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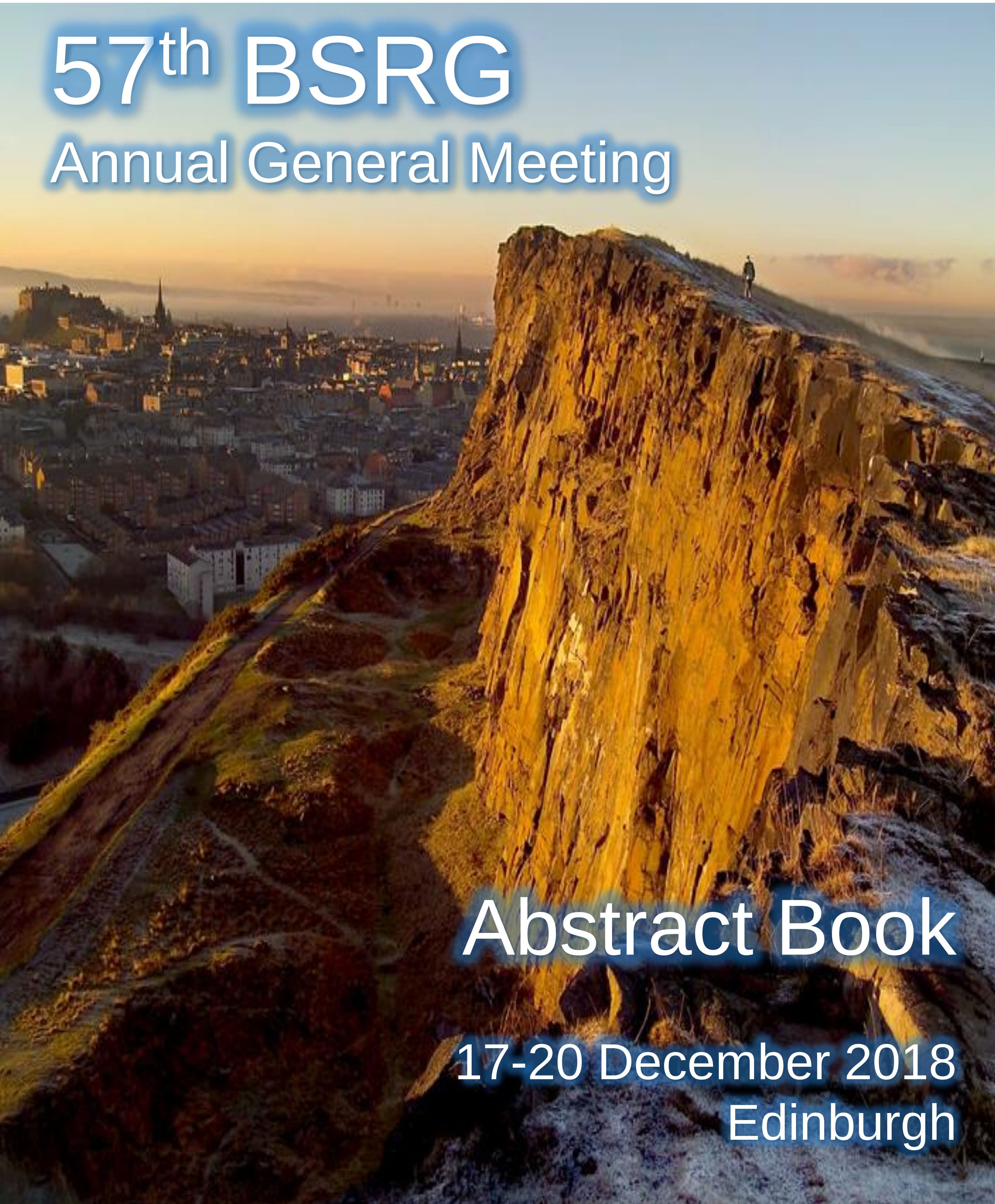
57th BSRG Annual General Meeting



Abstract Book

17-20 December 2018
Edinburgh






57th BSRG Annual General Meeting 17-20th December 2018, Edinburgh

Abstract Book

HERIOT WATT UNIVERSITY

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British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

57th BSRG

Annual General Meeting

17-20th December 2018, Edinburgh

Conveners

Dorrik Stow (Chair)
Zeinab Smillie (Secretary)
Matthew Booth
Rachel Brackenridge
Jim Buckman
Tom Dodd
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Babette Hoogakker
Tim Kearsey
Helen Lever
Uisdean Nicholson
Romesh Palamakumbura
Heather Stewart
Dominic Tatum
Tom Wagner

Sponsors:

Programme

Monday 17th December: Field Trips and Workshops
Field Trip 1: Siccar Point and Pease Bay (09.00-17.00)
(meet Enterprise Building, Heriot-Watt University)

Field Trip 2: Fluvial Geo-Modelling (09.00-17.00)
(meet Enterprise Building, Heriot-Watt University)

Field Trip 3: Building Stones of Edinburgh (16.30-18.30)
(meet Scott Monument, Edinburgh City Centre)

Workshop 1: Contourites (09.00-16.30)
(meet Lyell Centre, Heriot-Watt University)

Workshop 2: Sedimentary Structures (09.30-15.30)
(meet Main Reception, Heriot-Watt University)

For meeting points – see maps overleaf

Ice Breaker (18.30-21.00)
The Signet Library, Parliament Square, Royal Mile, Edinburgh, EH1 1RF (city centre – see map)

Tuesday 18th December: Talks and Posters (09.00-18.00)
James Watt Conference Centre, Heriot-Watt University, (Riccarton Campus). Access from 08.00 for poster set-up and coffee.

Dinner and Ceilidh (19.00-24.00)
The Dynamic Earth, Holyrood Road, Edinburgh EH8 8AS
Buses to Dynamic Earth from outside James Watt Conference Centre at 18.15 (or see map)

Wednesday 19th December: Talks and Posters (08.30-18.00)
James Watt Conference Centre, Heriot-Watt University, (Riccarton Campus). Access from 08.00. Closing drinks from 17.00.

Thursday 20th December: Field Trip
Field Trip 4: Spireslack Quarry (09.00-16.00)
(meet Enterprise Building, Heriot-Watt University)

For meeting point – see maps overleaf

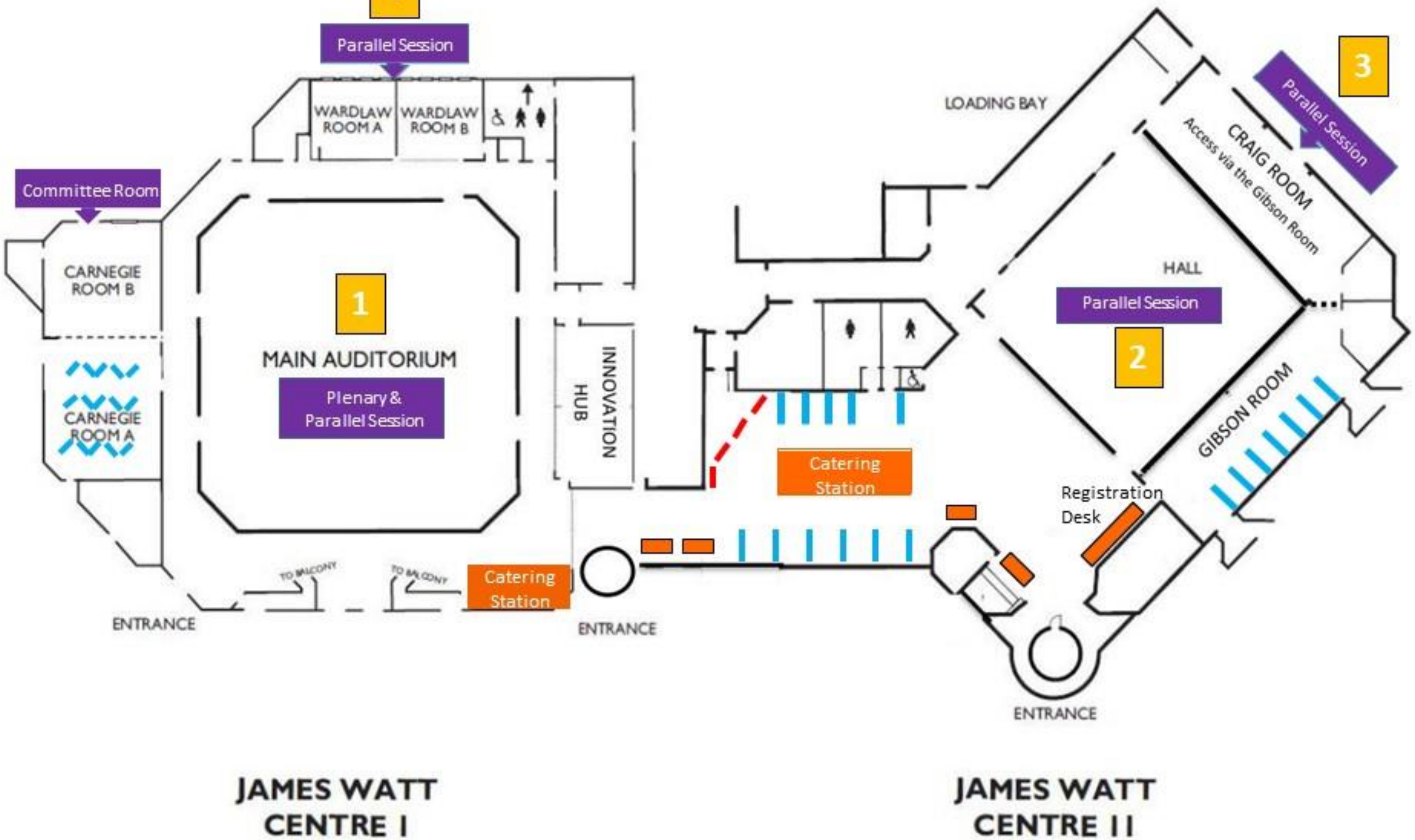
Summary Programme – Tuesday 18th December

	Room 1 - Main Auditorium	Room 2 - Main Hall	Room 3 - Craig Room	Room 4 - Wardlaw Room
9.00- 9.15	Welcome			
9.15-10.00	Keynote 1 - Dick Kroon			
10.00-10.30	Posters and Coffee			
	Deepwater - channels	**Continental - fluvial**	**Carbonates & Evaporites**	**Nearshore 1**
10.30-10.45	Allen	Gray	Peel	Poyatos-More
10.45-11.00	Morris	Na Yan	Bastianini	Zimmer
11.00-11.15	Odeh	Franzel	Murray	Van der Vegt
11.15-11.30	Bell	Prieur	Stanmore	Reynolds
11.30-11.45	Pope	Russell	Corbett	Simon
11.45-12.15	Poster session 1			
	Fuhrman	Ghinassi	Xi	Bilton
	Mitchell	Goldring	Yang	Cosma
	Heijnen	Mitten	Benjakul	Swindles
	Bozetti	Dodd	Nadhem	Alshammari
	Eliassen			McMillan
	Reynolds			Mounteney
12.15-13.15	Lunch break			
13.15-14.00	Keynote 2 - Ru Smith			
	Deepwater - channels to lobes	**Continental - pre-vegetation**	**Contourites & Mixed Systems 1**	**Nearshore 2**
14.00-14.15	Palm	McMahon	Rebesco	Sleveland
14.15-14.30	Brooks	Bonsor	Smillie	Van Yperen
14.30-14.45	Heijnen	Krabbendam	Fuhrmann	Phillips
14.45-15.00	Lopez-Cabrera	Whittaker	Nicholson	Jude
15.00-15.15	Boulesteix	Banham	Koller	Zuchuat
15.15-15.45	Poster session 2 and coffee			
	Pohl	Davies	Beelen	Emery
	Bello	Le Heron	Ng	Elsayed
	Lee	Tunwal	Hall	Healy
	Martínez-Doñate	Shillito	Buckman	Wang
	Cunningham-Gray		de Weger	
	Halotel			
	Caruso			
	Deepwater - confined systems	**Continental -basins & glacial**	**Contourites & Mixed Systems 2**	**Carbonate Systems**
15.45-16.00	Howlett	Lyster	Brackenridge	Van der Land
16.00-16.15	Cumberpatch	Gilmullina	Mayer	Vallack
16.15-16.30	Pizzi	Le Heron	De Castro	Buckman
16.30-16.45	Kane	Kurjanski	Bankole	Hoogaker
16.45-17.00	McArthur	Thuesen	Stow	Jacinto
17.00-17.30	Poster session 3			
	Wigan	Papadopoulos	Rodrigues	Adlan
	Tek	Allison	Pan	Pettigrew
	Ostrelic	Verhagen	Kirby	Herlambang
	Pinter	Roseby	Duarte	Buckman
	Butler	Eaton	Rebesco	
	Johnson			
17.30-18.00	BSRG awards			
18.15-18.30	Buses to Dynamic Earth			

Summary Programme – Wednesday 19th December

	Room 1 - Main Auditorium	Room 2 - Main Hall	Room 3 - Craig Room	Room 4 - Wardlaw Room
08.30-10.00		BSRG plenary		
10.00-10.45	Keynote 3 - Tom Wagner			
10.45-11.15	Posters and Coffee			
	Deepwater - MTCs and triggering mech	**Continental - aeolian & alluvial**	**Tape Recorders - provenance**	**Geochemistry & Diagenesis**
11.15-11.30	Wu	Priddy	Gough	Robertson
11.30-11.45	Nugraha	Zhidong Gu	Nauton-Fourteau	Barshep
11.45-12.00	Steventon	Somerville	Blowick	Hendry
12.00-12.15	Bailey	Sinclair	Anders	Worden
12.15-12.30	Heerema	Hoey	Vincent	Paxton
12.30-13.00	Poster session 4			
	Abu	Quick	Kearsey	Stancampiano
	Wu	Gu	McKenna	Okunuwadje
	Nugraha	Somerville	Ganti	Gundu
	Ayckbourne	Sinclair	O' Donnell	Beaumont
	Chang	Hoey		Wasielka
	Harrald			
13.00-13.30	Lunch break			
13.30-14.15	Keynote 4 - Esther Sumner			
	Deepwater - monitoring & modelling 1	**Sedimentology & Society**	**Tape Recorders - sediment routing**	**Geochemistry & Carbon burial**
14.15-14.30	Ferguson	Parsons	Brewer	Muhammed
14.30-14.45	Baas	Emery	Roquette	Li
14.45-15.00	Spychala	Clare	Bertolini	Simmons
15.00-15.15	Baker	Jerrett	Lavarini	Elson
15.15-15.30	Tilston	Noad	Watkinson	Walker
15.30-16.00	Poster session 5 and coffee			
	Xiaokaiti	Silva	Okwara	Clancy
	de Vet	Rabab	Watkins	Hamlyn
	Dorrell	Gatter	Lamb	Emmings
	Patel	Vendettuoli		Charlaftis
	Azpiroz-Zabala	Manville		
	Walsh	Rice-Birchall		
	Crisostomo Figueroa	Liu		
		Murphy		
		Noad		
	Deepwater - monitoring & modelling 2	**Sedimentology & Society**	**Tape Recorders - stratigraphy**	**Carbon burial**
16.00-16.15	Peakall	Froude	Brooke	Atar
16.15-16.30	Soutter	Nyberg	Barrett	Mertesdorf
16.30-16.45	Stevenson	Richardson	Toby	Wang
16.45-17.00	Simmons	Hage	Cullen	Narman (Wagner presenter)
17.00-17.15	Christie	Wilkinson	Cosgrove	
17.15-18.00	Closing drinks			

JAMES WATT CENTRE



Not to Scale

Oral presentations

High latitude submarine channel-fills, levees, and terrace deposit architecture in palaeofjords and above MTCs.

Charlotte Allen[1]*, Jeff Peakall[1], David M Hodgson[1], Juan-Pablo Milana[2]
[1] School of Earth and Environment, University of Leeds
[2] CONICET, Universidad Nacional de San Juan
**Corresponding author: Charlotte Allen, C.Allen1@leeds.ac.uk*

Models of flow processes in submarine channel and the sedimentary architecture of their fills are predominantly based on the study of mid- and low-latitude channel systems; however, it remains unclear how applicable these models are to high-latitude systems. Furthermore, the role of different styles of confinement on channel behaviour is also poorly understood. This study documents two exhumed high-latitude channel systems that evolved above complex seabed topography, using facies mapping, high-resolution sedimentary logging and bed-scale correlation, and examines how these differ or conform to current models developed from low-latitude settings.

Sedimentological analysis and sampling in the Carboniferous Las Lajas palaeofjord enables the architecture and evolution of multiple stacked channel bodies to be examined. Systems propagated over frontal splay deposits, with multiple channel-levee systems existing coevally. A new model for levee interaction between two contemporaneous proximal channels is proposed, with contemporaneous levees showing a high degree of inter-fingering at a bed-scale. Secondly, a new stratigraphic model for submarine channel-fill atop mass-transport complexes (MTC) is proposed from the La Pena Canyon, Argentina. Multiple, vertically-stacked channel complexes are observed in the main conduit, with a smaller, secondary 'overflow' channel also present. Both field areas exhibit a distinct paucity of clay, with fine grain-size factions dominated by silts, and the MTC primarily composed of silt.

Architectural features observed in Las Lajas and La Pena are compared with both high and low latitude seismic analogues, to highlight the similarities and differences between both groups of channel systems. Progradation of channel systems over frontal lobe deposits, and the cut and fill method of progradation over an MTC are similar to their low latitude counterparts. However, high latitude channel systems are dominated by vertical stacking of successive channel-fills, with a lack of lateral migration, in marked contrast to lower latitude systems. The present work demonstrates that the latitudinal location of a channel exerts a major control on the degree of lateral and vertical sediment accumulation that occurs.

Mixed Signals – Unravelling Cryptic Provenance of a Carboniferous Delta with Multiple Proxies

Anders, B.,[1] Tyrrell, S.,[2] Murray, J.,[3] Graham, J. R.,[4] Mark, C.,[5] Chew, D.,[6]

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This study aims to explain source to sink processes in a complex deltaic system utilising a multi-proxy provenance approach. This type of approach allows effects such as shelf mixing, transportation and point sourcing to be recognised. Various facies and repetition of these facies packages can be analysed using multiple provenance proxies to investigate any variation between methodologies. Deltas are ideal dynamic environments to study how these factors may impact provenance signals. They comprise of a wide range of facies, show variable input points from distinct source terranes, and sediment is impacted by various processes which can effect mixing and sand composition. The Mullaghmore Sandstone Formation (MSF) in the NW of Ireland in the North West Carboniferous Basin (NWCB) is used as the study section. It is a mid Viséan lobate fluvial/deltaic sequence, deposited during a regional lowstand. Not only are cycles of various facies packages present, but there are also spatial variations such that the provenance signal can be investigated through a number of sections from different parts of the basin. These results will also provide a better insight into the palaeogeography of this part of NW Europe during the Carboniferous.

To date, four sections through the MSF have been logged and facies packages identified. High resolution sampling through the successions was conducted and a multi-proxy provenance approach, using optical microscopy, scanning electron microscopy, U-Pb zircon and apatite geochronology, trace elements in apatite and Pb-in-K-feldspar analysis, has been utilised. Three main grain populations have been identified which suggest derivation from the NW; broadly agreeing with palaeoflow data. Lewisian material from basement highs offshore Ireland and Scotland appear to be the main contributor, with possible input also from equivalent Archaean and Palaeoproterozoic rocks of Greenland. There is also a minor Caledonian component. Pb-K-feldspar data seem to better reveal changing sources, while zircon data show little variation throughout the sequence. Apatite geochronological data differs from that of zircon, as it yields a large proportion of Caledonian aged grains – which, by trace element analysis, have been identified as being metamorphic in origin. These are likely to be derived from Neoproterozoic to Lower Palaeozoic sedimentary rocks and have been partially reset during the Caledonian Orogenic Cycle. Interestingly, provenance data are more unimodal in channelised sandstone facies, compared to a broader "mixed" signal in shoreface facies sandstones, likely indicating point sourcing and shelf mixing respectively.

Atmospheric controls on large-scale source rock deposition: A case study for the Kimmeridge Clay Formation

Elizabeth Atar[1], Prof Andrew Aplin[1], Dr Olaf Dellwig[2], Dr Violaine Lamoureux-var[3], Dr Thomas Lesley Leith[4], Prof Daniel Lunt[5], Dr Christian März[6], Dr Bernhard Schnetger[7], and Prof Thomas Wagner[8]

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Atmospheric dynamics exert a fundamental control on marine sedimentation through variations in precipitation, affecting sediment, nutrient, and fresh water supply to the oceans, and in wind strength and direction, affecting ocean currents and upwelling, especially in shallow ocean settings (e.g. shelves, epicontinental seaways). Using knowledge of these processes derived from the modern, models can be used to simulate global climate systems for intervals in the geological past. The validation of these simulations with observational geochemical and sedimentological data is essential to make informed predictions in areas where observational data is lacking.

The Late Jurassic Kimmeridge Clay Formation (KCF) was deposited across NW Europe along a shallow seaway that connected the low latitude Tethys Ocean with the paleo-Arctic. Recent climate modelling results suggest that at least the southern sector of the seaway experienced intermittently tropical conditions, comparable to the modern day monsoonal system, due to the orbital and potentially seasonal poleward migration of the inter tropical convergence zone (ITCZ, Figure 1; From Armstrong et al., 2016). To further test this hypothesis and to explore the processes controlling sedimentation from mid to sub-polar paleo-latitudes, three time-equivalent Upper Jurassic sections were studied from the Boreal Seaway (Dorset, Yorkshire, and Svalbard). The sections were analysed in large detail for major and trace elements, mineralogy, organic carbon, bulk-rock oxygen isotopes, total organic and inorganic carbon, and sedimentological information from petrography. The new comprehensive and high-time (orbital time scale) resolution records were then set in the context of new model results, combining high resolution HadCM3L atmospheric with low resolution FOAM coupled atmosphere-ocean simulations, to better understand the Late Jurassic dynamic depositional environment of the Boreal Seaway where organic carbon enrichment was persistent, but influenced by different climatic processes, throughout the seaway.

The use of this combined model approach paired with orbital time scale geochemical and sedimentological time series provides a powerful tool to constrain the controls on widespread organic sedimentation, shedding light in the underlying biogeochemical and physical controls and feedbacks across the seaway. Furthermore, this information can be used to extrapolate and potentially predict source rock presence and quality in areas further north (the paleo-Arctic), which is of both scientific and economic importance.

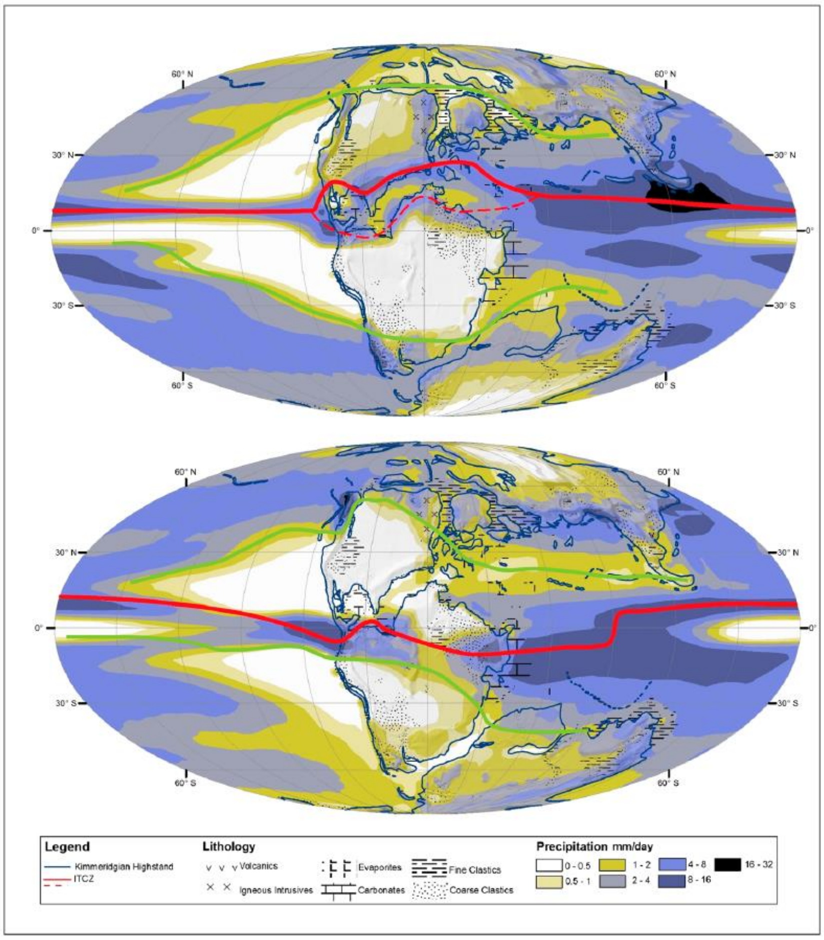

Figure 1. From Armstrong et al., 2016. Modelled precipitation (contours, mm/d), location of the Intertropical Convergence Zone (ITCZ, red line) during the deposition of the KCF based on HadCM3L model and a paleogeography of the Late Jurassic (155.5 Ma [Getech, 2013]). Upper map is boreal summer (June, July, and August), and lower map is boreal winter (December, January, and February). During boreal summer the ITCZ lies in a more northerly location than at the present day placing the boreal sector of the NW European seaway temporarily under tropical-like conditions. The green line shows the approximate 1 mm/d precipitation contour, whose position is influenced by the location of the descending limb of the Hadley cell and the subtropical jet, as indicated in Figures 3b and 3c.

Reference

Armstrong, H. A., T. Wagner, L. G. Herringshaw, A. J. Farnsworth, D. J. Lunt, M. Harland, J. Imber, C. Loptson, and E. F. L. Atar (2016), Hadley circulation and precipitation changes controlling black shale deposition in the Late Jurassic Boreal Seaway, Paleoceanography, 31, 1041–1053, doi:10.1002/ 2015PA002911.

Is silt the new clay? Silt as driver of deep-marine gravity flows of extremely high density

Baas, Jaco H.[1], Baker, Megan[2], Spychala, Yvonne[3], Eggenhuisen, Joris[4], Buffon, Patricia[5], Strachan, Lorna[6], Bostock, Helen[7], Hodgson, David[8]

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Deposits of turbidity currents, debris flows, and slides store the world's largest volumes of sediment on the planet. However, the physical processes by which these flows transport this sediment over distances that may exceed several thousands of kilometers and over gentle slope gradients to form submarine fans are poorly understood. Novel 2D and 3D experiments combined with theoretical models for sediment transport efficiency show that silt and very fine sand may play a pivotal role in this long-distance transport, because these sediment types are non-cohesive, have a low settling velocity, and their flows remain mobile up to extremely high densities.

The ability to interpret the shape, size, transport distance, and internal organization of submarine fans as a function of intra- and extra-basinal controls depends largely on accurate flow mobility predictions. Flow mobility is often expressed as flow efficiency, which depends on the maximum grain size (flow competence) and the maximum volume of sediment (flow capacity) a flow can carry. A combination of laboratory experiments and theoretical models for flow competence and capacity[1,2] is used to show that, because of their low settling velocity, silt and very fine sand have a high mobility, even on gentle slope gradients. This high mobility extends to remarkably high suspended sediment concentrations (~50% by volume, thus close to the cubic packing density of water-sediment mixtures) (Fig. 1). Non-cohesive silt and very fine sand are inferred to show a primary control on the long transport distance of deep-marine gravity flows, which extends to dense flows that have previously been associated with short transport distances.

In contrast to silt and very fine sand, the efficiency of flows to carry coarser sand and gravel over long distances is inhibited by their high settling velocity. This enhanced gravitational settling needs to be compensated for by enhanced upward directed components of turbulent flow to keep these coarse particles in suspension. Theoretically, this can be achieved by increasing the bed slope gradient and increasing the density difference between the flow and the ambient water. However, the required slope gradients are most probably too high and too spatially constrained in the deep ocean for long-distance transport of coarse sediment, and the flow density cannot extend above the cubic packing density of sediment particles, which the silt-laden flows were already close to reaching in the laboratory experiments[1]. Moreover, the presence of finer-grained clay particles in dense flows also inhibits long-distance sediment transport, because the efficiency of such flows is inhibited by physicochemical cohesive forces between clay particles that attenuate the turbulent forces and often cause *en-masse* settling on gentle slopes, as shown in previous laboratory experiments[3].

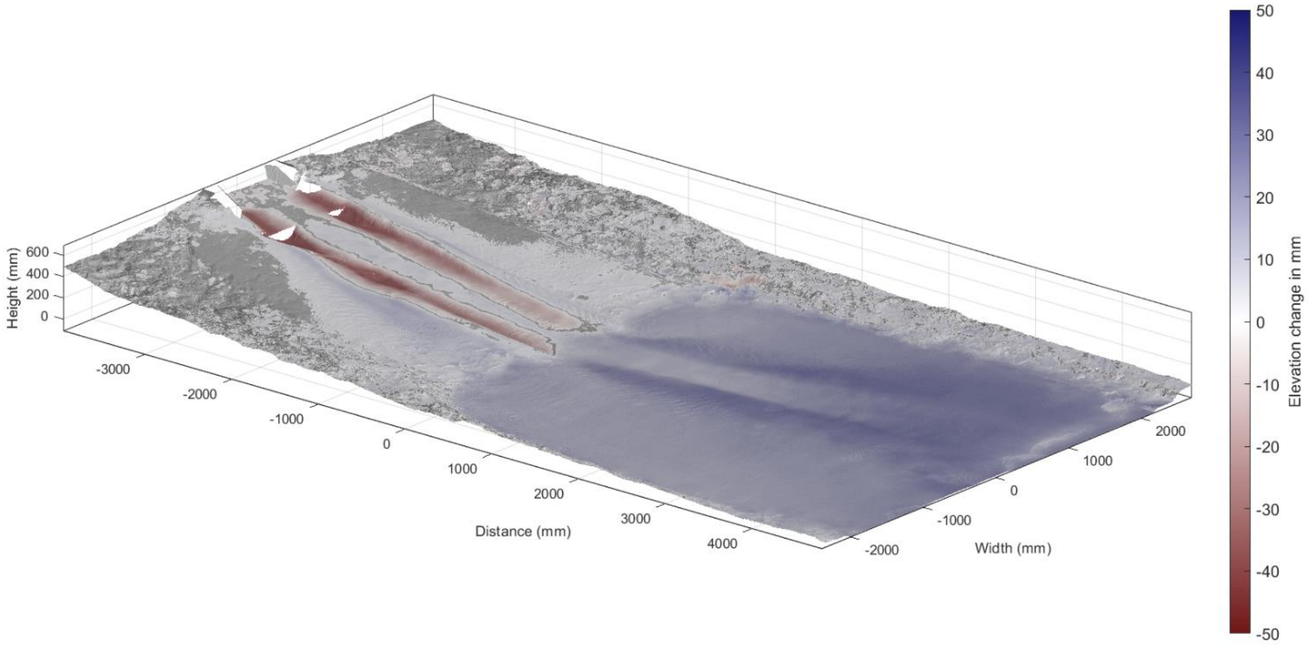

Figure 1 *– Erosion-deposition map of a channel-lobe system formed in the Eurotank, Utrecht University, by a hyper-dense silt-laden gravity flow (42% initial volumetric concentration). Erosion and deposition are given in red and blue, respectively. Note that this flow eroded most of the channel on the slope and formed a depositional channel with levees along most of the length of the flat basin. The tank was too small to form a clear lobe at the end of this channel, supporting the high mobility of this hyper-dense flow.*

References

[1] J.T. Eggenhuisen, M.J.B Cartigny, J. de Leeuw, *Earth Surface Dynamics*, *J1-ESURF*, 2017, **5**, 269-281.

[2] T.C. Halsey, A. Kumar, M.M. Perillo, *Journal of Geophysical Research, Oceans*, 2017, **122**, 5260-5285.

[3] M.L. Baker, J.H. Baas, J. Malarkey, et al., *Journal of Sedimentary Research*, 2017, **87**, 1176-1195.

Can Powerful Turbidity Currents Initiate Without a Major Trigger? New insights from detailed measurements in Monterey Canyon

Lewis Bailey[1], Michael Clare[2], Kurt Rosenberger[3], Matthieu Cartigny[4], Peter Talling[4], Charles Paull[5], Roberto Gwiazda[5], Daniel Parsons[6], Jingping Xu[7], Kate Heerema[4] and the Monterey CCE Team

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Individual turbidity currents can reach velocities up to 20 ms^{-1} and may transport globally significant quantities of sediment. These flows pose a threat to subsea infrastructure such as hydrocarbon pipelines and seafloor cables, which underpin our daily lives. Avoidance of areas prone to turbidity current activity is not always possible, therefore determining the tempo and triggering mechanisms of turbidity currents is integral. It is generally thought that turbidity currents are triggered by large events, such as storm waves, earthquakes or river floods. Directly linking turbidity currents with a trigger is challenging due to uncertainties in age dating of deposits left by past flows. In recent years, advances in technology have enabled direct monitoring of turbidity currents so their precise timing can be determined; however, statistical analysis of triggers has been problematic due to the small numbers of flows that were recorded. Here, we show data from the Coordinated Canyon Experiment in Monterey Canyon, offshore California, where both turbidity currents and background oceanographic conditions have been monitored at unprecedented detail. During the 18-months of instrument deployment 17 turbidity currents were detected, with velocities of >8 ms^{-1} and runouts up to 50 km down-canyon. We show that turbidity currents do not require a major event for their initiation. Throughout this monitoring period no clear or consistent triggering mechanism was identified. Instead, events cluster within a window of heightened sediment delivery to the canyon head during the winter months. We propose this sediment delivery preconditions the upper canyon slopes to failure, enabling relatively minor perturbations in oceanographic or other conditions to trigger failure. Our results indicate that caution should be applied when using turbidite deposits to extend historical catalogues of natural hazards, as event trigger magnitude does not appear to correlate with turbidity current run-out distance or velocity.

Using the Rheological Properties of Mixed-Clay Sediment Gravity Flows to Understand Their Flow Behaviour and Deposits

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The majority of experimental work on cohesive sediment gravity flows (SGFs) has focussed on flows carrying a single clay type. However, this is not realistic for natural SGFs, which typically contain a mixture of clay minerals. To improve our understanding of these natural flows, lock-exchange experiments were conducted, investigating the run-out distance, head velocity, and visual properties of SGFs carrying mixtures of strongly cohesive bentonite clay and weakly cohesive kaolinite clay at a fixed 20% volumetric concentration. In addition, rheological tests were conducted on samples of the same composition as the laboratory flows to obtain rheological parameters, *i.e.* yield stress, of the initial flow material in the experiments.

As the proportion of bentonite within the flow was increased to 20% of the total clay concentration, the maximum head velocity of the flows increased. Thereafter, further increasing the amount of bentonite within the flow dramatically reduced the maximum head velocity. The run-out distance for the mixtures containing 0% to 20% bentonite reflected off the end of the 5-m long tank; from 35% bentonite the run-out distance decreased as the proportion of bentonite increased. The clay mixture rheology data shows an initial decrease and then exponential increase in yield stress of the mixed clay suspensions with increasing bentonite concentration.

Unexpectedly, these results suggest that small amounts of bentonite clay destabilise a pure kaolinite clay suspension, reduce the flow yield strength and increase the flow mobility. Once a threshold amount of bentonite replaces kaolinite in the fixed concentration suspension, the strongly cohesive bentonite strengthens the network of particle bonds, which increases the yield strength of the flow and thus reduces head velocity and run-out distance.

The experiments demonstrate that within mixed clay suspensions individual clay mineral types interact and change the flow rheology, and hence flow behaviour, in a non-linear manner. Thus, the behaviour of high-density, mixed-clay, SGFs may be different from the simple addition of the single clay-type equivalents. Improving our understanding of SGFs composed of mixtures of clay minerals will make an important contribution to our understanding of the continuity and deposit shape of SGFs in the modern environment and in the geological record.

A journey to the centre of an ancient extraterrestrial aeolian erg

Steven G. Banham[1], Sanjeev Gupta[1], Dave M. Rubin[2], Kenneth S. Edgett[3], Jason Van Beek[3], Jessica A. Watkins[4], Lauren A. Edgar[5], Chris Fedo[6], and Ashwin Vasavada[7]

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4 National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, TX, USA
5 U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA
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The stratigraphic architecture of aeolian sandstones preserves a record of ancient dune field environments and processes. Ancient aeolian sandstones on Mars provide an opportunity to consider transport and deposition under conditions which might have differed from present-day Mars, as well as Earth. The Stimson formation, exposed in northern Gale crater, Mars, is an aeolian sandstone for which the current best estimates of absolute age place it sometime about 3.5–3.2 billion years ago. These sands accumulated on a deflationary unconformity stratigraphically above and contacting lacustrine mudstones and very fine sandstones of the Murray formation.
Initial exploration of the Stimson sandstone by the Mars Science Laboratory science team, using the Curiosity rover, occurred within the Emerson plateau area (Figure 1). This work showed that it is predominantly composed of simple metre-scale cross-bed sets (Figure 2). These are bounded by decametre-length sub-horizontal bounding surfaces, which are interpreted to be interdune surfaces formed by scour-pit migration ahead of advancing dunes. Fine-grained interdune deposits were not recorded in this region. Internally, these cross sets consist of millimetre-thick uniform laminations, interpreted as wind ripple strata. No evidence for grainflow strata was observed, but textural analysis of grains using the rover's Mars Hand Lens Imager suggests transport by aeolian processes. Measurement of foreset dip-azimuths across the Emerson Plateau show a record dominated by sediment transport toward the northeast.

Traverse of the Curiosity rover to the west and south resulted in exploration of excellent exposures of the Stimson in a series of outcrop among the Murray Buttes (Figure 1). Here the Stimson sandstone consists of compound cross sets (co-sets), with co-set thicknesses up to 4 m (Figure 2). The co-sets are bounded by sub-horizontal bounding surfaces that can be traced laterally for tens of metres across the width of the outcrop. Within these co-sets, inclined bounding surfaces, interpreted to be superposition surfaces, divide individual cross sets which have thicknesses up to 1 m. Although close inspection of cross laminations could not be conducted within the Murray Buttes, owing to camera range to the outcrops, they have the same visual expression and apparent uniform thickness as those observed at the Emerson Plateau. Again, no evidence of fine-grained interdune deposits or damp aeolian processes were recorded in the rocks. Interdune surfaces are interpreted to have formed by passage of a scour pit preceding a migrating draa-scale bedform (also described as a complex or compound dune), with superposition surfaces being scoured during the transit of superimposed dunes down the lee of a given draa slope. The superposition surfaces record the orientation of the draa lee slope, and can be used to determine sediment transport direction for the draa, while the cross lamination dip-azimuth can be used to determine sediment transport direction in the superimposed bedforms. In the Murray Buttes, draa migration was toward the north-northwest, while superimposed bedforms migrated to the northeast.

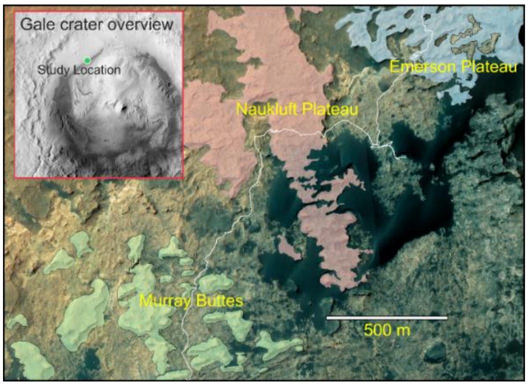

Figure 1: Map of Stimson outcrops (Stimson shown in blue, red, and green), and their distribution. Curiosity's traverse is shown in white.

