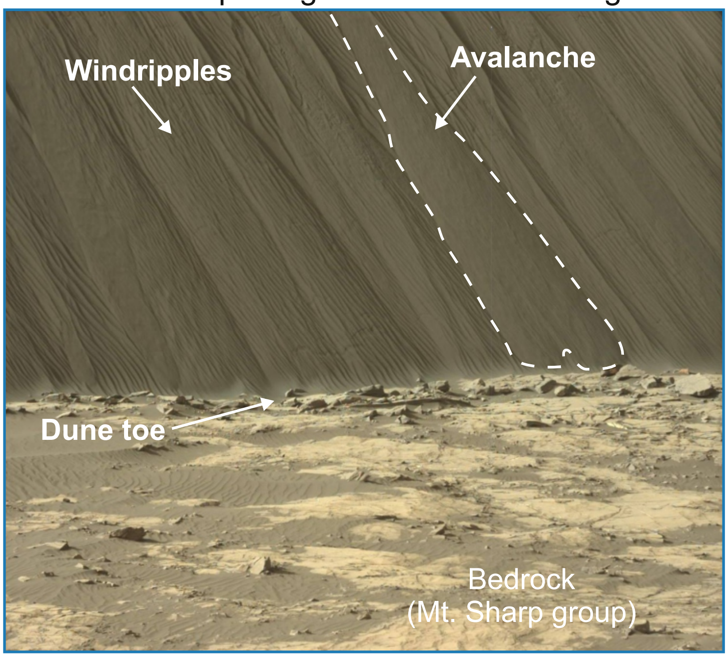
Dune Plinth

Preserved basal section of the dune, composed predominantly of sediments deposited on the lee slope of the dune.

Dune Toe

The downwind limit of the dune, where the lee slope angle shallows and merges with interdune facies, or the preceding dune. This part of the dune is characterised by windfall and wind rippled deposits. Only the furthest flowing grain avalanches will reach this far down the lee slope.

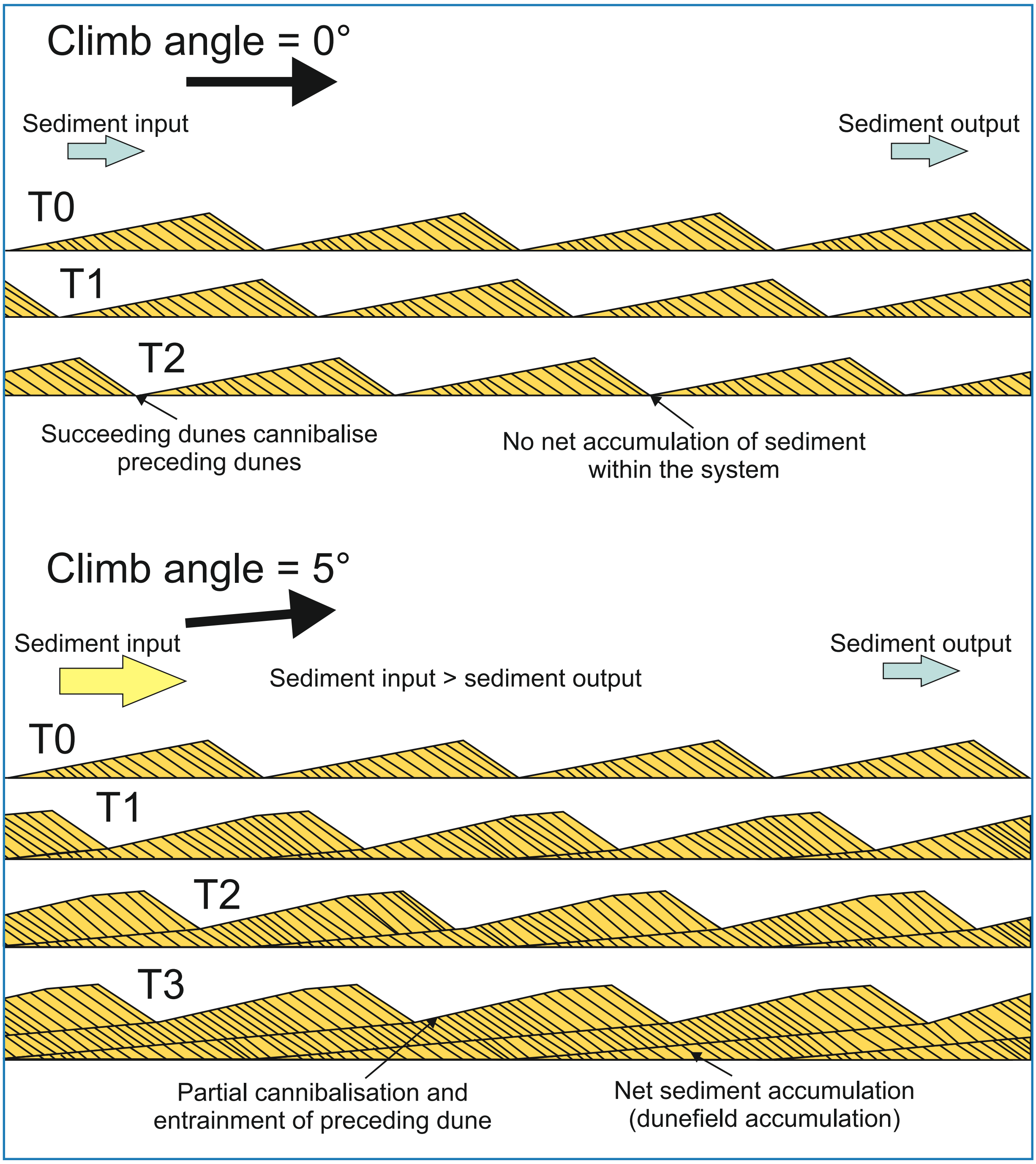
Active dune slip-face, featuring avalanche deposits and wind ripple strata. Bagnold dune field, Gale Crater, Mars (JPL/NASA, 2015)



Aeolian climb & preservation

Climb angle

This describes the angle at which migrating dunes climb over the back of older dunes, and is controlled by the rate at which sediment accumulates within the dune field. Where the angle of climb is 0°, dunes will migrate over a surface with no net accumulation of sediment within the system. When the angle of climb is greater than zero, sediments will accumulate within the system. Dunes will begin to migrate over preceding dunes, cannibalising the upper part of the dune stoss slope, while preserving a proportion of the lee slope (the dune plinth). The greater the angle of climb, the greater the proportion of the lee slope will be preserved.



Windripple strata

Windripple Strata

Windripple strata (also referred to as pinstripe lamination) is expressed by small lamination-scale features. One mechanism for the formation of pinstripe laminations are by the accumulation of fine-grained sands and silts concentrated in the lee of wind-formed ripples as they migrate downwind. These finer materials become buried by coarser sediments which form the crest of the advancing ripples, generating inverse-graded laminations and preventing erosion of the fine-grained layer (Fryberger & Schenk, 1988). These segregated laminations containing silt grade material can result in early cementation of windripple strata, which can cause distinctive proud-weathering layers within these cementation zones (Fryberger & Schenk, 1988), or can act as barriers to later fluid flow. Windripple strata can form on the stoss side of dunes (although the preservation potential is limited), and on dune slip faces where wind blows parallel to the dune crest (Eastwood et al., 2012).

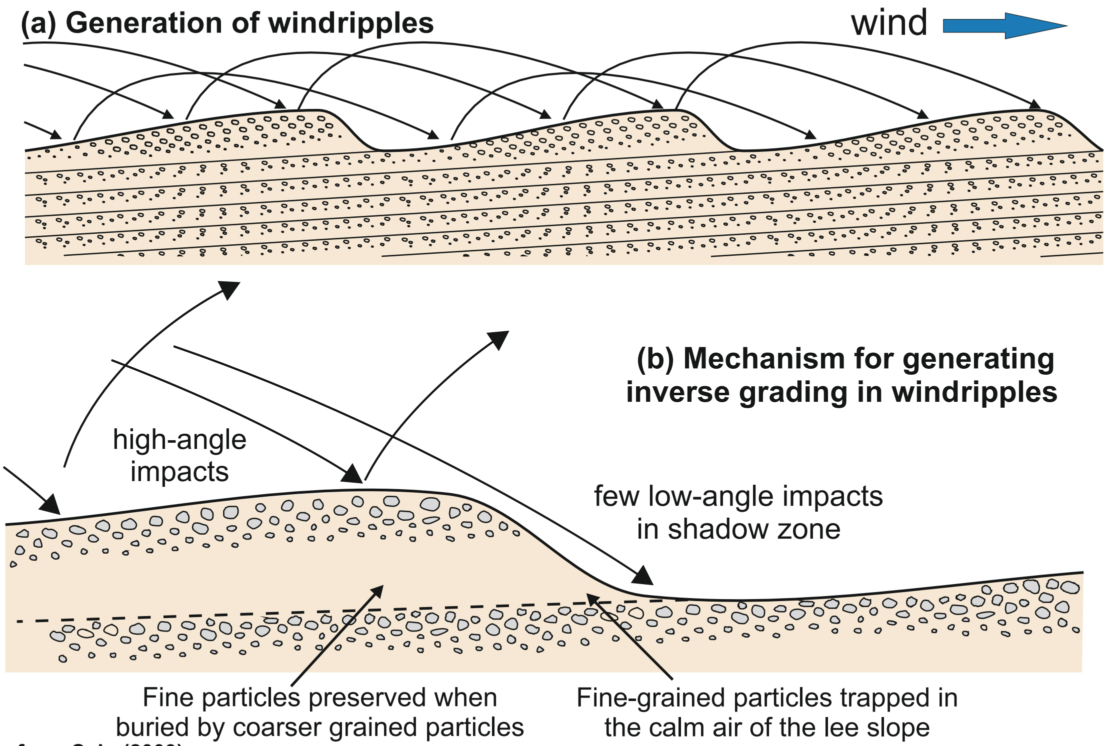
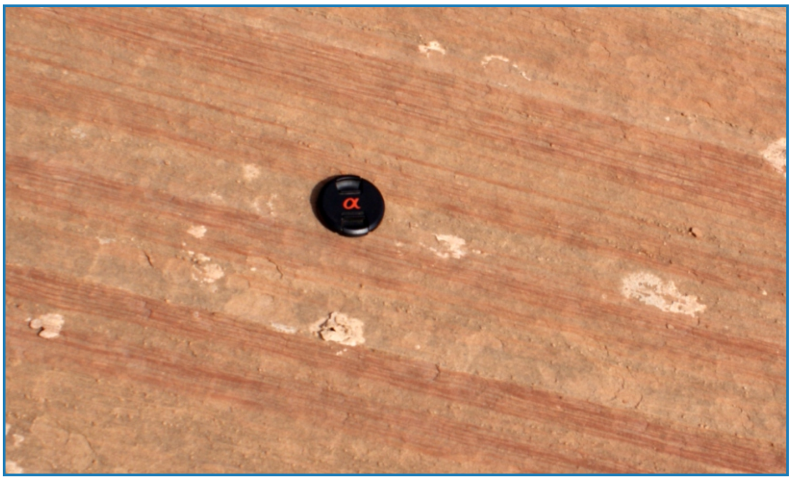


Diagram from Cain (2009)

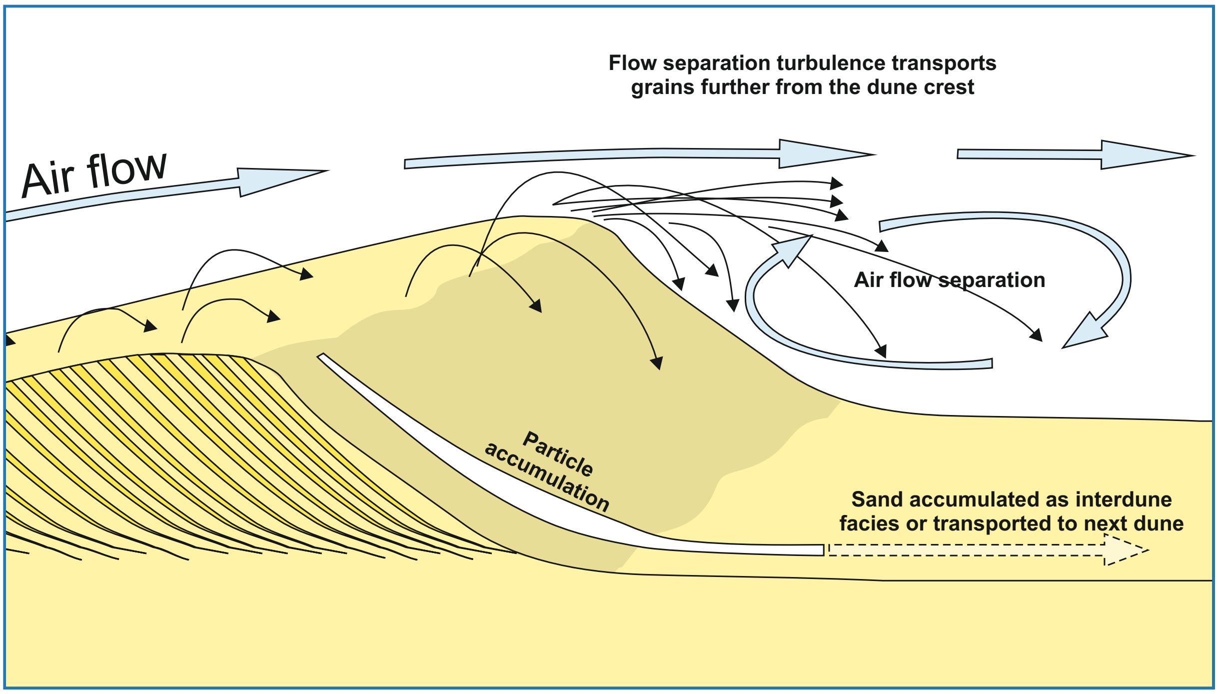


Preserved windripple strata (Navajo Sandstone, Utah). Alternating tan-red colours are caused by a reduction of permeability within the more argillaceous parts of the laminations, reducing the intensity of bleaching, as seen in the more coarse segments of the laminations. Lens cap = 55 mm.

Grainfall strata

Grainfall Strata

Grainfall strata is formed by fallout of ballistic particles onto the lee slope, the dune toe, and the area preceding the dune (Hunter 1977). Grainfall deposits form indistinct laminations which cover the dune slipface from the dune crest to dune toe, which have an intermediate packing. Grainfall strata can be difficult to discern from closely associated wind-ripple strata, which can rework the grainfall strata. Preservation potential of grainfall strata is high, particularly in the lower slipface, and dune toe, where a moderate angle of climb of migrating dunes will result in the burial and preservation of this facies.



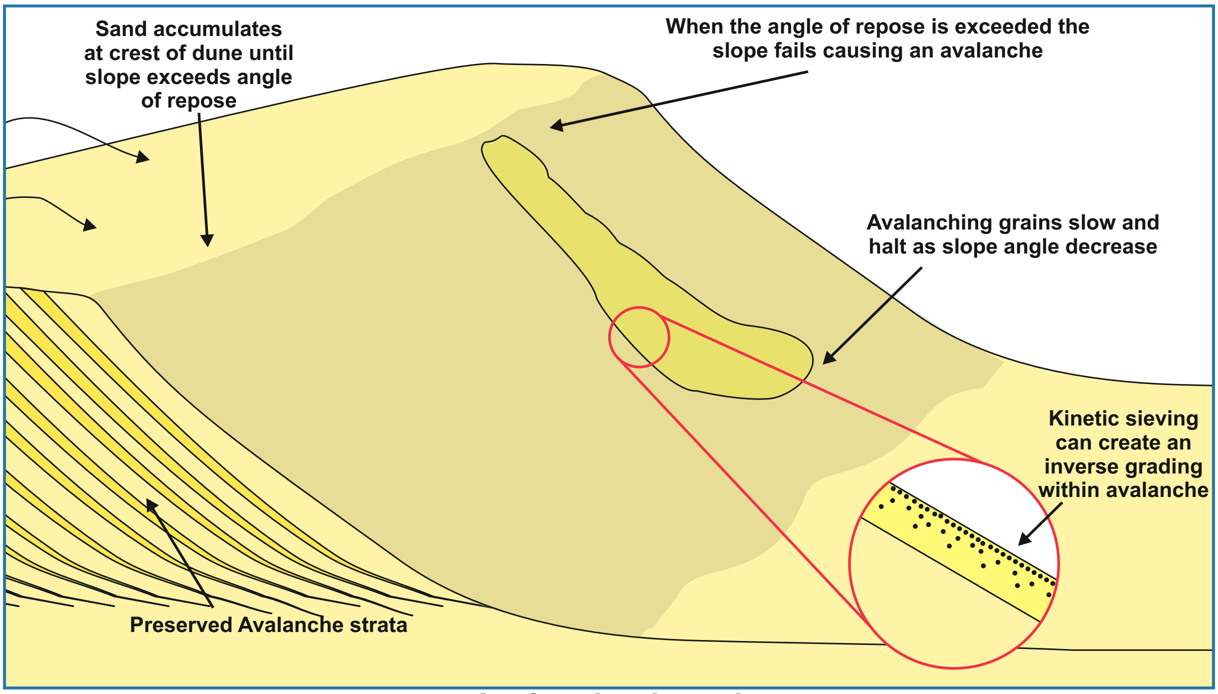
Flow separation at dune crest

Preserved grainfall strata (Cedar Mesa SDST, Utah). Grainfall strata, with indistinct laminations preserved within a dune plinth. Note differential bleaching within outcrop acting as a proxy for cementation and permeability.