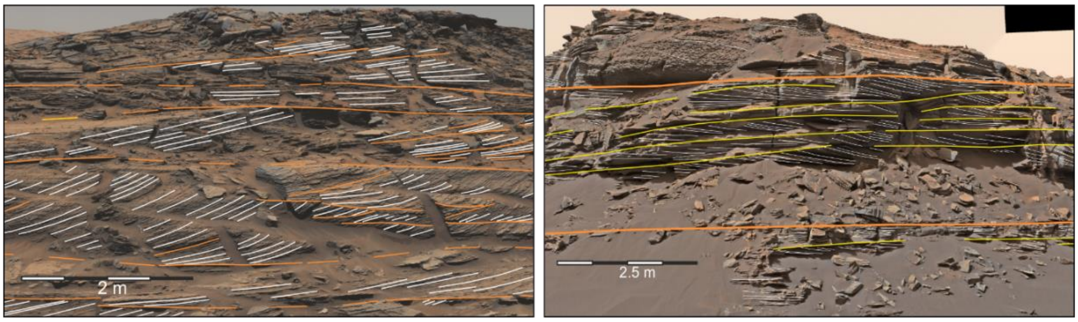

Figure 2: Representative outcrops examples. Left: Williams outcrop, Emerson Plateau. Right: Butte 9, Murray Buttes

A palaeoenvironmental reconstruction based on these observations records a transect across a dry aeolian system. The outcrop at Emerson Plateau represents a more distal section of the erg, characterised by simple dunes approximately 10 m high, with wavelengths of ~160 m. The outcrops in the Murray Buttes area represent the preserved expression of a more central part of the Stimson erg, where draas with estimated heights up to 60 m, and spacings up to 900 m were present. Superimposed bedforms migrated obliquely across the lee slope of the draas indicating a complex wind regime.

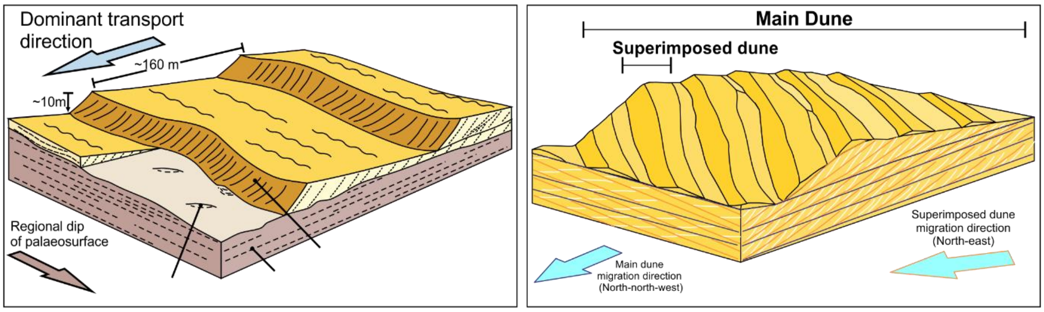

Figure 3: Reconstruction of bedforms in the Stimson formation. Left: Simple dunes, Emerson Plateau. Right: Draas, Murray Buttes.

Mudrock microstructure: A proxy for distinguishing among deep-water fine grained sediments.

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Muddy contourites, hemipelagites and fine grained turbidites constitute the most prominent sedimentary facies within the deep-water environment. There is a process continuum between the mechanisms that give rise to each of the sedimentary facies as their by-products. Distinguishing between each end member is very challenging especially in the fine grained sections where observation of sedimentary structures is difficult. Microstructure is an important attribute controlling many petrophysical properties of the rock. It is one of the only features that can be studied in a very small sample and it is partly controlled by depositional processes.

In this contribution, high resolution scanning electron microscopy and laser diffraction granulometry were employed to assess the microstructure as a recognising criteria to differentiate among the three principal sedimentary facies within the deep water, using core samples from the Gulf of Cadiz (contourites) and Western Iberian Margin (Hemipelagites) collected during expedition 339, and the Indus fan (turbidites) retrieved during expedition 355.

Grain size analysis shows that contourites are fine silt to coarse clay, typically symmetrical to very fine skewed, mostly platykurtic but with few mesokurtic and generally very poorly sorted. Hemipelagites are very fine grained and mostly fall within the coarse clay grain size. They are generally poorly sorted, fine skewed and mesokurtic. Turbidites are mostly between very fine silt to coarse clay. In terms of microfabric; orientation analysis of silt and clay size particles shows that contourites are generally random to semi random with occasional parallel bedding pattern. Hemiplegaites exhibit mixed microfabric, which is characterised by oblique to bedding and random bedding parallel pattern. Fine grained turbidites show the most preferred orientation, typically oblique to bedding and bedding parallel.

In summary, apart from the numerous controls that have been previously linked to microfabric development, which include, anoxic condition, high silt content and mechanical compaction among others it is suggested that the sedimentary processes in operation within the deep-water have a great influence on the microfabric pattern and in turns can be used as a proxy for distinguishing among the different sedimentary facies in the deep-water especially within the muddy sections.

Syn-rift deltaic interfans as basin evolution archives

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Interfan areas are rarely considered in synoptic models for interactions of syn-rift sedimentation, base level and tectonism in rift basins. However, the areas between fan deltas can offer an alternative, complementary record of relative sea level change and basin evolution to the axes of fan deltas. The Early-Middle Pleistocene Kerinitis and Selinous (K-S) fan deltas are positioned along-strike from one another in the hangingwall of the Pirgaki-Mamoussia (PM) Fault on the southern margin of the Gulf of Corinth, Greece. They offer an ideal field laboratory to assess interfan facies and architecture. Qualitative (facies, stratal geometries, nature of key surfaces) and quantitative (stratigraphic thickness, bedding dip, palaeocurrents, breakpoint trajectories) data were collected in the field and from UAV photogrammetry-based 3D outcrop models. Digital outcrop models allowed 167 bedding dip measurements (using structural planes in LIME) that refined the stratigraphic framework and allowed more confident correlation of bottomset deposits to their up-dip counterparts. Based on the geomorphology of modern fan deltas, we classify interfans into three types based on their separation relative to topset and foreset radius, which determines the degree of interfingering of delta topsets, foresets and bottomsets. We use this classification in the analysis of the exhumed K-S interfan and demonstrate how interfans can evolve through these types in response to allogenic forcing. The K-S interfan evolved through five distinct phases of progradation in response to basin evolution: Phase 1 - initial progradation of the fan deltas into the interfan area, starting with Kerinitis, Phase 2 - asymmetric delta growth towards the east, and Phase 3 - interfingering of the two systems and shallowing of the interfan. Phases 1 to 3 were influenced by growth of the Pirgaki-Mamoussia (PM) Fault causing *net subsidence* of the hangingwall basin. During Phases 4 and 5, the PM Fault ceased to be active and strain was accommodated on the basinward West Helike Fault located ~6 km to the N, in the hangingwall of the PM fault. Uplift of the West Helike Fault footwall and thus *net uplift* of the PM Fault hangingwall basin resulted in relative base level fall, erosion and reworking of sediments into the interfan area (Phase 4). Continued uplift caused lake level to fall below the West Helike fault scarp, sub-aerial exposure of the Early-Middle Pleistocene deltas, and accommodated growth of Late Pleistocene deltas in the hangingwall of the West Helike fault that are fed by the same drainage system (Phase 5). The K-S interfan provides a complementary, and in this case, more extensive stratigraphic record than the axial areas of the fan deltas, through high preservation potential and longer submergence during basin uplift, and thus provides further insight into basin evolution. In this first detailed study of syn-rift interfan evolution we also assess the impact of alternative basin evolution models (drainage reversal, landward fault set switch and post-rift thermal subsidence) on interfan architectures.
Funding for data collection and analysis was gratefully received from the BSRG Trevor Elliott Grant, IAS Post-Graduate Research Grant and the VISTA Visiting Program.

Impact of diagenesis on the Jurassic Corallian sandstones from the Weald Basin

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The Upper Jurassic shallow marine Corallian sandstones are important reservoirs in the Weald Basin. These reservoirs vary from low to moderately high porosity with many core plugs having less than 10% porosity. There is a paucity of data on the reservoir quality and reservoir quality evolution of these sandstones thus limiting the ability to predict reservoir quality away from wells. We present a detailed reservoir quality study of the Corallian sandstones from Palmers Wood and Bletchingley oil fields (present temperature: 40-50°C) of the Weald Basin using a combination of sedimentary core logging, petrographic, geochemical and petrophysical analyses to understand the fundamental controls on reservoir quality evolution of the Jurassic Corallian sandstones. These clastic sediments contained dominant quartz and minor feldspar grains, berthierine Fe-ooids, and abundant bioclastic materials. We conclude that the main control on reservoir quality is cementation, predominantly by calcite, with intergranular volumes of up to 40% being modified by cementation accounting for up to six tenths of intergranular volume loss. Early calcite cement prevented significant mechanical compaction and filled up to 98% of intergranular volume in some cases. Calcite cement (2 to 55%) was derived from dissolution and re-precipitation of bioclasts and possibly from bicarbonate in turn derived from carbon dioxide from early-stage source rock maturation. Apatite (< 3 %) was derived from phosphate bone fragments. Pyrite (< 2 %) was deposited in sulphide-rich carbonate-poor reducing conditions. Dolomite resulted from calcium derived from dissolved bioclasts and/or calcite cements with iron and magnesium derived from dissolved berthierine ooids. Siderite resulted from dissolved berthierine ooids. Illite is abundant in matrix (mean of 3.78 %) introduced by bioturbation and also occurs as an alteration product of alkali feldspars. Kaolinite is probably the result of feldspar alteration due to influx of carbon dioxide derived from decarboxylation of source rocks which also released silica to form small quantities of somewhat unexpected (given the low temperature) quartz overgrowths (up to 7 %). Reservoir quality shows no clear relationship to facies associations and grain size. Reservoir quality is mainly destroyed by carbonate cementation and enhanced by detrital grain dissolution, cement dissolution and iron-clay coats. Reservoir quality can therefore be predicted from considering abundance of bioclasts, organically derived carbon dioxide and iron-clay coats.

What causes carbonates to form “shrubby” morphologies? An analog case study from a hyperalkaline leachate.

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Abstract - The South Atlantic Aptian “Pre-salt” shrubby carbonate Formations of Brazil and Angola are of major interest for the oil industry due to their potential hydrocarbon accumulations. Although the general sedimentology of these deposits is associated to saline, alkaline lakes in rift volcanic settings, the specific genesis of shrubby carbonate morphologies remains unclear. This study is focused in the analysis of 8 different types of carbonate microfacies grown under contrasting physico-chemical conditions given in steel slag leachates located in Consett (Durham, England, UK). The comparison between the microfacies formed in extremely rapid carbonate precipitation settings with the shrubby Pre-Salt carbonate fabrics has allowed to investigate the environmental causes behind shrub precipitation. Detailed long-term records of the leachate hydrochemistry have been used to chemically constrain the likely environments that gave rise to similar fabrics in the Pre-Salt Aptian lakes. Data from leachates suggest that shrubby carbonates arise from highly alkaline (pH 9-12), saline waters (conductivity 425-3200µS), rich in calcium (11-240mg/L) and moderately rich in dissolved inorganic carbon (50-330mg/L) at ambient temperatures (in our study, 12.5-13 oC). These fabrics display primary intercrystalline porosity and appear to grow under the presence of significant diatomaceous material and cyanobacterial biofilms despite the highly alkaline and saline conditions. No evidence of Mg-Si mineral phases was recognised in the leachate samples, and the shrubs appear to form directly from ambient water.

__Key words:__ Pre-Salt reservoirs / Alkaline steel slag / Consett / Shrubby carbonate / Microbial/ Hydrochemistry/ Crystal growth / Intercrytalline porosity.

Three dimensional architecture of an exhumed submarine channel system: implications for subsurface interpretations and sediment delivery to the deep-ocean

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Submarine slope channel systems are conduits for large volumes of sediment to the deep-ocean, and act as sinks for organic carbon and anthropogenic pollutants. Their fills also constitute globally important hydrocarbon reservoirs, typically identified and appraised using seismic reflection and well-log/core data. However, these methods lack the spatial resolution to capture the complicated 3D heterogeneity and associated reservoir quality distribution. Outcrop analogues can help bridge this gap, although most only afford 2D constraints of the depositional architecture. Most studies of exhumed ancient submarine channels are derived from relatively coarse-grained, tectonically active systems, making them poor analogues for passive margin systems. A rare example of an accessible fine-grained, passive margin slope channel system that offers seismic-scale, 3D down-dip and across-strike exposure is the Klein Hangklip area, Tanqua-Karoo Basin. An architectural hierarchy is documented, in which eight channel elements stack to form two channel complexes which constitute a channel complex set. Twenty-three detailed sedimentary logs and tracing of key surfaces in a 3 km^2 area reveal that: 1) basal channel elements in the channel complexes fill relatively deep channel axes, have low aspect ratios, and show the greatest lateral facies variability. Later channel elements are bound by relatively flat erosion surfaces and exhibit high aspect ratio geometries; 2) channel axis facies are dominated by amalgamated, structureless and mud-clast rich sandstones, whereas channel margins are characterized by bedded, laminated and climbing-ripple dominated sandstones; 3) the lower channel complex is relatively straight and has a symmetrical facies distribution. Conversely, the upper channel complex is sinuous at the scale of the outcrop, and has an asymmetric facies distribution; 4) stratigraphic architecture does not vary strongly in the same sub-environments both down-dip and across-strike; channel-base-deposit facies vary spatially, and hierarchically. Results demonstrate that facies variability within the channel-fill can be predictable across-strike and down-dip on a km-scale in both channel axis and channel margin deposits. Facies, architectural and channel-base-deposit heterogeneity are linked to the evolution of flow-process in time and space to understand the stratigraphic evolution of the system. The data presented provides insights into the architecture of slope channel-fills in passive margin settings, and can be utilized to improve interpretations from low resolution and 1D well data, and inform how and when sediment is stored or transported to the deep-ocean.

Tracking sediment pathways in a paleodesert, Cretaceous Botucatu Formation, northern Region, Cental Brazil

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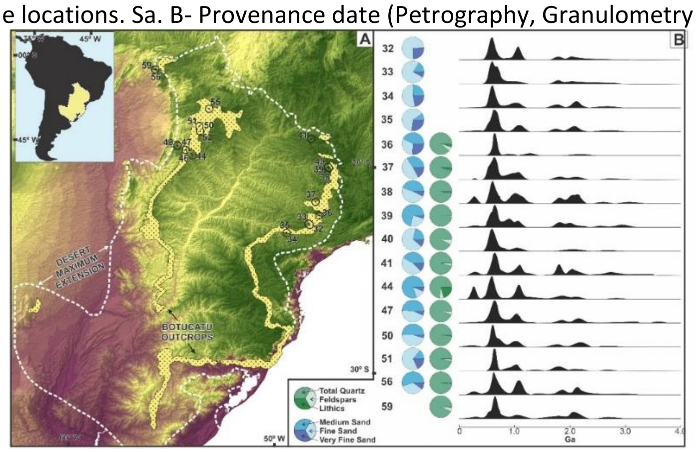
The Botucatu Formation represents a Cretaceous aeolian desert that occupied the central portion of Gondwana, covering present day South America and SW Africa. The Botucatu desert was partially covered by the Parana-Etendeka basalts. The Cretaceous climate of Gondwana was affected by monsoon causing regionality in paleowind directions. The northern portion of the basin shows a steady paleowind direction towards S/SE, contrasting with NE directed winds in the southern region. Cratonic domains (Amazonian, Rio Apa, São Francisco/W-Congo) and orogenic belts (Ribeira, Brasilia, Paraguay) around the northern margin are likely to have provided the source area for the aeolian sediment. To determine the provenance of the Botucatu aeolian sediment we have analysed 16 samples collected across the northern margin from distinct stratigraphic levels (the base and top of the Botucatu Formation as well as sandstones interbedded with lava flows). The methodologies applied are petrography (point counting), granulometric analysis (grain size class measurement) and U-Pb dating on detrital zircons (LA-ICP-MS). Bulk petrography reveals the majority of samples to be quartz arenites with one sublitharenite (PB-47). The Dickinson tectonic setting plot indicates a cratonic to recycled orogenic provenance. Sediment grain-size shows a bi-modal distribution with fine-to-very-fine sand and fine-to-medium sand. Detrital zircon (DZ) data show a complex age signature, with major Neoproterozoic (Early to Late Brazilian Cycle), Tonian-Stenian (Sunsás Cycle) and Orosirian- Rhyacian (Transamazonian Cycle) peaks and minor Neo- to Paleoarchean, Late Paleoproterozoic and Late Paleozoic to Mid Mesozoic ages.

Previous work on the southern margin of the Botucatu aeolian system shows a lateral regional variation in DZ ages from SW to SE, however, the northern portion of the basin shows no lateral variation with similar compositions in both the NE and NW, with only minor changes in Sunsás and Brazilian Ages. The North DZ ages do show a variation across the stratigraphy of the Botucatu Formation. Overall from base to top there is a decrease in Sunsás ages (20 to 11%), in the NE region there are enhanced Early Brazilian ages (base 30.1/top 33.8/ Intratrap 40.1%) and in the NW there is an increase in Transamazonian ages upward (13.2% to 19.1%).

Figure 1 – A- Sample locations. Sa. B- Provenance date (Petrography, Granulometry and Detrital Zircon)



The stratigraphic variation might indicate 2 distinct processes: (1) provenance source shift during desert development or (2) reworking of earlier aealian deposits followed by an extrabasinal 1st cycle source in the later top/intratrap succession. Consistent sedimentology and paleowind directions likely indicates the maintenance of sources during desert development, supporting the reworking hypothesis. In conclusion, the aeolian system responsible for the desert construction in the studied region was highly mature (quartz arenite dominance) with the bimodal grains size variations related to aeolian cross-stratification types. Detrital zircons reveal the importance of the Brasilia and Ribeira belts (Brazilian Ages) and Amazonic Craton (Sunsás Cycle ages) in the Botucatu desert sediment budget. The virtual absence of Permian ages which form major peaks in the southern region indicates little or no interaction between the southern and northern regions

Deciphering first-cycle versus polycyclic supply in the Scotian Basin, offshore Nova Scotia: A Multi-Proxy Provenance Approach

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During the Late Jurassic-Early Cretaceous, the Scotian Basin, offshore Nova Scotia, accumulated several kilometers of deltaic sandstones which today act as important oil and gas reservoirs. These sandstones were deposited in response to, and thus cryptically record, the evolution of the North Atlantic rift and associated changes in palaeodrainage along the Canadian passive margin. Yet despite these major tectonic transitions, several lines of evidence including heavy minerals, U-Pb zircon, monazite and muscovite geochronology suggest that the bulk of the sediment delivered to the offshore was consistently derived from the Appalachian Orogen, with only minor input from Proterozoic and Archaean rocks as far north as the Grenville Province in Labrador.
However, uncertainty remains as to the volume of recycled of grains in offshore wells. The potential for recycled material in the Scotian Basin is high, owing to the fact that the hinterland source terranes strike parallel to the basin margin. As a result, large quantities of material may have been stored, concentrated and recycled through Palaeozoic cover rocks, which covered large areas of the hinterland. In order to decipher first cycle from polycyclic supply this study fingerprints Pb isotopes in detrital K-feldspars from over ten wells across the basin and combines this data with previously acquired provenance proxies to produce a paleogeographic model. K-feldspars are unlikely to survive multiple sedimentary cycles and thus can be used to track first cycle supply.
Pb isotopic compositions reveal a striking change in sand supply which can be linked with regional topographic variations as a result of the evolving Labrador Rift, but which are not observed in detrital zircon datasets. Detrital K-feldspars record a sharp change across the Jurassic-Cretaceous boundary throughout the entire basin from proximal Appalachian to distal Grenville and older signatures. The results indicate significant recycling of zircons in the lower drainage basin with only a small number of first cycle zircons being delivered from Meso-Palaeoproterozoic and Archaean rocks north of the Appalachians. Whole-rock geochemistry is alone insufficient to distinguish specific sources, whilst heavy mineral varietal studies indicate supply exclusively within the Appalachians but are hampered by diagenetic alteration and recycling. The study showcases the utility of Pb isotopic fingerprinting of detrital feldspar and demonstrates the importance of coupling individual tracers of varying resilience to unravel sedimentary provenance.
This research is supported in part by a research grant from Science Foundation Ireland (SFI) under Grant Number 13/RC/2092 and is co-funded under the European Regional Development Fund, by PIPCO RSG and its member companies, and by the Nova Scotia Offshore Energy Research Association (OERA).

Sedimentology a Grenvillian Neoproterozoic foreland basin succession in northern Scotland: a new combined interpretation

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Abstract

The early Neoproterozoic Moine and Torridonian rocks, which occupy much of the Northern Highlands in Scotland, have traditionally been interpreted as separate entities, deposited in distinct early Neoproterozoic rift basins. The rocks are now divided across the later Caledonian Moine thrust structure: the Torridonian rocks (>6 km thick) occur in the Caledonian foreland, and the Moine rocks (>3km thick) in the hanging wall of the Moine thrust. New work, based on structural geology, sedimentology and detrital mineral dating presents evidence for these successions to be now correlated, and to have formed in a single foreland basin in front of the Grenville Orogen. As such the deposits provide arguably the largest preserved and most accessible record of the Grenvillian foreland basin. This paper presents the sedimentological data collected over the last 10 years across the Neoproterozoic succession in northern Scotland, to present a new combined stratigraphic interpretation of these rocks.

Taken collectively, the early Neoproterozoic sequence is ca. 9km thick and displays alternating fluvial, and tidally-influenced shoreface lithofacies, within several cycles of progradation and retrogradation. Five main phases of sedimentological evolution are interpreted: (1) A progradational sucession from tidally-influenced shoreface facies to fluvial facies at the base of the succession (Sleat Group). (2) An abrupt but (near|)conformable switch to large-scale progradation with rapid and sustained high-energy braided river deposition (Applecross Fm and lower Morar group). (3) These high-energy fluvial lithofacies gradually are replaced upwards by lower-energy braidplain fluvial facies, or tidally-influenced braidplan and shoreface facies further east within a gradual large-scale (ca. 3km thick) retrogradational succession (Aultbea Fm and middle Morar Group). (4) This retrogradational phase is indicated to have culminated in a relatively rapid transgression and marine deposition (upper Morar Group). (5) A further progradation and retrogradation succession sequence is preserved in the uppermost Morar Group. The lithofacies suggest overall lower-energy depositional conditions in this phase - from with shallow-marine to tidally-influenced distal braidplain depositional settings. The final retrograding succession is followed by a second transgression to shallow marine conditions resulting in deposition of pelite. This represents the last phase of deposition preserved in upper most parts of the early Neoproterozoic rocks in Northern Scotland.

These five main phases of sedimentological evolution provide insight to the development of the depositional environments within the Grenville foreland basin, resulting from changes in the basin form, accommodation space and sediment flux.

Active fan sedimentation or regional system shutdown? Depositional processes in deep-water mudstones beyond sandstone pinchouts

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Commonly, mud volumetrically dominates sediments delivered to deep-water environments. However, the range of depositional processes responsible for mud transport and deposition beyond the shelf is still poorly understood. Mudstone successions are usually highly weathered in outcrop, which prevents the observation of sedimentary structures and bed contacts. Moreover, deep-water mudstones are rarely cored compared to sandstones, and where they are, they tend to display a homogeneous texture to the naked eye. A particular challenge when dealing with deep-water mudstones is to differentiate mud deposited by sediment density flows from mud deposited by background vertical suspension fallout. Here, we present data from a 200-m thick muddy succession from a 948.50-m cored research borehole underlying a basin-floor fan unit (Fan 3) of the Permian Skoorsteenberg Formation (SW Karoo Basin, South Africa). This study aims to characterize the range of processes responsible for the transport and accumulation of mud in distal basin-floor environments.

A combination of macroscopic and microscopic descriptions indicates that the succession is dominated by 2-20 cm-thick, stratified to erosive-based mottled fine mudstones. Beds are either ungraded or weakly normally graded. No preserved sedimentary structures are recognized and some beds are fully homogenized by bioturbation. The succession shows an upward increase in thick packages (0.5-4.0 m) of erosive-based, normally-graded fine to medium mudstone thin beds (0.2-1.0 cm-thick) with low bioturbation. Rare 1-30 cm-thick normally graded sandy beds are intercalated. These observations indicate that two modes of sedimentation alternated in the distal basin-floor environment of the Karoo Basin. The weakly normally graded mottled mudstone beds are interpreted to be deposited by muddy low density turbidity currents while the ungraded beds are interpreted to be deposited *en masse* from cohesive fluid mud flows with high fine-mud content. The high bioturbation intensity of these deposits suggests that relatively long depositional breaks occurred between depositional events for biogenic homogenization, indicating periods of fan retreat or lateral avulsion. The thinner mudstone beds with low bioturbation are interpreted to be deposited by more frequent low-density turbidity currents in distal fringe environments of lobes or lobe complexes. Their up-section increase in abundance is interpreted to record the distal expressions of underlying basin-floor fans (Fans 1 and 2).
This work demonstrates that deep-water mud can be transported and deposited by sediment density flows without evidence of background sedimentation. Therefore, a false dichotomy of fan activity *versus* system shutdown may exist in deep-water environments, with major implication for the stratigraphic prediction of submarine fan systems and the interpretation of clastic starvation in deep-water environments.

The Textural Characteristics of Sand-rich Contourite Facies

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A sand rich contourite depositional system (CDS) is identified in the eastern Gulf of Cadiz, offshore the Iberian Peninsula. Targeted acquisition of six gravity sediment cores from across this CDS was completed as part of the CONTOURIBER research project and through the Integrated Ocean Drilling Program Expedition 339. Extensive core sampling allowed for grainsize analysis of 675 samples – the largest study to be conducted on a sand-rich contourite system to date.

Grain size distribution curve parameters were gathered including: mean grainsize, sorting, skewness and kurtosis. In addition, cumulative frequency curves were compiled to identify trends within the data. Distinctive trends in textural properties linked to depositional processes under the action of bottom currents. The finest muddy contourites (<20 μm) show normal grain-size distributions, poor to very poor sorting, and zero or low skewness. These are deposited by settling from weak bottom currents with a fine suspension load. Muddy to fine sandy contourites (20 to 200 μm) trend towards better sorting and initially finer and then coarser skew. These are typical depositional trends for contourites. As current velocity and carrying capacity increase, more of the finest fraction remains in suspension and bedload transport becomes more important. Clean sandy contourites (>200 μm) are better sorted. They result from the action of dominant bedload transport and winnowing at high current speeds.

The results highlight the importance of bottom current velocity, sediment supply and bioturbational mixing in controlling contourite facies. This work complements a full analysis of the facies within the sediment cores collected using CT scanning and details sediment logging, as published in Sedimentology 2018 (Brackenridge et al., 2018). The work continues with researchers both at Heriot-Watt University and The Drifter research group at Royal Holloway University of London integrating and comparing the results on sand-rich contourites with that of finer deep sea and downslope facies. This research has important implications for developing understanding of these deposits and aiding the correct interpretation of deep marine sands and depositional processes.

Brackenridge, R. E., et al (2018). Textural characteristics and facies of sand-rich contourite depositional systems. Sedimentology. DOI: 10.1111/sed.12463

Source-to-Sink Analysis of Facies Distribution in Early-Eocene Sediment Routing Systems, northern North Sea

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Reservoir presence and quality are key risks in hydrocarbon exploration. We combine conventional analysis of stratigraphic architecture with sediment mass balance to develop a predictive approach to characterising sediment volumes and grain-size distributions with the aim of reducing the key risks associated with regional-scale screening of reservoir-lithology deposition.

Our approach is being tested using a data-rich Early-Eocene sediment routing system comprising fluvial, deltaic (Dornoch Formation) and coeval slope to basin-floor deposits (Hermod Sandstone Member) found on the East Shetland Platform and across the North Viking Graben, offshore UK and Norway. Ongoing mapping using 3D seismic reflection data integrated with 34 key wells shows that there are at least five distinct sediment routing systems in the area of interest, each inferred to have a separate erosional catchment. Shelfal clinoforms in the Dornoch Formation define a curvilinear deltaic shoreline in plan view, implying strong sediment transport along the shoreline. Thus, the Dornoch-Hermod sediment routing systems were not closed, but there was sediment transfer between them. The basin-floor fan deposits of the Hermod Sandstone Member represent the sinks of the routing systems and show both spatially distinct and amalgamated basin floor fans derived from each of the five systems. Ongoing work is using these mapped seismic data to calculate the sediment volumes in each Dornoch-Hermod routing system and its component parts.

Grain-size distributions in the mapped sediment volumes will be characterised using core and wireline-log data, to capture down-system fining of grain size. When combined with accurate geochronological data, the sediment volumes give estimates of sediment supply rates that can be compared with independent first-order sediment flux estimates derived from paleohydrologic and paleogeomorphic methods. Trunk fluvial channel dimensions vary along depositional strike, with the larger southerly channel system being 27 km in length and 1.3 km in width compared to the 6 km length and 0.6 km width for the four northerly trunk channels. We use a range of empirical geomorphological relationships to calculate ranges for the size of the catchment areas from which the sediment was derived, and the initial sediment fractions generated in these catchments. Integration of grain-size data into the volumetric framework allows a sediment mass balance approach to be implemented, which allows the position of grain-size “fronts” (e.g. down-system limit of sandstone) to be constrained. Such down-system trends in grain size can be normalised relative to accommodation space to give generic, predictive trends that can potentially be applied to exploration in data-poor frontier regions.

Modelling hydraulic and stratigraphic responses to rainfall variability in threshold landscapes

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Sediment routing systems offer a unique opportunity to study the metaphorical conveyor of sediment as it is eroded, transferred and deposited downstream. Measurable sedimentological and geomorphic elements can help unlock changes in sediment supply and paleohydraulics; key indicators of changing environmental boundary conditions. However, an important research challenge is to understand whether stratigraphy records mean climate conditions, or climate extremes, with the greatest fidelity. Catchment-fan systems may represent the simplest and least complex source to sink system we can study to address this question, especially in areas such as Death Valley in the United States, where coupling between rainfall and alluvial fan sedimentology is expected to be pronounced. Using detailed fan mapping and field measurements of grain size and a newly developed iteration of a 1D numerical catchment-fan model, we explore the sensitivity of catchment-fan systems to rapid climate change, and we evaluate the extent to which their deposits record this variability.

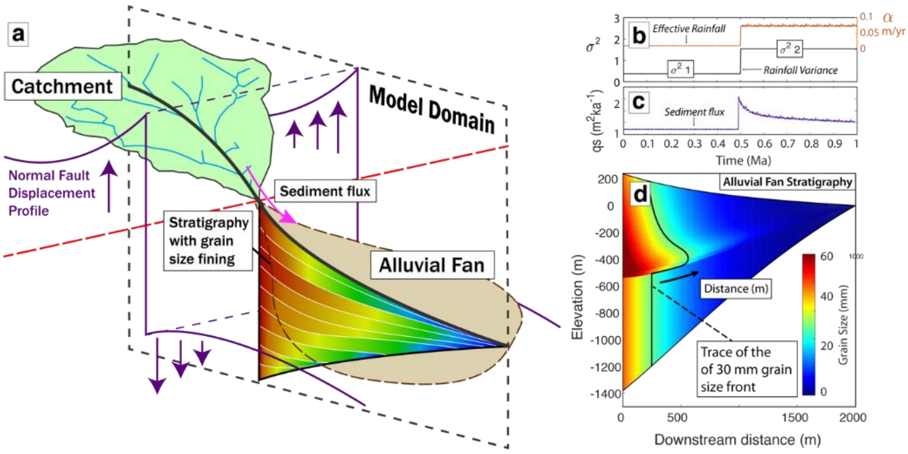

*Figure 1. **a:** Schematic diagram of the 1D catchment-fan model, **b:** An input signal of effective rainfall through time, **c:** the resulting pulse in sediment flux into the basin **d:** 2D stratigraphic architecture of an alluvial fan, coloured according to the predicted grain size input and downstream fining rate onto the fan, showing a stark grain size excursion in response to the increase in effective rainfall.*

Using an effective rainfall threshold in our 1D catchment-fan model, we show that observed changes in grain size may be the product of a sequence of sudden changes in storm magnitude-frequency rather than a simple increase in mean rainfall. From this finding, we have conducted paleohydraulic analyses on further catchment-fan systems to assess whether the presence of conspicuous and extensive coarse-grained deposits in Death Valley may be the product of rapid shifts in storm activity. This work illustrates how short, arid-climate catchment-fan systems are capable of transmitting signals of rapid climate change, in particular of storm magnitude-frequency, into the stratigraphic record. We highlight how threshold landscapes may be preferentially sensitive to a given portion of the input distribution of events and their sequencing, ultimately controlling how climate signals are preserved in the stratigraphic archive.

Channel lobe transition zone dynamics: examples from active and passive continental margins.

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Submarine channel-lobe transition zones (CLTZs), which separate well-defined channels from well-defined lobes, are commonly located at breaks in slope in deepwater turbidite systems. Despite frequent recognition of CLTZs on the modern seafloor, they are rarely recognised in outcrop, and where documented are only partially exposed with limited correlation. Consequently, existing models for CLTZs are largely based on snapshots from the modern seafloor and lack a detailed three-dimensional understanding of their deposits, evolution and preservation over time. Here we present a detailed comparison of two uniquely exposed outcrops from different time periods and basin settings: Unit E of the Permian Fort Brown Formation, Karoo Basin, South Africa, and the Pleistocene Otadai Formation, Kazusa Basin, Japan. The excellent palaeogeographic constraint of these systems allows correlation to genetically related up-dip channel-levee systems and down-dip lobe. This study compares for the first time bedforms and stratigraphic architecture of CLTZs from both an active and passive tectonic margin, in order to summarize key recognition criteria for these zones that can be applied more globally to less well constrained datasets.

Key features such as: composite erosional surfaces; coalescing scours and megaflutes; remnant sediment waves; bypass lags and hybrid beds are documented in these systems, arranged in a zone of repeatedly juxtaposed remnant erosional and depositional features. The CLTZs are many km's in length and width, with the outcrops allowing recognition of several evolutionary stages. Key differences between outcrops include: the coarser grain-size of the Kazusa basin sediments, allowing recognition of grain-size breaks and the formation of larger bedforms; the abundance and variety of hybrid beds and debrites within the Kazusa basin CLTZ; and the overall aggradation of the Kazusa basin CLTZ stratigraphy vs. the progradation and retrogradation of the Karoo basin CLTZ.

These variations are likely due to a variety of auto- and allogenic factors including: proximity to the sediment source area; the gradient and length of the continental slope; the dimensions and evolution of the channel/levee system; the size, grain-size and stratification of the flows; and the ongoing tectonic activity of the slope etc. Strike variations and changes in the dimensions of the Karoo basin CLTZ through time are interpreted to be the result of physiographic fluctuations in flow dynamics across the base of slope. The dynamic nature of CLTZs results in a complicated and composite stratigraphy, with preservation potential generally low within the Karoo basin CLTZ but higher within the aggradational Kuzusa basin. This study allows the development of generic models to account for dynamic CLTZ development in various tectonic settings, encompassing distinctive recognition criteria, morphodynamics and the composite transfer of these into the sedimentary record.

A simple effective method for the 3D modelling of cementation, fracturing and dissolution of carbonate rocks: Illustrated through oolitic limestone

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Three-dimensional modelling of the relationships between pore and solid for porous media such as sandstones and carbonates is firmly established within the literature. Such work effectively produces a binary snap-shot of rock pore architecture, frozen in time, usually representing the sample at the end of its diagenetic journey. Although such models are extremely valuable in assessing porosity and permeability, they can provide no information concerning changes that may have occurred during burial and subsequent uplift, and often rely on in-house specialist software, or can be costly in terms of computation. Some authors have applied information to 3D models, relating to diagenetic phenomena such as compaction, grain-bridging, random pore filling, formation of quartz overgrowths and patchy cement formation. However, again these usually require access to particular proprietary software, and some knowledge of scripting or programming. A pilot study currently under investigation uses freely available open source software to model changes in pore architecture that are likely to have taken place through diagenesis, providing information on potential changes over time. The pilot study on oolitic limestone was based on a 3D model constructed from a simple binary cartoon sketch. The constructed model was then manipulated (in 3D) to observe the effect of adding two phases of cement (simple grain-surface lining cement, followed by a more massive pore blocking sparry cement). This was then followed by a phase of dissolution, and also a phase of fracturing followed by dissolution. Although relatively simplistic in nature, the models produced are reasonable real-world proxies, and allowed the tracking of changes to both porosity and permeability. On-going work is currently being developed using this technique, to improve the modelling (introducing compaction), and the application to other carbonate systems, as well as to sandstone systems.

Probabilistic Modelling of Gravity Flow Deposit Distribution in Complex Deep Marine Basins

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Understanding the tectonostratigraphic evolution of a basin, and making a predictive interpretation of the architecture of reservoir and seal units, are key to efficient hydrocarbon exploration and extraction. However, such stratal predictions are difficult in locations where seismic interpretation is compromised due to poor image quality or sparse data.
I am developing a 2D geometric stratal forward modelling package, called *Onlapse*, that can be used to predict the tectonostratigraphic evolution of deep marine basins in locations with limited data. *Onlapse* is able to produce a large number of iterations rapidly and efficiently because it uses a limited number of key physical inputs, which include Structural Growth Rate, Background Sedimentation Rate, and Clastic Limiting Surface rise. *Onlapse* currently outputs geologically realistic cross sections and chronostratigraphic charts for each iteration, along with probability diagrams derived from all iterations. These outputs can be used to assess sediment thickness, basin structure, and the nature of pinch outs. Onlapse is currently being rigorously tested using well and seismic from the Gulf of Mexico. Onlapse will then then be used to investigate the range of combinations of structural and stratigraphic growth that can lead to the same final pattern of basin fill, particularly in basins currently considered to be entirely structurally or stratigraphically controlled.

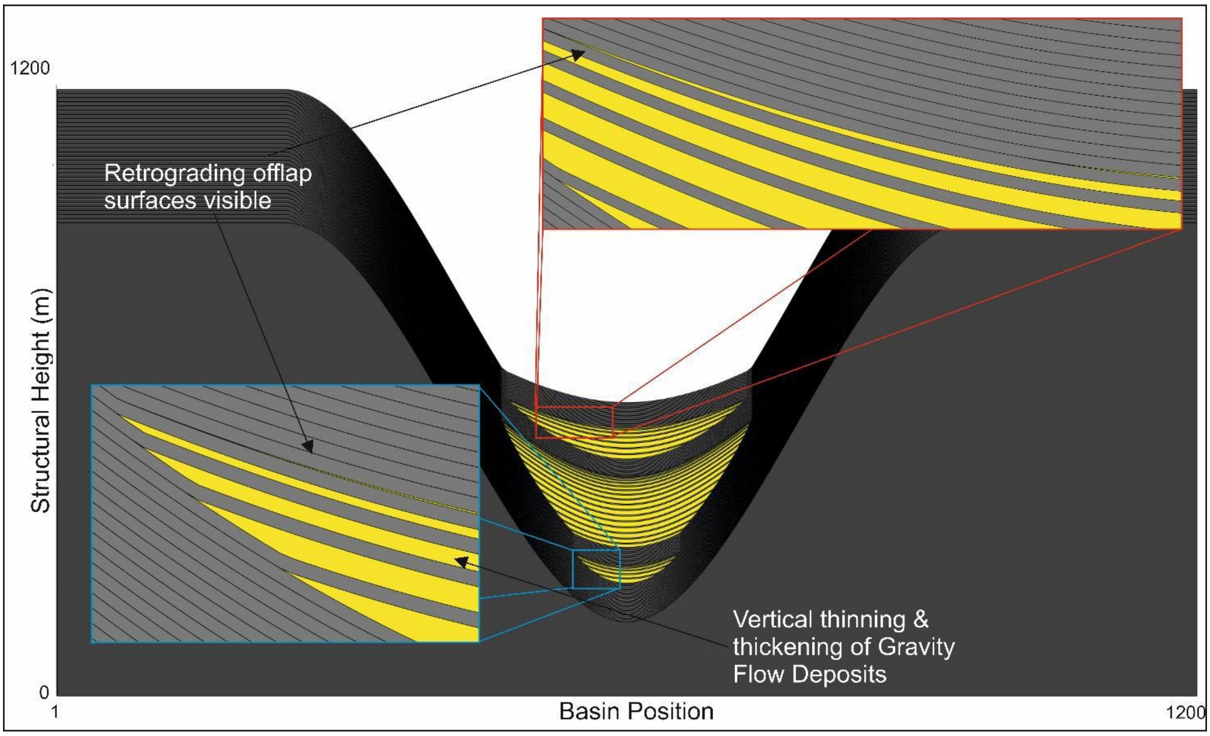

Figure 1- Example output from Onlapse showing a simple symmetrical basin with insets highlighting details of the final basin structure, infill and distribution. This example uses a Clastic Limiting Surface rise of 1.1mm/y.