Grainflow strata

Grainflow (Avalanche) Strata

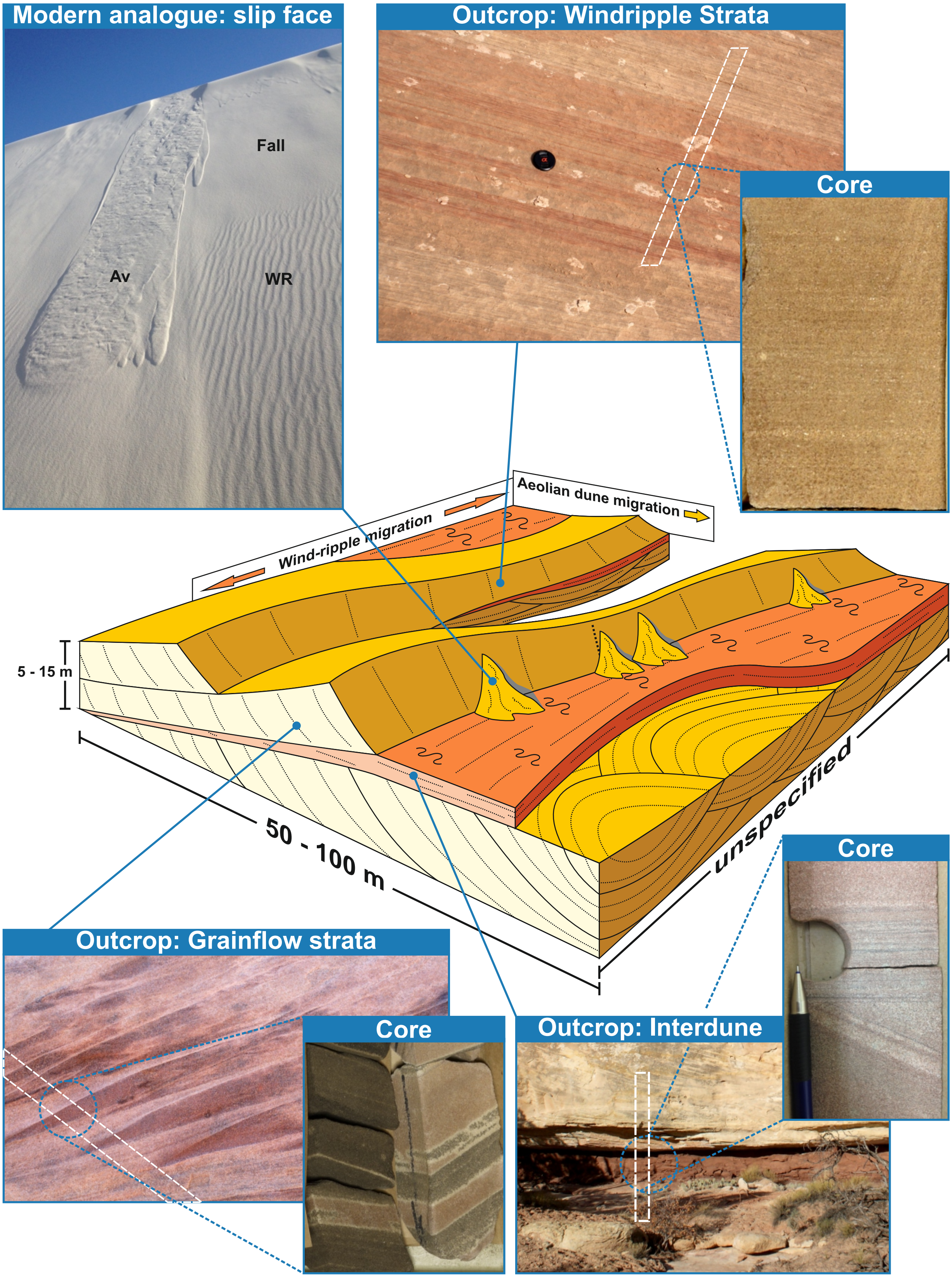
Grainflow facies are the result of grains sliding down the lee slope of a dune, which is at or near to the angle of repose. Sediments transported by surface creep and saltation can accumulate at the crest of the dune, causing over-steepening of the upper part of the lee slope. Failure of this build-up of loose sand can cause avalanches. As dune lee slopes have a concave geometry, the grainflow will abate and typically stop before it reaches the dune toe, forming a tongue-like deposit on the slipface. As the sediment avalanches, kinetic sieving can occur giving an upward coarsening of the facies. Sand within this facies are typically unimodal and texturally coarser than grainfall strata; the finer-grained sediments are preferentially winnowed by increased wind velocity at the crest of the dune (Lancaster, 1981). In addition, poor grain packing occurs during grainflow down slope, giving an increase in pores pace between the grains (Hunter, 1977; Lindquist, 1988).



Avalanche deposit. Note limited failure of the slope in 3D space

Preserved grainflow strata (Cedar Mesa Sst, Utah). Note down-slope pinchout of avalanche deposit towards the base.

Aeolian facies



Relationships of aeolian facies and their expression in core
(After Cain, 2009; Core images, British Geological Survey materials © NERC 2015; Slipface image, Biosphere 2 REU, Uni. Arizona)

Subaqueous facies

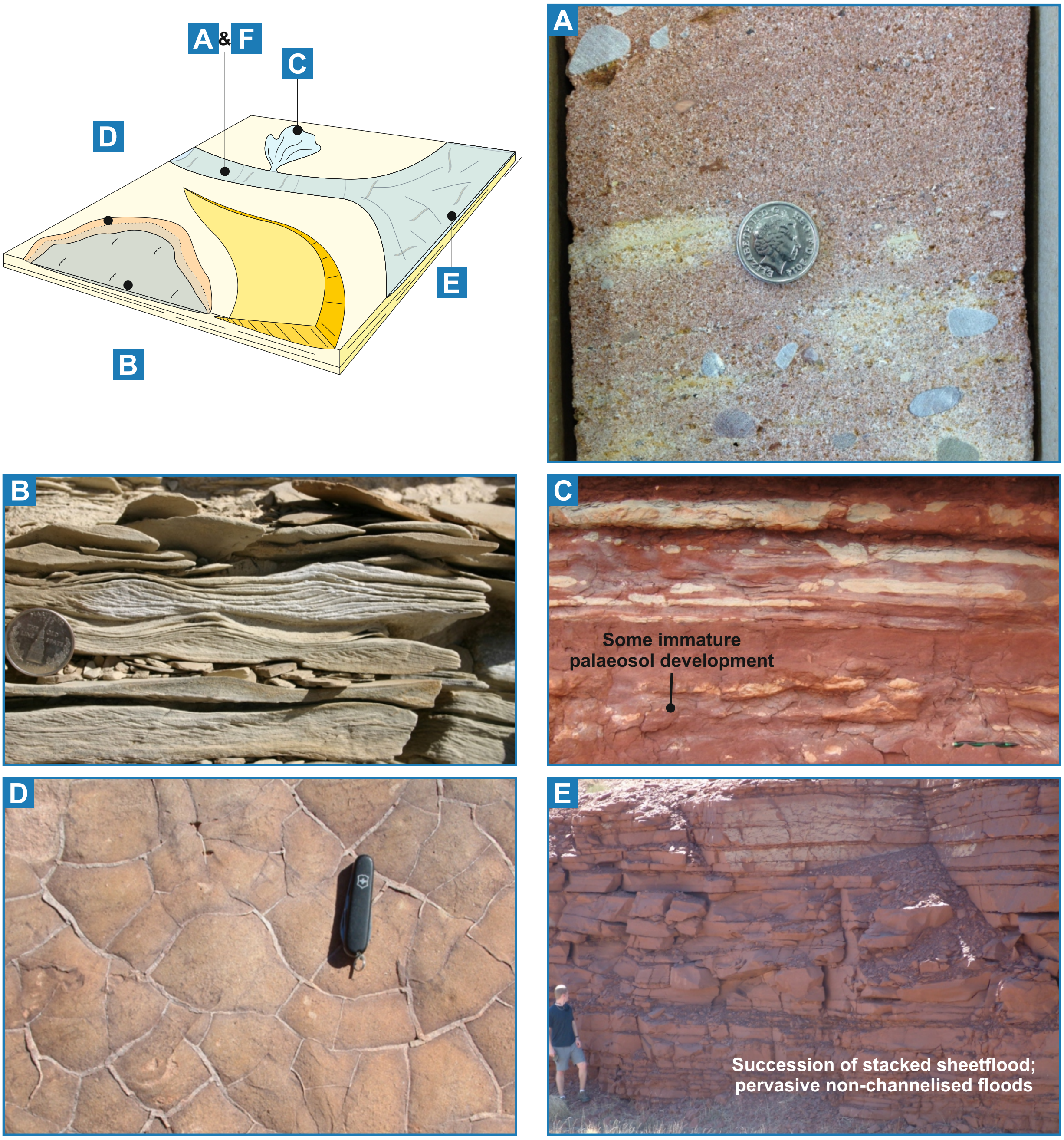
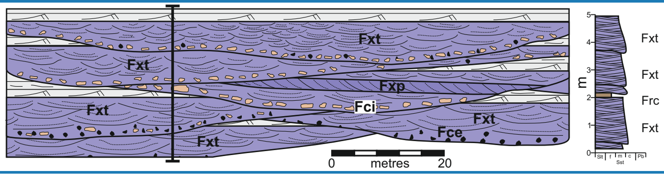


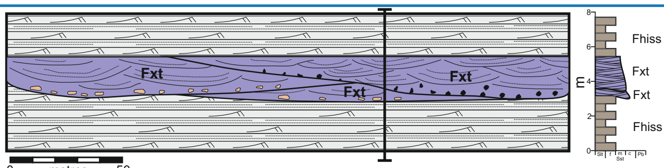
Figure Caption: Photographic examples of typical fluvial and lacustrine facies in dryland settings. A) basal-fluvial channel fill with 'floating' pebbles, B) wind-aggitated subaqueous ripples within small pond, C) stacked fine-grained overbank deposits with some horizontal calcrete nodules, D) desiccation cracks, E) multiple stacked distal sheetflood deposits, F) fluvial trough-crossbeds cut broadly perpendicular to flow.

Architectural elements

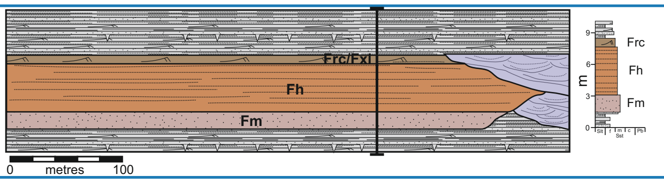
Fluvial Channelised



Multi-storey, multi-lateral amalgamated channel-fill complex
Vertically and laterally amalgamated, generally restricted to the Ali Baba and Parriott Members; most prevalent in the Fisher Basin where sediment supply was greatest.

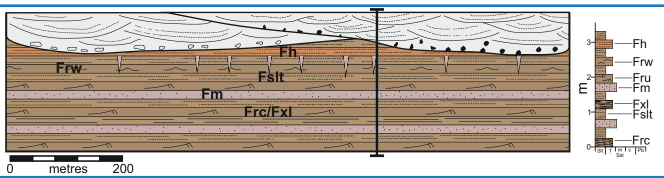


Single-storey, multi-lateral channel-fill complex
Laterally but not vertically amalgamated; common in the Sewemup Member and the central parts of the Parriott Basin in the Parriott Member; infill finer-grained than that of F1 elements, possibly reflecting accumulation in more distal locations.

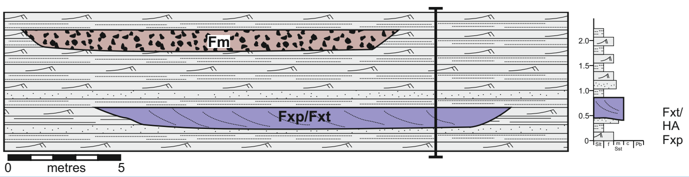


Massive (structureless) & horizontally laminated channel-fill element
Occur laterally adjacent to F1 & F2 elements in locations proximal to salt walls; composed of massively-bedded sand at base (Fm); overlain by horizontally-laminated sand (Fh); implies high-energy, initially erosional flows; rapid sedimentation via suspension settling.

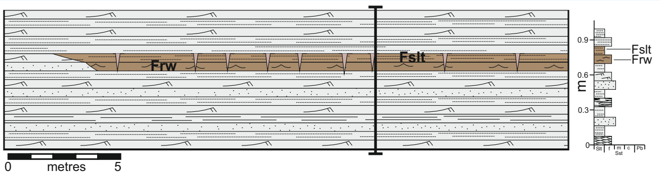
Fluvial non-channelised (overbank)



Sheet-like heterolithic element
Laterally extensive sheet-like bodies composed of interbedded silts and fine-grained sands; deposited in response to the dispersion of non-confined flood waters across floodplain areas; floods sourced via overflow from main channels or via overland flow during rain storm events.

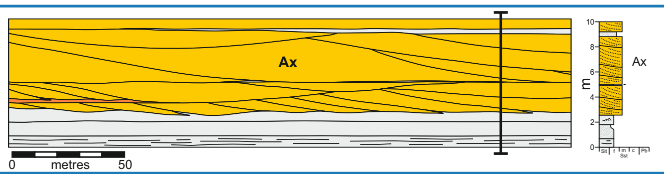


Minor gravel chute element
Small scale chute; originate from the convergence of non-confined flows in overbank settings; generally shallow (<0.3 m deep) and narrow (<20 m wide); typically filled with massive sets of medium-grained sandstone to granulestone (Fm) or crudely developed cross-bedding (HA Fxp/Fxt).

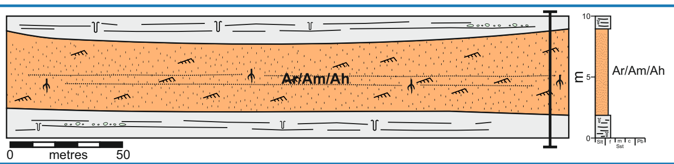


Pond element
Sheet-like body containing symmetric wave- ripple strata, overlain by thin siltstones; formed in response to wind blowing across bodies of standing water in floodplain areas; siltstones overlying wave-ripple strata represent the accumulation of wind-blown loess.

Aeolian

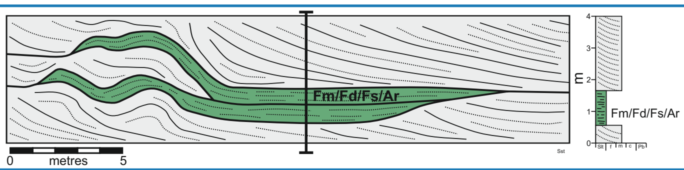


Aeolian dune elements
Migration of aeolian dune elements under dry, damp, stabilising and wet conditions. Represent laterally extensive dune fields that periodically dominated medial and distal regions of the succession. Show common reworking by fluvial processes.



Aeolian sandsheet element
Laterally extensive, low relief sandsheets deposited during period of a restricted aeolian sediment supply. Regional pinch-out in a downwind direction. Composed of windripple (Ar) flat-bedded (Ah) facies though also commonly structureless.

Interdune



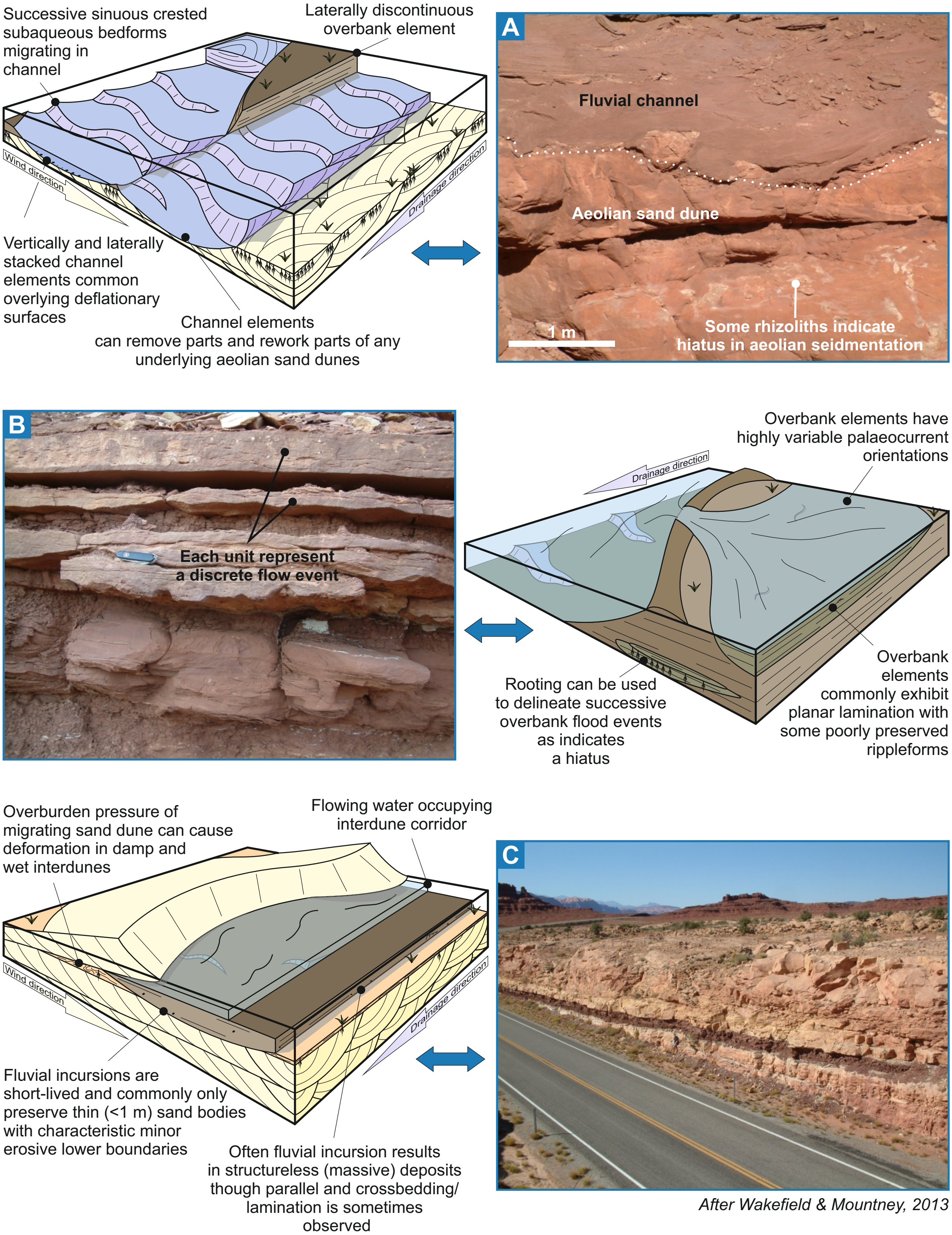
Aeolian interdune element
Lenses and laterally extensive sheets indicative of development under dry (windripple strata - Ar), damp/stabilising (convoluted laminations - Fd; mudst./siltst. - Fsh/m) and wet conditions (massive sandstone (Fm).

Key

Massive sandstone (Fm)	Cross-bedded Sst. (Fxt, Fxp)	Interbedded Heterolithic strata, sand-prone (FHiss)	Deformed bedding (Fd)
Hzl.laminated sandstone (Fh)	Ripple-lam. Sst. (Frc, Fxl, Frw)	Interbedded Heterolithic strata, silt-prone (FHiss)	Aeolian Dune (Ax)

Expected architectural elements within a dryland fluvial and aeolian environment (After Banham & Mountney, 2014; Cain & Mountney, 2009)

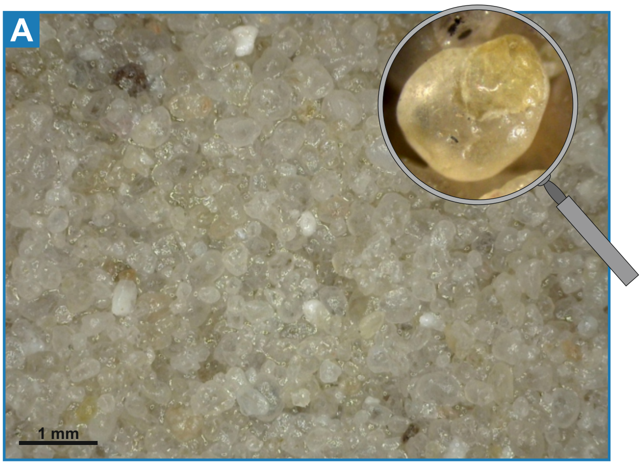
Architectural elements *cont'd*

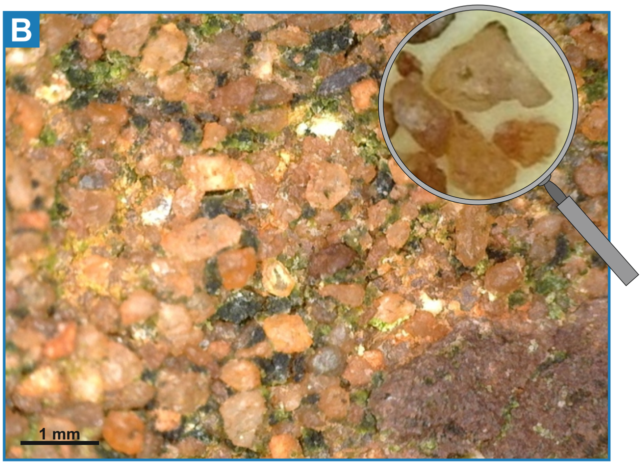


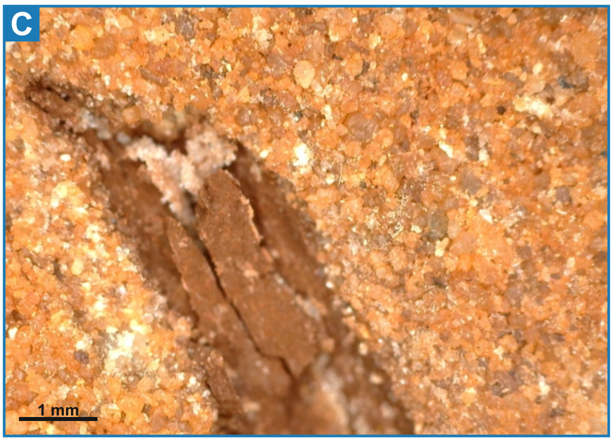
After Wakefield & Mountney, 2013

Figure Caption: Conceptual model and accompanying photographs of; A) fluvial channel insicion into underlying aeolian sand dune elements, B) pervasive fluvial overbank floods, note the development of rippleforms indicating prolonged flow at lowerflow regime, C) flooded interdune (darker brown red unit) within aeolian sand dunes.

Differentiating aeolian & fluvial







The dominant method of aeolian transport (saltation) results in a large number of grain to grain collisions, with the relatively low viscosity of air providing no appreciable 'cushioning' to such impacts. Moving air as a depositional medium is also very discriminating in its ability to entrain sediment. This discriminating selection combined with a collision dominated preferred transport method generates deposits that are commonly well-sorted, homogeneous, and with grains composed of harder minerals (able to withstand repeated collisions). By comparison water is a much denser depositional medium, and as such, is less selective in the range of grains sizes it can transport (transporting a greater variety of clast sizes).

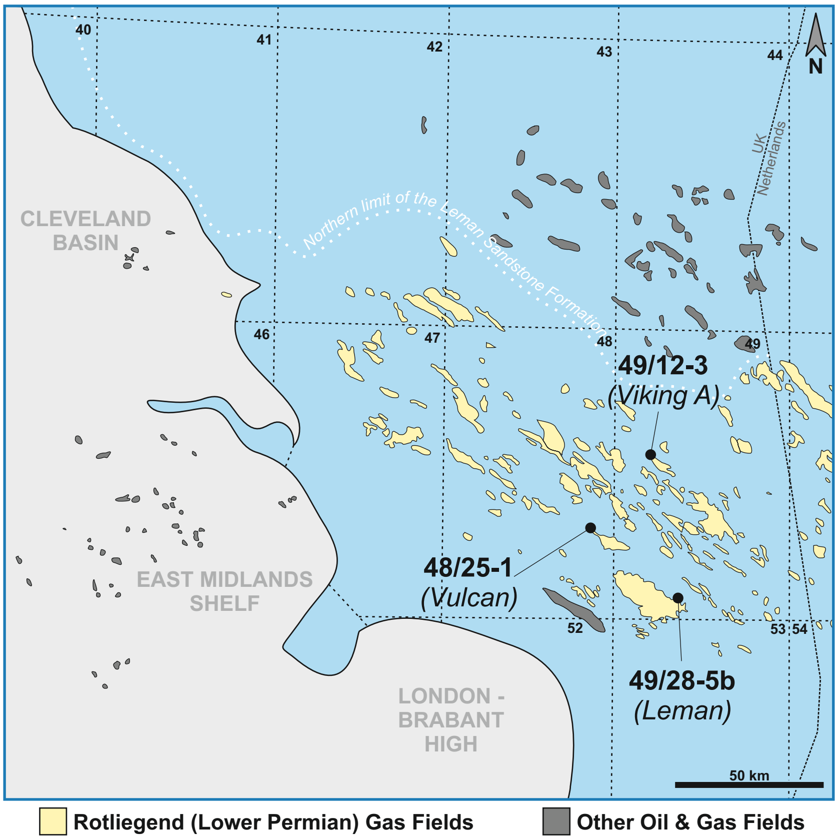
Additional complexity in differentiating aeolian and fluvial facies arises in instances where water is sourced directly within the aeolian system (eg. intra-system precipitation). Such events can generate floods without deriving the addition fluvial sediment normally expected for fluvial flood events. In such instances the loss of primary aeolian structure (reworking of aeolian facies by water) and/or indicators of the presence of water (e.g. fluid escape) are key in the determining the depositional history.

*Figure Caption*s: Digital microscope images of; A) aeolian grainflow, B) fluvial channel fill, C) fluvial facies with a small elongate mud clast, D) intra-system flood with pronounced interdune deformation.

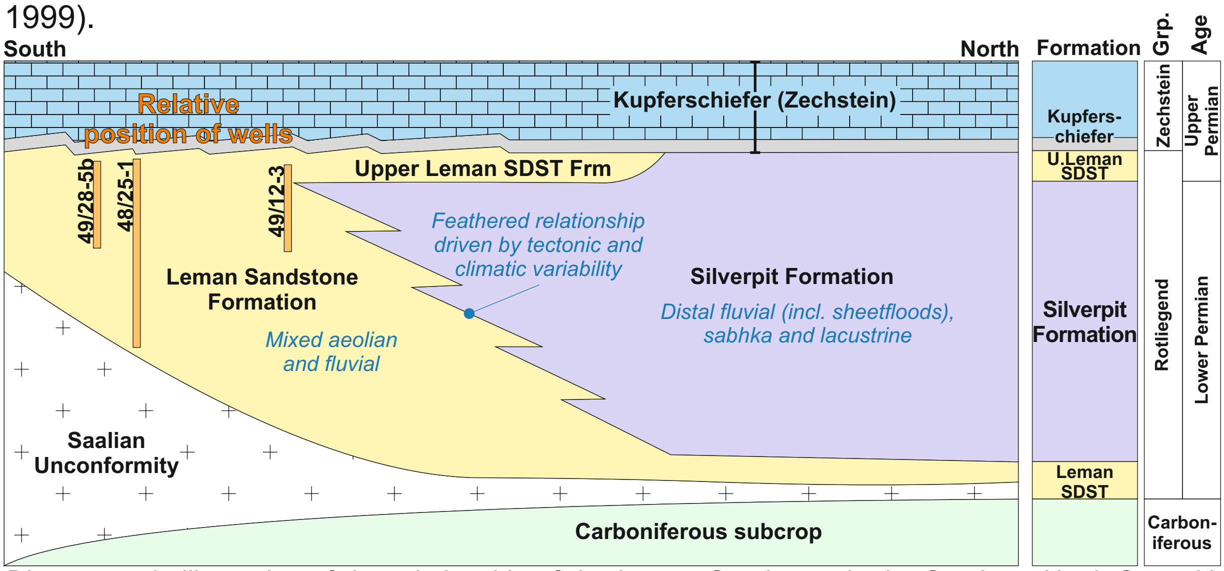
Rotliegend Group

The Permian Rotliegend Group is major economic importance, being responsible for a large portion of the producing fields in the Southern North Sea (*see map*). Parts of a study conducted by George & Berry (1993) is included in this handout (the position of the used wells is illustrated on the accompanying map).

In the Southern North Sea the Rotliegend Group is comprised on the Leman Sandstone and Silverpit Formations (Sarginson, 2003a,b). The Leman Sandstone is a mixed aeolian-fluvial succession representing a large aeolian erg with episodic fluvial incursions. The laterally equivalent Silverpit Formation (see correlation diagram at bottom of page) represents the distal fluvial and lacustrine setting that fringed the aeolian erg system of the Leman Sandstone. The prevailing climate during the deposition of the Rotliegend was arid to semi-arid (Glennie *et al.*, 1978; George & Berry, 1993; Howell & Mountney, 1997; Sweet, 1999).



Southern North Sea region with Rotliegend fields highlighted.



Diagrammatic illustration of the relationship of the Leman Sandstone in the Southern North Sea with accompanying stratigraphy column. After Howell & Mountney, 1997.