How are turbidity currents triggered at offshore volcanic islands and what are the implications for Small Island Developing States?

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Submerged flanks of volcanic islands are prone to hazards including submarine landslides that may trigger damaging tsunamis and fast-moving sediment-laden seafloor flows (turbidity currents) that break critical seafloor infrastructure. Small Island Developing States are particularly vulnerable to these hazards due to their remote and isolated nature, small size, high population densities and weak economies. Despite their vulnerability, few detailed offshore surveys exist for such islands, resulting in a geohazard 'blindspot', particularly in the South Pacific. Understanding how these hazards are triggered is important; however, pin-pointing specific triggers is challenging as most studies have been unable to link continuously between onshore and offshore environments, and focus primarily on large-scale eruptions with sudden production of massive volumes of sediment. Here we focus on a situation where volcanic sediment supply produces a long-term elevation over a "normal" regime, which is more similar to the long-term elevated sediment production cases at many sites (volcanic or not) where human-induced vegetation change over-supplies sediments to coastal margins.

We address these issues by integrating the first detailed (2 m x 2 m) bathymetry data acquired from Tanna Island, Vanuatu with a combination of terrestrial remote sensing data, onshore and offshore sediment sampling, and documented historical events. Mount Yasur on Tanna has experienced low-magnitude Strombolian activity for at least the last 600 years. We find clear evidence for submarine landslides and turbidity currents, yet none of the identified triggers are related to major volcanic eruptions, in contrast to conclusions from several previous studies. Instead we find that cascades of non-volcanic events (including outburst floods with discharges of >1000 m3/s, and tropical cyclones), that may be separated by decades, are more important for preconditioning and triggering in chronic sediment oversupply regimes such as at Tanna. We conclude with a general model for how submarine landslides and turbidity currents are triggered at volcanic and other heavily eroding mountainous islands. Our model highlights the often-ignored importance of outburst floods, non-linear responses to lands-use and climatic changes, and the complex interactions between a range of coastal and tectonic processes that may overshadow volcanic regimes.

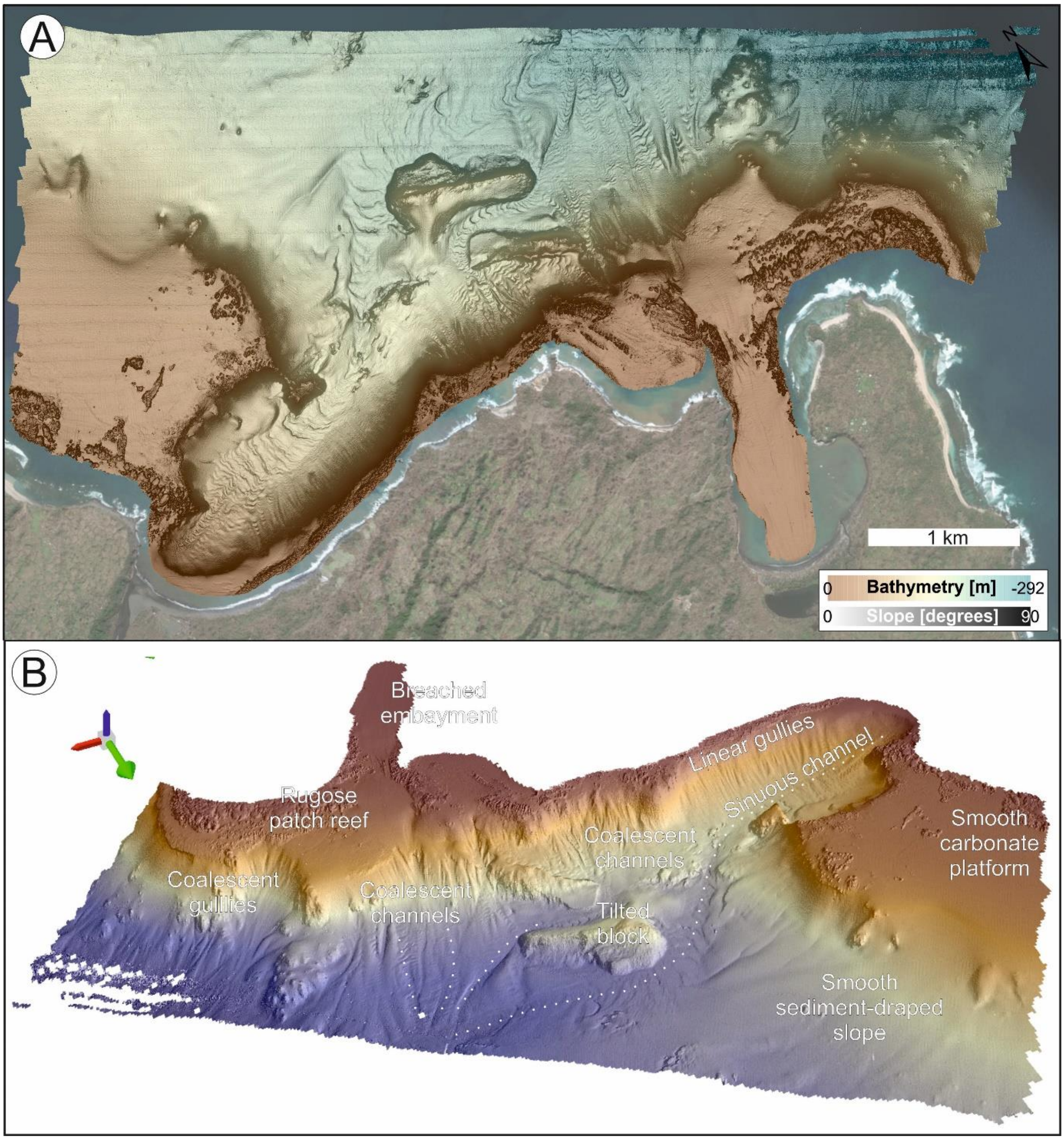

Figure 1: Overview of seafloor topography and main features offshore Tanna, Vanuatu. (A) Colourwash bathymetry overlain on greyscale slope map. Terrestrial data from Google: Digital Globe. (B) 3D rendering (3 x vertical exaggeration) of hillshaded bathymetry (illumination from the north-west) annotated with main geomorphologic features and north-arrow (green).

A review of petrophysical challenges in Pre-Salt carbonate rocks requiring sympathy, synergy and synthesis.

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Reservoir quality in Pre-salt carbonate rocks from the South Atlantic is of major importance. These deposits, largely discovered in the last decade, are characterised by several petrophysical challenges, as might be expected with any carbonate reservoir, but also compounded by relatively little industry experience with non-marine, essentially lacustrine, carbonate facies. Drawing largely on outcrop analogue materials and the limited publications, we have investigated several key issues which we wish to emphasise here:

- Understanding of how pore topology effects the porosity-permeability relationships, rock typing schemes and resistivity pathways. We illustrate this in series of plug-scale measurements of coquinas with combination of resistivity index measurements, micro-CT and numerical pore scale models. Resistivity anisotropy is documented.
- The role of representative volume scale in the rocks that demands consideration of what scale/volume should be measured and associated upscaling challenges as these volumes change. This can be illustrated by consideration of both coquina and shrub facies examples incorporating outcrop scale models and running flow simulation to calculate effective metre-scale properties.
- How variability of rock types is present in single beds over the m-scale, as illustrated by NMR measurements on coquina plug data and assessing the relative contributions of macro, meso, microporosity – micro-porosity appears to be a minor component of these rocks.
- Evidence for metre-scale lateral variability of pre-salt coquina facies and modelling the impact at the inter-well scale
- Comparison of effective well test permeability with permeabilities averaged from core plug data (across various pre-salt carbonate facies) and from various models for permeability prediction from logs quantifies the importance of 'missing' permeabilities in statistically under-sampled (by plugs), highly heterogeneous, rocks.

Several studies have been conducted over the last few years by the authors and co-workers leading to insights that are relevant to the understanding the variation of reservoir properties in these highly heterogeneous systems. We emphasise the need for sympathy with the petrophysical challenges, and synergy between different measurements (i.e., scale of measurements) and subsurface disciplines and the need for careful synthesis of all geological and engineering data, as it is possible and cost-effective to obtain, in order to predict reservoir performance.

Shelf process regime change recorded as distinct grain character stratigraphy: a high resolution study of an individual clinothem offshore New Jersey, USA (IODP Expedition 313)

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Clinothems are valuable archives of basin margin evolution. The geometries and trajectories of successive clinoform rollovers at outcrop and in the subsurface are widely applied to predict deep-water sand deposition. However, the internal architecture of individual clinothems remains relatively understudied. Improved documentation of the internal architectural complexities of complete topset-foreset-bottomset clinothems (including grain-size, grain-shape and sand-to-mud ratios) is key to understanding *how* and *when* the basinward transfer of sediment occurs.

This study uses high resolution, core-based analysis from three research boreholes recovered during IODP Expedition 313, offshore New Jersey, USA; 267 samples were analysed using a CamsizerXT to produce a fully quantitative grain character database. The cored intervals target genetically-linked topset, foreset and bottomset deposits of seawardly prograding, intrashelf clinothem sequences of Miocene age. Clinothem sequence m5.4 is examined in detail; the topset deposits of seismic sequence m5.4 are subdivided into three (m5.4a-c) sedimentary packages based on distinct sedimentological texture and structure. Facies analysis of the topset deposits suggests that sedimentary packages m5.4a and m5.4c correspond to deposition under a river-dominated shelf process-regime; sedimentary package m5.b corresponds to deposition under a wave-dominated shelf process-regime.

The grain character of seismic sequence m5.4 varies stratigraphically according to the dominant topset process-regime; as such, the interaction of river-, wave- and tidal-processes in the topset exerts a fundamental control on reservoir characteristics across the complete depositional profile. River-dominated sedimentary packages (m5.4a and m5.4c) have higher sand-to-mud ratios across the downdip profile, however, the grain-character of the river-dominated sedimentary packages are texturally less-mature than that of the wave-dominated sedimentary package (m5.4b).

Stratigraphic changes in grain-character have been used to correlate temporally equivalent sedimentary packages across the shallow-to-deep-marine transect at resolutions exceeding that which is possible using chronostratigraphic techniques. The correlation of genetically-related sedimentary packages and key surfaces at an intra-clinothem scale provides a unique perspective into the architectural complexities within a seismic clinothem sequence. These results challenge widely held ideas that clinoform trajectory and stacking pattern analyses are adequate to describe spatio-temporal sand body evolution within successive clinothems.

Stratigraphic architecture on a mixed input deep-water syn-rift fault terrace: The West Xylokastro Fault Block, Gulf of Corinth, Greece

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Complexity arising from multiple inputs and complex fault-related topographic evolution makes the prediction, characterisation, and subsurface imaging of syn-rift deep-water deposits challenging. This study aims to investigate the nature and variability of stratigraphic architecture in these settings focusing on the system sensitivities to the various allogenic and autogenic forcing mechanisms. For this, we integrate geological mapping, 3D outcrop models, and preliminary analysis of an onshore, fully cored, research borehole in exposures of the Gulf of Corinth, Greece.

The West Xylokastro Fault block, bounded to the south by the ~E-W trending West Xylokastro Fault on the southern margin of the Gulf of Corinth, Greece, presents a rare opportunity to study an exhumed deep-water syn-rift system where contemporaneous inputs from a Gilbert fan delta-fed axial deep-water fan system and transverse fault-apron interact. The proximal axial system comprises chutes, scour-fills and channel-fills, convex-up base of slope lobes, and sheet-like conglomerates within 1-2 km of the base of slope. Down-dip, over 8 km, the axial system is dominated by conglomeratic sheets and sand-rich lobes with minor channel-fills. The transverse system comprises a heterolithic mass-transport dominated apron extending up to 3-4 km into the hangingwall. This system varies in character from localised talus/rock-fall deposits to more laterally extensive, up to 300m thick, slumps and slides.

This mass-transport apron disrupted the axial sediment system, diverting it away from the immediate hangingwall of the West Xylokastro fault, forcing it 3-4 km across the fault block in a zone of variable width. Along-strike variability of this zone of interaction and its stratigraphic architecture can be linked to the nature, extent and timing of the transverse system with respect to the axial system. Correlation of the axial system into their up-dip delta equivalents puts these deposits in the stratigraphic context of key basin evolution events such as base level changes or supply fluctuations. Further tectono-stratigraphic complexity results from the growth of subsidiary depocentres from minor faults. These smaller ~NE-SW trending faults (50-150 m throw compared to the >800 m on the West Xylokastro Fault) are positioned in the hangingwall of the West Xylokastro Fault creating local syn-depositional lows. As the West Xylokastro Fault became inactive, strain shifted northward onto the Likoporia Fault. This led to the development of late-stage regressive features and development of unconformities above the deep-water sequence resulting from the change from overall subsidence in the hangingwall of the West Xylokastro Fault to uplift in the footwall of the Likoporia Fault. Ultimately this northward shift in fault activity created a ‘perched’ fault terrace. This study highlights the impact that multiple, competing inputs to a syn-rift depocentre have with regards to the distribution and character of axial fans and the importance of understanding broader fault and stratigraphic evolution in generating complex lateral and vertical stratigraphic relationships.

The stratigraphic record of deep-water sediment gravity flows interacting with an active salt diapir

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Deep-water successions deposited in basins affected by active salt diapirism often differ from those deposited in unconfined basins or against static topography, principally due to the progressive impact of growing slopes on depositional systems and their deposits. Typically, these successions, and associated seismic reflectors are poorly-imaged in seismic data due to ray path distortion beneath salt overgrowths, their steep dips and deformation. Resolution issues caused by variable lithological distributions further complicate seismic interpretation. This leads to increased uncertainty in prediction of facies and depositional environments via seismic methods such as amplitude mapping. Outcrop studies provide a valuable analogue to constrain sedimentary facies and geometrical configurations within these zones. The Triassic (Keuper) Bakio Diapir and Guernica salt structures in the Basque Cantabrian Basin, northern Spain, provide a rare opportunity to study exhumed salt structures flanked by salt-influenced deep-water successions. The structures grew reactively and then passively during the Aptian-Albian, and are flanked by deep-water carbonates (Aptian-earliest Albian) and clastics (middle Albian-Cenomanian) Black Flysch Group. The latter are exceptionally well-preserved at Matxixako Beach, with exposures providing a rare opportunity to study a salt-controlled mini-basin where palaeoflow is at a low angle to structural strike. The clastic succession shows an overall upward-coarsening and thickening of beds, along with a reduction in the percentage of fines. The succession is mudstone-rich in its lower part and dominated by thin-bedded, low-density turbidites that are overlain by thin hybrid beds and medium-high-density turbidites interspersed with slump deposits. The upper part comprises stacked, amalgamated, erosionally based, high-density turbidites, pebbly mega-debrites and slumps with thick hybrid beds. Axially derived turbidites and hybrid beds interfingered with laterally derived slumps and debrites complicate the onlap geometries. We interpret that the succession documents deposition from lobe-fringe through to channel-lobe transition zone and is interpreted to represent an allogenic progradational system influenced by halokinesis and autocyclicity. These findings are integrated into a model that documents spatial and temporal distribution and stratigraphic architecture of deep-water facies deposited in salt-influenced basins. The geometries captured in our model are comparable to seismic analogues from the Bay of Biscay and the eastern Central Graben, UK North Sea. The results are directly applicable to petroleum exploration and development in many salt basins globally, enabling better prediction of trap geometry, and reservoir quality and distribution even in areas where seismic imaging is challenging.

BOTTOM CURRENT REWORKED SANDS: SEDIMENTOLOGICAL INSIGHTS INTO A FACIES MODEL WITH IODP 339 U1389 AND U1388 SITES

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The ability to differentiate reworked turbidites from pure turbidites or sandy contourites in cores is still an issue for the deep-marine research sedimentologists. In order to evaluate the depositional conditions for these sandy layers and to recognize the involved processes, a rigorous assessment of facies description is needed since in many cases, the interaction of processes along- and down-slope has been underestimated. The currently available models for deep-water sedimentation bring us to the conclusion that they are inadequate to describe and interpret the complexity of real depositional patterns developed by the interaction of along-slope and down-slope processes. It is reasonable to consider that between the two end members as sandy turbidites and contourites a number of intermediate variants could exist, which show attributes of both facies, and they depend on which kind of sedimentological processes are interacting at the same time in a specific environment. In order to solve the absence of widely accepted criteria or a facies model to describe bottom current reworked sands (BCRS), we here propose a new approach to characterise BCRS based on the study of sediment recovered from the Integrated Ocean Drilling Program (IODP) Expedition 339 along the southwestern Iberian Margin (SIM), within the Gulf of Cadiz. These sites are located in a middle contouritic terrace crossed by gravitational valleys in the proximal ridges/channels sectors of the Gulf of Cadiz Contourite Depositional System, under the influence of the Mediterranean Outflow Water. Five Pleistocene association of sedimentary facies interpreted as BCRS are going to be studied and their regional and facies model implications presented. This detail study is based on a correlation of grain size analysis, microfacies, ichnological analysis, X-ray Florescence (XRF) scanning data and Computed Tomography (CT), as well as the correlation between seismic lines and the IODP Sites. The obtained results are contributing to a better understanding of BCRS as well as of deep-water processes. In addition, the studied deposits constitute recent / modern analogues of sandy contourite systems which could be compared with similar ancient sandy deposits and evaluate their potential reservoir characteristics, as the examples identified recently in the Mozambique continental margin. This project is funded by the Join Industry Project supported by TOTAL, BP, ENI, ExxonMobil and Spectrum and is done in the framework of "The Drifters Research Group" at Royal Holloway University of London (RHUL).

A Multi-Proxy Palaeoenvironmental Analysis During Deposition of the Mahogany Oil Shale Interval of Eocene Lake Uinta, Green River Formation, Utah

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The Green River Formation of Utah and Colorado represents a ~15 million-year Lower Eocene record of unusually large, productive lakes which deposited one of the largest oil shales in the world with an estimated 750 billion barrels of oil equivalent. Multiple drill cores through the Mahogany Oil Shale Zone, taken from both the basin margin and centre, offer an excellent opportunity to construct high-resolution records of competing lacustrine and terrestrial sources to explore their influence on organic matter deposition and preservation.

In this study, the isotopic expression of mid-latitude hydrological change during an unusually rich TOC (up to 40%) interval is investigated through compound-specific hydrogen isotopic analyses of *n*-alkanes extracted from the Mahogany Oil Shale Zone, Uinta basin, Utah. Comparison of this novel record with high-resolution sedimentary logs and traditional petrography work will allow for greater understanding of the hydrological cycle at the time of deposition of this key oil shale.

This study seeks to merge a multitude of scales, from field outcrops to microscopic imaging to molecular analysis, to bridge novel proxies with traditional methods in answering fundamental questions about carbon cycling. Variations in organic matter distribution and its interaction with a fluctuating carbonate and siliciclastic matrix should be mirrored in the biomarker records. We would expect variations in key biomarkers (e.g. isoprenoids, *n*-alkanes, hopanes) at the molecular scale when observing changes in the organic matter at a microscopic scale with detailed thin section imaging and analysis.

Disentangling the factors controlling deposition and preservation of organic matter in the Green River Formation through a combination of organic geochemical and sedimentological tools will lead to greater understanding and predictability of the organic-rich layers in the oil shale. This will help improve modelling of lacustrine source rocks and will also support the development of the U.S unconventional hydrocarbon industry, energy security and petroleum independence in the region.

Seismic stratigraphy of a proglacial lake: implications for deglaciation processes and engineering prediction of Dogger Bank, North Sea

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Dogger Bank, in the southern North Sea, is a large shallow bank surrounded by deeper waters, which makes it an ideal site for offshore wind turbine development. Site investigations as part of the Forewind wind farm project have provided a wealth of shallow seismic reflection and geotechnical data that permit geological investigation of the recent glacial and postglacial history of the North Sea. The complex stratigraphy revealed through these data has implications for improved forecasting of ground conditions for turbine footings and cable routes. Therefore, a more accurate understanding of the stratigraphy and geological history of the area will improve geotechnical ground models and ensure provision of clean, sustainable energy.

At the Last Glacial Maximum, the Dogger Bank area was covered by the British-Irish Ice Sheet. During ice sheet retreat, a large thrust moraine ridge formed, along with smaller moraines and outwash fans. The largest moraine, whose crest runs approximately north-south, dammed a large (approximately 750 km^2) proglacial lake. Subsequent sedimentation filled the lake with up to 30 m of glacial outwash sediments. Seismic reflection data show the lake fill to have a complex internal stratigraphy, with discrete units of both low amplitude, chaotic and moderate to high amplitude, rhythmic seismic facies. Two units of chaotic facies are related to ice-contact subaqueous fans. The oldest unit is c. 50 km^2, filling in a small basin. A strong reflector marks the boundary with the overlying chaotic unit, which thins towards the southeast. This has minor thrust faulting and folding at the toe of the wedge, which suggest gravity-driven mass movement. Overlying and onlapping rhythmic reflectors imply quiet water sedimentation. This represents ice sheet retreat, resulting in strong density stratification of the water column and a range of overflow-interflow and underflows that dispersed sediment in the lake. Cone Penetration Tests show these lacustrine sediments are overconsolidated, likely due to desiccation of the sediments through subaerial exposure. Subsequently, the lake-fill was subject to fluvial incision and marine transgression, resulting in deposition of shallow marine sands.
Ice retreated in stages from initial formation of the push moraine to the development of an ice-contact lake, then retreated to result in ice-distal lake sedimentation, before sediment supply finally switched off as the ice retreated further northwards. This staged retreat occurred after the LGM at around 27 ka and before a ribbon lake formed to the north of Dogger Bank that has been dated previously to 23 ka. This stepped but rapid retreat of the ice sheet from Dogger Bank (-15 to -20 m OD) northwards into the deeper (> -80 m OD) has implications for understanding topographic controls on ice sheet stability, provides vital inputs for ice sheet models forecasting future ice sheet collapse, such as for the Western Antarctic Ice Sheet. This also has huge implications for prediction of sea-level rise for protection of coastal communities and offshore infrastructure.

Autocyclic modulation of allocyclic signals in submarine channel-lobe systems: an experimental study

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The interplay between allocyclic and autocyclic controls dictates the timing, magnitude, and distribution of sediment supply on the slope and basin floor. Allocyclic controls are external to the sedimentary system and include sea-level, climate, and tectonics, whilst autocyclic controls are system-internal, including processes such as channel avulsion, levee growth and compensational lobe stacking. The degree to which autocyclic processes mask allocyclic controls, and the relative timescales at which they operate, is still poorly-understood. Here, successive experimental sediment-laden turbidity currents with incrementally increasing then decreasing sediment supply rates have been used to model the effect of allocyclic variability on submarine fan evolution. Increasing sediment supply rate led to channel incision and overbank deposition on the slope, and lobe progradation on the basin floor. Conversely, decreasing supply rate resulted in a reduction of channel incision and overbank deposition, and progressive back-stepping of lobe deposits that onlapped the slope. These observations suggest a direct correlation between sediment supply (allocyclicity) and submarine fan morphology and that predictions about sediment distribution can be made on this basis. However, autocyclic depositional relief created by earlier turbidity currents caused subsequent flows to deviate, favouring topographic lows, promoting lateral spreading and compensational lobe stacking. Continued lateral spreading of these deflected flow deposits led to partial infilling of available space on the basin floor, exacerbating the back-stepping trend of lobe deposits documented during the waning phase of the sediment supply cycle. During this back-stepping phase, the overall lobe continued to grow basinward, indicating that allocyclicity drives initial conditions, but progressively, autocyclicity modulates that signal, promoting compensational deposition, back-stepping and possible system avulsion. The resulting lobe demonstrably steps basinward with each flow, and the planform resembles that of an ‘ideal’ lobe, but internal time lines are much more complicated than a conventional prograding trend. The complex internal series of progradation, lobe switching, then back-stepping recorded here may account for bed stacking patterns observed in outcrop and core where lobe packages often coarsen and thicken upwards, then abruptly revert to fine-grained abandonment or distal fringe deposits.

The Permo-Triassic fluvial system of the Iberian Basin, NE Spain: Implications on fluvial architecture development and sand body geometry

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The three-dimensional geometry of fluvial channel sand bodies has received considerably less attention than their internal sedimentology, despite the importance of sandstone body geometry for subsurface reservoir modelling. The aspect ratio (width/thickness, W:T) of fluvial channels is widely used to characterise their geometry, with end members of 'ribbon' and 'sheet' sands. However, these approaches do not typically provide a full characterization of fluvial sand body shape, as many different W:T can create different channel geometries. Furthermore, calculating the W:T ratio still requires choosing an arbitrary boundary between 'ribbon-like' or 'sheet-like', and there can be significant overlap between these values (e.g. Gibling, 2006). Over- or underestimating the cross-sectional area of a sand body can have significant implications for reservoir models and hydrocarbon volume predictions. Thus, there is a clear need for the generation of versatile, quantitative and statistically robust models for sand body shape. The main aim of this research is to develop a new statistical-based approach to provide quantitative data, derived from outcrop analogues, to fully constrain stochastic fluvial reservoir models.

The Permo-Triassic fluvial system in the Castillian Branch of the Central Iberian Basin, northeast Spain, provides an excellent analogue for subsurface fluvial sandstone hydrocarbon reservoirs. Sedimentation in the intracratonic rift basin began with the Lower Triassic Buntsandstein fluvial deposit (Thuringian to Ladinian) which unconformably overly metamorphic basement. The sediments are characterised by continental redbed facies with a conglomeratic base that changes to finer-grained sandy facies upward (Ramos et al., 1986). The Tethyan progressive transgression in the Late Anisian overlies the Buntsandstein and forms the marine carbonate Muschelkalk facies (Muñoz et al., 1992). Chemostratigraphic data derived from outcrops of the Buntsandstein sediments of selected locations along a ca. 100 km long transect preserve an excellent stratigraphic correlation indicating a single fluvial system flowed along the western margin of the basin. The changing architecture and channel patterns observed at the locations in relationship to allocyclic controls (tectonic activity, climate change) can then be linked to the statistical shape analysis of the sand bodies.

The outcrops at Riba de Santiuste (Fig. 1a) provide exceptional insights into the architecture and development of the fluvial system. The beds define a monocline with a varying dip angle of about 45° to 75° exposing a cross-section of the sediments over a 1750 m wide and up to 600 m thick area, which is approximately perpendicular to the paleo flow direction. These dimensions are comparable to subsurface reservoirs and further emphasise the unique potential of this location as an analogue study.
A sedimentological analysis of the Permo-Triassic fluvial sediments was carried out to investigate the architecture and internal structures. Detailed graphic logs have enabled us to distinguish between fluvial facies (channel, floodplain, crevasse splay and paleosol) and show that floodplain and paleosol facies, consisting of very fine grained, silty sandstones, potentially limit or prohibit connectivity between the medium to very coarse-grained channel bodies (Fig. 1b). The internal structure reveals extensive cross bedding, pebble and rip-up clast layers, extensive bioturbation and grain size variations due to avulsion processes. Further investigations of the individual sand body shapes reveal a broad spread in terms of the cross-sectional geometry across the study area ranging from large scale sheet-like sands to narrow ribbon-shaped. Sand bodies are laterally extensive but show medium to poor connectivity vertically between individual beds, which are separated by floodplain and/or palaeosol facies. Based on chemostratigraphic

correlation, a correlation panel derived from the graphic logs and the sedimentological analysis of the ancient river system the development and controls can be inferred. From these observations RTK GPS (Real Time Kinematic) data to define the precise geometry of each sand body shape was collected as an input for the statistical analysis. Early results have identified unexpected associations of channel sand bodies and provide robust data sets for further statistical analysis.

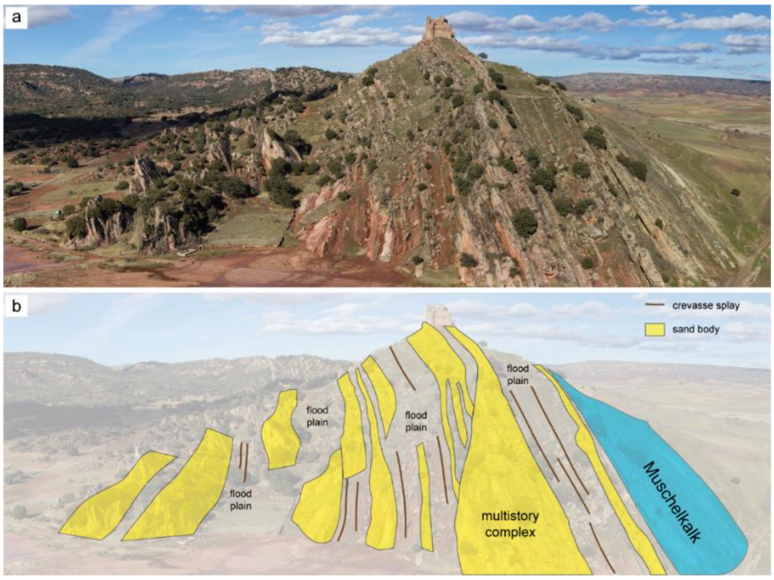

Figure 1: a) Permo-Triassic Buntsandstein outcrops at Riba de Santiuste showing the castle section in the foreground and the continuation of the monocline up to 4 km in the background. b) Interpretation of fluvial facies and the main architectural elements of the image shown in a).

Future research will focus on the statistical analysis of the fluvial channel sand bodies with a particular aim to provide improved reservoir models of fluvial systems and prediction for reservoir architecture. The points (polylines) from GPS measurements at Riba de Santiuste and potential LiDAR and photogrammetry scans from the other locations are used for statistical analysis and model building. Application of rigorous probabilistic models, such as Gaussian mixture model, will lead to statistically meaningful clusters, and hence to classifications of sand body shape, together with probabilities of class membership describing the uncertainty in the classification. The research will develop a predictive model to enable forecasting of reservoir channel sand body geometries and shapes that can be built into existing reservoir models, e.g. Skagerrak Formation, North Sea.

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Preservation of floods and landslides in the sediment record

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Over the last decade, landslides and floods have claimed the lives of nearly 100,000 people. Reducing the impact of these hazards on society is a challenge requiring multi-disciplinary expertise. By understanding the formative conditions and intensity of potential events, hazard managers can employ mitigation to reduce risks posed to vulnerable communities. Media reports, contemporary measurements from field instruments and remote sensing, and historical observations, provide insight into the magnitude-frequency and impact of landslides and floods over multi-decadal timescales. Records have shown the most devastating landslide events are triggered by earthquakes or extreme precipitation in mountainous regions, resulting in the sudden release of millions of tonnes of material from multiple hillslopes. Episodic mass wasting events, such as earthquake-triggered landsliding and volcanic eruption, can cause riverbed aggradation, increasing the frequency and intensity of flooding; thereby, extending the impact of the initial disaster downstream. There remains limited understanding of the residence times of sediments from mass wasting events in the landscape and the long-term processes of channel adjustment. By studying the characteristics and distribution of recent flood deposits in perturbed channels, sedimentologists can determine the present discharge regime. This informs the choice of numerical models used to simulate flood inundation, and applied in the design of river management engineering. Sedimentary archives in depositional fans and inland lakes provide a longer record of disturbances affecting the sediment routing system. While deciphering this record may be challenging, the study of deposits has proved fruitful in enriching earthquake catalogs and volcanic eruption chronologies, as well as providing evidence towards the debate on whether human disturbance or climate change may be more detrimental to future landslide and flood incidence. This talk considers the preservation potential of paleo-flow indicators in the sediment record in systems responding to mass-wasting events, including published examples from sediment-laden flash floods on Soufrière Hills volcano, Montserrat and Volcán de Colima, Mexico. Further research is required to relate stratigraphic successions with the dynamics of perturbed fluvial systems, so the sediment record may better inform the long-term management of flood and landslide hazards.

The Diversity of Bottom-Current Influence on Submarine Slope Channel Complexes: Insights from Offshore Tanzania

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The interaction of bottom currents with turbidity currents and their deposits can affect the distribution of submarine channel and lobe complexes as well as the facies distribution within them. This study combines high resolution 3D seismic, well log and core data of Block 2 area, offshore Tanzania, to investigate bottom current influence on Upper Cretaceous and Paleogene sedimentary systems. In the Upper Cretaceous, tectonic and drift related topography governed the distribution of channel and lobe complexes. Large drift deposits, 10s of km wide and up to 1.6 km thick, form the pathways for slope channel complexes that in turn erode and modify the drifts. Channel complexes striking in a NW-SE orientation are confined by long-lived drifts throughout the Turonian and Campanian, and step up-slope towards the SE. During the Paleogene the sedimentary system underwent significant modification, becoming dominated by extensive, unconfined lobe complexes on the lower slope that were incised into by two slope channel complexes. These slope channel complexes are characterized by an early stage of erosion and lateral migration, and late-stage aggradation of stacked channel complexes. Both channel complexes have asymmetrical levees being larger towards the NW leading to unilateral migration of the channel complex to the SE. The asymmetrical levees are interpreted as fine-grained deposits of low-energy bottom currents and overspilling turbidity currents. The depositional mechanism is a combination of: (i) the fallout of fines due to waning of the bottom current flow along relief; (ii) flow stripping of the turbidity current and subsequent reworking of unconsolidated sediments on the channel flank. The toes of the levee/drifts interfingered with the channel fill deposits and progressively stepped into the channel fills, pinning the channels to the slope over long periods of time. We infer that the bottom current drift deposits developed as lee waves, with accretion predominantly on the bottom-current upstream side, and consequently drift migration was in the upstream direction. The sedimentary characteristics of these mixed contourite and turbidite systems have several implications for reservoir facies and trapping mechanisms: (i) the potential of high net-to-gross sandstone bodies along steep slopes; (ii) the likelihood of stratigraphic trapping due to the fine grained drift facies surrounding reservoir facies; (iii) the risk of fluid flow baffles and barrier resulting from the "toes" of the drift stepping into the slope channel complexes. Understanding the influence of bottom currents on deep-marine depositional systems is crucial for the understanding of hydrocarbon plays on the East African margin and other plays globally.

SEQUENCE BOUNDARIES OR AUTOGENIC EROSIONAL SCOURS? SCALING BACKWATER HYDRODYNAMICS IN FLUVIO-DELTAIC STRATIGRAPHY

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Sequence stratigraphy relies on the identification of unconformity-bound sedimentary packages to understand variations in sediment supply, subsidence, and eustasy. Erosional surfaces that demarcate genetically-related sedimentary packages set the architecture of fluvio-deltaic stratigraphy, and they have classically been interpreted in terms of changes in boundary conditions such as climate, tectonics, and base level (allogenic forces). Intrinsic dynamics of sedimentary systems (autogenic dynamics) can also create a rich stratigraphic architecture, and a major knowledge gap exists in parsing the relative roles of autogenic versus allogenic processes. Emerging theoretical and experimental work suggests that backwater hydrodynamics play an important role in driving transient channel incision in river deltas, even those experiencing net aggradation. Here, we identify and quantify two autogenically generated mechanisms that produce broad erosional surfaces within fluvio-deltaic stratigraphy, namely, floods and avulsions. Using a simple mass-balance model, we show that flood-induced scours initiate near the shoreline, and avulsion-induced scours initiate at the avulsion site, and both propagate upstream over a distance that scales with the backwater length. We also develop scaling relationships for the maximum scour depths arising from these mechanisms, which are functions of characteristic flow depth and formative flood variability. Theoretical predictions were validated using a flume experiment of river delta evolution governed by persistent backwater hydrodynamics under constant relative sea-level. Results indicate that autogenic dynamics of backwater-mediated deltas under conditions of constant base level and constant ratios of water to sediment discharge can result in stratigraphic surfaces and shoreline trajectories similar to those often interpreted to represent multiple sea-level cycles. Finally, we reinterpret outcrop scale observations within the Castlegate Sandstone, Utah—type example for fluvial sequence stratigraphy—and show that field observations are consistent with scours resulting from floods, avulsions and backwater hydrodynamics alone. Our work provides a quantitative framework to decouple autogenic and allogenic controls on erosional surfaces preserved within fluvio-deltaic stratigraphy.

Large-scale correlation and sedimentation rates throughout the Triassic Barents Sea mega-basin

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Sedimentation on one of the largest delta plains in Earth's history took place in the Barents Sea during the Triassic. It is commonly believed, that the clastic sediments that filled this basin were predominantly sourced from the Uralide Orgeny. Recent studies indicates that the source-areas are more diverse, with one source located in the northern Uralides/Kara Sea, and anothers in Northern Fennoscandia and Northern Greenland. The extent and relative contribution of these very different source areas varied through time, but their role in the geodynamic history of the basin remain elusive. In this study, we use seismic and well data from the entire Greater Barents Sea, which has an extent of 1500 x 1300 km, to constrain sediment volumes, investigate sediment transport pathways and understand the paleogeography of the basin. The main goals of this study are to correlate the Barents Sea Triassic stratigraphy between Norway and Russia and understand the geodynamic evolution of the source areas.

Very high sedimentation rates in the basin occurred during the Induan, when the largest clastic wedges prograded into the basin. This sudden influx of sediment coincides with the main eruption pulse of the Siberian Traps Large Igneous Province, one of the most significant magmatic events ever recorded. It is likely that this event affected surrounding territories like the Polar Urals and Taimyr, which at the time accommodated great siliciclastic input. The West Siberan Basin rift system associated with the Siberian Traps possibly formed a sediment pathway that could transport material to the Barents Sea basin.

Conversely, low sedimentation rates occurred during the late Early Triassic and Middle Triassic, when no particular tectonic events took place in the source areas. During the Carnian, sediment supply rates increase and deltas progradet to Svalbard and likely beyond Svalbard. This phase is likely caused by uplift of the Novaya Zemlya mountain chain in the Late Triassic, creating an unconformity in the Uralian foreland, which led to widespread recycling of Triassic sediment and transport of this material into the Eastern Barents Sea. However, sediment supply rates during the Late Triassic were not as high as during the Early Triassic, but operated over a longer time and thus has a thickness at the same scale as the Induan succession. Moreover, sediments were also distributed over a much larger area in the Late Triassic covering the majority of the North Barents Sea, Franz Josef Land and Svalbard. The sediment source in Fennoscandia appears to continuously have supplied sediment throughout the Triassic.

Results show great temporal variations in sedimentation rates when quantified on regional scale sediment packages. Internal variations in the mega-basin reflect different forcing mechanisms acting on the basin through the Triassic that are important for how we understand geodynamic responses in a source to sink perspective. Information about the nature of the large-scale depositional systems can also be used to make inferences about the presence, nature and distribution of reservoir and hydrocarbon source rock intervals in the basin.

Limitations of QFL plots as a provenance tool in tropical environments: A large dataset from SE Asia

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Light mineral analyses of sedimentary rocks have long been used to provide a first-pass indication of sedimentary provenance. Ternary diagrams plotting the relative proportions of quartz, feldspar, and lithic (QFL) grains were developed in the late 1970s and 1980s to provide both a specific sandstone classification (e.g. quartz arenite, arkosic arenite, lithic arenite) and to identify the nature of the source area for the sands (e.g. basement, craton interior, recycled orogen). These categories were based on sandstones sampled mainly in temperate North America.