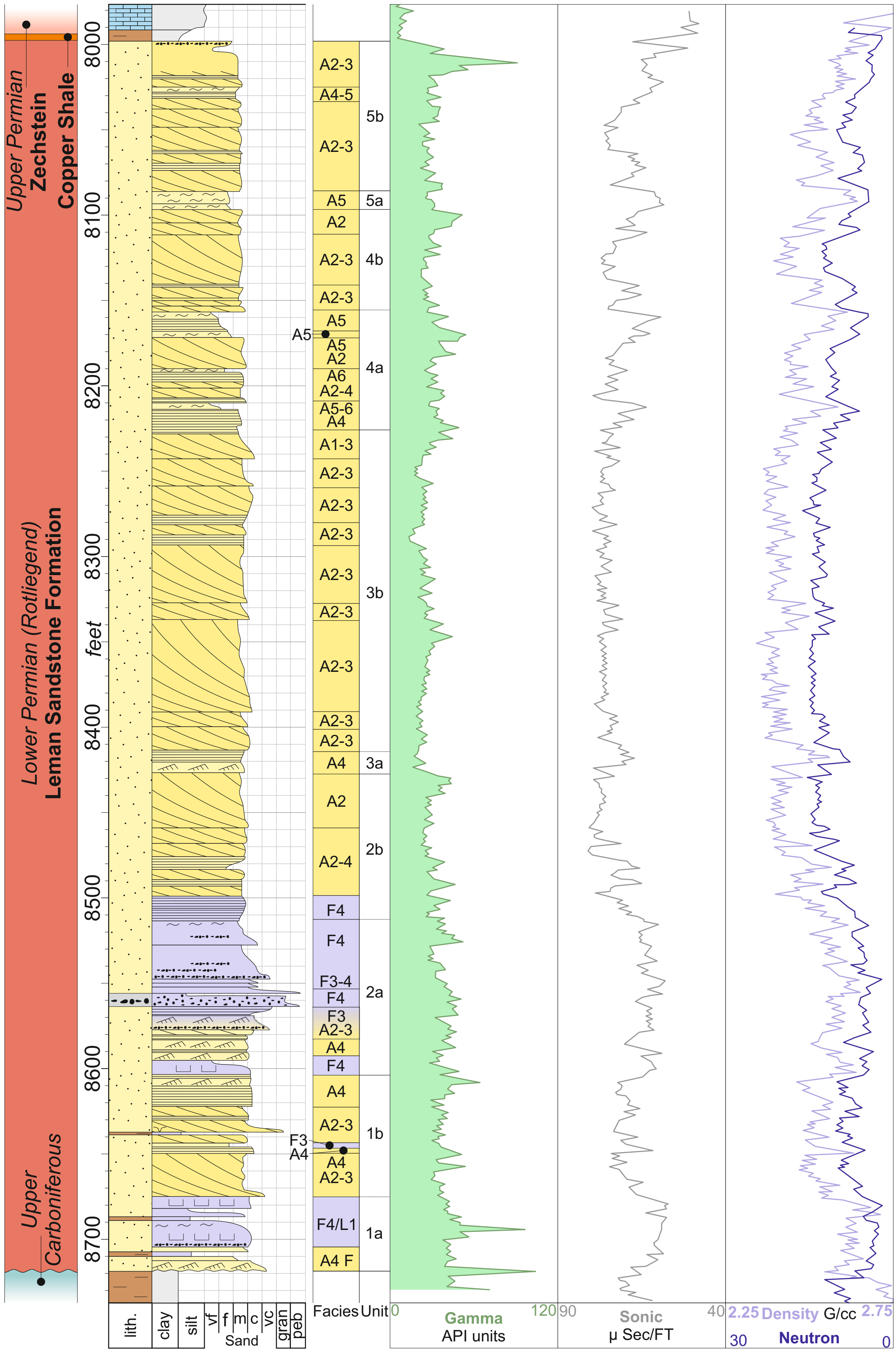
Rotliegend Group

Class	Association	Facies Name	Code
Lithogenic	Aeolian Dune	Dune top	A1
		Dune core	A2
		Dune base	A3
	Aeolian interdune	Dry Interdune/interdune sheet	A4
		Damp interdune	A5
		Wet interdune	A6
	Proiximal fluvial	Fluvial fan	F1
		Fluvial channel	F2
	Distal Fluvial	Structured sheetflood	F3
		Dewatered sheetflood	F4
		Subaqueous sheetflood	F5
	Sabkha	Lake margin sabkha	S1
		Inland sabkha	S2
	Lacustrine	Playa lake	L1
		Desert lake (permanent)	L2
		Desert lake (evaporative)	L2
Modified Lithogenic	Modified (Weissliegend)	Homogenised aeolian	Wa
		Homogenised fluvial	Wf
Reworked Lithogenic	Reworked	Serir/scree etc	F●
		Deflation lag	A●
		Fluvially redeposited Aeolian facies	A ➝F
		Biogenicallt rewordèd:	
		Aeolian facies	A*/Wa*
		Fluvial facies	F*/Wf*

The above table is the classification scheme used by George & Berry (1993). Note that this scheme is used in the following logs from their 2003 paper. The palaeogeographic models (pages 21-22) are also taken from George & Berry (2003) - note that the 'unit' column on the logs relates to the five palaeogeogrpahic models.

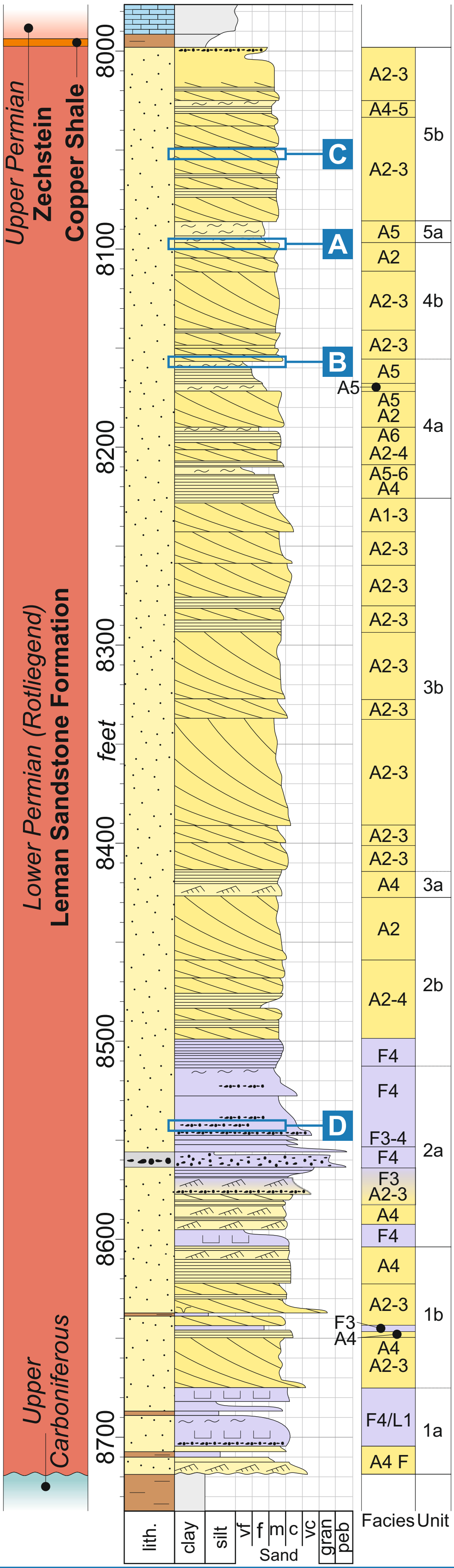
Depth range: 7954 - 8723 ft (2424.4 - 2658.8 m)
Description: The core is dominated by aeolian facies types (>80%); mostly aeolian sand dune elements. Some water reworked facies (damp and wet interdunes) are sometimes hard to identify in the upper portions of the core due to the relatively indistinct compositional difference between facies. At shallower depths in the core the reworking of aeolian facies by water is primarily restricted to the aeolian interdune elements. These can be identified readily by looking for aeolian toesets (the low-angle downslope 'toes' to crossbeds) that occur directly above the interdune bounding surface. Note that if the aeolian duneforms wavelengths were short there may be no interdune present; in such cases the interdune bounding surface will likely be directly overlying the upper parts of another aeolian sand dune element. At depths between 8500 - 8600 ft fluvial facies dominate. These can be identified most easily by the presence of small pebbles and mud clasts brought into the dunefield by the fluvial system. The majority of the interactions between the aeolian and fluvial system (especially the upper portions of the core) are interpreted as being coeval. This is based on; i) fluvial facies confinement to interdune areas (indicating an aeolian sand dune presence at the time of flooding) and, ii) an immediate return to aeolian sand dune sedimentation after flooding (easily achieved if the sand dunes are present at the time of flooding).

Borehole 1 - 48/25-1



Description on previous page

Borehole 1 - 48/25-1



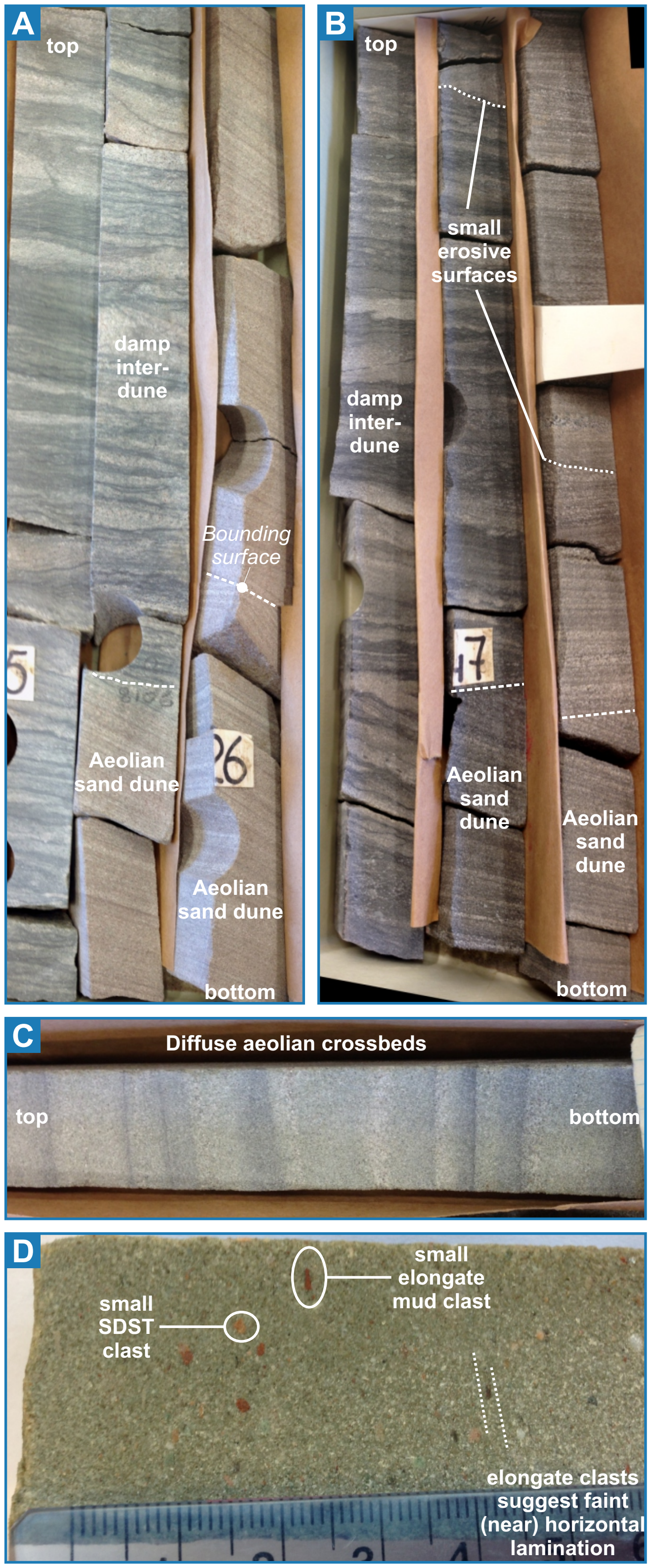
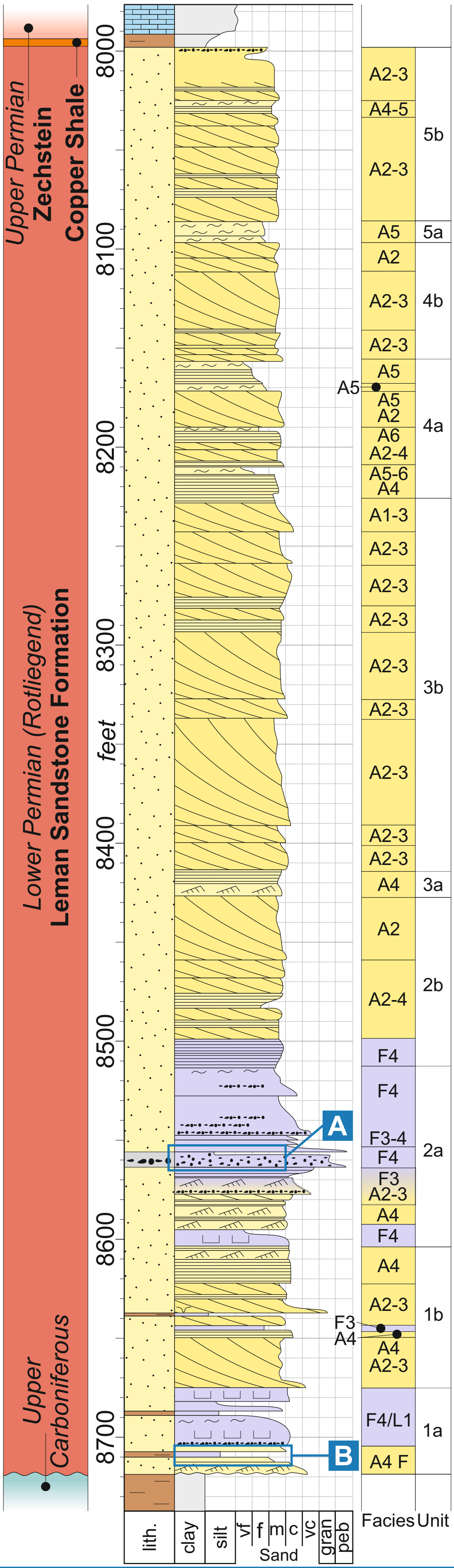


Figure Captions: A & B) Deformed damp interdunes overlying aeolian sand dune elements, C) faint diffuse-like grainflow and grainfall strata, D) close-up of rare fluvial facies with intraformational clasts.