Subsequent developments in analytical methods have significantly improved our understanding of provenance, allowing us to fingerprint many other components of a sediment. We now use a multi-proxy approach, including light mineral analysis, heavy mineral analysis, determination of mineral compositions, and dating of single grains (e.g. LA-ICP-MS U-Pb dating of detrital zircons). The methods can provide much more information about source types and specific source areas.

It has become clear that the ternary QFL diagrams have significant limitations, especially when applied to sediments that were not deposited in the same environments as those used in the original studies, such as the tropics. In humid environments a major limitation is that feldspar grains experience rapid breakdown. This occurs during source-area weathering, sediment transport, burial, and subsequent outcrop weathering prior to sampling. Feldspars often break down to authigenic clays, which can be recognised, but original feldspar concentrations cannot be accurately determined. Additionally, lithic fragments readily breakdown so they are not identifiable in thin section. Therefore, samples collected from tropical environments are often enriched in quartz and lithic grains compared to their original compositions. Much of tropical SE Asia is volcanically active and sands can also be enriched in volcanic quartz. This can be recognised, but the different quartz types can be difficult to identify and quantify and leads to misleading assessments of source types using the QFL technique.

This work compiles data from across SE Asia, collected from the mid-1980s to the present day. All of the QFL data were collected using a traditional point counting method, on slides stained for both plagioclase and K-feldspar, where over 500 individual grains were counted on a grid. The analysis of this large (711 samples) dataset shows that most samples plot in the craton interior or recycled orogen fields. However, this is misleading as the samples appear more quartz-rich than is reality. This extensive case study from SE Asia goes to prove that it is important to use QFL classification schemes carefully, and always in conjunction with a wider multi-proxy study, and to exercise caution when applying methods from other places with differing depositional environments and climatic regimes.

Quantitative reconstruction of continental Triassic fluvial systems of the North Sea

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The depositional systems of the Early Triassic Smith Bank and Mid-Late Triassic Skagerrak Formations in the North Sea have been quantitatively reconstructed through the interpretation of a regional subsurface dataset comprising wireline logs, core material and existing palaeocurrent interpretations. This reconstruction suggests multiple distributive fluvial systems with Scottish Highland and Fennoscandian sourced catchments during sandstone dominated deposition in the Triassic, with identifiable variations in facies proportions and characteristics.

The Skagerrak and Smith Bank Formations are composed of alternations of sandstone and mudstone dominated members in the region of nomenclature definition (UK Quad 30), these members correlate to principally sandstone dominated intervals in the interpreted proximal directions. The Skagerrak and Smith Bank Formations were deposited in an endorheic continental basin, with their sandstone dominated members representing periods of deposition dominated by fluvial processes. The sandstone and mudstone dominance of deposition at the distal end of these interpreted systems is thought to be a result of their basin and catchment climate variation controlled expansion and contraction.

The reconstruction of these systems is completed using facies proportions and characteristics from core sedimentological logging and core-learned neural network, wireline-log facies predictions, and draws on themes from outcrop studies of analogous systems. This study utilises 31 wells' cored intervals from across the basin, with each wells' core facies interpretation also acting as the learning base for an individual self-organising map (SOM) neural network. These SOMs allow the prediction of facies from wireline logs across this study's regional dataset of 400+ wells, permitting quantitative mapping of facies proportions and characteristics.

This quantitative mapping allows regional interpretation of discrete systems across the basin within each sandstone member, as well allowing the definition of proximal-distal facies proportion and characteristic trends (e.g. reduction in channel-fill facies association proportion and package thickness). This trend derivation can act as an important quantitative predictor of reservoir quality within the prolific hydrocarbon reservoirs of the Skagerrak Formation, as Skagerrak reservoir quality is directly linked to depositional facies.

The formation and evolution of an intraplatform trough in the Sichuan Basin, China, during the Late Ediacaran to Early Cambrian

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The Upper Ediacaran to Lower Cambrian of the Sichuan Basin, located in the South China craton, is considered to be dominated by shallow water depositional environments. Petroleum exploration, however, has revealed that a NW-SE trending intraplatform trough formed in the Sichuan Basin during the same period. The formation and evolution of the intraplatform trough is analysed by integrating the interpretation of seismic data, well correlations, field outcrops, and the analyses of tectonic subsidence. From isopach maps of the Upper Ediacaran the width of the trough can be seen to be at its widest in the NW (~ 200km) and it narrows to ~50 km in the SE. The 2D and 3D seismic data clearly display three stages of development of the intraplatform trough, with very good imaging of the carbonate platform edge through time, allowing it to be mapped clearly around the basin. The first stage, took place in the early Upper Ediacaran, and is characterized by significant thinning of the lower two members of the Upper Ediacaran from the platform margin to the trough. In the second stage, in the late Upper Ediacaran, the platform margin backstepped and the extent of the trough expanded significantly to a width of ~300 km. The third stage, in the early Lower Cambrian, was dominated by gradual filling of the trough and onlapping of the platform. The trough was finally filled by late Early Cambrian times.

Field outcrops, mainly from sections exposed in the foothills of the Longmen Shan to the west of the Sichuan basin, show that the platform facies consists of microbial dolomite with mounded buildups. The associated slope facies comprises slumped and brecciated dolomite and contourites. Intriguingly the distal equivalent of the trough facies consist of siliceous rock, interbedded with black shales and slumps. Within the Lower Cambrian manganese nodules occur within the black shales. This facies association of siliceous rocks and manganese nodules suggests deposition in abyssal water depths on oceanic crust. This would infer that an ocean existed to the west of the carbonate platform and associated trough.

Tectonic subsidence curves calculated for two wells on the platform and two within the trough display a generally concave upward shape decreasing exponentially over ~100 Ma, suggesting that this part of the Sichuan basin formed by extension associated with lithospheric stretching on the margins of an ocean that lay to the west of the South China craton. However the subsidence is modest; on the platform the total subsidence is about 1.5 km, with a backstripped, water-loaded subsidence of 0.6-0.65 km, and within the trough the total subsidence increases to 1.6-1.7 km of which 0.7-0.8 km is the tectonic subsidence. Fitting the subsidence curves with a simple finite duration stretching model suggests stretching factors in a range from 1.15-1.22.

First observations of a non-hyperpycnal river generating an ignitive turbidity current

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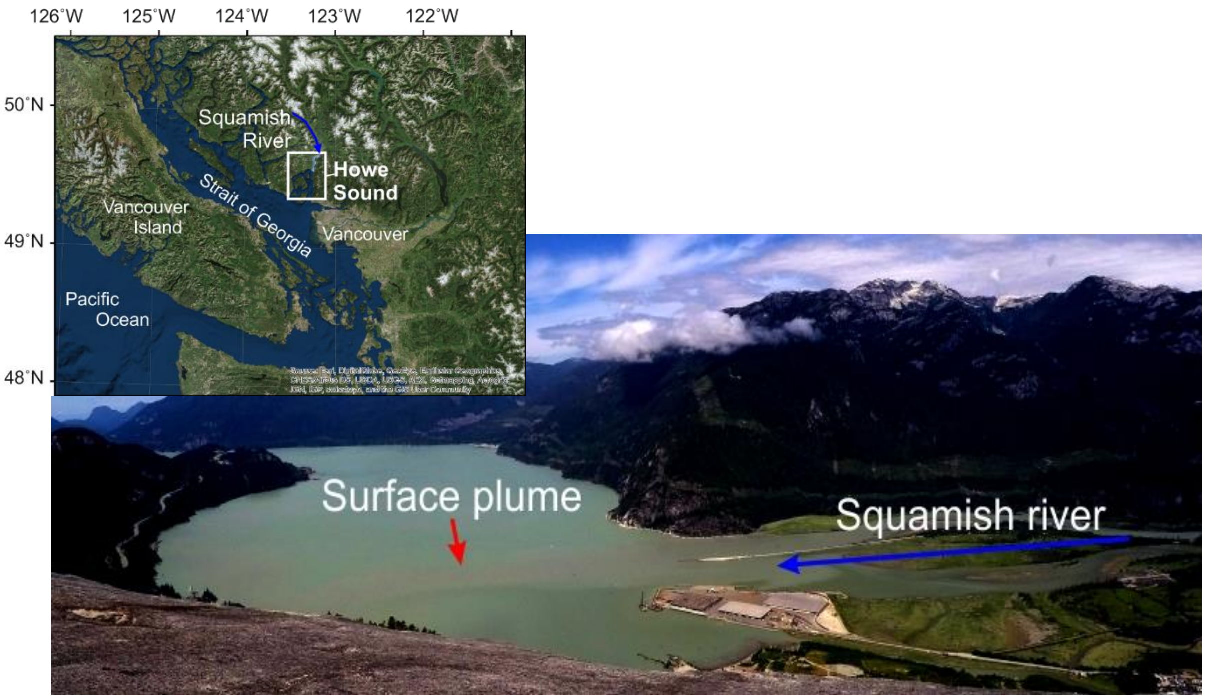
Rivers are the primary agent for particle transport on land (e.g. pollutants, nutrients, organic carbon, microplastics). These particles are transported into the deep sea by turbidity currents; particularly at river deltas. It is thus important to understand how such particle transport is initiated offshore from rivers. A number of processes can cause turbidity currents at river mouths: delta slope failures, plunging of a sufficiently dense (hyperpycnal) river, and sediment settling from dilute (<40g/L) river plumes. While the first two processes have been well documented, the mechanisms by which dilute river plumes trigger turbidity currents are still poorly constrained. This is despite dilute river plumes having been shown to be the most frequent trigger on some deltas and to be capable of generating long run-out ignitive flows (i.e. which self-accelerate by entraining bed sediment). Turbidity currents have been produced by 'dilute river plumes' in laboratory experiments and numerical models when sediment density is able to overcome the density difference with saline water, settling out slowly from the surface plume. However, in natural river plumes such conditions do not always trigger turbidity currents, suggesting that the mechanism is more complicated than experiments and numerical models suggest. There is thus a need for field observations to understand the processes by which slow sediment settling from dilute river plumes will and will not initiate a turbidity current.

Here we provide the first observations of a dilute river plume which generated one ignitive turbidity current during 5 days of continuous measurements. Our measurements took place in the Squamish River Plume, which enters Howe Sound Fjord in British Columbia (Canada). Density differences between the freshwater river plume and the saline ambient water were assessed based on a novel combination of methods: 1) water column acoustic imagery using a 70-100 kHz moving sonar and a fixed 600 KHz Acoustic Doppler Current Profiler (ADCP), 2) measurements of salinity and temperature using a Conductivity Temperature Density profiler, and 3) suspended sediment concentrations calculated from a calibrated optical backscatter probe and inversion of ADCP backscatter data. The turbidity current was measured (i.e. velocity and estimated sediment concentration) by the ADCP and a 1.0-24.0 kHz chirp profiler. Preliminary results reveal that the river plume can reach hyperpycnal conditions close to the bed during falling and low tide under high tidal range. However these localised hyperpycnal conditions are not sufficient on their own to generate ignitive turbidity currents – i.e. the plume may 'touch down' on the seabed without generating a turbidity current. We suggest that fine sediment needs to be available at the seabed in order to generate an ignitive turbidity

current from a dilute river plume. Understanding the triggering mechanisms of turbidity currents from dilute river plumes is important as, in contrast to hyperpycnal rivers, dilute river plumes are ubiquitous worldwide.



What determines submarine turbidity current runout distances?

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Underwater avalanches of sediments, turbidity currents, are the principle mechanism of moving sediment across our planet. Only rivers carry comparable volumes of sediment. Basic modes of flow behaviour have been proposed. Submarine flows can erode and accelerate, thereby causing increased erosion (ignite). Alternatively, flows can deposit sediment and decelerate (dissipate). Finally, flows can find a near-uniform state, balancing out erosion and deposition (autosuspension). However, turbidity currents are notoriously difficult to monitor in action, due to their location, episodic occurrence and ability to damage instruments placed in their path.

Here we analyse the most detailed measurements yet from oceanic turbidity currents in action. Seven moorings were placed in Monterey Canyon, offshore California, over 18 months. These moorings captured 13 separate flows, and include the fastest flows yet measured by moorings, with some flows that ran out for over 50 km.

We examine observed patterns of flow behaviour in Monterey Canyon. First, we look into spatial patterns in Monterey Canyon, which can have implications on basic modes of flow behaviour. We will use canyon topography to make inferences about influences of width and gradient on spatial changes. Next, we look into what determines if a flow runs out for longer distances. In studies of other granular flows, it has been found that the properties of the substrate can have a disproportional effect on flow behaviour. We compare the average velocities from Monterey Canyon with other locations globally, to infer if there are consistent trends amongst different submarine systems. We conclude with a generalised model for how flows behave in sand-floored canyons

How is sediment transported through submarine channels and onto the lobe? New insights from time-lapse bathymetry monitoring of an active channel

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Submarine channels are the primary conduit of sediment transport to deep-water, sometimes extending for hundreds to thousands of kilometres. The turbidity currents that travel through these systems deposit the most voluminous sediment accumulations on our planet. These often powerful flows pose a hazard to important seafloor infrastructure, such as pipelines and cables. The depositional termini of these channel systems (submarine lobes) have been proposed to hold valuable archives of Earth's history to reconstruct hazard frequency, palaeoclimates, and earthquake recurrence. Despite their global importance, our understanding of how submarine lobes are built remains unclear. This knowledge gap is largely due to the lack of direct observations of active submarine channel-lobe systems from source to sink. Therefore, we rely upon small-scale observations and scaled-down experiments to calibrate interpretations made from ancient deposits.

Here we present a unique monitoring dataset comprising: i) the first ever detailed time-lapse seafloor surveys performed over a decade along the full-length of an active submarine channel-lobe system (in Bute Inlet, British Columbia) to reveal its architectural evolution; ii) direct measurements of turbidity currents made over two years at multiple locations down the system; and iii) measured discharge from the river that supplies sediment. The integration of these three datasets gives an unprecedented insight to the dynamics of submarine channel-lobe systems on short timescales. We show that tens of flows occur annually in the upstream domain of the channel, coincident with periods of elevated river discharge. Most turbidity currents do not directly contribute to lobe-building, and instead dissipate within the channel. In contrast to conventional models that assume proximal channel erosion, medial bypass and distal deposition, we observe an alternation of zones of erosion and deposition down the channel length. These alternations are due to the upstream migration of steep-faced knickpoints, which erode sediment while migrating upstream and deposit this sediment further downstream of the knickpoint. This suggests that the sediment deposited by most flows is reworked several times and is transported step-wise downstream before reaching the lobe. Sediment delivery to the lobe is much more episodic than that deposited in the proximal parts of the system and does not necessarily require a strong external trigger. Periods of rapid aggradation on the lobe coincide with upstream migration of the knickpoint immediately upslope of the lobe. We suggest that submarine lobes partly preserve a record of autogenic perturbations, rather than the upstream flow events and their external triggers. This has important implications for how to interpret lobe deposits and their use in reconstructing Earth's history and geohazard assessments.

Understanding the Origin and Basin-Scale Distribution of Clay-Coated Sand Grains in Siliciclastic Reservoirs: Insights from Experimental Studies and Modern Analogues

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The presence of clay minerals in a siliciclastic reservoir can have complex implications for porosity and permeability. For example, pore-filling clay mineral cements such as illite or kaolinite often reduce reservoir quality, by decreasing the diameter of intergranular pore throats. However, clay coats developed around detrital sand grains (especially chlorite coats) can inhibit the precipitation of porosity-occluding quartz cement during burial and diagenesis. As a result, fine-grained sandstones with a moderate clay content (in the form of clay coats) may retain a higher level of primary porosity during deep burial, compared to conventionally targeted, cleaner, coarser-grained sandstones. Despite the significant impact clay-coated grains have on reservoir quality, the exact mechanism by which clay coats form remains poorly constrained. This makes the process of predicting the spatial distribution of clay-coated grains in the subsurface largely elusive.

Previous studies suggest biofilms play a key role in the formation of clay-coated grains, through forming an adhesive coat on the surface of sand grains which acts as a binding site for clay particles. Biofilms are ubiquitous to almost all aquatic environments and can be defined as a network of sticky extracellular polymeric substances (EPS) secreted by microorganisms such as cyanobacteria and diatoms. For the first time, we investigate the link between biofilms and the formation of clay-coated grains in both paralic and deep-water settings through the integration of experimental laboratory studies and modern analogues (Ravenglass Estuary, UK and Bute Inlet, a deep-water fjord in British Columbia, Canada). Petrographic thin sections of sediment samples collected across both modern analogue systems, along with compositional data (grain size, grain sorting and clay fraction content) and the total carbohydrate content of sediment (proxy for EPS content) were used to map and interpret the surface distribution of clay-coated grains. Initial results confirm that clay-coat grain coverage (determined petrographically) increases with increasing EPS content across Ravenglass Estuary. However, clay-coated grains appear to be absent in areas with a high EPS content at the head of Bute Inlet. These finding, question the relative timing of clay coat formation, with sediment resuspension and transport potentially playing a vital role in the formation of clay-coated grains in deep-water settings. Ravenglass Estuary was used as a model system to design experimental studies, which aim to form clay-coated grains under controlled laboratory conditions in the absence or presence of biofilms. Environmental scanning electron microscopy (ESEM) was used to image biofilm-sediment interactions in high-resolution at the grain-scale. This novel integration of experimental studies and detailed characterisation of two modern settings, provide new insights into the understanding and prediction of the distribution of clay-coated grains in subsurface siliciclastic reservoirs.

Morphodynamics of a confluence complex at a tropical mountain front

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Quantitative information on the planform, dynamics and sedimentology of tropical river systems remains sparse, and their sensitivity to changes in water and sediment discharges is often unknown. Here, we analyse of channel and confluence migration over the last ~40 years at a complex confluence between the Abuan, Bintacan and Pinacanauan de Ilagan Rivers (Luzon, Philippines). The confluence region begins as the Abuan and Bintacan tributaries pass through the mountain front and flow into the lower gradient Pinacanauan de Ilagan (Figure 1). Satellite imagery from the 1970s to present day shows the rates of channel change in this area.

Bed grain-size varies rapidly within the confluence region, from large boulders at the mountain front to sand and silt in the main river. The gravel-sand transition is driven by slope reduction, with particle breakdown likely to be an important, although secondary, factor. Downstream variations in slope, channel pattern and grain size are used to show how sediment transport and deposition control the observed channel morphodynamics. Sediment supply from the source catchment is high due to intense precipitation, often during typhoons, driving mass-wasting of hillslopes and contains a wide range of grain sizes. Transfer of this material to the alluvial plain results in high channel bed aggradation rates which enhance confluence and lateral channel migration rates, which can reach more than 300 m per decade. Valley topography produces local restrictions on valley width which further affect the locations of aggradation. Overall, the high aggradation rates influence channel pattern to the extent that previously proposed criteria for the boundary between single-thread and braided channel patterns do not hold, a result which is partly explained by the role of vegetation in stabilising river banks.

The results suggest that channel form and rates of change, and thus risk to communities and infrastructure, are not likely to be predicted reliably using established methods that have been developed in lower energy and mostly temperate settings. The sedimentology of the deposits requires further investigation to assess the persistence of the features that are observed at the present day.

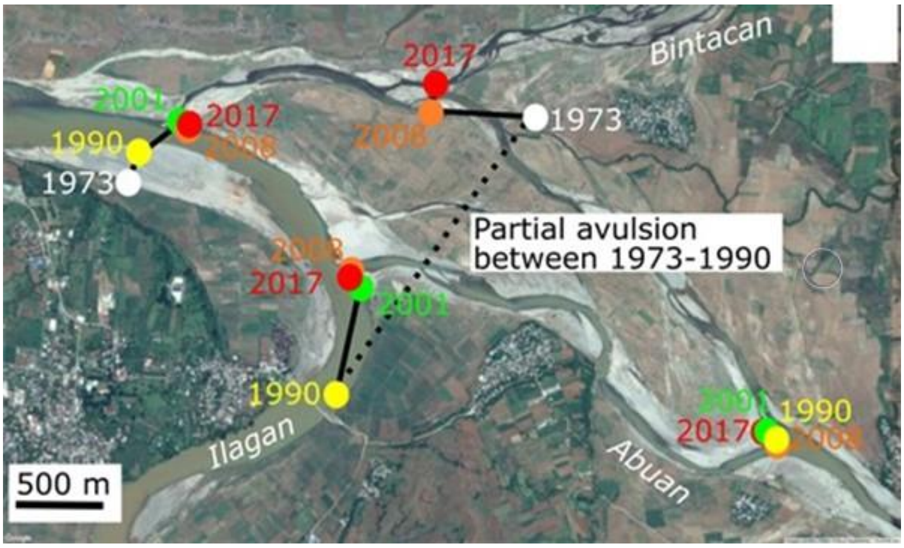

Figure 1. Confluence migration between 1973 and 2017 at the confluences of the Bintacan and Abuan Rivers with the Pinacanauan de Ilagan River. In 1973, the Abuan channel discharged into the Bintacan channel rather than directly into the Pinacanauan de Ilagan. A partial avulsion occurred between 1973 and 1990, however, such that the Abuan can now discharge directly into the Ilagan system. Base image from 2017 in GoogleEarth.

Glacial expansion of oxygen-depleted seawater in the eastern tropical Pacific

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#Deceased

Foraminifera (benthic and planktonic) from sedimentary carbonates can be excellent recorders of their surrounding environmental conditions and have been fundamental in developing an understanding of the evolution of climate, dating of rocks, and past chemistry in the oceans.

Increased biological carbon storage in the oceans has been proposed as a mechanism to explain lower concentrations of atmospheric carbon dioxide during ice ages. Reconstructions of oxygen concentrations in the past can provide information of changes in biologically mediated carbon storage. We constrain changes in the vertical extent of low-oxygen waters in the eastern tropical Pacific since the last ice age using qualitative upper-water-column (from planktonic foraminifera) and quantitative bottom-water oxygen reconstructions (from benthic foraminifera) reconstructions. Our new reconstructions provide evidence of a downward expansion of oxygen depletion in the eastern Pacific during the last glacial, and indication of greater oxygenation in the upper reaches of the water column, as previously suggested. Extrapolate across the Pacific, our reconstructions indicate that the respired carbon reservoir of the glacial Pacific was substantially increased, establishing it as an important component of the coupled mechanism that led to low levels of atmospheric carbon dioxide during the glacial.

Reference: Hoogakker et al. (2018). Glacial expansion of oxygen-depleted seawater in the eastern tropical Pacific. Nature 562, 410-413.

Topographic Tug-of-War: Evolution of Submarine Channel-Lobe Systems with Salt-Influenced Topography, Offshore Angola

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Topographic development along salt-influenced slopes can drastically influence the evolution of submarine channel-lobe systems. Numerous studies document the impact of individual structures on channel-lobe systems, but at the regional scale the spatio-temporal evolution of such systems around a network of active structures is not well recorded. We use regionally-extensive, high-resolution 3D seismic reflection data to investigate the influence of salt-cored structures on the geometry and evolution of Miocene deep-water systems, offshore Angola. Advanced seismic attribute mapping (spectral decomposition and RGB-blending) tied to seismic stratigraphic and seismic facies analysis in a series of minibasins reveals numerous channel-lobe systems that record the subtle changing interplay between structural development and sedimentation.

The mapped Miocene interval is divided into five regional seismic units (SU1–SU5) within a series of minibasins (average c. 160 km^2) separated by 10-40 km long salt-cored anticlines and salt walls, and c. 1-2 km diameter salt stocks. The sediment fairways within these seismic units vary from transverse-to-structure to oblique-to-structure. Channel-lobe systems in the oldest seismic unit (SU1) are blocked by salt-cored anticlines and salt stocks > 30 km in length, and are largely confined to upslope minibasins, eventually spilling over into the next minibasin downslope. Channel systems that are oblique-to-structure (< 30°) are often diverted by salt-cored anticlines and pass through a series of linked minibasins along strike before continuing further downslope. The sinuosity of these channels often increases immediately after a topographic disturbance, by a salt stock, salt wall or salt-cored anticline, but decreases once aligned axially along the minibasin. Later systems (SU5) contain complex arrays of compensationally stacked and backstepping lobes (confined lobe areas c. 10-43 km^2), as well as erosionally-confined channel systems with meander belt widths increasing (c. 1.5 km to 4 km) and more bifurcation nodes.

While a few high-relief salt stocks and walls have a strong influence on sedimentary delivery systems throughout the studied interval, the majority of salt-cored structures gradually lose their topographic influence as the minibasins are gradually filled. Autocyclic controls on deposition, such as compensational stacking of lobes, becomes progressively more significant than structural relief during the later stages of minibasin fill. However, positioning of avulsion nodes along elongate salt walls and salt-cored anticlines throughout the studied interval suggests some degree of local salt-tectonic control on sediment dispersal. Preference for younger channel systems to avulse towards the northwest also possibly indicates the influence of regional tilting. In addition, channel lobe transitions are often located along areas with subtle breaks in gradient. This study highlights the delicate and evolving topographic ‘tug-of-war’ between trains of salt-cored structures and submarine channel-lobe systems.

Reconstructing land mean annual temperatures in the ancient record: implications for future climate change, and understanding sediment budgets in the past.

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The Intergovernmental Panel on Climate Change (ICPP) project atmospheric pCO_2 levels to exceed 700 ppmv by 2100, and forecast anthropogenically-driven atmospheric warming to exceed 2°C above preindustrial temperatures. State-of-the-art numerical General Circulation Models (GCMs) are the main tool used to predict climate change, but another means of assessing this potential future change is to look to the geological past, especially the late Cretaceous to Eocene, when atmospheric pCO_2 levels were last as high those forecasted for 2100. Palm trees and reptilians inside the late Cretaceous and Eocene palaeo-arctic have been used to estimate global mean annual temperatures (MAT) as much as 8°C warmer than today at that time, with near total collapse of the equator-to-polar temperature gradient (the so called "Equable Earth" hypothesis).

We present the initial findings of a case study, utilising a palaeothermometer of land mean annual temperature (MAT) – that has been widely applied to the Pleistocene and Holocene in the last 10 years – to the latest Cretaceous-earliest Palaeogene. Glycerol dialkyl glycerol tetraethers (brGDGTs) are a molecule derived from bacteria that live in soils, and whose shape has been shown to vary predictable as a function of the temperature at which they were metabolised. The molecule occurs in coals (fossil peats) of lignite rank (R_0=0.4) that span the K-Pg boundary in North America. Coals are the best archives of environmental change in terrestrial settings, because accumulation is relatively continuous (by comparison to irregular, "flashy" deposition on floodplains), and because the organic matter is derived from plants that grew *in situ*. We show that the Ir-anomaly that is synonymous with bolide impact at the K-Pg boundary can be used as a datum to correlate coals that were deposited synchronously along the length of the Western Interior Basin of North America from palaeo - 39-75°N, allowing the correlation of reconstructed land MAT at continent scale. We also show that atmospheric $\delta^{13}C$ excursions recorded in the stratigraphy of coals, and high-resolution tephrachronology can be used to correlate continent-, or even global- scale variation in land MAT in deep time.

Initial results from a single site reveals land MAT of 20-25°C at palaeo- 60°N in the latest Cretaceous (immediately pre- bolide impact). Temperatures decrease modestly (<5°C across the K-Pg boundary) and stabilise at around 18-23°C in the aftermath of impact in the earliest Palaeocene. This compares to c. 5°C at the same latitude today. Although preliminary, the results seem to corroborate the "Equable Earth" of geological proxy data, and suggest that GCMs may be underestimating the potential for global warming, especially at high latitude. This data will be complemented in an ongoing project by a suite of MAT reconstructions for the remaining coals spanning 39-75°N.

Finally, because MAT are important to understanding chemical weathering, and clastic sediment transport rates on land, and rates of carbonate productivity on the shelves surrounding the continents, we discuss possible future implications of continent-scale temperature reconstructions to the understanding of ancient depositional systems.

Repeat surveillance data in hydrocarbon reservoirs as a tool for high-resolution sequence stratigraphy

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The supergiant Rumaila oil field in southeast Iraq, which has been on production for more than 60 years, is in a rare data-rich position. As an onshore field with an extensive wellwork programme, it benefits from very large volumes of high-density repeat surveillance data. These data (including repeat cased hole saturation logs, formation pressure data and production logging tool runs) are conventionally used to inform petroleum engineering and optimise production. However, they also represent a highly valuable resource to map the movement of fluids through the reservoir and therefore to refine the reservoir description.

The main producing reservoir in Rumaila, the Main Pay, represents the maximum regression of the paralic Zubair Formation. It is divided into three reservoir units, in terms of both stratigraphic expression and production performance. The units are bounded by major mudstone-prone flooding surfaces. They vary in heterogeneity and net-to-gross related to their stratigraphic position in higher order regressive-transgressive cycles.

The existing geological description of the stratigraphically lowest reservoir unit, known as the LN, was observed to be inconsistent with repeat surveillance data. This manifested as examples of early water breakthrough, multiple moved oil water contacts and bypassed oil. Re-evaluation of core sedimentology, biostratigraphy and image logs, together with openhole and surveillance data from over 600 wells led to the generation of two alternative stratigraphic correlations.

The new geological description differs from the previous model principally in the identification of several extensive coal-prone surfaces. These are capable of holding back pressure and fluids, but are locally removed by lowstand incisions imparting complex but predictable three-dimensional architectures. As net-to-gross changes across the field, so too do production challenges, ranging from unexplained produced water to oil trapped below. This change in model has generated significant business value, including prolonging the life of producing wells through completing bypassed oil zones, and identifying future well targets.

Submarine canyon initiation at a convergent plate margin

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Submarine canyon initiation and growth is often poorly constrained as their early evolution is obliterated by subsequent incision. Typically, canyon relationships to bedrock are not well-preserved in exhumed systems, or below seismic resolution in seismic data. Here, we examine a coarse-grained submarine canyon-fill, the Punta Baja Fm., which formed within the Late Cretaceous Peninsular Ranges forearc basin complex. The canyon is incised into fluvial bedrock, the Bocana Roja Fm., with a preliminary maximum depositional age (MDA) from detrital zircons of 95.3±1.4 Ma. The bedrock is rotated basin-ward and more strongly deformed by faulting and folding than the overlying canyon fill (preliminary MDA 89.6±1.5 Ma to 87.8±1.5 Ma). Extensional faults dominate the western margin of the canyon bedrock, whilst compressional faults and folding only occur on the Eastern side. In an approximate depositional strike section along the canyon base, there is evidence for progressive deepening, from margin to axis, of basal canyon erosion surfaces associated with extensional faults in the bedrock. The canyon-fill is ~120 m thick and up to 1.2 km wide, and comprises conglomeratic channel bodies with sand-rich margins that pass into thin-bedded successions interpreted as internal levees. The canyon fill, whilst suggestive of significant sediment bypass, was also strongly aggradational, with vertical stacking of channel-fills suggesting high sediment supply rates and the continual generation of accommodation space. The canyon-fill was buried, also rotated basin-ward, eroded and onlapped unconformably by the shallow-marine El Gallo Fm. dated at 88.6±1.5 Ma (preliminary MDA), which is statistically indistinguishable from the canyon-fill ages suggesting a very close age relationship. The structural, sedimentological and geochronological evidence suggest that strike-slip fault related topography formed at releasing (extensional) and restraining (compressional) bends along a potentially north-south orientated dextral strike-slip fault, related to oblique compression along the convergent Pacific plate margin. This structural topography can potentially explain the highly oblique angle of the canyon to the regional palaeoslope dip as a response to seafloor fault-related relief and synclines within the bedrock. This study provides new insights into submarine canyon formation and places new constraints on the relationship between strike-slip deformation, canyon initiation, accommodation space and sedimentation.

Bedforms generated by experimental turbidity currents and saline gravity currents.

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Density currents are flows established by the density difference between the current and the ambient fluid, which can be caused by difference in salinity, temperature, or suspended sediment concentration. Thermohaline currents are examples of ocean bottom currents and occur due the variation in water temperature and salinity along the ocean, generating a very important global circulation that establishes the characteristics of the oceans. Turbidity currents are a type of density currents whose difference in density is generated by the presence of sediments in suspension. These currents are responsible for the transport of considerable amounts of sediments from the continent to the deep oceans. Both salinity and turbidity currents can interact with mobile beds and generate bedforms. Understanding the differences between these bedforms is important for the justification of interpretations of hydraulic properties of the currents from sedimentary features. The present study aims to characterize the flow structure and hydraulic parameters (velocity and concentration profiles), and to calculate the shear stresses applied over the bed, for both saline and turbidity currents. Saline and turbidity currents were prepared with salt and glass beads (d_{50}~ 45 μm, R~2.5) respectively. The flows were inserted in a tilting, 18-mlong, acrylic flume with a fixed bed. Three bed slopes (0.5, 2 and 3º, respectively) and three different flow discharges for each slope were tested. Both salinity and turbidity currents were prepared with similar densities of 1040 kg m^{-3}. Velocity and concentration profiles were measured by UVP probes and siphons placed in three different locations throughout the flume. Sediment transport and depositional patterns were visualized using an ultrasound probe, and the current and bedforms generated by the turbidity currents were recorded by cameras installed outside and parallel to the channel. After the end of each experiment, the flume was drained slowly, and the deposit photographed. Samples were collected and evaluated by a laser particle size analyzer in order to know the grain-size distribution of the deposit along the flume. Turbidity currents generated ripples and developed lower mean velocities and higher shear stresses values than the saline currents. This study provided preliminary data from both types of currents and will be added to further studies, which will be performed over mobile beds (glass beads, d_{50}~ 200 μm), in order to analyze similarities and differences on the bedforms generation by both types of currents.

The evolution of the Grenvillian Foreland Basin in northern Scotland: detrital zircon and rutile dating in the Sleat and Torridon groups

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The Grenville Orogen, pivotal in the assembly of the Rodinia supercontinent, lacks a clear foreland basin in its type area in eastern Canada. However, Early Neoproterozoic siliciclastic rocks in northern Scotland are now interpreted as remnants of a proximal Grenvillian foreland basin. Analysis of the sedimentology and detrital zircon and rutile dating of the Torridon and underlying Sleat groups, previously regarded as different in source and setting, provide new constraints on the evolution of this basin. The Sleat Group, c. 3.5 km of shallow marine deposits, is overlain via a low-angle unconformity by the Torridon/Morar groups, which comprise c. 9 km of braided river to shallow marine deposits (Bonsor et al – this meeting) in a basin of large but unknown size.

Youngest U-Pb detrital zircon grains in all samples from both groups yield ages of 1070-990 Ma, consistent with a source from the Grenville Orogen. The proportions of older age peaks, however, vary throughout the sequence. The lower Sleat Group shows a dominant peak at ~ 1750 Ma, interpreted to be derived from a local (Scottish-Irish) Rhinnian source. In the upper Sleat Group and the overlying Torridon Group peaks at ~1650 Ma ages (Labradorian) and between ~1500-1100 Ma (Pinwarian, Elzevirian and early Grenvillian) become increasingly important. These latter peaks correspond to ages of exposed rocks in the Grenville Province in Canada and likely reflect uplift and erosion of different mid-crustal complexes within the Grenville Orogen. There is no difference in detrital ages across the low-angle Sleat/Torridon unconformity. Detrital rutile in the Torridon Group yield a significant c. 1070 Ma Grenville-age peak, but older grains (~1700-1200 Ma) are also present, suggesting derivation from the cool (T<600°C) upper crust of the Grenville Orogen.

The new work, based on structural geology, sedimentology and detrital mineral dating presents evidence for the successions to be now correlated, and suggest the following evolution of the Grenville Foreland basin in Scotland:

i) early deposition in a narrow marine foreland basin (lower Sleat Group), sourced from the Irish-Scottish (Rhinnian) sector of the Grenville Orogen, with orogen-normal fill;
ii) within the Sleat Group a gradual switch to more distal sources in the Canadian sector of the Grenville orogen, via axial transport, still in a narrow basin;
iii) a sudden switch in basin dynamics (but not in source) across the Sleat-Torridon boundary to fluvial braidplain deposition in a much wider, Torridon-Morar basin;
iv) followed by a gradual retrogradation of that basin.

The Torridon-Morar groups (phase iii) represent a major denudational event of the Grenville Orogen that we infer to be linked to deposition of more distal deposits in East Greenland, Svalbard and northern Norway.

Cool deltas. Sedimentary environments of Salpausselka I and II moraine ridges near Lahti, Finland

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Two large “moraine” ridges (Salpausselka I and Salpausselka II), extending to over 600 km in length, delineate two major stillstand/readvance positions of the Fennoscandian ice sheet during the last deglaciation, inferred to be chronologically related to the cool climate event known as the Younger Dryas (age). During this time the Baltic ice lobe and the Finnish Lake District ice lobe, constituting a part of the southern marigin of the Fennoscandian ice sheet, were grounded in a large proglacial lake, the Baltic ice lake, a predecessor to the modern-day Baltic Sea. Most of the sediments were delivered to the ice margin by meltwater and deposited in the form of ice-contact deltas, over a very short period (230 and 250 years respectively for Salpausselka I and II). As a result, the “moraine” ridge is mostly composed of glaciofluvial sands, gravels and boulders rather than diamicton which is more typical of moraine sedimentology.

In this study, high resolution LIDAR data (2m horizontal, 0.3m vertical), provided courtesy of the National Land Survey of Finland and processed by the Geological Survey of Finland, ground penetrating radar profiles and outcrops were analyzed and interpreted. These provide a record of rapid sedimentation from high-magnitude meltwater discharge, through subglacial channels, resulting in rapid buildup of ice contact fans to the water surface and subsequent progradation of deltaic forests. Renewed retreat of the ice margin lead to abandonment of the Salpausselka I and deposition of the Salpausselka II ridge, 25 km to the north. In the Lahti region, where the two ice lobes were confluent, the largest deltaic complex developed. Sediments of Salpausselkas in Finland are a world class example of a sedimentary environment which records, with great detail, the processes of the formation of ice-contact, Gilbert-type, deltas marking stillstand positions of the southern margin of the Fennoscandian Ice Sheet during the Younger Dryas.

Distortion of the sedimentary tape recorder by abrasion

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Pebble abrasion is a key factor controlling the release of minerals into sand, but few attempts have been made to assess how it could influence the liberation of minerals into the size fraction used in detrital geochronology. We perform a series of experiments with an abrasion model to test this influence using natural and synthetic datasets. Pebble abrasion is one of many factors that can change the mixing proportion of sands, including hillslope gravel supply, erosion rates, and mineral fertility. In our study case (Marsyandi watershed, Himalaya), the abrasion model predicts age distributions that are statistically indistinguishable from those predicted by a no-abrasion model. However, the relative erosion rates estimated by our model largely differ from the results of a no-abrasion model. Model results in a range of realistic scenarios demonstrate that pebble abrasion can change the zircon mixing proportions of upstream source units as well as the age distribution of mixed fluvial sands. They show that distortion is significant in settings with large contrasts in rock strength or short catchments. In long catchments with no resistant lithologies, most of the gravel initially supplied from the hillslopes will have been turned into sand by the time it reaches the outlet, leading to the release of most detrital grains and limited bias potential from abrasion. Conversely, gravel from resistant lithologies (e.g., quartzite, volcanics, mica-poor granite or gneiss) can persist for transport distances of hundreds of km, locking detrital minerals within them and increasing the bias potential from abrasion: abrasion will likely lead to the underrepresentation of units characterised by such resistant rock in a sand sample.

Reference: Lavarini, C., Attal., M., da Costa Filho, C.A., and Kirstein, L.A. Does pebble abrasion influence detrital age population statistics? A numerical investigation of natural datasets. Journal of Geophysical Research, https://doi.org/10.1029/2018JF004610, 2018.

Were Ediacaran-Cambrian ice sheets in North China thin and sticky?