Borehole 1 - 48/25-1



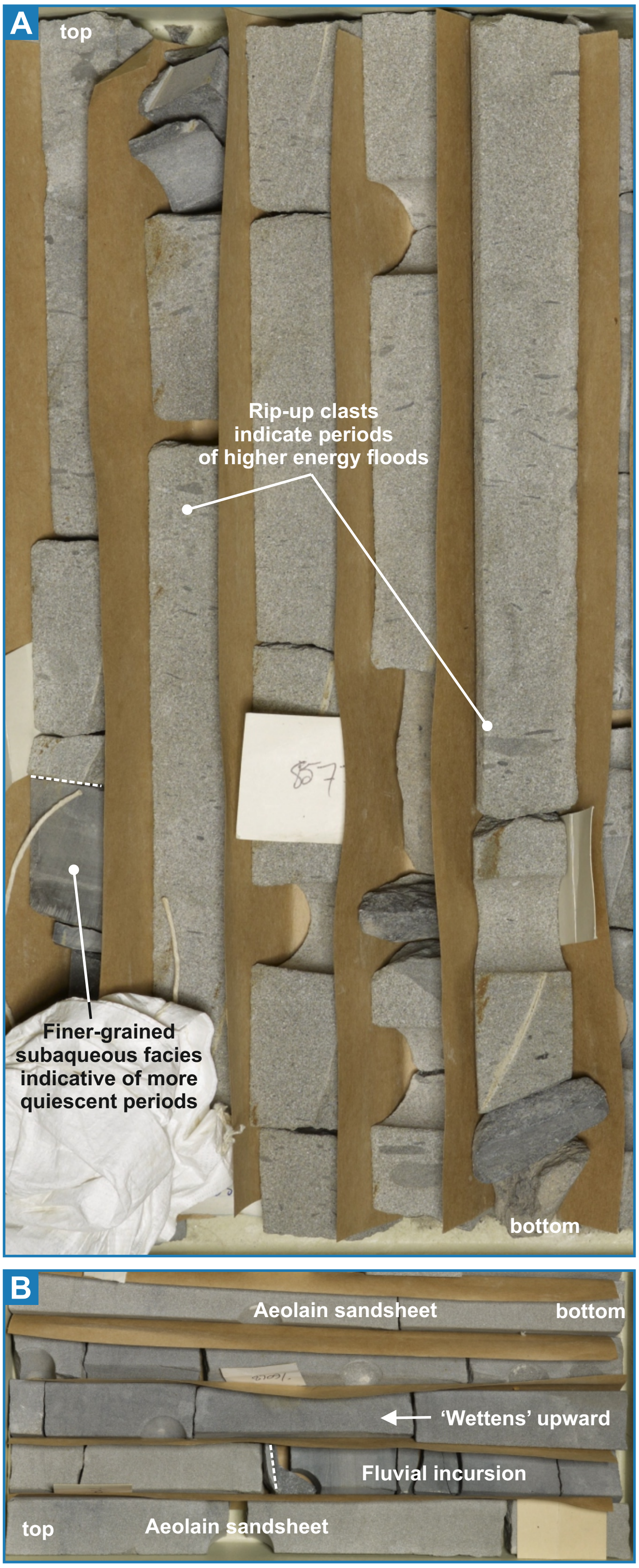
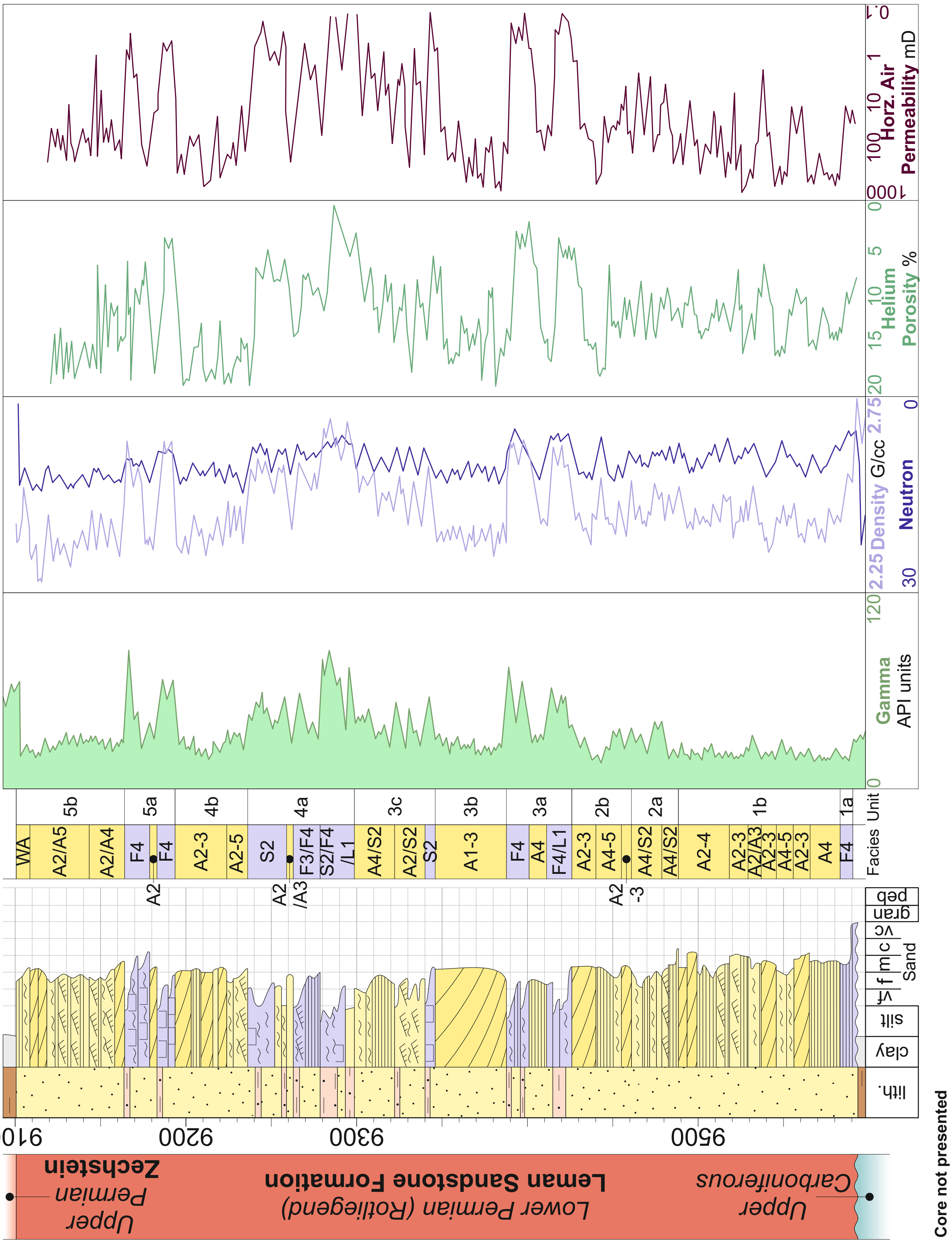
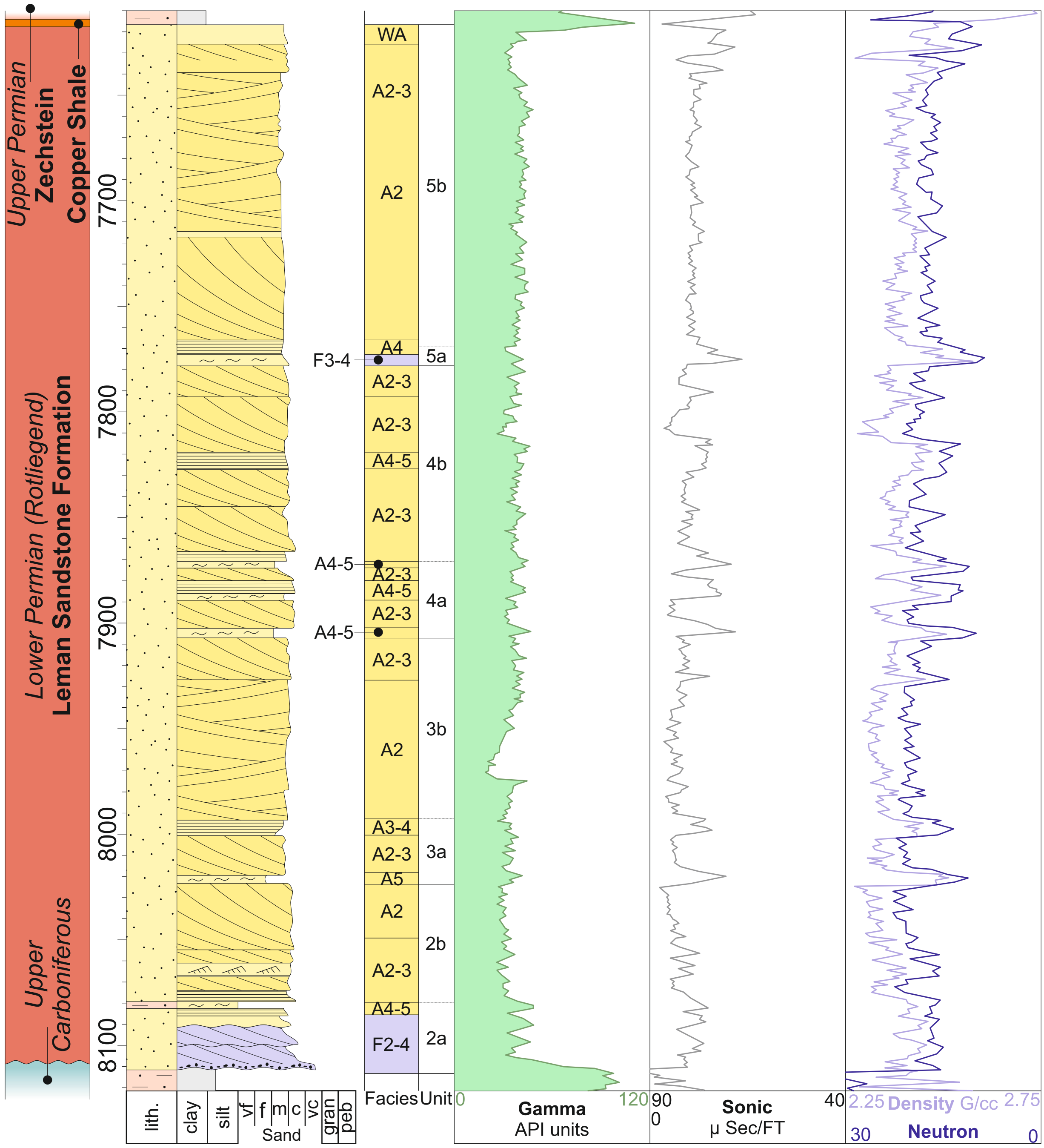


Figure Captions: A) Fluvial facies indicating periods of variable energy. B) Subtle wettening upward cycle within aeolian facies. The sharp upper boundary likely dennoting a rapid drying and return to aeolian sedimentation.

Borehole 1 - 49/12-3



Borehole 1 - 49/28-5b

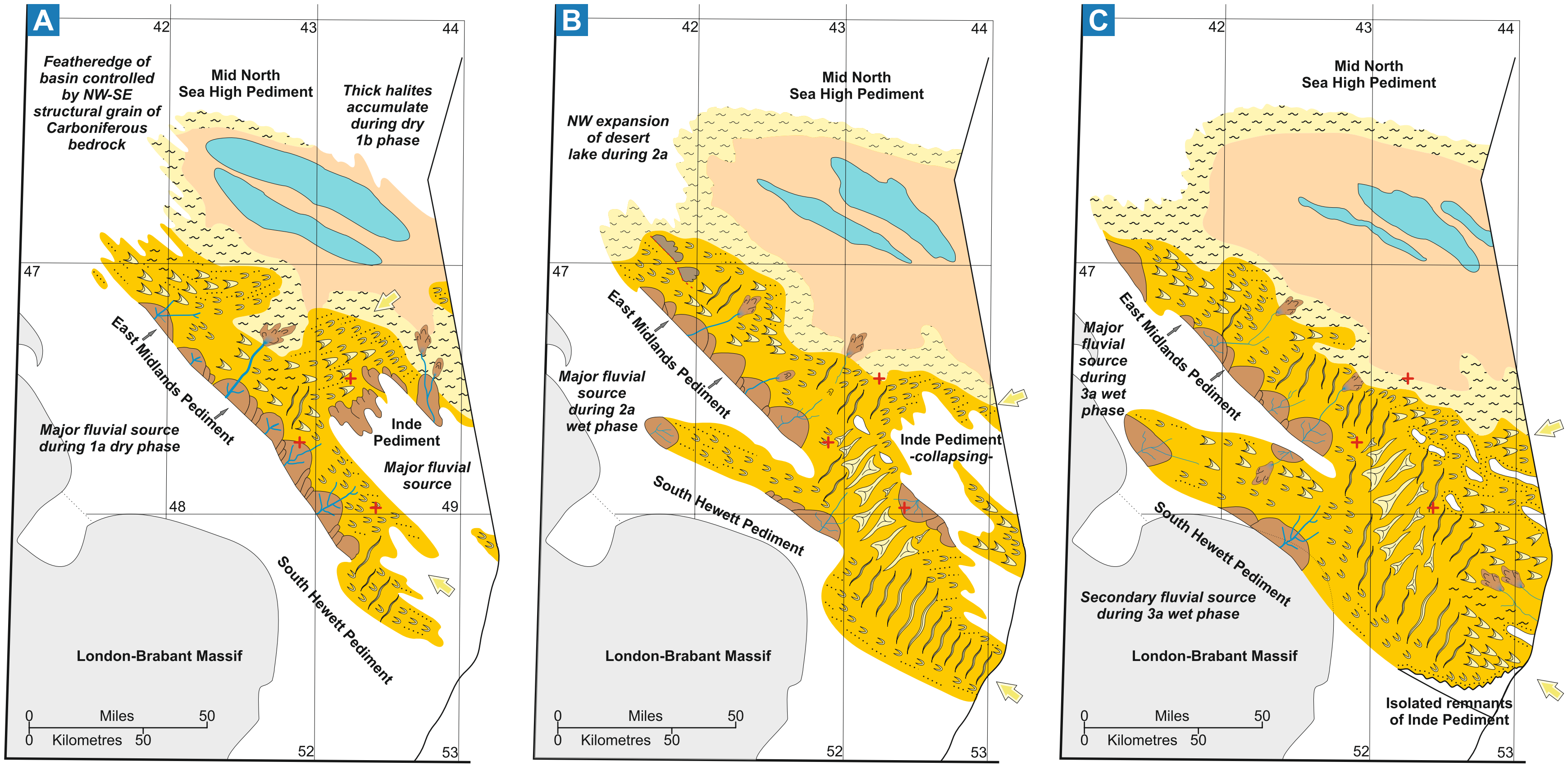


Though wells 49/12-3 (preceding page) and 49/28-5b are not presented key differences can be established between them. Well 49/12-3 represents a setting more distal to the erg centre. As a result there are fewer aeolian sand dune elements and they are relatively thinner compared to the other two wells. This reduction in sand dune amount and size likely resulted in larger dune spacing, as such, providing a reduced ability to baffle incursive fluvial flow compared to closely packed sand dunes. Comparatively well 49/28-5b represents a setting more towards the erg centre. This is indicated by the higher frequency of, and thicker aeolian sand dunes elements. Note that this core also has the least amount of fluvial facies types and lacustrine facies types.

Note that the northern limit of the palaeographic model is at the Mid North Sea High; an area of non-deposition during the Permain

The establishment of alluvial fans during the early deposition of the Rotliegend could explain the basal fluvial facies in well 49/28-5b

Note the interpreted position of well 49/12-3 on the margins of the aeolian erg system

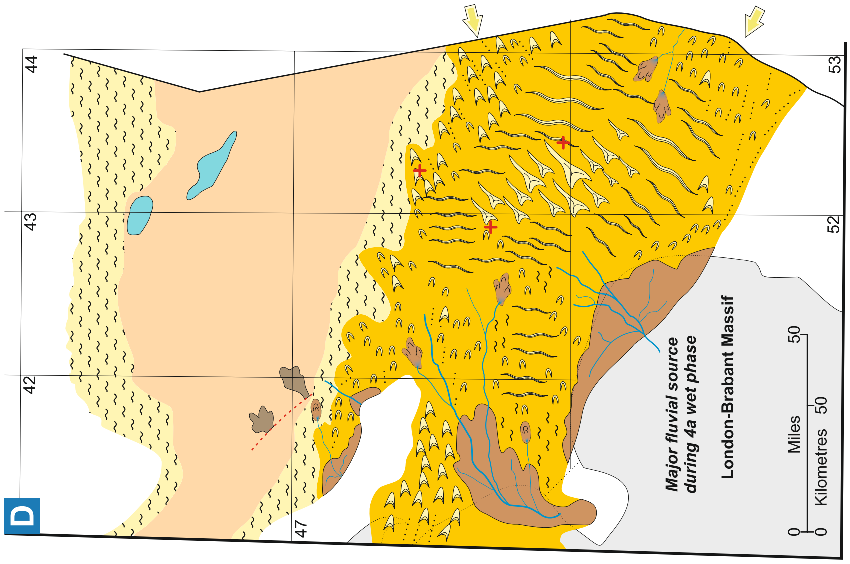


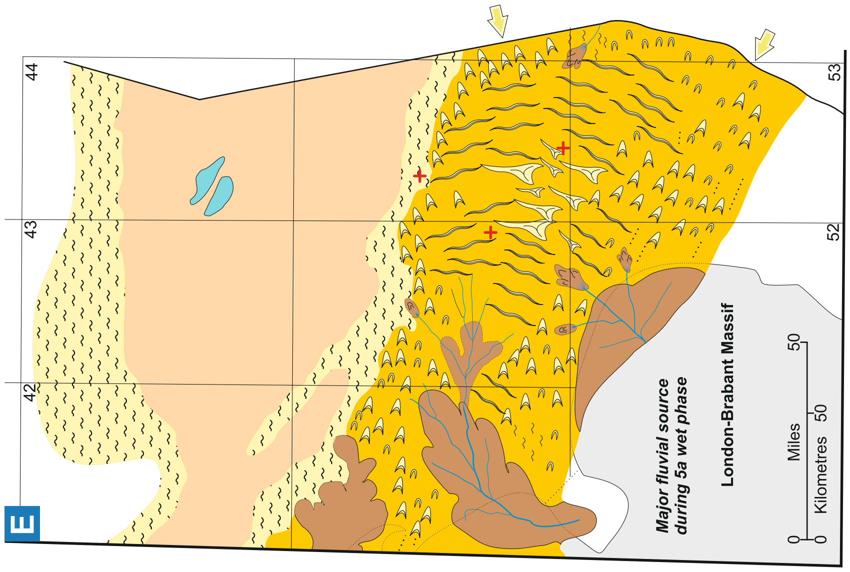
Palaeogeographical illustrative maps of the evolution of the systems during the deposition of the Rotliegend Basin in the UK sector of the Southern North Sea (*Modified after* George & Berry, 1993). Parts A to E correspond to 'unit' subdivisions 1 to 5 (respectively) as defined in the wells 48/25-1 (page 16), BH 49/12-3 (page 19), 49/28-5b (page 20). *Figure Continues overleaf.*

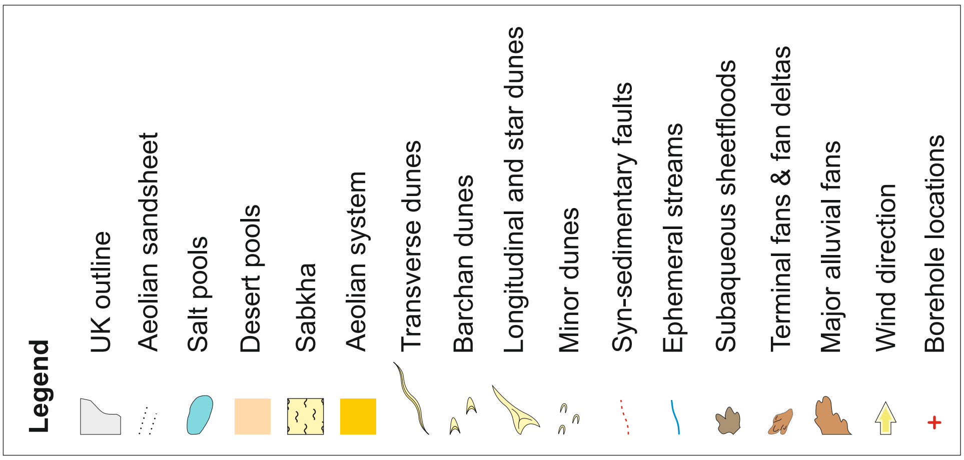
Palaeogeography

Note that wells 49/28-5b and 48/25-1 are situated in the erg centre where the largest dunes are accumulating