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Abstract

The North China Craton was positioned at low (equatorial) latitudes during the Ediacaran to early Cambrian, when ice sheets deposited diamictites of the Luoquan Formation which presently extends for 2000 km along the central China orogeny. Despite being known for more than 30 years, there have been no previous attempts to map, describe, or interpret striated pavements that occur beneath the Luoquan Formation. This paper presents new Unmanned Aerial Vehicle (UAV) imagery of spectacular striated pavements, one of only two sites of this age known worldwide. At Shimengou, orthorectified photographs and digital elevation models, to a resolution of up to 1 cm, reveal a series of scallop-shaped bedforms over a wide (ca. 1 km x 100 m) area of dipping sandstone beds. An assemblage of geomorphic features is described, including sichelwanne, müschelbruche, comma marks and spindle forms alongside striations: a classic “p-form” assemblage. Some of these features cross-cut orthogonal fractures and faults, the trend of which has been exploited during subsequent regional tectonism. The faults and fractures are interpreted as Riedel shears which developed in response to shear by an overriding ice mass. Thus, together with the p-forms, a preliminary story of progressive abrasion and significant ice-bed coupling emerges, with minimal subsequent meltwater reworking, emerges. It is tentatively proposed that this spectacular assemblage was produced by the consistent southward flow of a thin and sluggish ice mass with minimal meltwater reworking modifying the topography, perhaps pointing to rapid ablation during palaeo-climatic amelioration at the frosty dawn of the Phanerozoic.

Measuring connectivity in hierarchical deep-water lobe rule-based models

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Because of limited seismic resolution, the internal geometry of oil reservoirs hosted in deep-water lobe deposits is usually associated with a high degree of uncertainty. Therefore geological models capable of including realistic but uncertain geometries are crucial in order to minimize development risk of such reservoirs. Conventional cell-based modelling techniques struggle to reproduce the complicated spatial structures present in deep marine systems, and therefore a new modelling approach that merges object-based and rule-based modelling has been created, with the aim of reproducing complex geometries at different scales in binary sand/shale systems, and understanding the influence of different geometries on reservoir properties. In the present study the focus is on sandstone bed connectivity.

The numerical models are able to reproduce the four-fold lobe hierarchy often seen in natural systems (Figure 1a). From smaller to larger scale, the hierarchy comprises bed to bed-sets, lobe elements, lobes and lobe complexes, where smaller elements are stacked to define a hierarchically larger element (Figure 1b). The hierarchical stacking process can be set to generate anything from random to totally compensational systems, in which subsequent lobes are deposited in topographic lows. Hierarchy is controlled by defining larger elements as “containers” that will constrain the area where the smaller hierarchical elements will be deposited. For example, a bed is not allowed to be deposited outside of its container, which is a previously defined lobe element. The code is controlled by sequential events that deposit sandstone beds followed by shale drapes. Sandstone-to-sandstone connectivity can be achieved only through erosion of the shales: this is controlled in the numerical approach by assigning a hierarchical level-specific probability of erosion for each object. Objects can only erode into objects of the same or smaller hierarchical levels. Hence lobes cannot erode into an underlying lobe complex, but can erode into other lobes and their associated lobe elements and beds. This can lead to different scenarios where different elements can be connected with each other, or can be completely isolated.

Different models of systems containing over 600 beds have been generated to test how erosion affects the connectivity of the whole system (figure 2a). The amalgamation ratio (i.e. the proportion of sand bed bases in contact with an underlying sand bed) has previously been shown to be the principal sedimentological control on the connectivity in bed-scale models. Amalgamation is related to erosion, which is used in the present study (Fig 2b). When erosion is set to the same probability for every hierarchical level, a connectivity threshold is observed at an amalgamation ratio of 0.3, consistent with previous observations (figure 2c, d). Models show an efficient way of reproducing theoretical sand-shale deep-water lobe systems. Further work in idealised and real systems (i.e. the Ross Fm.) will allow us to achieve more realism.

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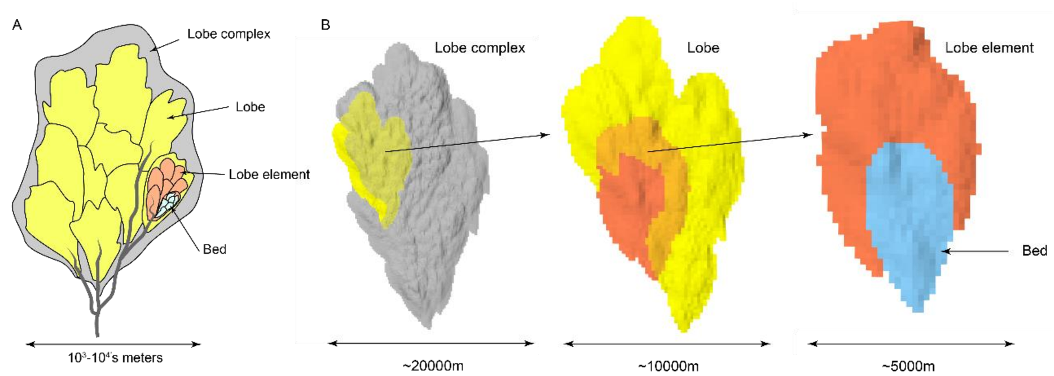
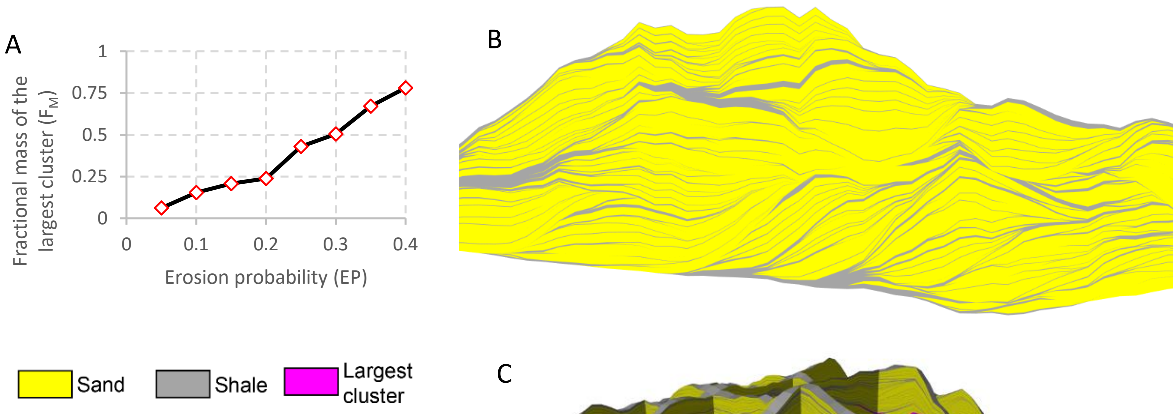
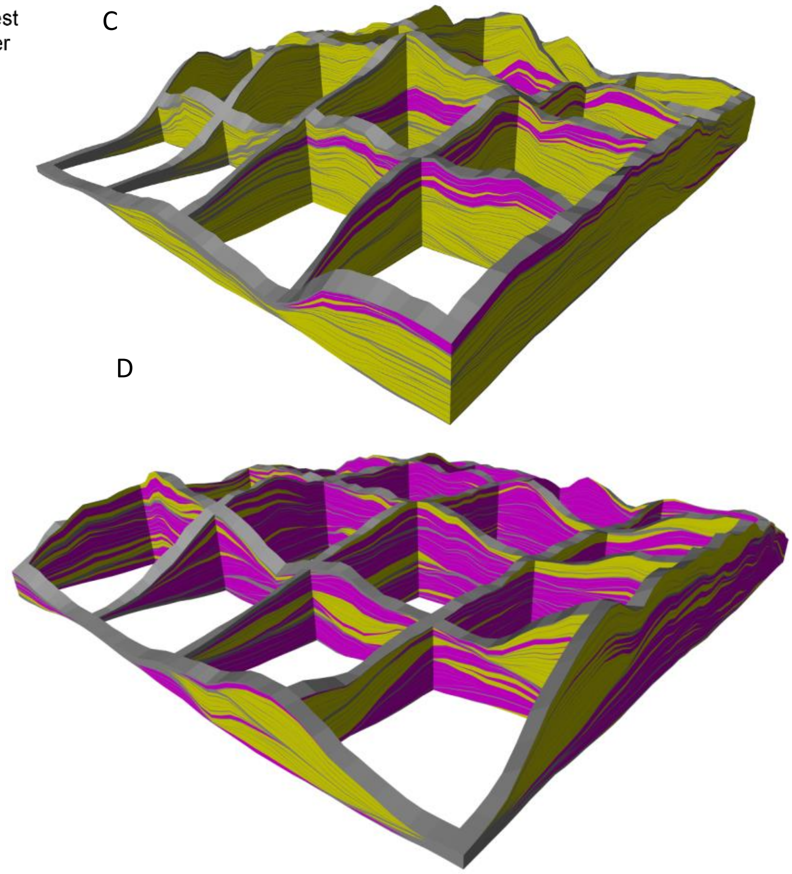


Figure 1. A) The hierarchical scheme used in this work. B) Modelled lobe complex with the code used in this study. Smaller hierarchies are constrained to their previous larger container.

Figure 2. A)





Erosion probability (EP) vs Fractional mass of the largest cluster (F_M). Five cases for each EP have been generated. A system is considered macroscopically connected in 3D if $F_M > 0.5$, which occurs at EP = 0.3. B) Random vertically exaggerated section with EP = 0.3. Note how erosion can partially remove shale drapes, eventually generating amalgamation and inter-element connectivity. C) Example model of EP = 0.1, in which F_M equals 0.102. D) Model with an EP = 0.35. This model is macroscopically connected, and a large connected volume is observed.

Predicting sediment discharges from the continents in deep time — examples from the Cenomanian and Turonian of North America

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Understanding how, when and where sediment was delivered from the continents to the oceans in deep time is a prominent research challenge. The flux of sediment to the ocean is governed by tectonic and climatic boundary conditions, which influence source area denudation rates and spatio-temporal patterns in sediment routing. Depositional stratigraphy therefore represents the time-integrated product of erosional fluxes from terrestrial catchments via palaeo-sediment routing systems. Here, we use newly available palaeo-digital elevation models (palaeoDEMs), based on high-resolution palaeogeographic reconstructions, and HadCM3L data to predict the geometries and climates of large continental palaeocatchments in the Cenomanian and Turonian North American continent. We then use the BQART sediment flux model to produce first-order estimates of fluvially-derived suspended sediment flux to the Cretaceous Western Interior Seaway (WIS) of North America.

In both Cenomanian and Turonian time slices, palaeoDEM analyses reconstruct over 1500 North American palaeocatchments with areas greater than 500 km^2. Of these large continental catchments, at least 500 deliver sediment to the WIS. Our results suggest continental-average denudation rates of ~0.1 mm/yr and sediment yields of ~150 t/km^2/yr, values which are reasonable when compared to large catchments draining upland topography today. We validate our estimates with published data from the Cenomanian Dunvegan Formation in Alberta, Canada, and the Turonian Ferron Sandstone in Utah, USA. Our BQART estimates of suspended sediment flux to the WIS are the same order of magnitude as those derived from previous field-based approaches and most lie within a factor of two. Additionally, we evaluate a range of uncertainty margins on BQART input parameters, including the palaeogeographic and palaeoclimate boundary conditions, and we quantify the univariate and multivariate sensitivity of our results to these uncertainties. Total continental suspended sediment fluxes are projected to be 3.5 GT/yr and 3.1 GT/yr for the North American continent in the Cenomanian and Turonian stages, respectively. This implies that late Cretaceous fluxes may have been a factor of 2 bigger than estimated Holocene pre-anthropogenic continental fluxes of 1.7 GT/yr.

Our results demonstrate the suitability of this approach for investigating palaeo-sediment routing, particularly where stratigraphic records are incomplete. Moreover, our results highlight the potential of this approach to predict the global spatio-temporal response of sediment supply to long-term tectonic and climatic events in the geologic past.

Multi-scale 3D/4D imaging of organic matter and pore in shales

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Microstructural variations, particularly the volume, geometries and connectivities of pores and organic matter, are critical factors which influence the generation, storage and transport of hydrocarbons in shale reservoirs. The imaging and quantification of microstructural variations and dynamic changes is a significant challenge in the macroscopic and microscopic characterisation of shale rocks. Combining X-ray tomography and 3D electron microscopy provides a powerful tool for multi-scale imaging and quantification of microstructural information in shales. With this combined approach, pores, organic matter, inorganic mineral phases and fractures can be visualized at range of scales over five orders of magnitude (voxel size ~ 44 µm to ~ 0.3 nm).

Samples were selected from several shale basins in Europe and America with variable compositions and properties representing the microstructural diversity observed in shale rocks. Organic matter primarily occurs in two geometries: lamellar masses (length: 1-100 µm, thickness: 0.5-2 µm) and discrete spheroidal particles (large particles: 5-20 µm, small particles: 0.5-2 µm). Organic matter network interconnectedness appears to be controlled by TOC concentration and geometries. It will become an interconnected network when organic matter content in selected region increases to a value between 6-18 wt.%. Pores within the samples are identified on the basis of the component which they are associated. The total pore volume vary, but in order of decreasing total pore volume are: inter-mineral pores (0.2 µm diameter, elongate), organic interface pores (0.2 µm diameter, elongate), intra-organic pores (0.05 µm diameter, spherical) and intra-mineral pores (0.05 µm diameter, spherical). Quantification of pore systems appears to indicate that the major pore system is composed of inter-mineral pores between clay mineral grains. TOC concentration can influence the capacity of organic matter-related pore systems while maturity controls the presence of intra-organic pores. Pore under 10 nm, which are only visible in TEM tomography, appears to present between clay minerals primarily and likely to form an interconnected pore network.

Recently, synchrotron-based time-resolved XCT (4D) makes the dynamic changes of the organic matter and pores visible at micro-scale. For example, the organic matter maturing with temperatures and micro-cracks propogation under indentation can be quantified in 3D with times.

In summary, multi-scale 3D/4D technique can image shale features leading to a greater understanding of the microstructural variation and dynamic change in shales. We use our data to demonstrate the applications in organic matter and pores to identify and quantify the properties of shale and improve the understanding of sedimentological characterisation and burial history.

Sedimentary characteristics of bottom-current controlled deposits on a pelagic carbonate platform. Erosional and depositional features of the Givetian-Frasnian limestones of the Tafilalt platform (Morocco)

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Bottom-current-controlled sedimentation is a widespread feature of modern ocean basins. Such sediments cover vast areas and can form contourite drifts in various depths of deep-marine environments. Although the seismic facies architecture and spatial distribution of current-derived sediments in modern ocean basins have been thoroughly mapped and described in large-scale marine surveys, fossil contourites are still poorly known from a small-scale perspective of deposits on land.

There is strong evidence that contourites and associated large-scale erosional features were formed by bottom currents during the Lower to Upper Devonian within the closing oceanic passages between Laurussia and Gondwana. They have been documented within pelagic and hemipelagic successions of Europe and northwestern Africa, which are strongly deformed and fragmented as a part of Hercynian orogeny. In this case study, coeval successions have been investigated in the Anti-Atlas of Morocco, where weakly deformed, large-scale, well-exposed records allow for a comprehensive analysis of the Eifelian-Famennian Devonian limestone succession on the northern Tafilalt platform.

The Tafilalt platform offers an excellent opportunity to study the temporal and spatial distribution of erosional and depositional episodes on a pelagic carbonate platform, where condensed carbonates, marls and shales are interpreted as pelagic and hemipelagic sediments. Within this deep-marine record, widespread hiatuses have been verified by detailed biostratigraphic analysis, which mainly occur at the Givetian/Frasnian and the Frasnian/Famennian boundary.

Detailed sedimentological work backed by lithologic logs, microfacies and outcrop data, are amended by thin section analysis and paleo-current measurements and geobody morphology, allowing for a detailed analysis on multiple scales from microfacies to regional drift-body architecture. The results of these investigations are interpreted in the context of rarely preserved primary traction structures as well as temporal and spatial trends in facies characteristics and geobody development.

This study aims to contribute to the identification of qualitative criteria for describing fossil contourite deposits, in order to provide a more comprehensive model for contourites and associated depositional systems that could be applied to economically significant plays.

Acknowledgements

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Trapping of sustained turbidity currents in complex slope accommodation: outcrop and subsurface examples from the Hikurangi margin, New Zealand

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Regardless of setting, deep-marine lobe complexes typically build thicknesses of meters to tens of meters before channel avulsion or external controls shut down deposition. Here we document lobe-like, stacked and amalgamated deep-marine sandstones, hundreds of meters in thickness, deposited within confined, trench-slope sub-basins of the Hikurangi subduction margin.
Sedimentary logging and mapping of outcropping Miocene aged examples, combined with petrography and biostratigraphy, document the occurrence of sand-rich deposits up to 200 m thick in discrete areas of the preserved sub-basins, which can be traced over tens of kilometres. The deposits are composed of tabular sandstones, each up to meters in thickness. Constituent beds typically comprise fine grained sandstone, with lightly scoured bases ornamented by sole marks. When not dewatered, beds may show low-angle cross-strata or parallel lamination in their lower divisions, typically grading to ripple lamination; grading into finer grained caps is very rarely observed, with truncation and amalgamation by subsequent events widespread. The beds are interpreted to have formed by trapping of the denser parts of turbidity currents in local accommodation, with finer portions of the flows bypassing, to create vertically stacked lobe complexes. Across the remainder of the outcropping sub-basins, contemporaneous deposits are represented by heterolithic sediments that thin towards sub-basin margins and are interpreted as the fringes of the systems. The lobe systems are eroded into and overlain by mass-transport deposits, which may have been responsible for modification of sedimentary pathways and cessation of lobe development. Similar architectures are observed in seismic data from the subsurface component of the offshore subduction wedge. Here, lobe complexes up to 15 km wide by 10 km long by 500 m thick are seen to stack within sub-basins.
These unusually thick lobe complexes are inferred to have developed in association with growth structures, which grew at a rate that allowed maintenance of partial barriers to flow, permitting flow stripping and partial bypass. Recognition of these vertically stacked, persistent lobe complexes is significant, as they document deposits substantially thicker than those recognised in unconfined (e.g. Karoo, South Africa) or semi-confined systems (e.g. Niger Delta slope). These deposits highlight the complexity of the interaction of sedimentary systems with evolving seafloor structures, may pre-condition of spill points from confined basins and form excellent potential hydrocarbon reservoirs.

Geological evidence for river behaviour in the absence of land plants

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At the present day, plants affect multiple aspects of river functioning and deposition and so those rivers that operated before the evolution of land plants largely lack modern sedimentological analogue. However, such rivers were the norm for the first 90% of Earth history and so a better understanding of their sedimentary product enables insight into both the fundamental underlying mechanisms of river behaviour and the ways in which fluvial processes operated on 'pre-vegetation' Earth. We present new insights into river functioning before land plant evolution, utilising results from numerous original fieldwork based case studies and an analysis of a holistic database of all of Earth's reported pre-vegetation alluvium. Together these research strands offer perspectives on the sedimentological characteristics and stratigraphic trends of pre-vegetation alluvium and the behaviour of pre-vegetation rivers. We then use this data to consider pre-vegetation alluvium as an analogue for Martian sedimentary strata. Rover mission imagery from Mars are, for the first time, enabling sedimentological analyses of strata beyond Earth. Yet a limitation on our interpretation of Martian sedimentary outcrops is that any investigation must utilize Earth analogues in the first instance. A profound contrast between Earth and Mars is that the former is home to a plethora of different ecosystem engineers, of which, land plants are without question the most powerful. Assuming Mars has always lacked vegetation, the most appropriate, ancient Earth analogue to consider are therefore those deposited in the absence of plants. In this regard, and not without its own limitations, pre-vegetation Earth provides the prime comparable archive against which to understand ancient deposition on a vegetation-free Mars.

Exploring iron and sulphur speciation in the Cleveland Basin Kimmeridge Clay

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Pyrite, an iron sulphide mineral, is commonly found in organic rich sedimentary rocks. Both iron sulphides and organic sulphur compounds can be formed by the reaction of reactive iron minerals or organic matter with the free reduced sulphur available in

water columns and sediments. The supply of dissolved reduced sulphur is redox dependent, being created in anoxic waters by the reduction of seawater sulphate. The same redox conditions enabling this process also enhance organic matter preservation, and sulphurisation can further protect organic matter, explaining the common occurrence of sulphides in TOC-rich rocks. However, the partitioning of sulphur into inorganic and organic forms is not yet fully understood. The fast reactions between reactive iron minerals and dissolved reduced sulphur would be expected to dominate, scavenging the available pool of reduced sulphur to form pyrite, so long as these iron minerals are present. The observed co-occurrence of reactive iron minerals with sedimentary sulphur forms other than pyrite runs counter to this, indicating that the dynamics must be more complex. Despite the longer timescales thought to be required for significant sulphurisation of organic matter in the sediment, fast sulphurisation of sinking organic matter in the water column has been observed in modern settings.

The samples considered here stem from the Kimmeridge Clay Formation in the Cleveland Basin, Yorkshire, UK. This basin lies next to the Pennine/southern Scottish High at the southern end of the Boreal Seaway, one of a series of similar basins on the Jurassic shelf. Though the organic matter present in these samples is dominantly marine, there is a large terrestrial mineral component. Iron speciation varies within the section, with an increasing proportion of magnetite present up the core. This is accompanied by a decrease in the pyritised iron fraction and a trend to less persistently stratified and euxinic conditions upwards. Despite the presence of unpyritised reactive iron minerals (seen also on SEM images), there is a significant and variable proportion of non-pyritic sulphur in these samples. Several environmental and mineral/organic matter input factors have been considered as possible controls on sulphur speciation in these samples. The role of different iron fractions (with varying reactivities) is explored using data from sequential extraction and SEM, and the nature and impact of the organic matter input is examined using biomarkers. The impacts of redox conditions, and of the different loci of these inputs and their reactions, on interactions between the iron, sulphur, and organic matter inputs is further considered.

Characterisation of thin-beds associated with submarine channels in Pennsylvanian Ross Sandstone Formation, Co Clare, western Ireland

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Submarine levee/overbanks are identifiable in seabed and subsurface datasets as constructional, wedge-shaped features that are positioned adjacent to channels; they form extensive deposits that can be tens to hundreds of metres thick and many kilometres wide. Previous outcrop-based studies have documented extensive levee deposits adjacent to channels on submarine slopes, however, detailed observations of the process sedimentology and depositional architecture of levee/overbanks on the base-of-slope to basin floor are less common due to limited outcrop exposure of the generally fine grain size.

Recent outcrop and core-based studies from the Ross Sandstone Formation, of the Clare Basin have demonstrated the occurrence of significant thin-bedded and fine-grained successions adjacent to channels on the base-of-slope to basin floor. Observations and interpretations of these features have shown that they have a complex depositional history that is governed by the distance from the parent channel, and consequently the magnitude of the depositing flows. These potential overbank/levee features display a predictable upwards facies transition from relatively thick-bedded sandstones with lateral pinch and swell geometries passing upwards to finer grained facies that is exclusively composed of well-structured thin to very thin beds of current-rippled sandstone isolated in siltstone. This fining upwards vertical motif has been observed in thin-bedded successions adjacent to channels within the mid- and upper-Ross Fm. Where they can be mapped laterally, they are characterised by a wedge-geometry that records a thinning and fining lateral facies transition over a distance of up to 10km.

Two different styles of channel margin to thin-bed relationship has been observed within the Ross Fm. Locally, thin-bedded successions are cut by laterally adjacent channel fills, suggesting that there is little-to-no connectivity between the channel-fill and the thin-bedded overbank. In addition, this cross-cutting relationship indicates that the channel and the thin-beds are not contemporaneous. However, lateral facies transitions and palaeoflow data in the thin bed packets suggests that there is a genetic relationship with the channels. Other examples preserve the thin-bed units above the level of the adjacent channel floor, and they can be followed laterally into channel margin facies without a break, preserving connectivity between the channel-fill and its overbank.

These observations and relationships suggest at least some of the Ross channels had low-relief levees and locally thin-bed frontal splays into which they were incised.

Sedimentary facies analysis based on multi-element XRF analyses.

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Sedimentary facies are distinguishable descriptive bodies of sedimentary deposits with different facies characterising different modes of sediment deposition, sedimentary facies are commonly employed in reservoir quality studies. However, several works have reported that the conventional sedimentary facies subdivisions are not always helpful in reservoir quality studies, for example there is no automatic link to primary mineralogy or even the presence of grain-coating clays. This research project is designed to understand how modern analogue studies can be employed in reservoir quality studies, mainly reservoir quality prediction by analogy. The work is focussed on the Ravenglass estuary located in north-western England, The Estuary, which encompasses the tidal reaches of the Rivers Esk, Irt and Mite, occupies an area of 5.6 km^2, of which ~86% is intertidal. In this work, an attempt has been made to characterise sedimentary environments based on multi-element XRF analyses, analysed ArcGIS and statistical tools. The estuary was mapped to define the distribution of 11 sedimentary environments. About 480 surface samples collected at an unprecedented high resolution, were sampled along a pre-defined transects to give a representative and approximately uniform distribution of the samples, covering the entire study area. These samples were subjected to X-ray fluorescence analyses using handheld XRF tool that produced concentration data from 41 elements with each analysis taking between 5 and 10 minutes. The results from the surface sediments include element distribution maps and cross-plots of different elemental indices. There is a good correlation between several of the depositional environments within the estuary and element concentration. Thus XRF data can be used to discriminate sedimentary environments; this will allow unequivocal identification of palaeo-environments from geotechnical cores drilled in the Ravenglass Estuary. Moreover, principal component analysis result also allows the delineation of some environments but limited to mud-flat, mixed-flat and sand-flat environments. This approach will ultimately be applied to post-glacial Holocene cores. This work has proved that there are strong and predictable relationships between clastic sediment environments and facies and element composition.

Geographic isolation of the Shannon Basin, western Ireland, during a late Viséan lowstand

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A unit of distinctive striped limestones of latest Asbian to lower Brigantian age (Viséan, Carboniferous) can be traced for at least 70 km across the Shannon Basin, western Ireland. It forms a significant component of the Parsonage Formation (c. 24m thick) and contrasts markedly with cyclical, skeletal limestones developed on the surrounding platforms. The 'stripes', are alternating light and dark carbonate laminations which vary from planar to crinkly in profile (Fig. 1a). Syn-sedimentary and shallow-burial deformation (brittle and ductile) is ubiquitous (Fig. 1b-c). Thin-section petrography reveals predominantly recrystallised microsparite textures, although grumeleuse textures are also occasionally encountered that are probably microbial in origin. With the exception of a poorly-preserved calcareous microflora and rare ostracods, striped limestone is unfossiliferous.

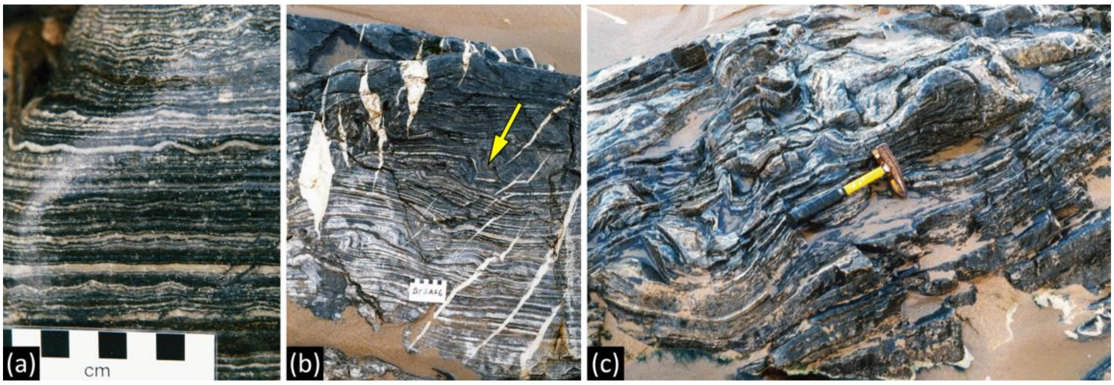

Fig. 1: Field views of striped limestone at Men's Strand, Ballybunion, County Kerry. (a) Wave-polished surface close to the base of the striped limestone sequence showing the fine detail of the laminae, (b) Laterally continuous laminite overlain by dislocated and deformed layering (yellow arrow); note also en échelon calcite vein development, (c) Highly contorted laminite.

The presence of rare gypsum pseudomorphs, length-slow chalcedony, aspects of the deformation of the laminite (which are analogous to those produced as a result of evaporite solution collapse) coupled with the restricted and impoverished biota, suggest that this facies association is best interpreted as representing hypersaline conditions. These sediments were deposited following a regional shallowing event characterised by development of oncoidal facies. The first appearance of striped limestone, a short distance above the oncoids, represents an event horizon created by isolation of the Shannon Basin during the subsequent period of low sea-level. The reasons for the restriction, or silling, of the water mass remains unclear, but may have been influenced by basin geometry and further enhanced by the cul-de-sac position of the Shannon Basin in the western arm of the northwestern European Carboniferous ocean.

The role of mass-transport complexes (MTCs) in preconditioning subsequent failure events

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Mass-transport complexes (MTCs) are ubiquitous on modern continental slopes and common in the deep-water stratigraphic record. One critical aspect of large MTCs is their role in dictating the distribution of subsequent mass transport events, which remains a key issue on all basin margins that are susceptible to failure. This study area is located on the NE flank of the Exmouth Plateau, offshore NW Australia, in the central part of the Kangaroo Syncline. We use high-quality 3D reflection seismic data to evaluate MTCs within a c. 600 m-thick Neogene, deep-water succession. The study focuses on analysing the geometry, and temporal and spatial distribution, of three MTCs. MTC 1 (oldest) has a tongue-shaped geometry, it covers an area of at least c. 720 km^2 (c. 140 m thick) and is dominated by chaotic seismic reflection patterns. MTC 2 is characterised by three different, laterally equivalent seismic facies (from east to west): (i) blocky (c. 360 m thick and 1100 m wide), (ii) chaotic, and (iii) thrusted. MTC 3 is similar to MTC 2, but with the opposite lateral relationship: i.e.: blocky, chaotic, and thrusts seismic facies, but changing from west to east. MTC 2 and 3 have a similar average thickness (c. 230 m) but thin in opposite directions; MTC 3 is thin where MTC 2 is thick, and vice versa. The results of mapping suggests that: 1) MTC-1 provided the substrate for the MTC-2 basal shear zone, as the subsequent MTC-2 eroded and entrained MTC-1; and 2) the c. 400 m vertical relief of MTC-2 provided sufficient seabed topography to offset the transport direction and accumulation of MTC-3.

Keywords: MTCs, Exmouth Plateau

Carbon Transfer into the South China Sea

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Shelf areas including river deltas and estuaries are a transition zone between terrestrial environments and the deep sea. Shelf systems exhibit diverse transport mechanisms for carbon, which influence its reactivity and exchange with the environment. These systems also serve a key role in carbon cycling and regulation of climate cycles, which are crucial to carbon sequestration. Indeed, over 90% of marine sedimentary organic matter (OM) is buried along continental margins. Yet, this sedimentary OM is a mix of marine primary productivity as well as terrestrial input. Previous studies have shown that that marine OM and terrigenous OM in coastal sediments can exhibit contrasting reactivity and fate.

This project focuses on the western part of the South China Sea (SCS), as a highly suitable region to investigate a variety of shelf systems, connecting the narrow shelf off Vietnam with the wide-ranged shelves of the Gulf of Tonkin in the north and the Sunda Shelf in the south. Furthermore, the SCS hosts one of the most biologically productive marine regions around Asia.To investigate the behaviour of organic carbon (OC) we identify and classify the abundance, origin, composition, and transport pathways of different types of OM from source-to-sink. Suitable techniques to investigate these processes are biomarkers, here with we focus on fatty acids, to identify sources of organic matter and its diagenesis, and combine these with age information from $\Delta^{14}C$ dating to obtain rates of production and transport and mineral surface area (MSA), recognising that OM and clay minerals closely interconnect.

We present data from 206 marine surface sediments confirming that organic carbon abundance correlates with water depth, strong current flow and monsoonal change. Inner shelf samples are impacted by alternating coastal-parallel currents with OM being remobilised and transported away towards areas with reduced current influence (e.g. Mekong Delta and Vietnamese Shelf) and the deep ocean basin.

Reconstructing the pathway of carbon from land to shallow and finally deep ocean is crucial and establishing a temporal framework is challenging due to high degrees of mixing and changing transport directions. This complicates the assessment of the implementation of carbon in organic matter deposited in marine sediments.

Our data confirm that OC abundance, composition and age in the study area is controlled by a variety of factors that strongly vary in local importance (hydrodynamics, oceanography, seasonality, tectonic regime, OM provenance and degree of degradation). The Sunda shelf/basin stores a relict signal of old OC whereas river mouth samples and upwelling regions (e.g. off S Vietnam) enhance capture of modern OC fractions. We conclude that interpretation of OM in the SCS must consider these local scale influences in addition to larger scale drivers.

These more conventional investigations will be paired with mineralogical data (e.g., radiocarbon composition of $CaCO_3$) from select samples, to test the idea that carbonate reefs and terrestrial carbonate influx might contribute to the ⍰^{14}C record of marine shelf samples. Further, the carbon load of Pacific water masses might cause considerable shifts in ⍰^{14}C composition, tentatively towards older records. The challenge of linking particular smaller-scale mechanisms with larger, regional-scale processes is further complicated by geographic and tectonic changes in sediment features, such as transition between active and passive margin scenarios, which impact carbon sequestration.

Heavy mineral variations and polycyclic provenance in a deltaic cyclothem

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The mid-Carboniferous Clare Basin, western Ireland, consists of a siliciclastic infill from deep-marine turbidites to shallow marine deltaic cyclothems. This study focuses on the provenance of the Tullig deltaic cyclothem, with an emphasis on heavy mineral analysis and the use of indices such as apatite-tourmaline (ATi). From source rock to final deposition, various processes (weathering, mixing or sorting) can affect the sediment composition. Apatite, less stable than tourmaline, is more likely to be removed by chemical weathering prior to ultimate deposition. By looking at such minerals, relative variations in the duration of storage residence time in the sedimentary system can be investigated. However, such changes in heavy mineral composition could also be linked with a change of provenance. Therefore, U-Pb geochronology has been performed in order to better constrain the source of the basin infill.

Detailed logging and sampling of the cyclothem sandstones was performed at three locations in the Clare Basin. Petrographic analyses indicate these are mineralogically and texturally mature quartz-arenites. Heavy mineral assemblages show intriguing variations, with ATi especially seeming to vary with facies. Mouth bar and interdistributary bay deposits have consistently lower ATi values than channelised sands. Rutile-zircon index (RuZi) variations appear to mirror the ATi signal. Zircon-tourmaline-rutile indices (ZTR) are relatively high throughout the samples, agreeing with the petrography. Zircon U-Pb geochronology from 6 samples across the sampled sequences present near-identical age distributions, with a dominant zircon population of peri-Gondwanan age (550-750Ma), a wide range of zircon interpreted as coming from Laurentia (900-2500Ma) and a population associated with Caledonian granites (400-470Ma). Given the lack of variation in detrital zircon age populations, the ATi variations are interpreted to be controlled by relative changes in pre-depositional settings. Channelised sandstones seems to be sourced more directly than mouth bar or interdistributary bay sands, with relatively less time spent in the sedimentary system or in intermediate storage. Intriguingly, variations in RuZi appear not to be linked to a change in provenance. An integration of these data suggests a polycyclic origin for the Tullig Cyclothem. A comparison of the U-Pb zircon data with published regional datasets suggests these sandstones could have been recycled from Devonian Old Red Sandstones to the south, with an additional input of fresh peri-Gondwanan-aged material potentially from the southwest. This sediment dispersal model is in agreement with some, but not all, of the published palaeodrainage models for the Clare Basin.

The Falklands Sand Sheet: a record of bottom current erosion and deposition since the Early Oligocene

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Sedimentary processes on the Falkland Plateau are profoundly affected by bottom current activities, particularly in association with the Sub-Antarctic Front (SAF), one of three high-velocity jets of the Antarctic Circumpolar Current (ACC). The various currents associated with the ACC together make up the largest moving body of water on Earth, and its evolution has been crucial to global ocean circulation and climate. However, the onset and evolution of the ACC is poorly constrained, with various proxies indicating inception dates ranging from the Eocene to the Late Miocene. In this study, we use a number of geotechnical boreholes to calibrate an extensive 3D seismnic dataset to provide new dates for a number of erosional features and depositional bodies in the Falkland Plateau region, which allow us to constrain the timing of onset, and subsequent evolution of this current. In particular, we note that a major erosional unconformity on the Falkland Terrace with distinctive geomorphological features indicating bottom current erosion (slope-parallel escarpments and circular-elliptical scours) is latest Eocene-early Oligocene in age. This erosional surface is overlain by an extensive Oligocene-Recent sand sheet, with clear evidence for bottom-current activity, and a history of intermittent erosion and deposition. By contrast, a plastered contourite drift on the south-west of the plateau consists predominantly of silt and mud of Pleistocene-Recent age, indicating a substantial change in bottom current conditions since that time. We propose an model of current strengthening and weakening since the Oligocene due to the latitudinal shifts of the south-westerly winds with respect to the Drake Passage.

Welcome to the Thermocene: the potential impact of global warming on the sedimentary record

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Much has been made of the Anthropocene and how, millions of years from now, alien geologists will use plastic debris to reconstruct recent Earth history. However the early Plasticene is only a thin sliver of the overall Holocene stratigraphy, and of equal importance is what overlies these beds. Whether or not you believe that man is responsible for global warming, ongoing climate change will also leave its signature in the sedimentary record.

While the precise nature of changes in weather patterns is not fully understood, there is already clear evidence of increases in flooding around the world. These inundations are matched by longer and more extensive droughts in other regions. Storms are of greater magnitudes and severity, with markedly larger storm surges, and the consequent uplift in rainfall is triggering more landslides. Hurricanes are already thought to have increased in size by around 50% since written records began. Overall there is a mappable rise in weather related disasters since 1980. Taking this as a starting point, what deposits are likely to be preserved over the next 200 years and what will they look like?

Organisms are also being affected, and probably the greatest biological impact on the geological record is the mass extinction of corals. It is thought that around 1% of coral is dying off each year due to warming and acidification of the oceans, bleaching and pollution. What will post coral, tropical coastlines look like, and what deposits will be preserved? In temperate settings there will be significant changes in erosion and depositional patterns, while at higher latitudes we can expect a return to a Cretaceous world devoid of glacial deposits.

Utilizing notional transects running from source to sink, a series of sedimentary profiles have been erected to highlight the potential succession of deposits ranging from flood deposits, arid aeolianites, tsunamiites and coastal shoreface settings through to hurricane and storm deposits. Obviously these extreme event beds will be superimposed on more normal, background deposits. Estimates will be made of the relative thickness of the event beds, and whether it will be possible to use these sediments to discern the Thermocene Epoch from older Pleistocene deposits. Finally we will look ahead to envisage the geological aspects of a greenhouse world where temperatures remain unchecked.