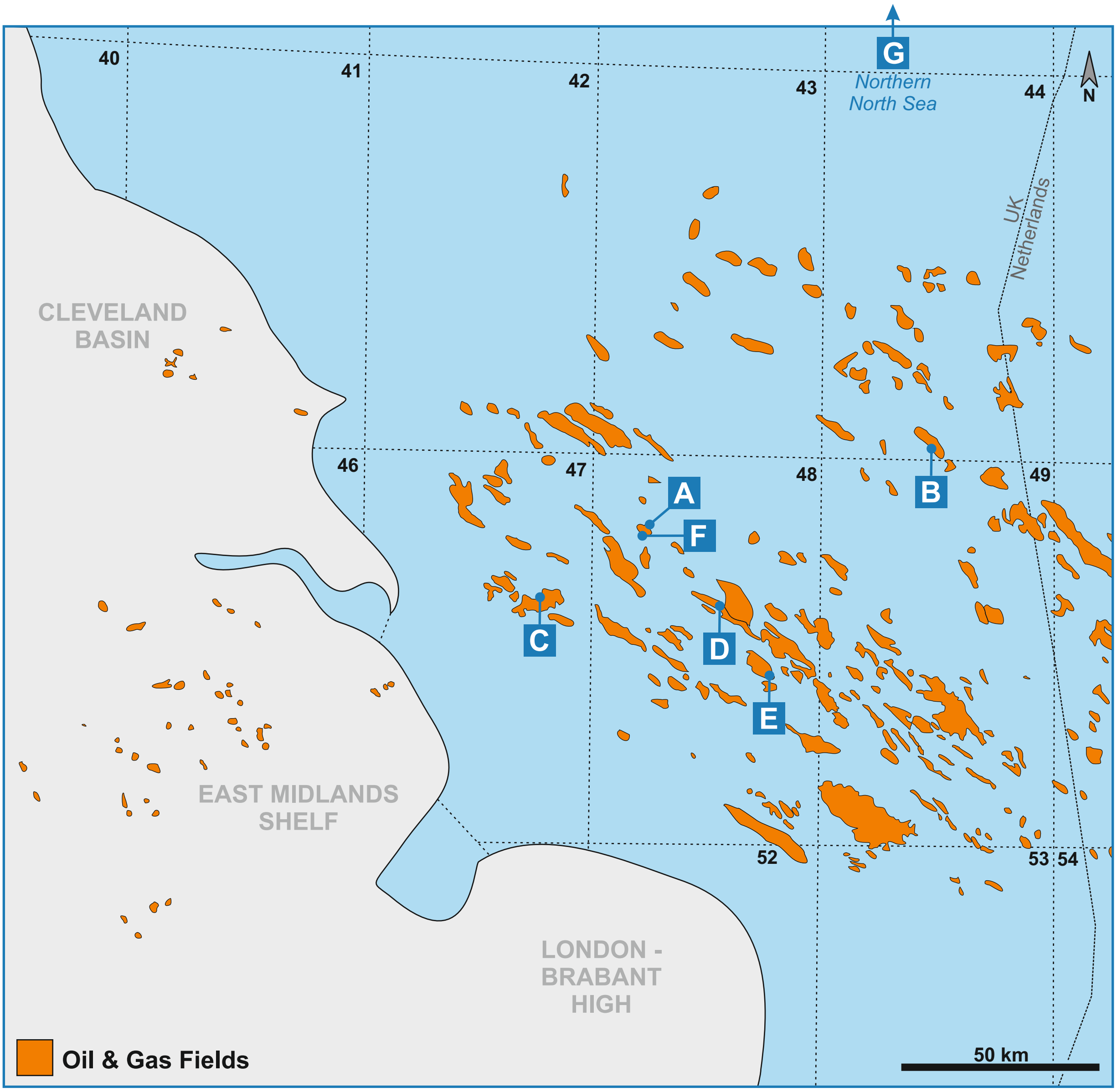
The waxing and waning of the erg system affects the sedimentation at 49/12-3 due to its distal (fringe) location







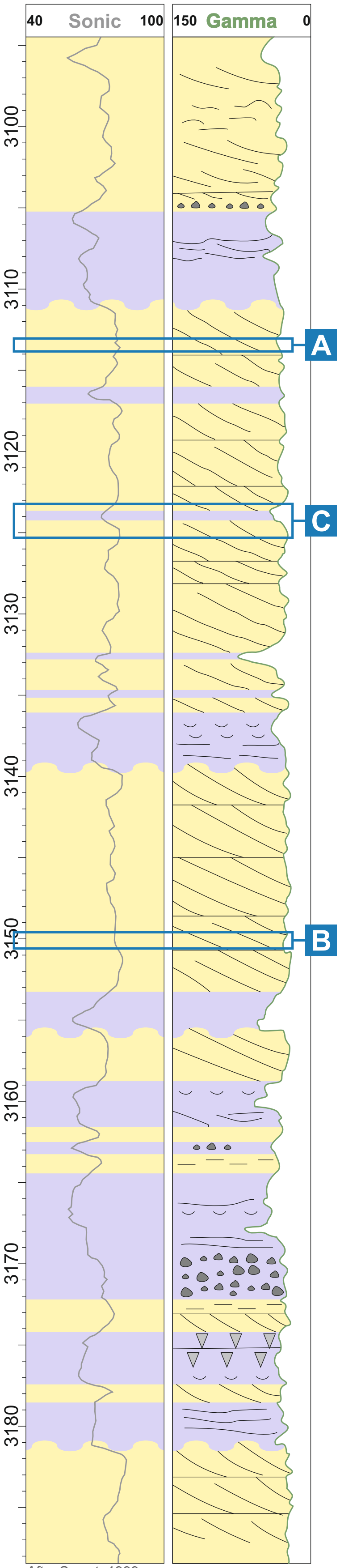
Borehole map



- **A** 48/7B-8 (Hoton Field) - page 24
- **B** 44/28-2 (Ketch Field) - page 25
- **C** 47/14a-k1 (Amethyst Field) - page 26
- **D** 48/13a-4 (Barque Field) - page 27
- **E** 48/19a-4 (Clipper Field) - page 28
- **F** 48/7B-12 (Hoton Field) - page 29
- **G** 30/16-2 (Auk Field) - page 30

Borehole - 48/7b-8

Hoton Field



After Sweet, 1999

Depth range: 10180 - 10465 ft (3102.9 - 3189.9 m)
Description: This log (on left) is taken from work done by Sweet (1999). The interpretation of the succession was done using sonic and gamma downhole geophysical data. Note that the fluvial facies are interpreted to have higher gamma (more argillaceous) and lower (slower) sonic responses.

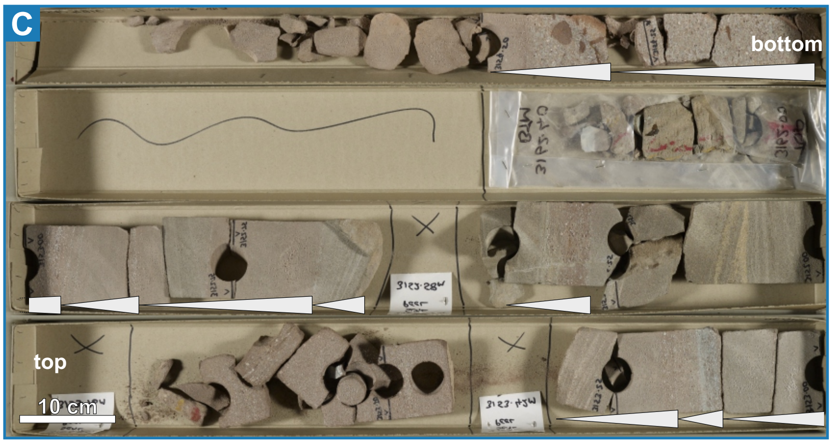
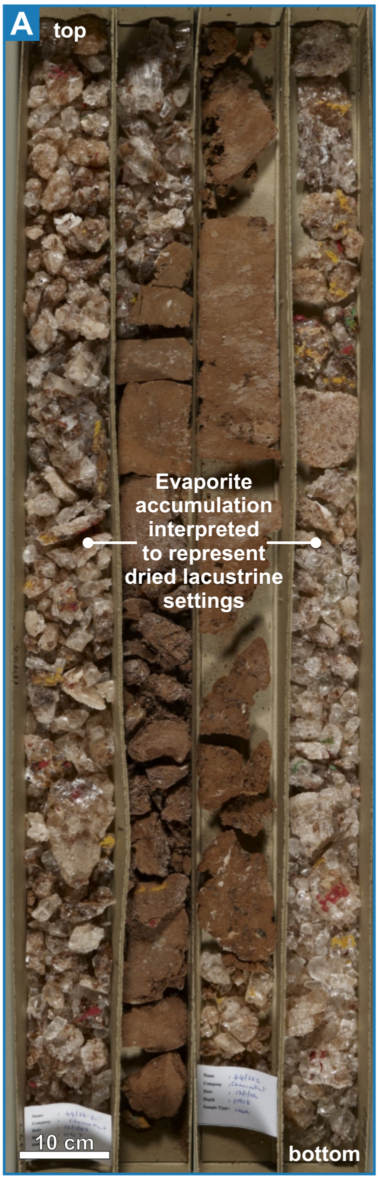


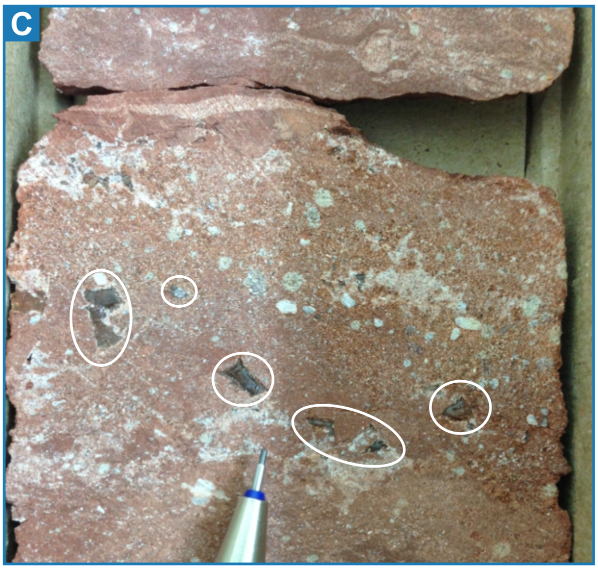
Figure Captions: A & B) Crossbedding/lamination with multiple set boundaries. Note the slight coarse-grain fraction overlying the boundaries in ‘B’. C) Stacked sequence of fluvial facies. Note that the original interpretation by Sweet (1999) was based on geophysical data. In this instance this methodology has underestimated the thickness for this fluvial succession.

Borehole - 44/28-2

Ketch Field



Depth range: 11901 - 12062 ft (3627.4 - 3676.5 m)
Description: Succession that contains good examples of primary and secondary evaporites. Two prominent ~1 m thick examples indicative of dried small lakes towards the top of the selected depth range. Some secondary evaporite precipitation can be observed in some small fractures throughout the core. Evaporite clasts (upto 4 mm in size) are also present. Sucession includes a conglomerate unit that when sprayed with water shows multiple clasts of variable composition and source.



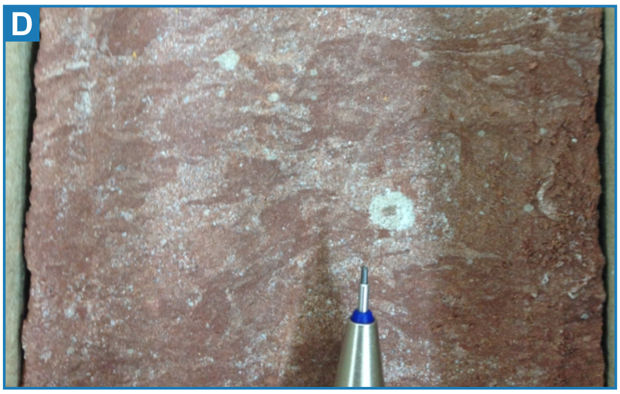
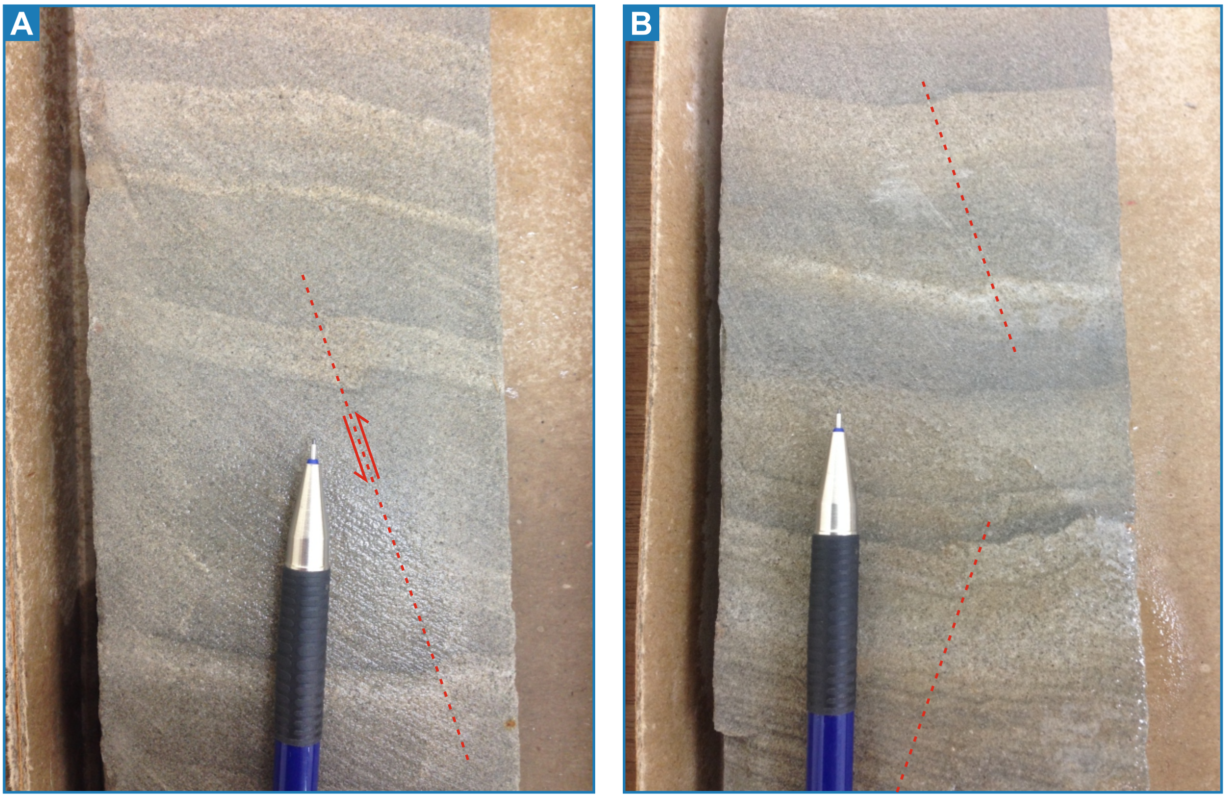


Figure Captions: A) Primary evaporite accumulation in an interpreted dried lake setting (11915-11933ft), B) conglomerate unit, C) evaporite clasts, D) irregular ‘disrupted’ texture indicative of reworking by water.

Borehole - 47/14a-k1

Amethyst Field



Depth range: 7954 - 9002 ft (2424.4 - 2743.8 m)
Description: Aeolian succession towards top becoming progressively 'wetter' downwards. Includes examples of reworking by water (convolution and contortion of the original depositional fabric). Also includes good examples of syn-sedimentary faulting towards the top of the selected depth range. Dark mudstones and shales at base denote entry into the carboniferous.

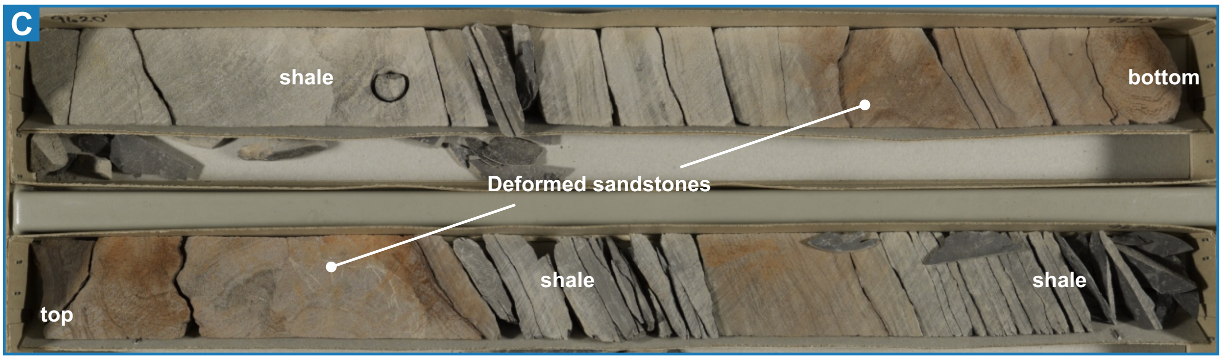


Figure Captions: A & B) Examples of syn-sedimentary faulting within aeolian duneforms. Note that the faulting is usually limited to a few crossbeds with the displacement decreasing along (up and down dip) the fault plane. C) Deformed sandstones and black shales of the underlying Carboniferous sediments.

Borehole - 48/13a-4

Barque Field

Depth range: 7868 - 8246 ft (2398.2 - 2513.4 m)
Description: Succession through the Leman Sandstone that is broadly characterised as being aeolian dominated towards the top and fluvially dominated towards the base of the selected depth range. At a depth of ~7900 ft the core appears dominated by aeolian facies types (predominately aeolian duneforms). This succession also includes examples of interdune elements. Some of the larger interdunes also show multiple cycles of drying and wettening.

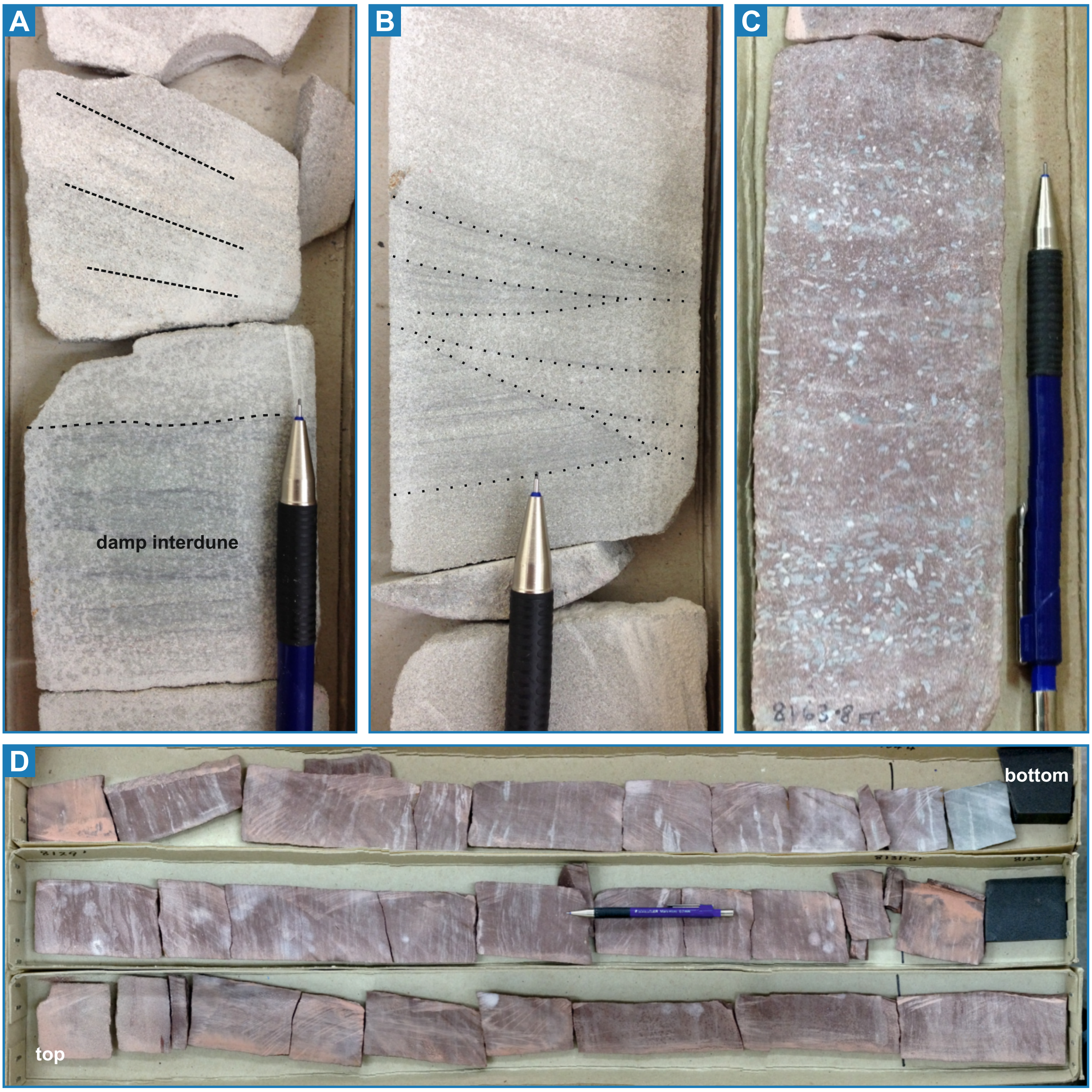
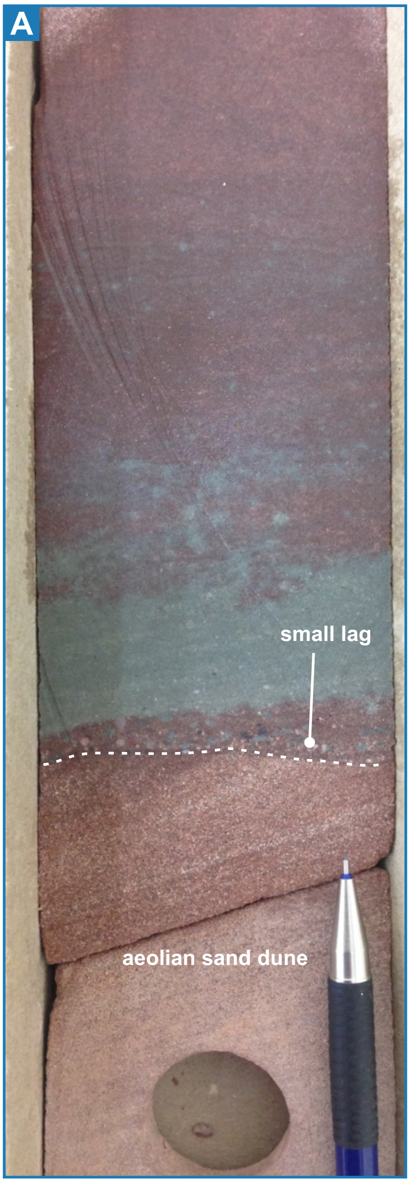


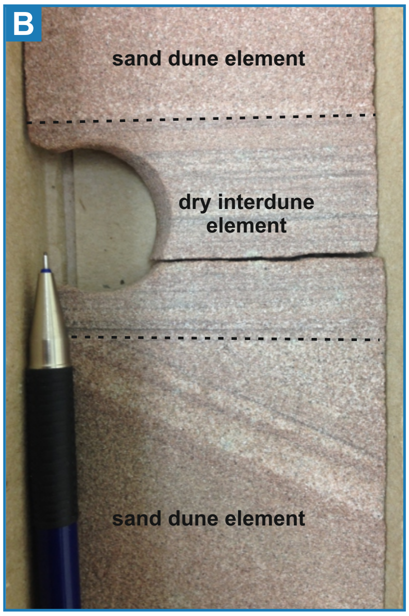
Figure Captions: A) Bedform toeset (note the asymptotic base) overlying an example of a damp interdune. B) Examples of variable orientated and sized trough crossbedding. C) Matrix-supported to muddy, pebbly sandstone (fluvial). D) Thicker succession of sandy siltstone and mudstone, contains numerous bedding parallel reduction patches.

Borehole - 48/19a-4

Clipper Field

Depth range: 8395 - 8620.7 ft (2558.8 - 2627.6 m)
Description: A well that for the selected depth range shows a good example of the 'B zone' of the Leman Sandstone (Sarginson, 2003a); a zone dominated by aeolian sand dune elements with minor occasional fluvial incursions. Some of the fluvial incursions into the aeolian dominated succession can be discriminated in some instances due to a very small grit/pebble lag. The lag in these examples are commonly only a couple of grain's thick.





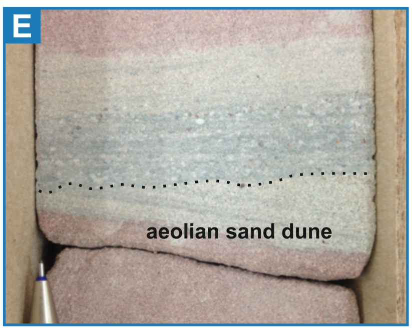
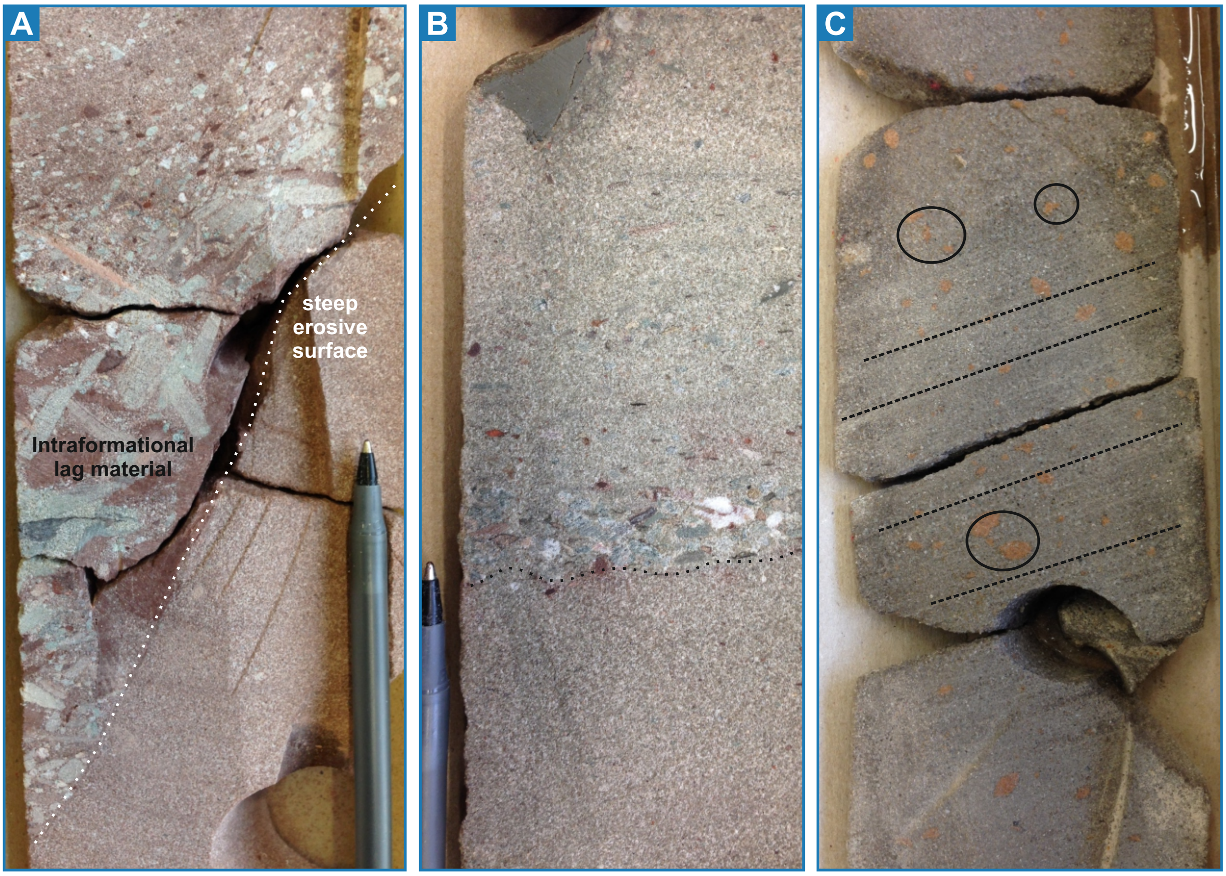


Figure Captions: A) Fluvial incursion within a predominately aeolian succession. Note the small 1-3 mm thick 'grit lag' overlying the minor erosive lower bounding surface. B) A thin dry interdune with upper and lower bounding surfaces shown. C) 'Crude' adhesion ripples in a damp interdune. D) Large aeolian succession. Note the top depth starts at 'top 1' and precedes to 'bottom 1' followed by 'top 2' etc. E) Possible thin fluvial incursion. Note the irregular minor erosive surface that defines the base of the incursion.

Borehole - 48/7b-12

Hoton Field

Depth range: 10465.9 - 10577.8 ft (3190 - 3224.1 m)
Description: A predominately fluvial succession that contains relatively large amounts of siltstone and mudstone material. Also contains some larger erosive surfaces overlain by channel lag deposits. Intra- and extra-formational clasts are relatively abundant throughout and indicate a more energetic fluvial system.



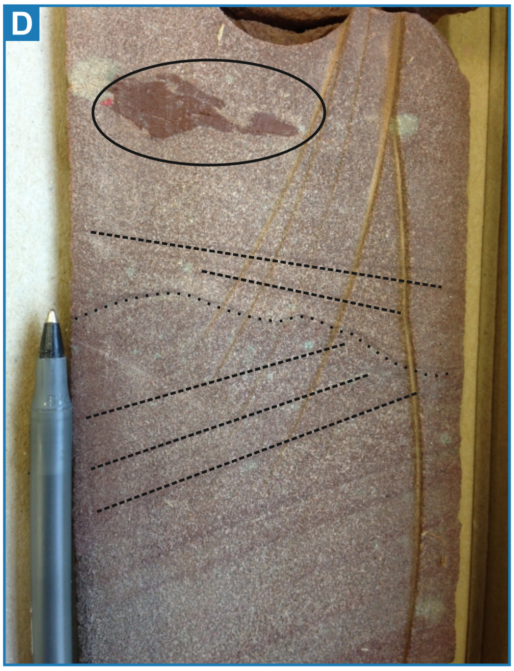


Figure Captions: A) Major fluvial erosive surface with relatively large channel lag deposits. Note that the lags includes a large amount of locally derived mudstone (intraclasts). B) Basal fluvial erosive surface with small pebbly ‘lag’. Compared to ‘A’ this represents the establishment of a relatively minor part of the fluvial system. C) Grey crossbeds covered with secondary diagenetic brown-orange stains. D) Fluvial facies that without the presence of the red-brown mudclast is texturally indistinct from some aeolian facies types.

Borehole - 30/16-2

Auk Field

Depth range: 7674 - 7818.3 ft (2339 - 2383 m)
Description: A well situated in the Central North Sea. The selected depth range includes only the Auk Formation of the Rotliegend Group. Contains large-scale aeolian crossbedding and dry interdunes with good examples of windripple strata. Also includes good examples of hydrocabron staining along grainflow and grainfall facies. Subtle porosity differences are well highlighted by such staining.

Figure Captions: A) Large continuous succession of windripple strata. The relatively thick sequence suggests a relatively prolonged period of dry conditions favourable to windripple development. B) Diffuse looking fluvially reworked windripples. Note the textural difference when compared to 'A'. C) Excellent examples of hydrocarbon staining in aeolian grainfall and grainflow facies. Note how the differing process (grainfall and grainflow) generate facies with slightly differing poro-perm properties that are being discriminated for staining.