Figure 1. Hurricane Katrina, 2005 (Wikipedia

Are mass-transport complexes (MTCs) strongly erosive? Insights from 3D seismic reflection data

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Mass-transport complexes (MTCs) are a key component of many deep-water successions, with individual deposits covering areas >100 km^2 and comprising volumes >10,000 km^3. MTCs may pose a significant hazard to coastal communities and offshore infrastructure, most notably through tsunami generation and seabed failure, respectively, making it important to understand the full spectrum of depositional processes, and forecasting runout distances. For example, while debris flows are typically interpreted as the result of laminar flow, seismic reflection and field data often indicate extensive, deep erosion during MTC emplacement. Also, MTC volume estimations are typically uncertain, and potentially underestimated, especially if only the size of the evacuation zone is considered. The proliferation of 3D seismic reflection and bathymetry data in the 1990's has enabled the geometries and volumes of MTCs to be evaluated more thoroughly than before. Here, five 3D seismic reflection cubes, have been used to investigate the recent Gorgon Slide (>65 km long, up to 20 km wide, 1,593 km^2, 500 km^3), offshore NW Australia. This study focuses on the discrepancy between the deposited (Vd) and evacuated (Ve) volumes. A new measure, Vd/Ve ratio, is introduced as a first order estimate to quantify the degree of substrate entrainment during emplacement of MTCs, where Vd/Ve>1 would suggest substrate entrainment and flow bulking during transport. Even when three different methods of volume calculation are applied (i.e. bulk, compacted, and theoretical volume calculations), the Vd/Ve ratio of the Gorgon Slide is > 1 (up to 11.95). Based on peer-reviewed literature, c. 85% of MTCs display strongly erosive bases and an average Vd/Ve of 2.13, with the final MTC volumes being approximately twice their initial failed volume. The very high Vd/Ve ratio of the Gorgon Slide (c. 11.95) suggests that this could be one of the most bulked up MTCs ever documented. The two cases where Vd/Ve<1 implies a volume loss during transport, which may reflect: (i) pore volume reduction due to continuous shearing during transport (i.e. shear compaction); (ii) partial flow transformation to a turbidity current; and/or (iii) subsequent MTC subduction or erosion. Vd/Ve ratio has no clear correlation with evacuated volume, degree of disaggregation (MTCs head-scarp height/length ratio) or run-out distance, suggesting these parameters do not control the degree of erosion at the base of MTCs. Instead, MTC basal erosion is more likely to be controlled by the lithology, its cohesion, and, thus the rheology of the failed sediment mass, substrate lithology, slope angle and bathymetric confinement.

Sedimentary Systems in a State of Anthropogenically Induced Change: Surveying the Earth through 30 Years of Satellite Imagery

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Society develops in response to sedimentary systems. At the same time these systems are increasingly modified by society. . For example, management of hydrological systems to meet water resource demands (e.g., dams, canals, weirs, etc…) reduces and restricts sediment supply to deltas and floodplains, thus increasing vulnerability of population, infrastructure and agricultural land to future flood events, land retreat and sea-level rise. In response, water diversion, land reclamation, river, barrier and coastal armouring are a few of the numerous techniques used to manage and protect coastal and deltaic sedimentary environments to preserve human livelihoods. Given that nearly a third of the world's population, ~22% of the world's cropland and ~21% of the world's pastures are supported by sedimentary systems that cover no more than 16% of Earths landsurface, it is imperative to study the influence of anthropogenic activity on sedimentary systems. However, relatively little is known from a global and quantitative perspective on the extent of the anthropogenic activity on sedimentary systems, and vice versa.

Here we show how recent advances in analyzing the spatial-temporal change in 30 years of satellite imagery by the Google Earth Engine can highlight anthropogenic influence on the surface geomorphology of sedimentary systems. Focusing on deltaic environments, the historical imagery show that upstream capture in water by dam constructions has a direct and observable impact on the propagation of downstream sedimentary successions. A decrease in both water discharge and total suspended sediment supply are a primary factor responsible for net land loss in coastal environments. As sea-levels are expected to rise and dam construction predicted to grow, half a billion people living on deltaic environments are of increasing risk to climate change.

Geomorphic evolution of Miocene submarine channel systems and implications for stratigraphic architecture; Taranaki Basin, New Zealand.

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Submarine channels are important conduits for sediment transfer from the shelf to the basin floor. Their planform at the seabed superficially resembles that of rivers, but, the transfer of this geomorphological expression into stratigraphic record is poorly-understood. To address this, a quantitative, borehole-calibrated, seismic geomorphological analysis of Middle Miocene submarine channel systems is presented that uses a high-resolution, post-stack, time-migrated, 3D seismic reflection cube (c. 1,500 km^2), and, well-logs and cuttings data from seven exploration and appraisal wells. Seismic attribute analysis utilising seven seismic horizons (H1 – H7) within two seismic units (SU1 - 2), allow identification of three main depositional elements (channels and intra-channel, levee/overbank, and slope/basin-floor).

SU1 contains N-trending, moderately sinuous (sinuosity index (SI) = 1.15), levee-confined channels with an average width and thickness of c. 342 m and 35 m, respectively. Several N-trending, partly coalesced, highly sinuous (SI=2.25) channel complexes are also observed in SU1. Attribute maps of SU1 channels shows bright amplitudes within the channel and channel belts, and within flanking overbank/levee environment. SU2 contains NW-trending, low sinuosity (1.01 – 1.40), erosionally-to-levee-confined channels that migrate laterally and stack vertically, forming channel complexes confined to a slope valley, these channel complexes are on average, c. 324 – 1080 m wide and c. 32 – 104 m deep respectively. Attribute maps of SU2 channels shows bright amplitudes mostly in the overbank or levees environment, with the channels themselves being only weakly reflective. Well-logs and cuttings suggest the channel-fills deposit are dominated by sandstone, muddy-sandstone, siltstone and claystone, with an overall upward decrease in sandstone content. Cuttings information from two wells show the levee/overbank deposit to be characterised by muddy, very fine-to-fine-grained sandstone interbedded with siltstone and claystone.

The main differences between SU1 and SU2 channel complexes are (i) palaeoflow direction, with a northerly direction in SU1 suggesting a southern sediment provenance and north-westerly direction in SU2 suggesting a sediment provenance from the SE; (ii) the high sand-to-shale ratio in SU1 channel complex-fills, as defined by a dominantly blocky, GR log signature, compared to SU2 channel complex-fills, which have a lower sand-to-shale ratio and are defined by an overall bell-shaped GR log signatures; and (iii) the degree of confinement and related channel-complex stacking, with SU1 channel complexes being unconfined and characterised by lateral migration, and SU2 channel complexes being confined to valleys. We infer that reasons for these changes in orientation, scale and architecture of the channels are related to (i) a gradual change in basin and hinterland geometry during the middle Miocene, which led to a pulse of coarse clastic input into the basin (ii) a fall in relative sea level.

We conclude that the internal stratigraphic architecture of submarine channel complexes records changes in the geomorphology of individual submarine channels as they migrate laterally and stack vertically. A key observation is that, the mapped basal erosion surfaces are therefore highly time-transgressive, which has implications for the timing and location of down-dip sands.

Width variation around submarine channel bends

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Submarine channel evolution observed in three-dimensional seismic reflection data suggests that bends evolve primarily via lateral bend expansion rather than dominantly through downstream migration as occurs in most rivers. However, numerical simulations and laboratory experiments of submarine channels capture a downstream bend-migration, reflected in process-based models. This enigma suggests that a key part of our understanding of submarine channels is missing. Here we note that a constant channel width has been used in all of the experiments and numerical simulations, and ask if this is realistic for submarine channels, and if it is not whether variations in channel width around bends might be key to solve this enigma. In this study, our aim is to identify the nature of channel width variation around submarine channel bends. The dataset consists of 108 bends from three inactive channels, and one active channel, from the axial Congo Submarine Fan. Each bend was divided into 13 cross-sections from upstream to downstream inflection point and at each cross-section, channel width was measured from channel bed to channel banks, at height intervals of 10 metres. The results of the study have identified that submarine channels almost never exhibit constant width around bends, and thus the assumption implicit in the numerical and physical modelling results is incorrect. Submarine channels display variable width around submarine channel bends, with variations within bends with increasing height above the bed, and between bends within a given reach. These observations have implications for the flow and sedimentation processes around submarine channel bends and can be used as input for more realistic numerical models and laboratory experiments. Such physical and numerical modelling will allow the hypothesis to be tested that width variation around bends holds the key to the present enigmatic observations.

Microplastics in the natural environment – challenges and opportunities for sedimentology

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It is estimated that there is currently over eight billion tonnes of microplastics in the Earth system, with projections of 40 billion tonnes by 2050. Despite these large quantities, and the recent high-profile political attention given to reducing plastic waste in the UK's 25-year environment plan, the pathways, transformations and ultimate fate of these plastics in the environment are poorly understood. Plastics reaching the oceans amount to around 10 million tonnes a year, but this is dwarfed by the amount of plastics at or near the Earth surface (around three billion tonnes) and locked away in landfills (around five billion tonnes). As these deposits are released, the flux of plastics to surface waters, coastlines and oceans is amplified with significant environmental, social and economic costs. There is thus a pressing need to address the gaps in our knowledge of how plastic behaves in relation to all aspects of the Earth's natural environment so that workable interventions can be developed. Sedimentology is one key discipline that can assist in understanding the answers to some of the key, but outstanding questions. What is the nature and scale of plastic sources to the Earth system? What are the main pathways of plastics across the Earth system? What are the potential stocks and flows of plastic between terrestrial, freshwater and marine systems? What are the key physical mechanisms that control fate, behaviour, concentration, decomposition, distribution, and transport over various timescales? What environmental processes promote their degradation or fragmentation? At what point, if any, do plastics no longer interact with the environment and cease to present a risk to the biosphere? Here, an overview of these challenges, and some potential solutions, are presented, with the aim of motivating the sedimentological community to assist in addressing this societally important issue.

Taking the heat out of clumped isotope paleotemperatures from concretions

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Thought to be mineralized by-products of microbial activity, ancient carbonate concretions may provide a freeze-frame of the ambient environment and microbial communities involved in their formation.
Many shale-hosted concretions contain distinctive septarian fractures, which are typically infilled with early diagenetic brown fibrous calcite and/or later (burial) diagenetic sparry calcites. Pore fluid evolution can thus be deciphered from the geochemistry of the concretion matrix carbonate and the successive fracture filling cements. Over the last 70 years, pore fluid conditions have been interpreted using traditional stable isotopic techniques, which usually rely on estimations of paleotemperature or water isotopic compositions. Interestingly, recently published clumped isotope formation temperatures from concretion bodies and syndepositional fracture fills in Jurassic Oxford Clay concretions, disagree with geologically rather well-constrained 'traditional' paleotemperatures. This impasse in approach is the focus of our wider research project.
This part of our study focuses on shale-hosted septarian concretions from the Upper Jurassic Oxford Clay and Ampthill Clay of southern England and the Staffin Shale Formation of Skye (Scotland). The evolution of concretion cementation is being examined using clumped isotopes, allowing the reconstruction of mineralization and cementation temperatures and $\delta^{18}O_{FLUID}$ compositions of the concretions and fracture fills.
We have already established that clumped isotope analysis of calcite phases contaminated by clay and/or organic matter gives what appear to be spurious (unreasonably cool) values. We think this is due to contamination and we are currently working on protocols to recover more meaningful data from such phases.
Initial results on clean burial diagenetic sparry calcite fracture fills from Oxford Clay concretions are much more encouraging. The data suggest the spars were precipitated at temperatures between 20°C and 32°C, with $\delta^{18}O_{FLUID}$ compositions ranging from -5.2‰ to -6.6‰ (VSMOW), indicating a meteoric fluid source; both geologically reasonable outcomes. Ampthill Clay concretions yielded similar results, with formation temperature around 27°C and $\delta^{18}O_{FLUID}$ composition of -6.8‰ (VSMOW).
Sparry calcite from a Staffin Shale concretion was apparently precipitated at cooler temperatures (11.5°C) from a fluid with less negative $\delta^{18}O$. Moreover, results from the outermost edge of the early diagenetic brown fibrous calcite in this concretion, a phase thought to have begun precipitation concurrent with concretion formation, suggest a temperature of 26°C and a more marine pore fluid composition (+2.4‰ VSMOW). This sample may have yielded a geologically reasonable temperature because contamination was low (based on less opaque cement colour).

Groovy soles: Why the Bouma sequence is wrong

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Since Kuenen's famous 1953 paper, flutes and tool marks in deep-water systems have been linked to turbidity currents, as reflected in the standard Bouma sequence taught to generations of geologists. As part of this paradigm flutes and tool marks are thought to only be cut by the head of the turbidity current, and the overlying sediments are deposited very soon afterwards. Here we demonstrate that all of these long-held axioms of sedimentology are wrong. The certainty in interpretation of sole marks has meant that these sedimentary structures have all but been forgotten – no meaningful work has been undertaken on them for almost 45 years! They are sedimentology's 'great unloved' – forgotten alongside many of the pioneers who worked extensively on them. In contrast to ripples and dunes and other aggradational bedforms that continue to be the focus for much research, and a number of recent major breakthroughs, sole structures are solely (pun intended) used for palaeocurrent analysis. Groovy soles (grooves) and the closely related chevrons, offer perhaps the greatest example of how the current paradigm is incorrect; albeit other tool marks, and even flutes themselves do not conform either. Here we demonstrate that grooves are the product of debris flows, not low or high-density turbidity currents as has been thought. In turn these debris flows are mostly linked to the debritic components of hybrid flows. Thus the erosional surface composed of grooves and chevrons is unrelated to the turbidity current deposits that typically overlie them, as encapsulated in the Bouma sequence. Instead they reflect two entirely different processes, and a substantial temporal gap between them. In some cases, we argue that the erosive surface and the overlying deposits are the products of entirely separate flows. Another key implication of groovy soles as the product of debris flows, is that some of the more advanced models of hybrid flows are incorrect, based as they are on the current paradigm that grooves are the product of turbidity currents. Additionally, where present on the same surface, flutes cut tool marks and vice-versa, reflecting longitudinal transformation of the flow, and demonstrating conclusively that such sole marks are not universally formed at the head of a turbidity current. This work therefore demonstrates that sole marks can be used for far more than palaeocurrents. They can be used to provide key information about the flow dynamics during formation, and enable improved prediction of sedimentary deposits both up- and downstream.

The results described in this talk are part of a larger radical reinterpretation of flutes and tool marks that for the very first time explains the observations of their spatial and temporal distribution. The basic observations that: i) flutes are formed in thicker more proximal beds, and that tool marks form in thinner more distal beds; ii) flutes and tool marks are rarely formed on the same surfaces; and iii) flutes can cut tool marks or vice-versa, have been known since the early 1970s yet have proven to be enigmatic. For the first time we provide a process-based model that explains all of these observations.

Depositional model for the Louann Salt Supergiant Evaporite: hellish, hot and fast

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The present is the key to the past… unless the geological event has no modern equivalent. Existing models for deposition of giant salt deposits, such as the Mid-Jurassic Louann Salt of the Gulf of Mexico, have been built on observation of modern evaporite environments, and this has led many to believe that salt deposition was slow, spread over a very long time (many millions of years), and in shallow water; but the modern analogues are misleading.

Pulham et al. (2016) demonstrated that the onset of Louann Salt deposition occurred at 170Ma (Bajocian). This places its context in a supercontinent on the point of break-up during a global hot period, for which there is no modern analogue. A set of long, narrow marine basins formed along the incipient breakup, creating a narrow, deep, seaway, connected via a series of choke points to the source of seawater, the Neotethys ocean. This marine connection lay within the arid tropics and was surrounded by hot and dry desert; as marine water passed along the chain of basins, it would have experienced evaporation and brine concentration. Our mapping indicates that the final part of this water flow, the connection to the proto-Gulf of Mexico basin, was via a constricted waterway through a series of narrow rift valleys. Consequently, it is likely that the water entering the basin was already strongly concentrated relative to seawater, and that the connection was one-way (no reflux).

Given these conditions, our models of evaporation strongly indicate salt precipitation was very rapid - perhaps of the order of meters per year - so that deposition of the entire 3-5km thick salt mass could have been achieved in as little as a few thousand years. When water supply was cut off, the basin dried out, leaving a hot, dry and in places very deep hole, surrounded by a global scale desert. High temperature and air pressure amplified the effect of regional winds; extreme wind conditions are indicated by sand dunes large enough to be seen on seismic data, that are more than three times the height of the largest dunes seen on the modern earth's surface.

The Dakota Sandstone a transgressive shallow marine system of the San Rafael Swell region, Utah, U.S.A.

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Transgressive shallow marine systems are less well-studied than their regressive counterparts. More focus is needed on these systems as they can be highly variable. The rocks of the Dakota Sandstone of the western San Rafael Swell region (including the northern Henry Mountains Basin) provide an ideal case study. The Dakota Sandstone records the transition between the fluvial systems of the Cedar Mountain Formation and the offshore marine deposits of the Mancos Shale. This transition occurred as a result of the flooding of the Cretaceous Western Interior Seaway of the USA.

The Dakota Sandstone is composed of dominantly tidal deposits with subordinate tidally influenced fluvial deposits. It is composed of several facies associations that are arranged in a predictable manner. Where present, tidally influenced fluvial deposits form the base of the formation. Sigmoidal and compound dune subtidal bars overlie these fluvial deposits. Associated with the subtidal bars are intertidal point bars composed of inclined heterolithic stratification as well as bedded coals and carbonaceous mudstones that represent coastal plain deposits. The uppermost surface of the Dakota Sandstone is sometimes capped by a thin transgressive lag composed of shell debris, and/or pebbles, that marks the final transition into the fully marine Tununk Shale Member of the Mancos Shale. Tidal indicators are present throughout the formation: mud or carbonaceous debris draped ripples and dunes, bi-directional flow indicators, sigmoidal and herringbone cross-stratification, and wave rippled sandstone. Paleocurrent data supports the idea of a tidal origin for these sandstones. An estuarine environment is favored due to the areal distribution of the tidal deposits, and the increasing marine influence up section. Virtual outcrops provide a mechanism for digitally capturing the outcrops and can be used to better understand vertical and lateral relations of each facies association. Fluvial deposits of the Dakota Sandstone to the east of the study area have a limited lateral extent but are typically less heterolithic than the deposits around the San Rafael Swell. Tidal deposits of the San Rafael Swell tend to have a more heterolithic nature but, have a much larger lateral extent. Marine shoreface sandstones of the Henry Mountains Basin are the most laterally continuous and are much thicker than deposits elsewhere in the study area. In two areas, the Dakota Sandstone is thin to absent. These locations are at the northern tip of the Henry Mountains Basin and on the eastern flank of the San Rafael Swell where Interstate 70 crosses the outcrop belt. A pre-Laramide tectonic history for the San Rafael Swell could explain the lack of Dakota Sandstone at these locations as well as the thicker succession and preservation of shoreline deposits in the Henry Mountains Basin.

Quantification of structural impact on the distribution and architecture of deep-water systems in the Niger Delta

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In the last two decades researchers have shown great interest in understanding the tectono-stratigraphic evolution of deep-water environments. Many of these locations are found on continental passive margins where thick sedimentary clastic prisms have developed on top of either salt (Gulf of Mexico, Angola, Brazil) or shale (Nigeria and NW Borneo) layers. Over time these layers act as mobile substrates and, in shale detachment settings, gravity-driven deformation produces large deep-water fold and thrust belts. As deep-water sedimentation occurs at the same time as structural growth, understanding and quantifying the rate and style of deformation, and its impact on sedimentation has become an increasingly important research aim. In this study we focus on the deep-water fold and thrust belt of the southern lobe of the Niger Delta to (i) quantify the structural evolution of folds and thrusts in time and space; (ii) investigate the relationships between the magnitudes and rates of deformation and the distribution of turbidite channels and (iii) show how this interaction controls the stratigraphic architecture of deep-water elements.

The fold belt has developed since middle Miocene times and is imaged by a 3D seismic survey covering an area of 6200 km^2. Thrust faults, oriented perpendicular to the slope, have controlled the distribution of the main depositional elements. Using data for 7 key horizons, we calculated strain along the strike of the major thrusts from 17 dip-oriented seismic sections, using the principles of line-length balancing. From this, we evaluated cumulative strain profiles over time and along-strike for each structure, and quantified interval strain rates. In general, the growth of the fold- thrust belt followed a low-high-low (up to 7% Ma^{-1}) strain rate pattern, however, not all the structures were active at the same time and for each time interval strain rates varied both between and along the strike of the same structures.

Seismic mapping was conducted simultaneously with the strain analysis to subdivide the stratigraphy into major units. The sedimentary record is divided in a lower pre-kinematic section, where obvious growth strata are not visible, consisting of localised large fans and numerous small, linear turbidite channels. This contrasts with the upper syn-kinematic section consisting of larger and more localized channel complexes showing variable amounts of either aggradation (levees) or incision. The upper section also comprises smaller sheets locally ponded around growing structures. Our results demonstrate that deformation controlled the location and distribution of the sedimentary systems, even during the initial period of slow growth. In particular, strain rates of 1% Ma^{-1} were sufficient to deflect channels into the strain minima between growing folds. Our results give new insights into the growth of thrust faults in gravity-driven settings, demonstrate that submarine systems are sensitive to deformation even when shortening and strain rates are low, and allow us to quantify how deformation influences stratigraphic architectures in deep water systems.

Controls on the formation of turbidity current channels associated with the Greenland ice sheet

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Submarine channels are a common feature of the world's oceans where large volumes of sediment are introduced into coastal waters, or where continental shelf and slope processes are episodic such as the advance and retreat of ice sheets. These channels, and the sediment density flows which navigate them, act as conduits for the transport of sediment, macro-nutrients, fresher water and organic matter from coastal environments to deeper waters. Where submarine channels are fed by rivers, their presence is commonly linked to rapid deposition of large volumes of sediment on sufficiently steep offshore gradients, leading to slope failures or plunging river flood discharges. However, the exact conditions that permit or prevent submarine channel formation in these locations remain poorly understood. In contrast, to the world's largest rivers, submarine channels are rarely associated with the largest ice streams and the trough-mouth fans which they produce. Nevertheless, perhaps the world's longest submarine channel, the Northwest Atlantic Mid-Ocean Channel, is found on a glaciated margin. The controls on submarine channel formation on glaciated margins are therefore even less well understood than river-fed margin.

Using a remarkably extensive bathymetry dataset from offshore Southeast and Northwest Greenland we investigate the controls on channel formation in fjords fed by marine-terminating glaciers. We investigate the impact of ice sheet history, climatic setting, drainage basin size, meltwater and ice discharge rates, and fjord morphology on the formation of submarine channels. Our analysis shows that channels only form where glacier stillstands have occurred as documented by moraines or grounding zone wedges. Fjords must also slope consistently seaward with gradients in excess of 1° and not contain overdeepenings. Our analysis also suggests that channels are more likely to be found in warmer climatic settings where meltwater sedimentation is more prevalent and are generally associated with larger catchments with greater ice and meltwater fluxes at the terminus.

Differential subsidence controlling sediment distribution and reservoir quality in transgressive shallow-marine systems: a case study from the Lower-Middle Jurassic Stø Fm (SW Barents Sea, Norway)

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Transgressive shallow-marine systems are often challenging to interpret in subsurface, due to their common amalgamated, low-gradient nature, often below seismic resolution. Detailed studies of such systems are therefore scarce, and their depositional architecture, facies distribution and reservoir properties often poorly understood.

The Lower-Middle Jurassic Stø Formation, within the Realgrunnen Subgroup, is one of the most prolific reservoir packages of the SW Barents Sea. Due to its highly condensed and low-gradient nature, it is hard to recognize internal characteristics on seismic, but distinctive well log patterns distinguish the Stø Formation from the underlying units. Thickness information from correlating well and seismic data shows an overall W-E thinning, although the formation is present in most of the basin.

Core facies analysis reveals a relatively thin, clastic nearshore to inner shelf succession, deposited on a shallow epicontinental platform, with wave-dominated clastic offshore to foreshore deposits, with local storm-generated beds and tidally-influenced deposits. Common marine macro-fossils, chamositic and glauconitic grains and authigenic phosphate occur in distinct beds, with several horizons of extraformational pebble grade conglomerate, suggesting a balance between sediment input and basin subsidence. Stacking patterns reflect variations in relative sea-level during an overall transgressive regime, punctuated by progradation of individual parasequences, with regional flooding surfaces and extensive depositional hiatuses.

The succession is divided in different sub-units that allow studying the facies and thickness distribution of the Stø Formation through time. Regional correlativity of most units across the study area suggests synsedimentary faulting did not isolate different depozones, although it contributed to the local creation of higher accommodation conditions, with consequent facies and thickness changes. Analysis of the porosity/permeability of sandstones evidences tectonic uplift and differential subsidence were also a first order control on reservoir properties, as they controlled the reworking of older strata. But the considerable variability of reservoir quality within the same stratigraphic interval evidences that provenance, depositional environment and process regime also acted as second order control, evidencing the need to integrate multiple techniques to critically evaluate the presence of several factors controlling sediment distribution and reservoir quality in other transgressive shallow-marine systems.

A multi-scale approach to ephemeral fluvial-aeolian interactions: Implications for reservoir characterisation

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Endorheic dryland sedimentary basins commonly comprise sedimentary fill from both fluvial and aeolian environments and while the preserved facies associations within each environment, and their broad scale interactions has been studied in great depth, past work has not considered the strongly ephemeral nature of the fluvial systems or the impact of the interactions at multiple scales on reservoir characterisation and migration pathways. We present results from extensive fieldwork studies of sedimentary interactions between the deposits of fluvial and aeolian systems from the Kayenta Formation of the Colorado Plateau, USA, along with insights into the allocyclic controls upon them.

The Kayenta Formation comprises fluvial-aeolian associations of highly varied reservoir quality. Relationships between them are spatially predictable, governed by one system's dominance. The temporal evolution between systems preserves unique facies, but a switch in dominant system takes place quickly, severely limiting the vertical extent of interactions and potentially isolating reservoir intervals of basin fill. Complex interactions between ephemeral fluvial and aeolian environments are present throughout the whole expanse of the Kayenta Formation and occur at a variety of scales, from small-scale reworking of aeolian sediment into the fluvial system, to large-scale intertonguing of the aeolian and fluvial strata within the top third of the Kayenta.

Field data coupled with three-dimensional photogrammetric models allow reconstruction of ancient channel forms and dune fields, providing quantitative data on architectural elements for reservoir models. Statistical analysis of these data provides a framework for calculating likely sizes and geometries of equivalent elements recognised in subsurface core, to provide representative input for reservoir models. Understanding the interactions between fluvial and aeolian environments, at multiple scales, is vital in accurate reservoir characterisation and determining permeability pathways.

Our work is applied to a case study of core from the Lower Permian Leman Sandstone of the Rotliegend Group, a principal gas reservoir in the Southern North Sea Basin, to reconstruct geometries and dimensions of elements for reservoir characterisation, in order to further enhance recovery from this longstanding and exploited resource.

A system scale study of a plan view characterisation of meander deposits

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Understanding the planform of fluvial deposits has important implications when trying to understand sandstone body shape, dimensions, connectivity and internal variations of key reservoir bearing deposits. Recent remote sensing work has shown that meandering fluvial deposits can constitute a large proportion of sedimentary basins, and should therefore constitute a significant proportion of the fluvial rock record. However, meandering systems are underrepresented in the rock record which has been attributed to the fact that a typical one-dimension sedimentary log for braided and sandy-meandering systems are very similar in nature, and without large scale detailed mapping or planform exposures misinterpretation for braided deposits can be made.

This remote sensing based study looks to characterise meander deposits from both modern and ancient datasets within a spatial context to understand whether there is a spatial control on fluvial meandering characteristics. Key characteristics analysed include meander size, migration type and migration rate in a downstream transect. Two systems were analysed within this pilot study, the modern Bermjo River in the Andean Basin and the uniquely exposed Late Jurassic aged Salt Wash fluvial system of south-western USA.

In the modern Bermojo River, meander bend migration through expansion, rotation and translation is observed and although meander migration through expansion dominated, no downstream trends can be observed. In addition, the size of the active and abandoned meander deposits does not substantially change across the 740 km length of the system. Similarly, no downstream trends in meander migration type and size is observed in the Late Jurassic aged Salt Wash fluvial system dataset. However, meander bend migration rates during the time period 1984 – 2016 for the River Bermejo did vary considerably across the system.

These results have important implications with regards to understanding point bar and channel body dimensions within the rock record. In addition, valuable insights into fluvial morphodynamics and hazards associated with the flooding and erosion of river banks can be gained by undertaking system scale analyses of modern fluvial systems.

THE ODYSSEA DRIFT (ROSS SEA, ANTARCTICA)

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The Hillary Canyon is one of the main conduits for dense shelf water forming in the Ross Sea, which over-flows the shelf edge and transforms into the Antarctic Bottom Water (AABW). The main changes in past ocean circulation are recorded in the adjacent ODYSSEA Contourite Depositional System that is located at 2000-3000 m depth west of the Hillary Canyon. Seven depositional units are identified in the seismic data. Unconformity UR3 marks the transition from the lower units with thickness controlled by basement depressions to the overlying units that conversely present many lateral thickness variations not clearly associated with the underlying topography or active tectonics. The sedimentary succession above UR3 is, hence, interpreted to be controlled by bottom currents and gravity flows. In particular, a series of mounds, 2 to 5 km wide and between 50 and 200 m high, are elongated in NNE direction, obliquely with respect to the continental slope. They are separated by erosional (turbiditic) channels and landslide scars and interpreted as small mixed sediment drifts. Prominent landslide scars and a giant landslide deposit over 200 m thick and covering 750 km^2, are also visible. The gravity cores show sedimentary facies typical of contourites including well-developed planar laminations. Local cross bedding suggests a dynamic bottom environment. The oceanographic data show that the ~200 m thick bottom layer is occupied by AABW (with potential temperature < 0° C). In that layer at the base of the slope, flow speed recorded by the Lowered Acoustic Doppler Current Profiler is larger with respect to the upper layers, and reaches about 30 - 35 cm/s. Near bottom currents are weaker further offshore. The energetic mixing between the along slope current and the down slope currents coming from the continental shelf, increases the turbidity of the bottom boundary layer. Our results will be merged with those obtained from the 2018 IODP drilling expedition 374 to develop a conceptual model of sediment deposition relating marine-based ice sheet and oceanic processes along the Ross Sea continental margin during the Neogene and Quaternary.

The Analysis of Grain-Size in Siliciclastic Systems - a step Forward? Applications to Paralic Systems

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Analysis of grain-size is central to clastic sedimentology. Coarser sediments generally indicate more proximal settings or movement by stronger currents, so that bed-scale fining-upwards trends are recognised as the product of waning flows, and large-scale coarsening-upwards trends are interpreted to reflect progradation of entire depositional systems. Such models are invaluable in deciphering depositional history. In general they are applied following recognition of vertical grain-size trends rather than a detailed description of the actual grain-size.

This talk argues for a break from that tradition and uses outcrop examples from paralic systems to show that a detailed, quantitative record of absolute grain-size has significant value. The approach has opened up several avenues of interest. For example, it appears that grains of different size partition in a consistent manner along systems tracts and in to given depositional elements. The data have also allowed (for the first time?) analysis of downstream fining rates, provided a robust means to calculate the overall grain-size of depositional systems, and informed a view of the influence of stratigraphy on grain-size trends.

Data collection is simple, if somewhat laborious. Conventional sedimentary grain-size logs are digitised to allow the calculation of thickness-weighted grain-size proportions for intervals of interest - facies, facies associations, and interpreted depositional or stratigraphic elements. The approach is illustrated by five case studies founded on “type logs” and extensive correlation panels in the published literature: major studies of the Cretaceous Ferron Notom and Last Chance deltas, reviews of the Jurassic Ravenscar Group and the Late Miocene and Pliocene Orinoco delta, and a focused study in the Book Cliffs.

Though the approach appears to have significant value in the presented case studies, three broader questions have arisen over the likely quality of data generated in the manner proposed: (a) are published logs robust to detailed grain-size analysis; (b) are high quality type logs representative of grain-size patterns, and (c) how accurately do different sedimentologists record grain-size, would 100 geologists all record a given sample as being vfl in grain-size, what might the spread of values be? At present, answers are respectively: some are; probably and don’t know.

Muddying the picture? Identification of particulate sources, and forecasting sediment dispersal and concentration in catchments

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One of the major uncertainties facing the global water industry is forecasting the distribution and impact of particulates and pollutants in the water supply system. Advances will require a whole system approach to improve evaluation of their source areas, and entrainment, transport, and deposition processes, over different temporal and spatial scales in order to manage catchments in an integrated way. Fine grained sediment (as a diffuse pollutant) is a common reason for a waterbody in the UK to fail to reach a good ecological Water Framework Directive (WFD) standard. However, mapping of erosion hotspots using digital elevation model (DEM) data rarely integrates seasonal variation in discharge, future climate change scenarios, or artificial drainage networks, and typically results in a single output map. High resolution satellite imagery and climate change projections improve our ability to map sediment sources and pathways at higher resolutions.

The Yorkshire River Derwent, UK, is dominated by large areas of lowland agricultural land and has a recognised fine grained sediment problem that impacts water treatment costs and ecological standards. Erosion hotspot mapping was undertaken using satellite imagery from 2016. A range of scenarios were tested against traditional erosion risk mapping outputs to understand variation in erosion risk under different conditions; 1) seasonal land use maps vs. traditional static land use maps; 2) monthly rainfall data vs. long term average; 3) current climate data vs. climate change projections; and 4) incorporating the artificial drainage network. Outputs from the modelling indicate there are clear spatial and temporal trends in erosion risk within the catchment, which are not picked up by using traditional methods. When using climate change projections the source areas are unlikely to change, although the volume of sediment may increase. In addition, modelling often underestimates the contribution of erosion risk in lowland areas due to the bias in gradient and due to the lack of incorporation of artificial drainage, which increases connectivity. Output data was compared to sediment sensitive species to ground truth the modelling. By producing end member scenarios, model outputs help inform where catchment management should be targeted, and if the interventions should be seasonal or not. This information is vital to show landowners, who will often lose productive agricultural land in order to put in place catchment management such as sediment traps and earth bunds.

Traditional erosion risk modelling needs to be adapted to incorporate artificial interference, in which human activity is impacting the 'natural' sediment source-to sink-process by producing new pathways and stores due to land use and management.

Unusual Messinian-aged stratiform manganese deposition in NE Cyprus related to cyclical redox changes in a silled marginal-marine carbonate basin

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The late Messinian salinity crisis in the Mediterranean, associated with eustatic sea-level fall, desiccation and evaporite accumulation in as international cause célèbre. During the preceding Messinian time interval (c. 7.25-5.97 Ma), a wide range of bathyal to shallow-marine and even hypersaline deposits accumulated, including pelagic and hemipelagic carbonates (marls), organic-rich muds (sapropels), siliceous deposits (diatomites) and localised marginal evaporites. Here, we document and interpret a very unusual occurrence of stratiform manganese deposits within early Messinian (<6.82 Ma) hemipelagic carbonates. The Messinian-aged manganese deposits occur as six main laterally continuous beds (up to 80 cm thick). Compositionally, they are dominated by poorly crystalline manganese oxy-hydroxide (birnessite), with associated mild enrichment in some trace elements (e.g. Ba, Ni, Cu, Mo, As, U). Background minerals are mainly magnesian carbonate, together with minor kaolinite, chlorite, mixed-layer clays and talc (serpentinite-derived). The manganese accumulated during a time of increasing isolation of the Mediterranean Sea from the Atlantic Ocean but prior to major sea-level fall and evaporite precipitation. A small, silled marginal-marine basin is inferred to have existed; this alternated between, first, well-mixed and oxidising, and, secondly, stratified and oxygen-depleted at depth. Manganese entered the basin following pedogenesis in a fluctuating warm-wet to warm-semiarid climate. After entering the marine basin, the manganese was retained in solution below the chemocline during stagnant low-oxygen periods. Manganese oxy-hydroxide (and associated trace elements e.g. Mo>U) accumulated, together with hemipelagic carbonate, during periods of oxidising seawater influx. To allow the repeated formation of manganese layers, with up to c. 20% MnO, we propose that soluble manganese fluxed upwards from a suphidic environment beneath. The likely source reservoir was Messinian-aged sapropels (organic-rich sediments) that are exposed in subjacent sections. The manganese precipitation events diminished through time giving way to well-oxygenated hemipelagic carbonate accumulation, with bioturbation and a shelly infauna. Gypsum appears abruptly upwards above the hemipelagic sediments in adjacent sections. Rather than relating directly to desiccation, the unusual Mn deposition records an extraordinary interplay of tectonically controlled basin formation (regional to local scale), changing ocean hydrology, climatic change (local to regional), chemically suitable source rocks, and particularly the inferred upward diagenetic supply of dissolved manganese from sapropels beneath. The regional tectonic setting of the Messinian-aged (pre-evaporitic) basin formation in N Cyprus relates to the latest stages of northward subduction of the Southern Neotethyan ocean, as a precursor to collision of the African and Tauride (Eurasian) plates.

New constraints on source to sink systems of NW Africa: provenance analysis of the Mesozoic post-rift evolution of the Essaouira-Agadir Basin

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Recent thermochronological work has established several uplift phases in the main orogenic belts of Morocco (the Moroccan Mesetian and Atlasic domains). The results identify: (1) km-scale uplift and subsidence episodes recorded during the post-rift evolution of the margin (Jurassic to Lower Cretaceous) and (2) well-constrained highly asynchronous dynamic vertical movements in the northern (Meseta and Western High Atlas) and southern domains (Anti-Atlas and Reguibat Shield). This evolution highlights a more tectonic active flank of a passive margin than previously recognised, which will have controlled both the origin and distribution of sediments delivered to the subsiding basins along the margin. Untangling the complex post-rift evolution of the NW African margin is fundamental to constraining the behaviour of the shallow-marine to fluvial transition zone as well as the formation and distribution of potential reservoirs.

The Lower Cretaceous regression recorded in the Essaouira-Agadir basin with shallow-marine to fluvial coarse siliciclastic units, and potentially deepwater facies, are an exploration target offshore. However, limited success in recent drilling campaigns reflects the poor understanding of the depositional systems from source to sink and its links to the eroding hinterland.

This integrated provenance analysis offers new constraints on a regional source to sink model of North West Africa by deciphering the controls, timing and volume of the sediment supply to the margin and by providing new evidence of the importance of sediment recycling, mixing and storage. The main focus is on the late Early Cretaceous (Latest Barremian to Earliest Aptian) marine regression that is associated with substantial input of detrital sediments into the deep-water basins. The study area offers a unique opportunity to study a well constrained source to sink system, where integration of data from superbly exposed outcrops with tectonic analysis allows testing of models for delivery, mixing and storage and development of new models for the evolution of passive margins and controls on sediment delivery.

To assess the multiple origins of the sediment supply, a detailed petrographic study has been conducted along with SEM and QEMSCAN imagery. It has demonstrated the occurrence of various granitic and volcanic clasts mixed with recycled sedimentary grains, likely from both intrabasinal and hinterland origin. Generation of reconstructed palaeogeological maps integrated with detrital zircon geochronology indicates a source shift between the Jurassic and the Cretaceous, with an input of sediments likely from the Anti-Atlas during the Lower Cretaceous. The study is currently focusing on source discrimination based on the heavy mineral populations and erosion modelling. This would yield data not only on the provenance but will have implications on the sediment volumes and nature allowing a better prediction of the potential offshore reservoirs.

Assessing and Predicting the Diversity of Fluvial Point-Bar Architecture from Outcrop, and the Morphometric Analysis of Meander Bends

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Meandering fluvial reaches exhibit highly variable morphological form, yet published interpretations of ancient meander-belt deposits do not reflect the stratigraphic complexity known to be associated with such variability. An improved understanding of the causes of stratigraphic complexity is important to enable subsurface predictions of sedimentary lithofacies distribution and architecture from analysis of relatively low-resolution seismic datasets. Quantification and classification of plan-form geomorphologic details of active and recent fluvial point bars, and integration with small-scale lithofacies distributions and heterogeneity observed in outcropping successions, has enabled the development of tools with which to predict the 3D geometry, and sedimentary architecture of ancient successions.

Active fluvial systems were studied to quantify spatio-temporal relationships between scroll-bar behaviour and meander shape. The rivers selected were classified by a range of parameters, including climatic regime, gradient and discharge. Quantitative comparison of meanders with markedly differing morphologies has been enabled through the development of a novel method. Measurements of 35 morphometric parameters of 200 active meander bends from 13 different rivers were acquired using Google Earth Pro. Twenty-two scroll-bar geometries were assessed according to a classification scheme independent of meander shape. Abandoned point-bar deposits have also been studied in order to better interpret the abandonment process, and hence final geometry, of ancient point-bar deposits.