Conclusions

Fluvial vs. aeolian: an "ideal world" guide

Aeolian

Textural

- Uniform grainsize (very well sorted)
  - ~0.15 mm - ~0.3 mm
- Well rounded grains
  - -Millet seed texture
  - -Frosted surfaces of grains
- Monomineralic or near monomineralic composition
  - -Predominantly quartz

Facies

- Wind ripple strata
  - -Inverse grading
  - -Can accumulate on slopes up to angle of repose
- Grain flow strata (kinetic sieving induced inverse grading)
- Deflation-derived deposits (reworking of fluvial deposits)
  - -Very well sorted angular grains

Architectural

- Dune size: m scale to 10s m (flow depth is controlled by atmospheric conditions)
- Large curved dune toes (related to size of dune)
- Broad-wavelength deflationary surfaces

Fluvial

Textural

- Mixed grain size (poorly sorted)
  - -Mud to boulders
- Angular to rounded grains
- Polymineralic, due to transport processes
  - -Quartz, feldspars & micas

Facies

- Climbing ripple strata
- Gravel lags
- Mud rip-up clasts & intraformational conglomerates
- Upper-phase plane-beds
- Deflationary residue
  - -Concentrated grains over >0.4 mm - coarse skew

Architectural

- Dune size: up to metre scale (limited by depth of flow)
- Small tangential dune toes (related to size of dune)
- Sharp short-wavelength channel-related erosive surface

Fluvial vs. aeolian: real-world pitfalls!

Aeolian

Textural

- Non-uniform grain size
  - -Surface creep caused by impacts of saltating grains and reptition
- Can contain angular grains
  - -Reworking of fluvial deposits containing angular grains
- Can be polymineralic
  - -Reworking of adjacent fluvial deposits containing feldspars and micas

Fluvial

Textural

- Can have Uniform grainsize
  - -Depends on original provenance
  - -Reworking of aeolian strata.
- Can be very well rounded
  - -Reworking of adjacent aeolian strata
  - -Saltation of grains directly into a stream
- Can be monomineralic
  - -Reworking aeolian strata

↑ Textures can be mimicked simply by reworking of preexisting strata ↑

Aeolian

Facies

- Can contain pebble lags
  - -Surface creep & deflation can concentrate coarse sediments

Fluvial

Facies

- Inverse grading
  - -Intensifying energy within a flood (uncommon)

↑ Similar facies can be generated by different processes within these environments ↑

Aeolian

Architecture

- Preserved dune plinth may give impression of smaller dune (low angle of climb)
- Deflation surfaces can look like any other erosive surface
  - -Concentration of coarse particles which aren't easily wind transported can give the impression of a gravel lag

Fluvial

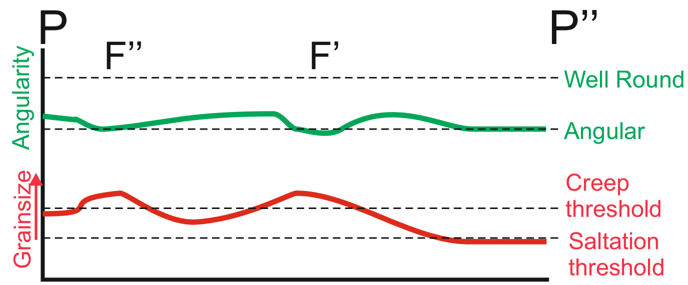
Architecture

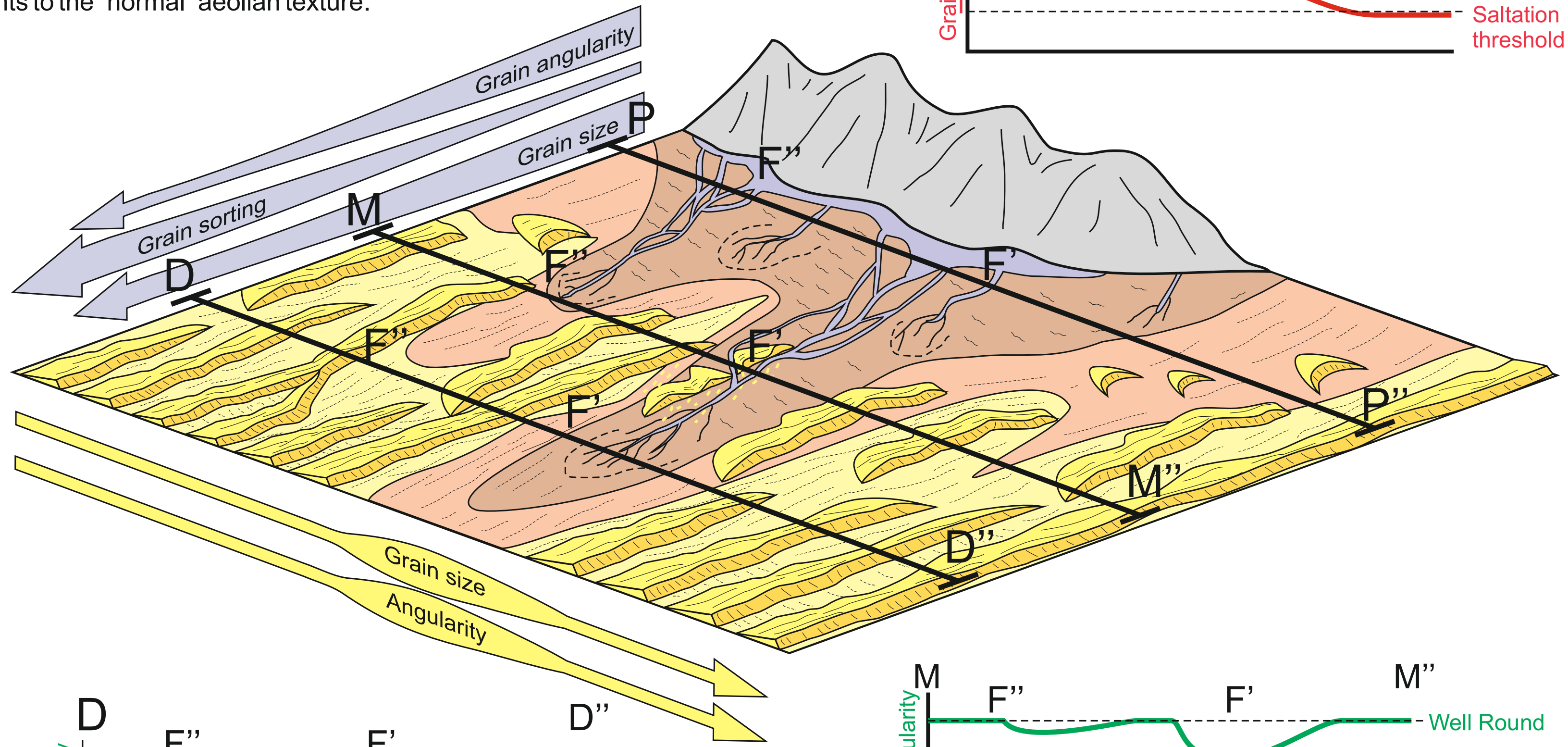
- Dune size: can be 10s m (but you need a massive river...)
- Channel bases in core can be difficult to determine from set bounding surfaces, let alone any other regional erosional surface
- Core intersecting channel margins are rare (or that preserve undulating surface within a few inches width of core)

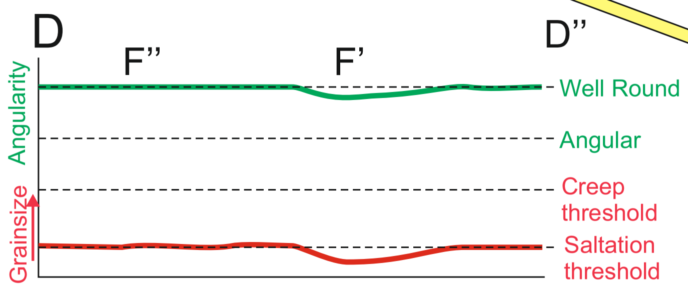
↑ Architectural elements are difficult to determine within core ↑

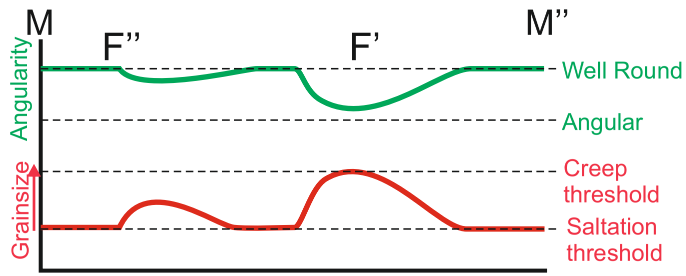
Conclusions

Hypothetical model depicting grainsize and grain angularity in transects across the fluvial system. Entrainment of fluvial material by aeolian processes will alter the grain size and angularity characteristics of the dunes adjacent to the fluvial strata. With increasing distance from fluvial sediment sources, wind winnowing of sediments and rounding of transported particles will return the character of the sediments to the "normal" aeolian texture.









Further reading

Al-Masrahy, M.A. and Mountney, N.P. (2015) A classification scheme for fluvial–aeolian system interaction in desert-margin settings. Aeolian Research, **17,** 67-88.
- Modern Classification of aeolian-fluvial interactions

Bagnold, R.A. (1941) The Physics of Wind Blown Sand and Desert Dunes. Chapman and Hall, London, 265 pp.
- First systematic study of wind-bllown sands

Clemmensen L.B., & Abrahamsen K. (1983) Aeolian stratification and facies association in desert sediments Arran basin (Permian), Scotland. Sedimentology. **30,** 311-339.
- Details aeolian dune succession containing fluvially-derived pebbles

Eastwood, E.n., Kocurek, G., Mohrig, D. & Swanson, T. (2012) Methodology for reconstructing wind direction, wind speed and duration of wind events from aeolian cross-strata. Journal of Geophysical Research: Earth Surface, **117,** F03035.
- Describes the distribution of facies on a dune form in relation to wind directions

Fryberger, S.G. & Schenk, C.J. (1988) Pin stripe lamination: A distinctive feature of modern and ancient eolian sediments. Sedimentary Geology, **55,** 1-15.
- Key paper describing windripple strata

Hunter, R.E. (1977) Basic types of stratification in small eolian dunes. Sedimentology, **24,** 361-387.
- Further descriptions of aeolian stratification

Langford, R.P. (1989). Fluvial-aeolian interactions: Part I, modern systems. Sedimentology, **36,** 1023-1035.
- Classic aeolian-fluvial paper looking at modern systems

Langford, R.P., & Chan, M.A. (1989) Fluvial-aeolian interactions: Part II, ancient systems. Sedimentology, **36,** 1037-1051.
- Classic paper foccusing on the rock-record examples of aeolian-fluvial systems

Mountney, N.P. (2012) A stratigraphic model to account for complexity in aeolian dune and interdune successions. Sedimentology. **59**, 964-989.
- Describes complicated relationships between dune and interdune successions

Rubin, D.M., & Hunter, R.E. (1982) Bedform climbing in theory and nature. Sedimentology, **29,** 121-138.
- Bedform migration and accumulation

Pye K., & Tsoar, H. (1990) Aeolian sand and sand dunes. Unwin Hyman, London. pp.396.
- Mechanics of aeolian transport, and ensuing deposits

References

- **Bagnold, R.A.** (1941) *The Physics of Wind Blown Sand and Desert Dunes*. Chapman and Hall, London, 265 pp.
- **Banham, S.G. and Mountney, N.P.** (2014) Climatic versus halokinetic control on sedimentation in a dryland fluvial succession. *Sedimentology*, **61,** 570-608.
- **Cain, S.A.** (2009) *Sedimentology and stratigraphy of a terminal fluvial fan system: the Permian Organ Rock Formation, South East Utah*. unpublished Keele University, 341 pp.
- **Cain, S.A. and Mountney, N.P.** (2009) Spatial and temporal evolution of a terminal fluvial fan system: the Permian Organ Rock Formation, South-east Utah, USA. *Sedimentology*, **56,** 1774-1800.
- **Eastwood, E.n., Kocurek, G., Mohrig, D. and Swanson, T.** (2012) Methodology for reconstructing wind direction, wind speed and duration of wind events from aeolian cross-strata. *Journal of Geophysical Research: Earth Surface*, **117,** F03035.
- **Fryberger, S.G. and Schenk, C.J.** (1988) Pin stripe lamination: A distinctive feature of modern and ancient eolian sediments. *Sedimentary Geology*, **55,** 1-15.
- **George, G.T. and Berry, J.K.** (1993) A new lithostratigraphy and depositional model for the Upper Rotliegend of the UK Sector of the Southern North Sea. Geological Society, London, Special Publications, **73,** 291-319.
- **Glennie, K.W., Mudd, G.C. and Nagtegaal, P.J.C.** (1978) Depositional environment and diagenesis of Permian Rotliegendes sandstones in Leman Bank and Sole Pit areas of the UK southern North Sea. *Journal of the Geological Society*, **135,** 25-34.
- **Howell, J. and Mountney, N.P.** (1997) Climatic cyclicity and accommodation space in arid to semi-arid depositional systems: an example from the Rotliegend Group of the UK southern North Sea. *Geological Society, London, Special Publications*, **123,** 63-86.
- **Hunter, R.E.** (1977) Basic types of stratification in small eolian dunes. *Sedimentology*, **24,** 361-387.
- **Lancaster, N.** (1981) Paleoenvironmental implications of fixed dune systems in Southern Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **33,** 327-346.
- **Lindquist, S.J.** (1988) Practical characterization of eolian reservoirs for development: Nugget Sandstone, Utah—Wyoming thrust belt. *Sedimentary Geology*, **56,** 315-339.
- **Mountney, N.P.** (2006) Eolian facies models (Eds H.W. Posamentier and R.G. Walker), *Facies Models Revisited*, **84**, pp. 19-83. Society of Economic Paleontologists and Mineralogists Memoir.
- **Sarginson, M.J.** (2003a) The Barque Field, Blocks 48/13a, 48/14, UK North Sea. In: United Kingdom Oil and Gas Fields. Commemorative Millenium Volume (Eds J.G. Gluyas and H.M. Hichens), Geological Society, London, Memoirs, **20,** pp. 663-670.
- **Sarginson, M.J.** (2003b) The Clipper Field, Blocks 48/19a, 48/19c, UK North Sea. In: United Kingdom Oil and Gas Fields, Commemorative Millennium Volume (Eds J.G. Gluyas and H.M. Hichens), Geological Society, London, Memoir, **20,** pp. 691-698.
- **Sweet, M.L.** (1999) Interaction between aeolian, fluvial and playa environments in the Permian Upper Rotliegend Group, UK southern North Sea. *Sedimentology*, **46,** 171-187.
- **Wakefield, O.J.W. and Mountney, N.P.** (2013) Stratigraphic architecture of back-filled incised-valley systems: Pennsylvanian–Permian lower Cutler beds, Utah, USA. *Sedimentary Geology,* **298,** 1-16.
- **Ziegler, P.A.** (1990) Geological atlas of Western and Central Europe. Geological Society of London, 2nd edition pp256.

Notes

Notes

Notes

Risk Assessment

Field Activity	BSRG AGM Core store workshop
Field Leader	Oliver Wakefield (BGS) & Steve Banham (Imperial)
First Aiders	Oliver Wakefield (BGS)

Nature of hazard	Cause	Worst Outcome	Probability	Risk	Control Measures	Person Responsible	Residual Risk Rating
Transport	1) On / off road accidents	Fatality	Low	Moderate	Wear seat belts, load / unload from coach in safe surroundings	Participant	Moderate
	2) Coach safety	Fatality	Low	Moderate	Ensure the coach driver has passed all checks.	Driver	Low
Core Store							
	1) Fire	Severe injury / fatality	Low	Moderate	Know where fire exits are and the assembly point for the building. Note where first aid and fire saftey equipment is within the building. Note alarm testing times	Participant	Low
	2) Unfamiar surroundings	Severe injury	Low	Low	read through, know and abide by the saftey guidelines provided by the BGS for conduct within the core store. Know who the first aiders on the trip are and make them aware of any problems with may arise.	Participant	Low
Security							
1) Local crime	Mugging	Minimal - moderate injury	Low	Moderate	Usual precautions - do not have valuables on view, do not wander off on your own	Participant	Low
2) Participants	Fight	Minimal - moderate injury	Low	Moderate		Participant	Low
Communications							
Mobile phones	Out of battery	Severe injury / fatality	Low	Low	Make sure that your phone is fully charged, for H&S reasons	Gutteridge, Beaumont, Nolan	Low
Satellite phones	Not useable	Severe injury / fatality	Low	Low			Low
Emergency phones in local area	Does not work	Severe injury / fatality	Low	Low	Know the location of nearest phone, always carry your mobile phone	Gutteridge, Beaumont, Nolan	Low

MEDICAL EMERGENCIES	Closest medical facility to….	Hospital Address	24 hour Care	Contact Number
	BGS Keyworth	Nottingham University Hospital, Derby Rd, Nottingham NG7 2UH, Tel: 0115 924 9924	YES	0115 924 9924