An ancient point-bar deposit, from the Pennsylvanian in Wales, served as a test data set for accurate reconstruction of meander morphology. Lithofacies distribution and paleocurrent readings highlight subtle yet predictable variations in ripple, dune and bar growth histories. Changes in lithological heterogeneity, and flow and migration directions were used to determine scroll-bar styles. Scroll-bar style interpretations were used to infer a range of possible barform aspect ratios and preserved point-bar shapes. Lithological variability in the channel fill provided implications for style of meander abandonment, i.e. neck cut-off, chute cut-off, or avulsion.

The following findings arise: (i) the most likely scroll-bar configuration relates to expansion and rotation, which accounts for 18% of meanders; (ii) meander-bend shape can be classified into four groups that collectively comprise 25 specific shapes; (iii) the most likely paths of temporal evolution in scroll-bar types in a bend becoming mature and approaching cut-off are quantifiable, thereby improving understanding of a fragmented geologic record. These methods can be applied to predict high-resolution lithological heterogeneity from relatively low-resolution seismic slices, thereby helping to constrain reservoir models and predict stratigraphic heterogeneity prior to drilling.

Reconstruction of paleo-depths based on recent benthic foraminifera. A novel methodology applied to a 550,000 years long record on the East Corsica margin

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Foraminifera have been ubiquitous in the marine environment for several hundred millions of years and hence a powerful proxy in the marine sedimentary archives. Nature of sediment, nutrient concentration in sea water, transport and stability of marine deposits may be discussed on the basis of benthic foraminifera assemblages. In addition, their calcite tests are commonly used to measure the oxygen isotope ratios that provide estimation of global temperature evolution and allow to build-up age models for depositional sequences.

Several qualitatively and quantitatively attempts have also been made to reconstruct sea level variations based on methods exploring microfauna assemblages as a proxy of paleo-depths. These methods are based on the distribution of foraminifera assemblages and hence on a multivariate statistical approach where often the number of observed assemblages and the number of species in these assemblages are of the same order of magnitude. These methods are based on a very good knowledge of modern ecology, the spatial distribution of living foraminifera and on the assumption that the ecological requirements of each specific taxa have not changed over time.

In this study we use this same principle to evaluate the performances of a transfer function in which recent foraminifera assemblages of the East-Corsican margin are used for modelling paleo-depths.
The evaluation, calibration, validation and robustness of the transfer function proposed are discussed on the basis of 33 benthic foraminifera species in 45 surface samples collected from interface cores at depths ranging from 7 to 868 m, where up to 101 benthic foraminifera taxa were identified.
The obtained depth-model is applied to the fossil benthic foraminifera from the borehole GDEC-4-2 drilled at a water depth of 491 m, in the East-Corsican basin, covering the last 550,000 years. Variations of modelled paleo-depths show a medium correlation with the oscillations of relative sea level and the fluctuations of the oxygen isotopic ration (δ_{18}O G. bulloides and δ_{18}O C. pachyderma – C. wuellerstorfi).
Based on a rich data set, where both calibration and validation are quantitatively robust, the obtained model shows that transfer function based on benthic foraminifera assemblages and preserved environmental requirements might be applied for long time scales where sea level amplitudes are larger and taking in account bottom trophic effects affecting the assemblages.

Direct measurements show how turbidity currents with dense basal layers evolve in Monterey Canyon

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Recent studies have demonstrated that Acoustic Doppler Current Profilers (ADCPs) can be successfully deployed in submarine channels to obtain high resolution measurements of turbidity current velocity structure. Inversion of ADCP backscatter acquired in the Congo Canyon has also demonstrated how simultaneous measurement of suspended sediment concentration can be estimated. However, velocity and concentration measurements have only thus far been achieved at a single location in a submarine canyon, leaving questions about how turbidity currents evolve as they flow down canyon.
Here, we present an analysis of data from the Monterey Coordinated Canyon Experiment, which shows how ADCPs can not only record how the flow and sediment structures evolve down canyon, but also record noise emitted from dense basal layers within turbidity currents. This is the most extensive monitoring campaign yet undertaken of sediment transport events within a submarine canyon. An array of moorings and instruments recorded data over an 18 month period from October 2015 to April 2017. Paull et al. (2018) have shown how powerful these flows can be: with observed movement of heavy objects in the proximal channel demonstrating that flows are initially driven by a fast moving, dense basal layer. However, questions remain regarding the sediment concentration of the flows, and whether the basal layer persists, or flows become entirely dilute (such that turbulence alone supports sediment).
We first describe ADCP data from downward pointing instruments on moorings, in water depths of 285 to 1850m, followed by ADCP data from a benthic lander at 1850 m (called a SIN). Acoustic inversions of backscatter recorded by the six downward-looking moored ADCPs were combined with optical backscatter sensors. This analysis demonstrates how suspended sediment concentrations imaged by the ADCP are relatively dilute. We demonstrate how acoustic noise generated by particle collisions is present in the ADCP data, for the majority of the flows observed during the 18 month deployment period. The source of the noise is the near bed region. We infer that it is generated by a dense basal layer of at least 9% concentration. The noise reaches a peak magnitude soon after flow arrival and slowly decrease with time, which we relate waning basal flow velocities. Of the 14 events observed at the most proximal mooring, 11 exhibit particle collision noise at the last mooring they were observed at. The other 3 flows have only weak backscatter when sighted at their last mooring, with a decelerated and fragmented flow structure at this location.

Three upward-looking ADCPs mounted on a Seafloor Instrument Node (SIN) recorded noise from particle collisions during the most powerful flow event on January 15, 2016. Further evidence of a step change in sediment concentration towards the base of the flow is provided by the severe attenuation of light recorded by the optical backscatter instrument mounted on the SIN. The SIN frame itself was transported 26 metres down the canyon by the flow in two pulses around 80 seconds after flow arrival. We demonstrate how the movement of the SIN is related to a peak in the particle collision noise magnitude, and a sudden reversal of the vertical velocity profile, as recorded by the three ADCPs on the SIN. The maximum flow speed is located at the base of the ADCP profiles for the first 6 to 7 minutes of the flow. The velocity maximum then detaches from the base of the flow when the particle collision noise subsides. This suggests that the dense basal layer continues to play a significant role in driving the flow at this distal location. We relate the sediment structure of these flows to deposition sequences of vibracores taken at the SIN site after the end of monitoring period. We infer that the flows observed in the canyon are characterised by a dense basal layer that persists for the majority of the duration of the turbidity currents. Dilute suspensions of sediment overlie this dense basal layer, and outrun it by a relatively short distance.

Paull, C. K., et al., (2018), Powerful turbidity currents driven by dense basal layers, Nature Communications, NCOMMS-18-09895A.

Hydrocarbon Exploration Insights from IODP and its Predecessors

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IODP and its predecessors have revolutionised our knowledge of Earth history and this, along with the data gathered by the drilling campaigns of the last 50 years, have significant impact in hydrocarbon exploration. The geological uncertainties inherent in exploration can be better understood through direct evidence for or against the presence of petroleum systems elements (i.e. source, reservoir, seal) and indirectly through the context provided by the new understanding of the processes controlling sedimentary deposition on the Earth during its history.

ODP drilling on the Eratosthenes Ridge in the Eastern Mediterranean demonstrated the presence of Miocene and mid-Cretaceous platform carbonates deposited on this remnant high of rifted continental crust. Industry seismic data identified smaller detached highs to the south and west of the Eratosthenes Ridge with potential carbonate build-ups present. Because ODP drilling had proven the presence of carbonates on such highs in the region, risk on reservoir presence was reduced. Reservoir presence was proven when the giant Zohr gas field was discovered by ENI in 2015. 30 Trillion Cubic Feet (TCF) of recoverable biogenic gas is located within mid-Cretaceous and Miocene shallow-marine carbonates. This play is now being expanded to similar structures in the region, with Total discovering the Calypso field in 2018.

Some of the most exciting hydrocarbon discoveries of the last few years have been on the margins of the Atlantic, in offshore Senegal and offshore Guyana. In these regions the presence of good quality Cenomanian – Turonian source rocks related to Ocean Anoxic Event (OAE) II was proven by DSDP and ODP drilling – a significant factor in encouraging optimism pre-drilling.

The task of the exploration geologist is to better understand geological uncertainties ahead of selecting basins and plays for focussed studies, these eventually leading to drilling of the most prospective. Data from IODP and its predecessors de-risks frontier exploration where data is limited through indirect or contextual information. Lithological, sedimentological, palaeontological and isotopic data that has been gathered from deep-sea and oceanic drilling are important inputs into (i) Earth systems modelling (including palaeoclimate and source-to-sink studies); (ii) the development of sequence stratigraphic and eustatic models; (iii) the recognition of global events such as OAEs; and (iv) the generation of biostratigraphic schema for inter-regional correlation. All of these are useful in the ongoing prediction of the presence of source, reservoir and seal.

Relationship between Grain Size Distribution and Sedimentary Environments in Modern Estuarine

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Grain size is a fundamental property of sediments, affecting their entrainment, transport and deposition. Grain size analysis of modern sediment provides clues to the mode of transportation and the energy condition of the transporting medium. Grain size distribution is used as an important tool for discriminating sedimentary environments including potential analogues of reservoir rocks in mixed tidal-fluvial environments. Existing schemes and models, however, do not consider complex mixing in tidal-fluvial depositional environment e.g. in an estuary. Here, we provide data from a detailed study relating depositional environment and grain size distribution from the Ravenglass Estuary, Cumbria, United Kingdom. The Ravenglass estuary is a shallow, mixed energy, and macro-tidal estuarine system with an area of about 5.6 km^2 of which approximately 86% are intertidal. Aerial imagery and detailed ground surveys were used to define a suite of 11 estuarine sub-environments. 482 surface sediment samples were collected from the estuary and nearby coast and subjected to grain size analysis using Beckman Coulter laser particles size analysis (LPSA) and GRADISTAT© soft-ware. Sand abundance was used to subdivide tidal flats into mud flat (15 %-50 % sand), mixed flat (50 %-90 % sand), and sand flat (>90 % sand). The quantified mean grain size (micron), grain size sorting, clay and sand abundance, skewness and kurtosis obtained from Beckman Coulter laser particles size analysis (LPSA) and GRADISTAT© software were plotted using MINITAB©, Excel© spreadsheet and ArcGIS© for grain size distribution and environmental discrimination. We will show subtle mapped variations in grain size distribution across all 11 sub-environments, detailing both differences between environments and within given environments. Specific morphology of a given depositional environment and estuarine hydrodynamics are the main controls on grain size distribution. This study may be used by analogy, to better predict the spatial grain size distribution and discrimination of sedimentary environments in ancient and deep buried sandstone.

Reciprocal Expansion and Contraction of Himalayan River Catchments: Implications for Sediment Routing to the Gangetic Plains

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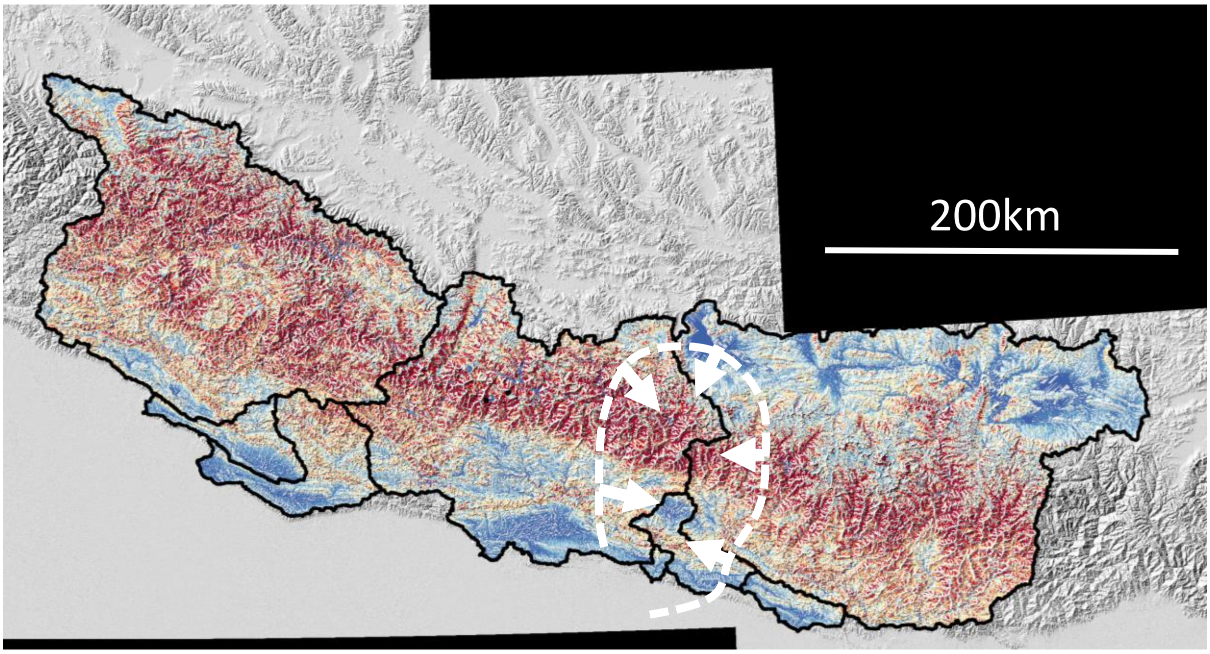
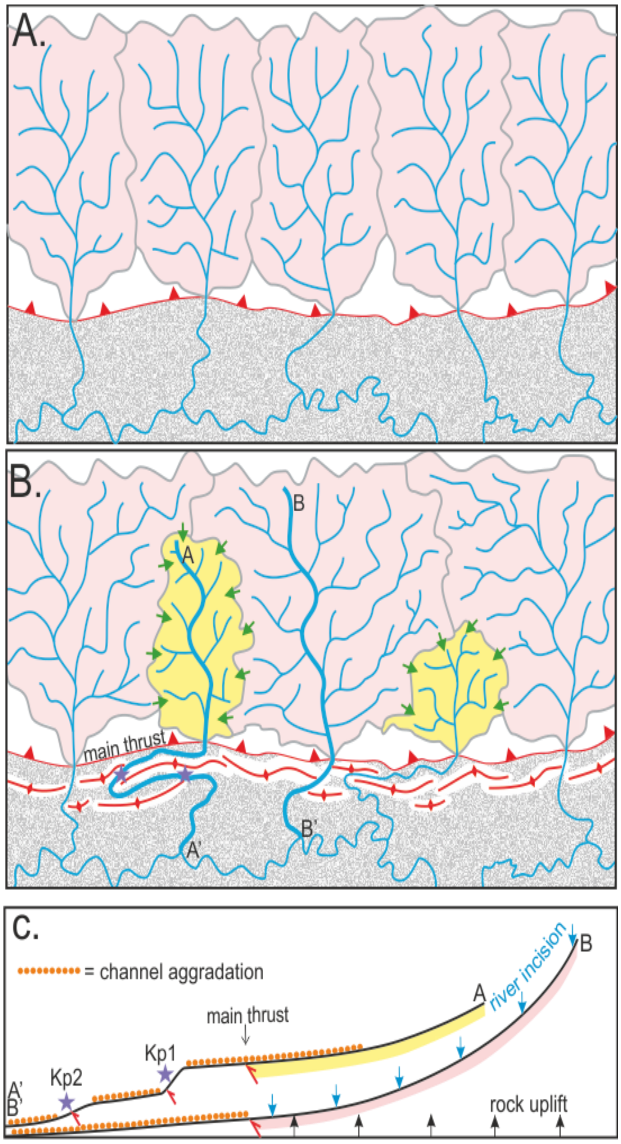
River catchments form the first-order topographic unit of mountain belts and dictate the sediment supply points to foreland basins. Most river catchments across the globe have an aspect ratio of their length and width of approximately 2:1 relative to the strike of the range. This ratio does not apply to the Himalaya where some catchments at the margins of the range are extremely elongate, while others that drain the front of the range are nearer equant in shape. We explore the relative roles of crustal strain versus lateral expansion of catchments in determining their shapes. Structural mechanics across the Himalayan thrust belt discount the possibility of strain modification to catchment shape, and hence mechanisms of lateral expansion through migration of drainage divides are examined. We demonstrate that the catchments with the lowest aspect ratios are also the largest catchments, and so evaluate the topographic evidence for divide migration at the margins of the largest catchments. In Nepal, the three largest catchments are the Karnali, Gandaki and Kosi. Between the large Kosi and Gandaki catchments is the Kathmandu Valley which comprises a relatively elevated, low gradient, alluviated catchment. The valley records ~300m of sediment dated from 2.8 Ma to present, starting with fluvial boulder conglomerates overlain by lacustrine sediments (1Ma) and subsequent fluvial sedimentation. The record of sediment accumulation in the valley was controlled by partial blocking of the river channels by the propagation of thrust ridges to the south. The elevated, sediment filled catchment of the Kathmandu Valley is bound to the east and west by steeply incising catchments draining into the Kosi and Gandaki trunk streams. Through analysis of geomorphic characteristics across the drainage divide (normalised channel steepness, local relief and mean slope) we propose that the Kathmandu Valley represents the remnants of a once larger catchment that has been captured by divide migration and expansion of the neighbouring catchments. These aggressor/victim catchment dynamics have recently been documented by Willett et al., 2017: *Dynamic Reorganization of River Basins*. Science. Vulnerability to capture of the Kathmandu Valley was initiated by the perched fluvial base-level caused by ponding behind propagating thrust ridges.

Based on this new geomorphic understanding of the reciprocal behaviour of Himalayan river catchments along the mountain front, we explore the implications for equivalent reciprocal responses in the downstream alluvial fans of the Gangetic Plains. We note marked diachroneity in the timing of upward sediment transitions in the Siwalik Molasse, and consider the possible role for reciprocal expansion and reductions in sediment delivery in response to catchment dynamics.

The figures overleaf illustrate the three main catchments of Nepal coloured by the channel gradient normalised to upstream area (a proxy for transport capacity of rivers). The white dashed lines represent the proposed shrinkage of the Kathmandu Valley in response to the expansion of neighbouring catchments. The lower figure outlines the proposed development of aggressor/victim catchments across the Himalaya.





1. Self-similar growth of 2:1

2. Along-strike changes in local base-levels drives competition between aggressors and victims; migration of drainage divides (ca. 50 km in ca 3 Ma in Kathmandu)

3. Aggressors incise and expand, victims are elevated, flatten and shrink

Architecture of mixed-process mouth-bar deposits; compensational stacking in the Mulichinco Formation, Neuquén Basin, Argentina

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Mixed-process coastal deposits offer great challenges in understanding as they are constructed by a dynamic interplay of multiple coastal processes (fluvial, tidal, wave), all of which are active at once and carry the capacity to rework and redistribute sediments across the basin. This study reports on the detailed examination of the Valanginian Mulichinco Formation outcrops in the Neuquén Basin, west-central Argentina. Deposits therein comprise contemporaneous continental and shallow marine strata of mixed-process coastal and inner shelf origin, which crop out along flanks of multiple eroded structural domes in the Andean fold and thrust belt. The upper Mulichinco Formation contains mouth-bar deposits that preserve interbedded fluvial-, swash-, storm-, and tidal deposits distributed along a 12 km continuous north-south oriented outcrop. This interbedded relationship readily testifies the intrinsically complex and dynamic nature of mixed-process coastal environments and is considered key to understand the interaction of their parental processes. High resolution (down to 2 cm) photogrammetric models at outcrop scale have been coupled with measured sections to confidently trace and correlate key stratigraphic surfaces, and map spatial distribution of architectural elements. Storm- and tidal deposits occur within both distal and proximal mouth-bar deposits, both separately and interbedded. Where they occur together, storm deposits are encapsulated within heterogeneous tidal deposits, and are sharp-based homogeneous sandstones with lensoidal- to tabular bedforms. An upward gradual increase in tidal signature is common, which is attributed to a gradual increase in tidal reworking capacity in the aftermath of storm events. Storm deposits increase and decrease in abundance, from proximal to intermediate and then to distal directions, respectively, indicating that the storm wave oscillation in such mixed-process environments has the strongest erosional-depositional impact at the intermediate position. Furthermore, as the outcrop transects parallel to the palaeo-shoreline, observed parasequence thickness variations are excellent examples of compensational stacking in a nearshore depositional environment.

Key words: Mixed-process, deltaic, coastal, mouth bar, field analogue, Neuquén Basin, Mulichinco Formation

Deepwater dolomites and associated hiatuses in Gulf of Cadiz contourites.

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Deep-marine regional unconformities are common and significant features of the contourite depositional systems in the Gulf of Cadiz. Some of these unconformities are marked by the development of fine-crystalline dolomite layers, as observed at Sites U1387 and U1391. The timing and mechanism of the dolomite formation are not fully understood.

The mineralogy and geochemistry of these dolomites and adjacent sediments were investigated. Transmitted light microscopy, SEM, X-ray tomography, XRF and stable isotope geochemistry were employed to understand the mechanisms of the dolomite formation.

Although the dolomite layers at these two sites occupy similar stratigraphic position, the associated unconformities are considerably different in duration. At Site U1391, the unconformity represents the early Pliocene discontinuity of 0.05 Ma, separating the initial drift stage below from the transition stage. The unconformity at site U1387 represents combined two hiatuses (late Pliocene and early Quaternary discontinuities) with a time gap of 1.4 Ma. This unconformity separates the initial stages of the drift (Pliocene mixed system) from the modern drift stage (mainly Pleistocene contourites), with the transitional drift stage absent at this site.

The dolomites from both sites show replacement textures with subordinate relicts of the silicate minerals. Furthermore, the dolomites at site U1387 exhibits complex zoning and geochemical pattern compared to those of U1391, indicating a complex history of formation. Low oxygen conditions were deciphered from the foraminiferal assemblage in the associated sediments. Bacterial activities in a cold seep environment may have triggered the development of the dolomites and maintained alkaline medium for a prolonged time. However, the lithostratigraphic and structural regime may have played a considerable role in the dolomitization processes.

Depositional processes operating on footwall- and hangingwall-sourced alluvial fan systems: remotely sensed observations from active rift settings

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The geometries and depositional patterns of alluvial-fan systems developing in active extensional settings are directly influenced by the size and orientation of developing rifts, and the rate and magnitude of footwall uplift. Understanding behavioural response of these landforms helps to determine the distribution and stacking patterns of analogous hydrocarbon-hosting sediment geobodies in syn-rift depositional settings. The Turkana and Chew Bahir basins (Gregory Rift, Ethiopia, East African Rift System) are adjacent westward-deepening active half-grabens containing actively accumulating alluvial fans that are respectively sourced from hangingwall and footwall regions. As a result, drainage catchments feeding these systems are actively competing on the uplifted footwall block that separates these two basins, and this has led to the development of different catchment and fan geometries and depositional processes in the two basins. Here, data acquired from the analysis of a time series of satellite images of these fan systems are used to address three key research objectives: (i) to determine how catchment and fan morphologies vary between hangingwall-sourced and footwall-sourced alluvial-fan systems in terms of attributes such as catchment and fan area, and slope; (ii) to make observations regarding the nature of sediment input points for each fan set, and how they may persist or vary through time depending on catchment uplift and erosion; (iii) to record and detail different depositional processes on each fan set, from the fan apex to distal fan fringes, for fans sourced from the same uplifted hinterland and developed in similar climatic settings.
The following results are noted: (i) the gradient of drainage catchments has little impact on alluvial-fan size, with the dominant control being overall catchment area; (ii) hangingwall-sourced fans typically have one sediment input source (fan apex), whereas footwall- sourced fans may develop from multiple input pathways. This leads to the development of amalgamated fan-like bodies which can reach similar sizes to their hangingwall counterparts; (iii) alluvial fans sourced from the footwall are dominated by flash-flood deposition, with relatively infrequent lobe switching due to confinement by smaller depositional landforms sourced from the fan sides, whereas their hangingwall counterparts undergo relatively more frequent lobe and fan-apex switches, causing lateral bajada widening and deposition on new sections of the dipslope. From this research, progradation of hangingwall-sourced fans is observed by the abandonment and formation of new fans closer to the zone of maximum subsidence, leading to the formation of younger alluvial systems, forming a fan apex downstream, over older, relic alluvial fan units. Conversely, footwall-sourced fans retain a persistent sediment input source and fan-apex location. This can result in progradation of the fan toe. These results have implications for the potential vertical and lateral stacking patterns of different facies in thick alluvial-fan successions.

Stratigraphic Evolution of Confined Deep-Water Basins: Insights from Physical Models and Outcrop Analogs

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The stratigraphic evolution of confined deep-water basins are often used as a proxies for determining tectonic or climatic signals from developing hinterlands or for recording the structural evolution of the basin itself. The turbidity currents that flow into these basins generate deposits which may pinch-out abruptly or over longer distances, depending on the character of the flows and the basin margin topography. The deposits of these flows are often sub-seismic scale or are poorly constrained at outcrop, preventing accurate analysis of these topographically-affected flows and the resulting stacking patterns of their deposits. Here, physical models of turbidity currents are used to better understand the processes that govern the architecture of submarine lobe deposits adjacent to topography. The seafloor topography is formed by a 10 cm high, 40 cm wide and 25^{o} dipping symmetrical and erodible ridge that is rotated around a common point to be 1) parallel, 2) oblique and 3) perpendicular to the incoming flow. An unconfined control experiment was also performed for comparison to the confined experiments.

Flow-parallel confinement on one side causes the deposit cover a lower areal extent than the unconfined deposit, with the flow eroding and running up the lateral topography, forming a lateral fringe that onlaps the confining relief. This fringe thickens away from the topography toward the axis of the deposit, resulting in the creation of accommodation space adjacent to the topographic barrier. Flow-oblique confinement generates a deposit with a run-out length similar to the unconfined deposit. The oblique confinement, however, causes the deposition of a secondary deposit that was deflected by the confining ridge, resulting in two deposits created by one sediment influx to the basin. Each of these deposits has a lower volume than the unconfined deposit. Perpendicular confinement results in up-dip ponding and lateral spreading at the barrier, along with axial erosion and down-dip overspill that forms a deposit deeper in the basin. The results of these experiments are compared to field observations from the well-exposed and confined Cenozoic Annot Basin of SE France and the Mesozoic Basque-Cantabrian Basin of northern Spain. Many stratigraphic relationships within these outcropping basins have previously been interpreted as the result of allogenic processes, however the findings of this study indicate that many of the relationships seen can be explained by autogenic processes. These findings have implications for the physical understanding of topographically-affected sediment gravity flows, the interpretation of stacking patterns within confined basins and, therefore, the paleogeographic reconstructions of structurally complex deep-marine basins.

The dimensions of submarine lobe elements and the role of silt-prone distal deposits

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Submarine lobes have been identified within various deep-water settings, including the basin-floor, the base of slope and the continental slope. Their dimensions and geometries are postulated to be controlled by the topographical configuration of the seabed, sediment supply system and slope maturity (disequilibrium/equilibrium). While confinement has been suggested as a main control factor for lobe dimensions in passive and active tectonic settings, it does not explain the spread of lobe dimensions within specific system.

Ten experiments were conducted in the 6x11 m Eurotank 3D-flume to study the depositional characteristics of lobe associated with 1) different basin floor dipping angles (0-4°), 2) different sediment concentration of the parent turbidity current (11-19 % Vol), and 3) varying discharge (25 - 40 m^3/h). After passing a sand-sculpted, preformed channel-levee portion the turbidity currents were free to spread onto the unconfined basin floor. Most runs produced lobate deposits that onlapped onto the lower slope independent of basin floor-dip and concentration. We determined that the deposits best describe the hierarchical level of lobe elements. Lobe element length is proportional to basin-floor angle and sediment volume concentration. These boundary conditions also had a strong influence on the overall geometry of the deposits with deposits that show a higher amount of bypass in the proximal area as the basin-floor angles get steeper and concentrations higher. Deposits of runs with lower discharge could be traced higher upslope while runs with higher discharge produced an area of low deposition behind the channel mouth making the discharge the main control factor whether lobe deposits are attached or detached from their channel-levee systems. Flow properties show only subtle differences in initial velocity, shear velocity and height after the break of slope as they can spread freely in an unconfined setting.

Silt is still transported after all sand has been deposited in the main lobe element, effectively increasing the lobe element length by a factor of four. This has strong implications on the debate of intralobes vs distal lobe fringes and the question if these depositional intervals are allogenic or autogenic in origin. Our results suggest a clear autogenic origin.

Understanding meteoric diagenesis in mixed carbonate-evaporite systems: hydrochemical evidence from modern groundwaters in the State of Qatar

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Inter-bedded limestone, dolostone and evaporite sequences are typical shallow carbonate deposits of arid climates and their chemical reactivity makes them prone to diagenetic alteration, particularly by circulating meteoric waters. Continuous rock core was recovered to a depth of 130m below ground level at three locations along a North-South transect extending 70km on the crest of the Qatar Arch. Observations during core description allow four hydrostratigraphic units to be delimited 1) the crystalline calcite and dolomite of the Middle Eocene Dammam Formation deposited in an open marine environment (upper aquifer), which overlies 2) the Early Eocene Rus Formation comprising shallow marine carbonate and clay deposits (middle aquifer) and 3) crystalline gypsum / anhydrite of the underlying Rus Evaporite deposited in a marginal marine environment (aquiclude) and is underlain by 4) dolomite of the Paloecene Upper Um Er Radhuma (UER, lower aquifer) comprising shallow-marine deposits formed in relatively restricted conditions overlying fining-upward cycles of open marine deposits with clay rich caps.

At each site a series of nested piezometers were installed, allowing estimation of the vertical hydraulic gradient governing flow within each aquifer system. In southern Qatar a substantial thickness (between 20m to ~120m) of crystalline Rus Evaporite gypsum/anhydrite confines the underlying relative saline UER which is fed from recharge in the mountains in eastern Saudi Arabia. This leads to an upward hydraulic gradient and potential localised leakage of waters from the UER to the shallow aquifers. To the north, the absence of the Rus Evaporite means that the different aquifers are in hydraulic continuity and there is a downward hydraulic gradient driven by meteoric recharge.

Chemical analysis of groundwater samples from different stratigraphic intervals indicate differences between northern and southern Qatar within similar rock types in the same aquifers. Using chloride as a conservative tracer, concentrations of Ca^{2+}, Mg^{2+} and SO_4^{2-} in excess of those predicted from simple dilution of local seawater were calculated to determine whether they were derived from dissolution or removed by precipitation of calcite, dolomite and/or gypsum/anhydrite.

Sulphate enrichment within and beneath the Rus Evaporite in the south, as well as sulphate enrichment in the UER in the north indicates dissolution of gypsum increasing with depth. The deeper UER waters of the southern wells were depleted in Mg^{2+} relative to local seawater. This suggests that along the flow path from the recharge area in Saudi they had already been involved in dolomitisation or had mixed with waters that had already formed dolomite (or dissolved halite). As the waters ascend, they become progressively more enriched in Mg^{+2} and less enriched in Ca^{+2} relative to concentrations predicted from the SO_4^{2-} enrichment. The vertical contrasts suggests that the process of de-dolomitisation (replacement of dolomite by calcite) is ongoing in the UER and driven by the release of Ca^{2+} from gypsum dissolution.

Further work to understand the diagenetic processes within the shallow aquifers of Qatar will be undertaken by comparing the hydrochemical observations relative to the chemical makeup of the rock. In addition, influences from anthropogenic activities such as injection of excess surface and treated water, as well as abstraction will be included in the analyses.

Reconstructing flow properties from Agadir Basin deep-water turbidites

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Submarine gravity flows are the principle agent by which sediment is moved across the Earth's surface, and are responsible for the largest sediment accumulations on the planet. They influence global nutrient cycles and pose a significant geohazard to seafloor infrastructure. However, they are poorly understood because we lack validated data on key flow properties such as sediment concentration. Deposits from these flows are abundant in the rock record, yet typically cannot provide sufficient data to allow quantitative reconstruction of their parent flows. Here, we utilise an exceptionally detailed modern seafloor data set of individually correlated turbidite beds from the Agadir Basin to reconstruct parent flow properties. This is achieved by establishing flow thickness from basin margin pinch outs, and combining this with estimates of basal shear velocity from thousands of grain size analyses. To accommodate the high proportion of mud within the turbidite sands a flocculation condition is imposed. This calculates the minimum floc size required to deposit mud and sand together. Our reconstruction allows us to quantitatively reconstruct the spatial and temporal evolution of the flow in terms of its sediment concentration, grain size distribution and speed, and to assess the behaviour of mud flocculation. The results show a quasi-steady flow proximally with a high-concentration basal layer. This progressively diminishes to a dilute pulsing flow distally. Coincidentally, the turbidite deposits record a down slope transition from structureless sands to ripple cross-laminated sands. This study provides an important step towards quantitatively understanding submarine flows, and linking their dynamics with deposits in the geological record.

Lateral variability in basin margin physiography as a control on clinoform trajectory: the Santos Basin, offshore Brazil

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Construction of continental margins is driven by sediment delivered across the shelf-edge by a combination of wave-, tide- and river-influenced deltas and clastic shorelines. However, periods of slope degradation, resulting in remobilisation of previously deposited material onto the lower slope and basin-floor, may stall continental margin progradation. Conceptual understanding of how these processes contribute to the long-term development of continental margins is focused on the use of two-dimensional dip, which could be misinterpreted using 2D sequence stratigraphic models and/or trajectory analysis alone. In contrast, lateral (strike) variations in process regime and margin evolution are not commonly constrained, due to lack of data. We use a post-stack time migrated 3D seismic-reflection survey located in the Santos Basin, offshore SE Brazil, to investigate the role that outer-shelf to upper-slope collapse and mass-transport complex (MTC) emplacement have on margin progradation. These data image a series of early Palaeogene to Eocene, south-eastward dipping clinoforms (clinothems). Periodically, large (c. 30km along-strike) tracts of the outer-shelf-to-upper slope collapsed, emplacing slope-attached MTCs (up to 200ms thick, 8km length) on the proximal basin-floor. Degradation of the margin generated accommodation space on the outer shelf to upper slope; this accommodation was filled by clinoforms (75-500ms tall) that nucleated at the margin-collapse headwall scarp and prograded basinwards, downlapping onto the underlying MTCs and facilitating renewed margin construction. Seismic geomorphological analysis, in conjunction with clinoform trajectory analysis, reveals marked along-strike variability (10s km) in the timing of progradation, demonstrating the key role outer-shelf to upper-slope collapse, MTC emplacement, and subsequent slope re-establishment have on long-term margin construction and physiography (Fig. 1). Trajectory analysis suggests that shelf degradation and MTC emplacement most commonly, but not exclusively, occurs during rising trajectories (i.e. relative sea-level rise). Our analysis highlights significant along-strike variability in the depositional style, geometry and evolution of degradational continental margins. This results in distinctly different stratigraphic architectures of coeval adjacent strata and emphasises the need for a 3D understanding of basin margin evolution.

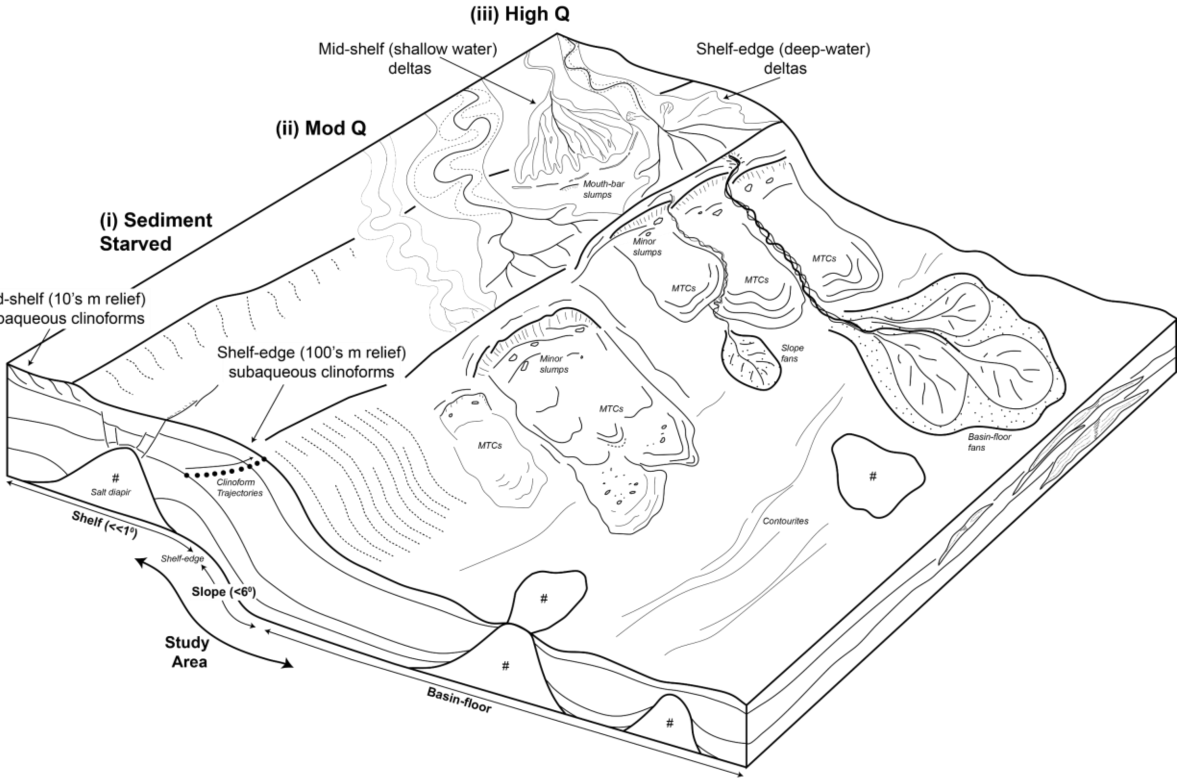

Figure 2: Conceptual block-diagram illustrating the along-strike variability inherent in the Eocene succession of the central Santos Basin. Note the end-member models are for simplicity, (i) sediment starved to (iii) high sediment supply (Q). In reality, the shelf-edge changes gradually with an intermediate model (ii) of moderate sediment supply characterising most of the shelf-edge. The concept illustrated the importance of understanding basin margin physiography when trying to use sequence stratigraphy for prediction.

The Contourite Sequence: A 21st Century Update

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The past decade, in particular, has seen a greatly renewed interest in contourite systems – modern, ancient and subsurface. IODP Expedition 339 to the Cadiz Contourite Laboratory along the Iberian margin in 2012 recovered over 4.5km of contourites. Current work in the Alboran Sea has further extended understanding of contourites and associated facies. Ancient contourites in outcrop have been well-documented in the Rifean Gateway in Morocco, the Lefkara Drift in Cyprus, and the southern margin of the Ordos Basin, China Miocene-age. Hybrid contourite-turbidite systems are under scrutiny from industry data offshore west and east Africa, and offshore Brazil. The plethora of studies on these sediments have provided a rigorous test for the contourite paradigm and fully endorsed the primary role of alongslope bottom currents in continent margin sedimentation globally. However, considerable debate still surrounds contourite identification and distinction from other deepwater facies.

The bi-gradational sequence model is found to be the dominant expression of contourite sedimentation in muddy and mixed muddy-sandy contourite drifts. Statistical analysis of these sequences indicates a mostly irregular sub-Milankovitch cyclicity of between 4,000-12,000 years. This periodicity is most likely due to either an ocean-resonance or sediment-supply control. Evidence from compositional, textural and structural attributes of the sequences implies that a combination of two principal controls has caused individual bi-gradational sequences: (a) variation in bottom-current velocity, and (b) episodic lateral supply from downslope turbidity currents. A third control, that of surface productivity leading to excess pelagic fallout of biogenic material, is found to be less significant. These muddy, silty and muddy-sand contourites are very uniform in their colour, siliciclastic-bioclastic composition, lack of primary sedimentary structures, and an intense bioturbation throughout with a distinctive, small-scale, monotonous ichnofacies and local omission surfaces. The bi-gradational grain-size variation is closely mirrored by other proxies, including mineralogical, geochemical, organic, biogenic, and microfabric. Individual sequences can be correlated over at least 5 km across the drift surface.

By contrast, sand-rich contourite facies, which occur within and proximal to oceanic gateways, in contourite channels and plastering contourite terraces, show less distinctive, more-block-like sequences of alternating sand-mud facies. The sandy contourites show clear evidence of parallel-lamination and cross-lamination, with sets from 5cm to 1m in thickness. Composition, geochemistry, and ichnofacies proxies all mirror grain-size variation. Detailed grain-size study reveals a marked trend for deposition of fine muddy to coarser sandy contourites that indicates deposition from uniform suspension at low bottom-current velocity (< 10 cm/s), suspended load with progressive winnowing at increasing velocity (up to about 50 cm/s), and the onset of more dominant tractional bedload transport at higher velocities (>50 cm/s). Distinction from the deposits of other deepwater processes, including turbidity currents, remains difficult. It can rarely be achieved by simple visual examination of facies, but requires a more thorough three-scale approach.

Source-to-sink in a western Norwegian fjord: How does landslides, floods and grinding glaciers influence sediment supply in the Holocene?

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Western Norwegian fjord-valley systems represent archives of changes in sedimentary processes, and typically exhibit a pronounced change in depositional environment related to the transition from glacial to interglacial conditions. During a glacial situation, the fjord-valley system is emptied of its sediments and further deepened by sub-glacial erosion, both removing sediments and increasing accommodation space. This process is thought to excavate almost all sediments within a fjord-valley system, indicating that most of the sediments in the fjord today have been deposited during and after the retreat of the last glacial ice sheet. Western Norwegian fjord basins typically represent a depositional system where turbidity currents, avalanches and slides interplay with glacimarine and hemipelagic sedimentation.
Here, we present results from a cruise with R/V G.O. Sars to Fjærlandsfjorden in 2018, where several sediment cores, TOPAS high-resolution seismic profiles (<30 cm vertical resolution), and bathymetric data was collected. Fjærlandsfjorden is a 27 kilometers long tributary fjord of Sognefjorden in Western Norway. The fjord-valley system is located just southwest of Jostedalsbreen, and covers an area of about 300 km^2. The sediment cores are examined using several instruments (XRF, MSCL and CT-scanning) and sedimentological methods, including dating using radiometric methods (^{14}C AMS).
The data reveal that the Fjærlandsfjorden basin infill consists of basal till, overlain by a thick, acoustically well-laminated glacimarine unit (up to a maximum of ~105 metres in thickness), occasionally disrupted by acoustically transparent lenses interpreted to be avalanche deposits. A 2-3 metre thick hemipelagic unit drapes the glacimarine unit. Seismic and bathymetry data also give evidence of massive avalanche deposits, the largest one measuring up to a minimum volume of 5 million cubic metres. Within the sediment cores several layers interpreted to be related to flooding events can be observed. Preliminary ^{14}C dating indicate a sedimentation rate of 6.5 mm/yr for the prodelta basin.

Surficial (topography) matters: channel to lobe transition zone (CLTZ's) morphodynamics as a first order control on submarine lobe sedimentation patterns

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Conceptual models of lobe evolution are largely born out of outcrop and seismic studies, where their initiation is associated with an avulsion in the up-dip channel-levee system, producing a down-dip lobate deposit. Though largely unconfined, most of the coarse sediment load of sequential currents are preferentially routed through subtle topographic lows to produce distinctive compensational stacking patterns until a later avulsion event results in lobe abandonment. Yet it is not possible to determine how much of the lobe undergoes active sedimentation during a single flow event. Presumably deposition is constrained to only part of the lobe's total surface area, implying the presence of an upstream forcing mechanism unrelated to levee breaching, which is associated with a higher level in the hierarchy of submarine fans. One interesting hypothesis is that after losing lateral confinement, the current is then steered by large scours that populate the CLTZ, but in the context of lobe morphodynamics, the connection between up-dip processes and down-dip response is largely speculative.

The present study attempts to bridge this spatial disconnect by physically modelling the evolution of a submarine lobe. A total of 10 unconfined turbidity currents were released in a fully three-dimensional laboratory flume, initially consisting of a steep (11°) channelized section, and a shallowly dipping (4°) unconfined plain. The basin deposit from each current was left intact to simulate lobe evolution. Pre and post flow topography was captured using a high-resolution laser scanner, and the current's velocity and density structure were measured with a lateral array of 9 ultrasonic velocity profilers (UVP's) located immediately downflow of the CLTZ. The internal architecture of the deposit after the final flow is reconstructed and compared with the lobes of the Golo Fan system, between which there is a striking degree of similarity. Moreover, the lateral velocity and density profiles demonstrate that pre-flow topography acts as a first order control on how sediment is preferentially routed across the deposit's unconfined surface through topographic lows, as is confirmed by difference maps between each flow event. This highlights the complex interactions between morphology, flow structure and depositional response, and suggests that apparently uncorrelated stratal elements are may be genetically linked.

We conclude by proposing a simplified morphodynamic (conceptual) model to describe the avulsion of lobate sedimentary bodies, which is summarized as 1) backstepping due to a longitudinally (weak) adverse slope condition on the lobe surface; 2) bifurcation due to a laterally (weak) favorable slope condition on the lobe surface; 3) flow steering due to a longitudinally (strong) adverse and laterally (strong) favourable slope conditions at the CLTZ; 4) flow choking due to a longitudinally (strong) and laterally (strong) adverse slope conditions at the CLTZ.

How much can a landscape take? Autogenic thresholds and the transfer of allogenic sediment supply signals to stratigraphy

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Stratigraphy is a unique archive of past Earth-surface conditions as it is a physical record of the response of landscapes to environmental perturbations. Signals of sediment supply rate to sedimentary basins are of particular interest, as they relate to climate change, tectonic activity and anthropogenic influences in a catchment. However, autogenic distribution of sediment over a basin and subsequent reworking complicate the storage of allogenic supply signals in stratigraphy. We build on recent work on stratigraphic storage thresholds to develop a new theoretical framework that accurately predicts the conditions necessary to store a periodic sediment supply signal in the stratigraphic record. We show that the minimum amplitude to store a supply signal decreases with signal duration. For example, our quantitative framework explains why the signal of a single large flood can leave significant deposits in a landscape but may leave no trace in the sedimentary record. This theory is graphically represented by a new 'stratigraphic stability diagram' and validated by physical fan delta experiments run at the Tulane University Sediment laboratory. Importantly, given that we use parameters readily measurable or, at the very minimum, approximated from stratigraphic successions, we anticipate that our new theory can guide future work on stratigraphic interpretation of environmental signals across different environments and over timescales of anthropogenic influences up to timescales of orbital forcing and tectonic processes.

Variations in modern carbonate hardground formation in Abu Dhabi in relation to associated biogeochemical drivers

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Authigenic carbonates, in the form of concretions and hardgrounds, are common early-diagenetic features of sedimentary rocks and have been linked directly to the global carbon, sulphur, and iron cycles. Authigenic minerals have been identified as important indicators of palaeoenvironmental conditions, however, a direct interpretation of these palaeo-proxies is challenging as a comprehensive understanding of the direct drivers of authigenic carbonate precipitation is limited.
The sea floor of the modern Arabian Gulf is characterised by extensive areas of recently-lithified carbonate sediments. Previous work has characterised a laterally-extensive marine hardground comprising bioclastic grains cemented by calcium carbonate. This diachronous surface also occurs at shallow burial depths within the adjacent late Holocene sabkha. In the marine realm, active lithification, via the precipitation of acicular aragonite and high Mg-calcite cements, forms a variety of firmgrounds and hardgrounds. Variations in cement textures and crystal morphologies are observed between study sites in the intertidal-supratidal sabkha, subtidal-intertidal lagoon and open marine. Environmental controls of early cementation are investigated and discussed in relation to the porewater chemistry profiles occurring both above and below these hardgrounds. Formation processes are also considered in relation to the development of hardground porosity and permeability.

This study focusses on evaluating the physical variability of cements and associated environmental and biogeochemical processes that control hardground formation, through the analysis of pore-water chemical profiles and shallow sediment cores from above and below hardgrounds at three contrasting sites on the Abu Dhabi coast. Hardgrounds at all sites are cementing within a few 10s of cm of the sediment-water interface and are associated with narrow intervals of elevated porewater pH. Sediments above and below the hardgrounds in the intertidal zone show sharp contrasts in redox state, indicating that the hardgrounds may form a barrier to fluid exchange, possibly promoting the development of underlying anaerobic conditions that may further promote hardground cementation. The analyses of porewater chemistry (dissolved ions, nutrients, isotopes, DOC and CH_4 content), microbiology (16S and 18S rRNA), as well as complete sediment and hardground characterisation allow development of a process-based model for the formation of these marine hardgrounds.

Biosignatures in sabkha-associated microbial mats

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Microbial mat ecosystems have been operating at the sediment-fluid interface for over 3400 million years, influencing the flux, transformation and preservation of carbon from the biosphere to the physical environment. These ecosystems are excellent recorders of rapid and profound changes in earth surface environments and biota as they often survive crisis-induced extreme paleoenvironmental conditions. Their biosignatures, captured in the preserved organic matter and the biominerals that form the microbialite rock, constitute a significant tool in understanding geobiological processes and the interactions of the microbial communities with sediments and with the prevailing physical chemical parameters, as well as the environmental conditions at a local and global scale. Nevertheless, the exact pathways of diagenetic organic matter transformation and early-lithification, essential for the accretion and preservation in the geological record as microbialites, are not well understood.

The Abu Dhabi coastal sabkha system contains a vast microbial mat belt that is dominated by continuous polygonal and internally-laminated microbial mats across the upper and middle intertidal zones. This modern system is believed to be the best analogue for the Upper Jurassic Arab Formation, which is both a prolific hydrocarbon reservoir and source rock facies in the United Arab Emirates and in neighbouring countries. In order to characterise the processes that lead to the formation of microbialites we investigated the modern and Jurassic system using a multidisciplinary approach, including growth of field-sampled microbial mats under controlled conditions in the laboratory and field-based analysis of microbial communities, mat mineralogy and organic biomarker analysis. In this study, we focus on hydrocarbon biomarker data obtained from the surface of microbial mats actively growing in the intertidal zone of the modern system. By comparing these findings to data obtained from recently-buried, unlithified mats and fully lithified Jurassic mats we are able to identify those biochemical signatures of organic matter preserved in microbialites which survived diagenetic disintegration and represent the primary microbial production.

Biomarkers, in the form of alkanes, mono-, di- and trimethylalkanes (MMA, DMA, TMA) were identified in surface and buried mats. Previous studies reported a bimodal distribution of n-Alkanes in the buried mats due to the relatively rapid decline in the abundance of MMAs and DMAs in the C16-C22 range with C24-C45 exclusively found in buried mats, however, this bimodal distribution was not found in our samples. Furthermore, we were able to improve the subsurface facies model for the Jurassic microbialites with our biomarker data as it shows that microbial mats growing in tidal pools or lagoons within the sabkha system form the most prolific hydrocarbon source rocks

The relationship between sediment supply composition and preserved deposits in fluvially dominated deltas

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Source-to-sink studies examine basin-scale partitioning and preservation of sediment though time. Such studies are still largely volume-based, but new work is deciphering grain size distribution across the system. Numerical models simulating the transport of sediment along parts of the source-to-sink trajectory can help to understand the distribution of different grain sizes within the geological record.

We present results from four numerical models simulating a wide-range of physical processes acting on sediment during delivery, deposition and preservation within a deltaic environment. The four simulations differ only in sediment supply composition, and the results show the sorting processes within the delta partitioning this supply composition across the architectural elements. For the purpose of this study, the deposited sediment has been classified, using depositional processes, into the following architectural elements: channel accretion, channel fill, delta top background sedimentation, mouth bars, delta front background sedimentation and prodelta. For all of these elements, we show the relative mass contribution to the final delta at the end of the simulation. We also analyse the sediment composition in each element over time as it is being deposited, but also the compositions of the preserved element at the end of the simulation. A sample of these analyses can be seen in Figure 3. In the simulations, only fluvial supply is varied between the four simulations and the initial bathymetry, tides, and wave conditions are the same for all simulations.

The simulations show the different architectural elements each have a unique composition, which remains relatively stable throughout the delta evolution. The exception to this is the prodelta deposits, which becomes coarser over time. The sorting processes within the delta ensures that each architectural element type experiences the same sediment composition amplification of the supply composition, across all the simulations. Therefore, fractionation of the delta supply composition creates a potential for biased reconstructions of: (1) sediment source, (2) geomorphology, and (3) reservoir distribution. This study highlights the contribution which process-based models can make to unravelling the relationships between sediment supply and preserved deposits across the sediment routing systems.

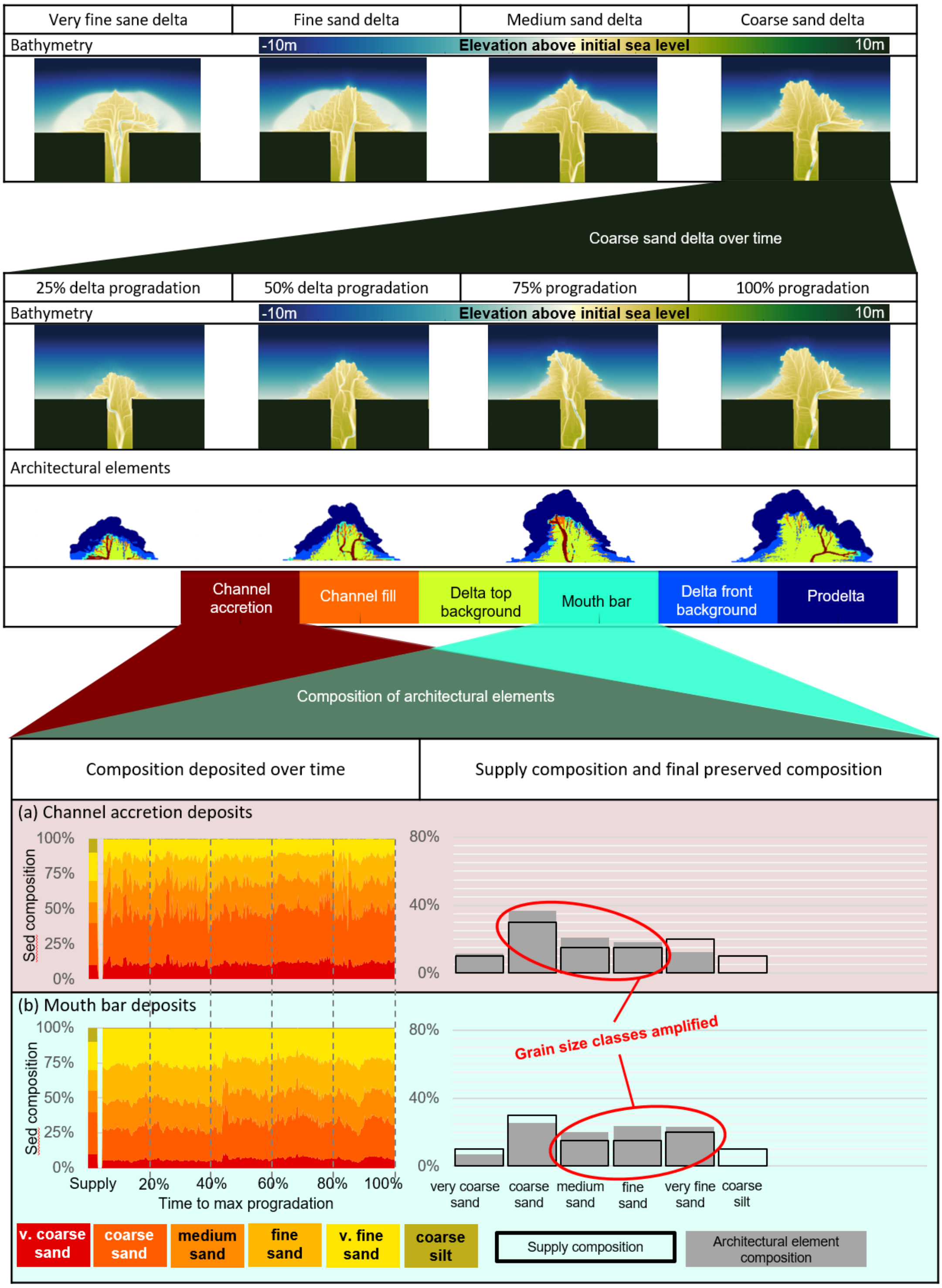

Figure 3: Data was analysed for simulated deltas with different sediment supply compositions. For each delta analysis was conducted over the entire evolution of the delta. Deposited sediment was classified by architectural elements and grain size compositions were analysed for each architectural element and each delta.

The “filtering” effect and internal delta-lobe variability in low-accommodation fluvial-marine transition zones: the Cretaceous Mesa Rica Sandstone (New Mexico, USA)

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The complex interaction between marine and terrestrial processes at the fluvial-marine transition zone is challenging to decipher in low-accommodation systems, characterized by relatively thin, condensed, and often top-truncated sections. This study investigates the exhumed Albian-Cenomanian Mesa Rica Sandstone (Western Interior Seaway, USA), which is exposed along a ~450 km, NNW-SSE oriented depositional profile, from southeast Colorado to central-east New Mexico. The profile covers a complete transect from channel belt deposits upstream to fully deltaic deposits downstream. The study area is located within the fluvial-marine transition zone, approximately ~70 km updip from the most distal deltaic expression that can be studied. 23 sedimentary logs (total of 390 m) are spatially correlated within a ca. 20 km2 study area. Detailed analysis of facies distribution, depositional architecture, and spatial extent of stratigraphic surfaces reveals a lower 7-11 m-thick, sharp-based and sand-prone deltaic succession, occasionally incised by composite erosional surfaces with multi-storey fluvial and marine-influenced sandstone-filled channels (12-20 m-thick, 100-250 m-wide). Internal geometries are characterized by tabular and laterally-extensive deltaic lobes. Based on differences in grain size, sedimentary structures, bed thicknesses and bioturbation, four different delta lobe sub-environments can be distinguished, ranging from lobe axis, off-axis, fringe to distal fringe. They reflect differences in depositional energy but also the presence of intra-lobe variation in dominant process regime, with diminishing river-dominance and potential increase in tide-influence from the lobe axis to fringe. Fringe-sections are characterized by thoroughly bioturbated top surfaces which are interpreted as a result of early abandonment. Architectural elements and interpreted depositional sub-environments suggest an overall river-dominated delta, although with local preservation of tidal signatures. The combined effects of high sediment supply and low-accommodation resulted in a sheet sandstone that is significantly thin compared to both the upstream fluvial- and downstream fully deltaic strata. This supports deposition close to base level with vertical limits on aggradation and incision and thereby prompting lateral reworking of strata into amalgamated deltaic sheets. We caution against the resulting potential ‘filtering’ effect on the preservation and recording of interacting marine and terrestrial processes in low-accommodation fluvial-marine transition zones.

Using Strontium Isotope Stratigraphy and subsidence modelling to infer the timing of rift events in the Black Sea region

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In this presentation, we will show how the analysis of stratigraphic records in the eastern Pontides, Turkey, and the western Greater Caucasus, Russia, can be used to help constrain the timing of tectonic events in the intervening Black Sea. More specifically, strontium isotope stratigraphy and foraminiferal biostratigraphy carried out on the carbonate Berdiga Formation at the Kiraoca section in the Eastern Pontides has identified significant hiatuses during the latest Kimmeridgian to Tithonian or Berriasian, and during the Hauterivian to Barremian (Fig. 1a). Broadly contemporaneous stratigraphic gaps in multiple successions around the Black Sea provide additional insights and point to a regional driving mechanism (Fig. 1). The timing of these hiatuses does not correspond to periods of eustatic lowstand. However, it does broadly coincide with two phases of increased subsidence in the Greater Caucasus Basin near Sochi, Russia, following initial Aalenian to Bajocian basin formation. These subsidence phases occurred during the late Tithonian to Berriasian and Hauterivian to early Aptian. Thus, it is possible that subaerial exposure and hiatus formation in the Eastern Pontides was caused by rift flank uplift during periods of regional extension. We speculate that these phases of regional extension are likely to have affected the intervening Black Sea region and that this may help constrain initial rifting within the western, and possibly eastern, Black Sea basins to the ?latest Jurassic to Early Cretaceous. This is consistent with region al seismic data from the Black Sea.

Carbon on the move

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Carbon is always on the move, has been in the past, is presently and will be in the future, at very different rates and spatial scales, from fractions of a second and molecular to 10's of millions of years and global. As carbon moves and intermittently settles it supports life, controls climate and the environment, and provides energy, in a highly complex way. Global warming is exhilarating but difficult to predict, but most probably with severe and overall negative consequences for society, economy, and ecosystems.

Understanding the controls and consequences on carbon cycling in the modern world and during past periods of extreme warmth is therefore critical to separate human impact from natural variability, and to underpin our ability to better adapt to future conditions.

The presentation will summarize the role of carbon as primary driver of ecosystems, climate change and energy resource. Taking a geological approach using information from the sedimentary record combined with global climate modelling, the mechanisms and feedbacks of past extreme climate conditions are introduced, and assessed with regards to potential consequences for our progressively warmer world.

Geochemical Characterization of Mississippian Maximum Flooding Surfaces: A Case Study for Improved Correlation Within Carboniferous-aged Shale Gas Targets.

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We investigate the geochemistry of marine bands to further complement and improve biostratigraphic correlations in the Bowland Shale Formation, Bowland Basin. Currently, the Namurian mudstones of the Upper Bowland Shale Formation of the Bowland Basin are a UK shale gas exploration target. Reliable well correlations across the sub-basin is challenging as there are few regional-scale marker horizons, and the Bowland Shale accumulated in small, structurally complex sub-basins that today are characterised by folds, tilting and extensional faults. Currently, laterally extensive layers of mudstones enriched in goniatite index fossils and saline fauna - sometimes called 'marine bands' – are used to date and correlate wells. Marine bands, typically are interpreted as representing regional maximum flooding surfaces and can range from a few centimetres to a few metres in thickness. Marine bands are suggested to form during periods of enhanced fossil preservation and marine sediment starvation. However, the identification of marine bands in core is problematic due to indistinct sedimentary features, limited marine band sample availability as well as difficulties in identifying goniatite taxa. This study uses high resolution geochemistry to characterise the depositional environment and sediment-water interactions. This develops the reliability of well correlation. Furthermore, the methods and results of this study are applicable to other Namurian shale gas play analogues (e.g. Barnett Shale of the Fort Worth Basin, Texas).

A multi-faceted approach was used to determine marine band geochemistry using RockEval pyrolysis and X-ray fluorescence data from UK shale gas exploration and production cores. We found that: 1. well correlation is possible using geochemical techniques such as RockEval and redox sensitive trace element ratios (e.g. S1 and Mo/Al respectively) 2. Lithological homogeneity is reflected in Th/K ratios, however relatively high standard deviations for Th/K above and below the marine band may represent subtle changes in lithology that are not apparent in well logs or changes in mineralogy 3. Novel geochemical ratios (e.g. Mo/U) delineate transitions between marine band chemozones (below, within and above marine bands). These changes in geochemistry may characterize the marine band as a transition zone, separating a dynamic sediment-water interface (before maximum flooding) from a more stable, established environment (after maximum flooding). These results and methodologies may be applied to the succession to develop the reliability of biostratigraphic well correlations. These data better constrain the relationship between geochemistry and Carboniferous glacio-eustatic maximum flooding surfaces.

Carbon-isotope stratigraphy and geochemical signatures of the shallow carbonate platform in Pre-African Basin, Morocco: implication for the Cenomanian-Turonian organic carbon deposition

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The Cenomanian-Turonian oceanic anoxic event (OAE2) is a significant global event that has been linked to major source rock development in deep marine environments. Morocco has excellent exposures of Tethyan carbonate platform and basinal facies and this paper details a high-resolution sedimentology and geochemical analysis to examine the controls and timing of organic-rich intervals, and their relationship to the OAE2. Organic-rich mudstone deposition has been identified in the Errachidia section. Integrated planktonic foraminiferal, ammonites and carbon isotope dating indicates the black mudstones were deposited from latest Cenomanian to early Turonian, therefore being late-OAE2 interval to post-OAE2 interval.

The sedimentology, water conditions and paleoproductivity of the paleoenvironments were studied to characterise the lithofacies and geochemical signatures, and to analyse the controlling factors for organic–enrichment. In the study area during the lower OAE2 interval, a shallow water middle ramp environment prevailed with predominantly bivalve-rich limestone deposition. Later organic-rich mudstone development can be correlated with the late Cenomanian (late OAE2 interval) and early Turonian (post-OAE interval) transgression, which allowed development of anoxic to euxinic conditions in basinal settings, characterized by high TOC values from 2.67% up to 17%. Trace and major elements data from the C/T black mudstones show an extremely high concentration in paleoproductivity sensitive elements (P, Zn, Ni and Cu) and redox-sensitive elements (V, Mo, and U). The relative low Mo/TOC ratios, lack of a diverse biota indicate a restricted marine environment with redox environments that evolved from dysoxia to anoxia and sulfidic euxinia (modern Black Sea type), which finally controlled the considerable organic carbon burial in the Errachidia section.

The results suggest the importance of both local paleogeography and the late-Cenomanian/early-Turonian transgressions as controls on organic mudstone deposition. The onset of organic carbon burial could have been triggered by the high productivity, which led to the anoxic/euxinic conditions. Subsequently, the interplay between anoxic/euxinic bottom water conditions and high productivity facilitated the considerable organic matter burial in the Errachidia basins. Moreover, these transgressions are more regional or global rather than local events, influencing the organic carbon burial in Tethys influenced basins.

Tectonostratigraphic Framework for NW Madagascan Basins: integrating field and subsurface data

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Onshore Madagascar is a rarely visited part of the world, but includes spectacular coastal and inland sedimentary successions deposited during the complex tectonic evolution of the Indian Ocean. Integration of extensive field studies and offshore subsurface data has enabled the stratigraphy of NW Madagascar to be sub-divided into seven mega-sequences, which related to: 'Karoo' pre- and syn-rift extension; Early Jurassic rifting between East Africa and Madagascar and the opening of the Somali Basin-Mozambique Channel; Cretaceous strike-slip tectonics; Late Cretaceous rifting between West India / Seychelles and NE Madagascar; and subsequently changes in ocean spreading in the Indian Ocean during the Latest Cretaceous and the Cenozoic.

The basins of NW Madagascar do not pass directly to oceanic crust and can be thought of as a failed rift, with 1000's of meters of pre- and syn-rift continental clastics ('Karoo'), subsequently overlain by a retrogradational parasequence set developed in storm influenced carbonate ramp environment and Lower Jurassic delta front deposits. Throughout the Early Jurassic (Toarcian), and probably into the Early Cretaceous, the greater Ampasindava area was major and long-lived deltaic complex, where delta lobe shifting and abandonment led to establishment of non-deltaic shelf facies adjacent to active delta systems. During this time, palaeo-flow data indicate major sediment input feeding deep-water systems into the newly formed Mozambique Channel offshore. Areas of clastic by-pass at this time (inactive footwall highs) saw the establishment of now exhumed isolated carbonate platforms.

During the Jurassic and Early Cretaceous, potential reservoir sandstones are frequently overlain by organic rich marine shales, which strongly suggests that anoxic or oxygen-poor conditions were present in more distal offshore throughout the Mesozoic and spread nearshore during transgressions. The inter-fingering of potential reservoir and source intervals has implications for the prospectivity of the area.

Although mega-sequence boundaries can be directly related to regional tectonic events, internal mega-sequence and sequence architecture is modified by salt and gravity tectonics, most notably where salt kinematics, triggered by renewed sediment loading in the Eocene (it is also likely that salt tectonics was active in this basin during the Cretaceous).

Geological energy storage: new uses for old reservoirs?

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Energy storage has been practised for millennia as a pile of wood for winter, and more recently as coal stocks outside thermal power stations. With a move away from power generation using fossil fuels towards renewable sources, then storage requirements change. Storage on an hours-to-days timescale can bridge the gap between intermittent generation and consumer demand, the latter highest around breakfast and early evening. Seasonal fluctuations are also important, with demand (and prices) low in summer and higher in winter.

Methane gas is technically easy to store using proven technology developed for the production of natural gas. Depleted gas fields offer well-characterised potential sites, though with aging or decommissioned infrastructure. The UK's only large methane storage site, the offshore Rough Gas Storage Facility, has recently closed leaving the UK crucially dependant on imports. National Grid issued a Gas Deficit Warning in the winter of 2017-18, suggesting that large scale (e.g. 2 months of entire UK consumption) storage would improve security of supply. Burning methane generates CO_2 emissions, which while lower than coal, are significantly too high if ambitious emissions targets are to be met.

A large proportion of the UK's energy demand is for heating buildings ('space heating'), which is currently achieved in many cases using gas central heating. It is clearly impractical to capture CO_2 emissions from each boiler, so that using hydrogen in the national gas grid would eliminate the emissions. However, hydrogen has to be generated, either from fossil fuel (combined with geological CO_2 storage) or by the electrolysis of water. It is most efficient to generate hydrogen at a constant rate, rather than track peaks and troughs of demand. Hence, both short-term (e.g. in salt caverns) and long-term (seasonal) storage in porous rocks might be required, and both would aid security of supply. Storage of hydrogen in porous rocks has not been tested commercially, but offers huge storage potential especially in depleted methane-gas fields. Downsides include a reduced energy density compared to methane; possible reactions with the host rock and poorly quantified biological effects.

Similarly, energy can be stored in porous rocks (and salt caverns) as compressed air. For conventional gas turbines in a thermal power station, a significant proportion of the electrical output is used to run compressors. With a supply of compressed air, this parasitic load can be reduced or eliminated, giving a raised power output for times of peak demand.

With either compressed air or hydrogen storage, electricity can be utilised at times of low consumer demand, and re-generated at times of high demand. In some energy markets, off-peak electricity can have a negative value to the generator (but not to the consumer!), making storage commercially attractive. Storage could be located close to offshore wind farms, increasing the control on supply. Either technology could enable a massive expansion of renewable power onto the national grid, without causing a lack of stability. Either could offer enhanced security of supply, especially in the face of imported energy. Either will require a significant investment in infrastructure, and may face completion with geological carbon storage for subsurface locations, especially the depleted gas fields that many see as the 'low hanging fruit' of geological storage.

HOW SHOULD WE QUANTIFY MINERALS AND CEMENTS IN RESERVOIR ROCKS?

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Standard petrographic analysis (point counting) has been the main-stay of oil and gas field reservoir quality prediction for many years, although it is relatively expensive, time-consuming and requires a highly trained and, preferably, highly skilled petrographer to produce the data. So far, automated point-counting has proved impossible to develop. X-ray diffraction analysis is routinely used as a SCAL (Special Core Analysis) technique to quantify mineral, and especially clay mineral, proportion. XRD is also relatively expensive, time-consuming and requires a highly trained and, preferably, highly skilled diffractionist to produce the data. There are other quantitative techniques, such as infrared spectroscopy, but these have not caught on as common tools in industry or research. Automated scanning electron microscopy-energy dispersive analysis of X-rays (SEM-EDS) was developed over the last 10 years or so and promises to allow repeatable, high precision mineral quantification but the equipment is expensive, and a skilled operator is required, preferably with an advanced knowledge of mineral chemistry. In this presentation we will, for the first time, compare quantitative results from point counting, XRD and SEM-EDS. We will discuss the relative merits of the various reservoir quality analysis techniques as well as discussing their limitations. In our experience so far, standard petrographic analysis (point counting) has proved to be unexpectedly useful for detailed reservoir quality studies to define different types and morphologies of the same mineral (e.g. quartz cement from quartz overgrowth and pore filling versus grain-coating chlorite). However, the low errors and high precision resulting from SEM-EDS analysis has obvious appeal and usefulness. XRD analysis still has its place but the vagaries of sample preparation and low analytical precision mean that XRD data seem to be less useful than its widespread use during core studies would suggest. The quantitative comparison of point-count, SEM-EDS and XRD data presented here now permit a reasoned design of advanced studies of reservoir quality in sandstones.

Modelling Sedimentary Architecture and Heterogeneity of Meandering-River Successions in Half-Grabens

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The architecture of meandering-river deposits varies greatly within the infills of rift-basins, depending on how differential rates of fault propagation and subsidence interplay with autogenic processes to drive changes in fluvial channel-belt position and rate of migration, avulsion frequency, and mechanisms of meander-bend cut off. This process fundamentally influences stacking patterns of the accumulated successions. Quantitative predictions of the spatio-temporal evolution and internal architecture of meandering fluvial deposits in such tectonically active settings remain limited.

A numerical forward stratigraphic model, PB-SAND, is used to explore the relationships between differential rates of subsidence and resultant fluvial channel-belt migration, reach avulsion and channel-deposit stacking in active, fault-bounded half-grabens. The model is used to reconstruct and predict the complex morphodynamics of fluvial meanders, their generated bar forms, and the associated lithofacies distributions that accumulate as heterogeneous fluvial successions in rift settings, constrained by limited data from seismic images and outcrop successions. The 3D modeling outputs can be used to explore heterogeneity of both intra- and inter-bar deposits at various temporal scales.

Results show how the connectivity of sand-prone geobodies can be quantified as a function of subsidence rate, which decreases both along and away from the basin-bounding fault. In particular, results highlight the spatial variability in the size and connectedness of sand-prone geobodies that is seen in directions perpendicular and parallel to the basin axis, and that arises as a function of the interaction between spatial and temporal variations in rates of accommodation generation and tectonically driven changes in river morphodynamics. Optimal locations or 'sweet spots' for hydrocarbon exploration in half-grabens is primarily determined by the interplay between the frequency of fault slip, the rate of subsidence, the style of basin propagation, the rates of migration of channel belts, the frequency of avulsion, and the proportion and spatial distribution of variably sand-prone channel and bar deposits. The 3D model provides linkage between local outcrop measurements and large-scale evolutionary behavior, and allows quantitative assessments of possible scenarios depicted in traditional qualitative facies models. Outputs from this approach can be used to better inform reservoir models.

Clinoform dip along strike as a key to delta characterisation

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Wave-dominated deltas are important hydrocarbon reservoirs in places such as the North Sea, the Mediterranean, the Alaskan North Slope and the Gulf of Mexico. Whilst inter-well correlation of the large scale reservoir bodies is typically straight forward the prediction of internal heterogeneities, which are commonly associated with clinoform surfaces, are difficult to predict away from wells. In modern systems uncovering the depositional history can be challenging because only the most recent delta development is visible on satellite imagery and the reconstruction of past river courses and facies distribution again relies on geophysical or borehole data. To bridge this gap in characterising deltaic sedimentation we combine measurements from both the shallow, high-resolution section of 3D seismic data of an Eocene delta in the Outer Moray Firth with information from Google Earth's satellite imagery and digital elevation model on southeast Brazilian river deltas (São Francisco, Jequitinhonha, Doce, Paraíba do Sul) to present a means of predicting clinoform geometry with respect to the position of fluvial entry points.

The key measurement for this study is clinoform dip of the delta front which has been measured at multiple locations along strike of the coastline of the examined deltas. For the SE Brazilian deltas, clinoform dip has been measured along the current coastline while for the Eocene delta in the Outer Moray Firth measurements were taken along strike from 8 successive dip sections through the delta front.

Clinoform dip shows systematic variation with highs and lows along strike within the delta fronts examined in this study. Clinoform dip decreases away from the inferred river mouth for all deltas by 50% within a distance of 7.5 km. This is attributed to the possible position of older palaeochannels visible on the delta top for the Doce River Delta and faint imprints of palaeochannels on attribute maps for the Eocene delta in the Outer Moray Firth. The high clinoform dips and the location of palaeochannels appear to be associated with coarse sediment recorded in grab samples offshore the Paraíba do Sul Delta and in borehole cuttings in the Outer Moray Firth.

In summary we found that clinoform dip is highest at the location of the river mouth and decreases, along with grainsize away from it. This suggests that proximity to the channel mouth can be used to predict clinoform dip and reservoir properties if the clinoforms are not readily visible and conversely, changes in clinoform dip can be used to predict the position of fluvial entry points if these are not readily seen.

Why you should care about neighbouring sedimentary systems: Overprinted allocyclic processes by tidal resonance in the Upper Jurassic Curtis Formation, Utah, USA.

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Some shallow, tide-dominated sedimentary units and basins in the rock record do not correspond to any modern, tide-dominated and/or tide-influenced coastlines such as deltas, estuaries, and lagoons. The semi-enclosed, shallow, Utah-Idaho Trough foreland basin that the Curtis Sea transgressed during the earliest Upper Jurassic is one of these exceptions. It was transgressed from today's Wyoming, south-westwards into Utah. A severe starvation of perennial fluvial input due to the persistent aridity, which reigned over and around the basin prior, during, and after the Curtis Sea's transgression, characterises this basin, in which the lower, middle, and upper Curtis, as well as the Summerville formations were deposited. The shallow basin's protected nature, as well as its elongated morphology (ca. 800x190 km), allowed for efficient wave energy dissipation. Consequently, the semi-enclosed, shallow marine system was dominated by amplified tidal forces, resulting in an intricate arrangement of heterolithic deposits.

Intrinsic autocyclic processes acting upon the system were strongly impacted by allocyclic forcing, during the deposition of the lower Curtis. Relative sea-level variations, as well as uplift and deformation episodes, resulted in three parasequences, separated by traceable flooding and ravinement surfaces. The subsequent transgression defines the base of the middle Curtis, and its basal compound transgressive/ravinement surface can be traced throughout the study area, and beyond. As a consequence of this transgression, the shallow-marine part of the system entered into tidal resonance, which overprinted any evidence of allocyclic forcing and related traceable stratigraphic surfaces, because the basin reached the optimal length-to-width configuration. However, the contemporaneous Moab Member of the neighbouring coastal aeolian dune field, characterised by five stacked aeolian sequences, as well as the Summerville Formation's supratidal deposits, continued to register allocyclic signals, as the Curtis Sea regressed.

This study shows that (i) if the tide-dominated basin reaches its ideal configuration, it can enter into a resonant stage, in which autocyclic behaviours can overprint the impact of otherwise dominant allocyclic processes, and hence, (ii) if the system is alternatively dominated by auto- or allocyclic processes, it is necessary to study neighbouring and contemporaneous depositional systems if one aims at obtaining the researched basin's most complete sequence stratigraphic history.

Key word: Tidal resonance, autocyclic and allocyclic processes, stratigraphic surfaces, aeolian sequences, Curtis Formation

Poster presentations

Role of mass-transport complexes (MTCs) in controlling the distribution of deepwater sandstone reservoirs, Kwanza Basin, offshore Angola

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MTCs are created by gravity driven, debris flow, creep, slide and slump processes and typically initiated by shear failure and transported down slope largely as chaotic units. Mass-transport complexes (MTC) form 30-45% of many slope and basinfloor successions preserved along continental margins, with most previous studies focusing on the style and utility of features documenting the kinematics of their transport and emplacement. Here we instead focus on the role of MTC basal erosion in removing reservoirs, and how upper-surface relief control sediment dispersal and overall reservoir development in a frontier deepwater setting. To do this we use c. 9000 km^2 of 3D depth-migrated seismic reflection dataset from the salt-influenced Kwanza Basin, offshore Angola. We interpret key reflections that define the structural and stratigraphic framework of the study area, including the top and base of a particularly well-imaged, seismically chaotic MTC that is >350 m thick and trends NW. Seismic attribute analysis of these surfaces, in addition to seismic facies analysis of the MTC itself, are used to analyze the external and internal morphology of the MTC, and emplacement kinematics. We show that the lateral margins of the MTC is confined by growing salt structures. The MTCs base is broadly concordant with underlying stratigraphy, although grooves, striations and scours attest to seabed erosion during MTC transport and emplacement. Truncation of underlying turbidite reservoirs is highly likely due to erosion at the base of the MTC. The MTC is characterized by extensional features in the upslope domain and contains large (up to 230 m tall and 140 m wide), upward-tapering remnant and translated blocks, the latter having undergone rotation during downslope transport. The top of the MTC is highly irregular and characterized by up to decametre-scale topography, which is spatially related to underlying, intra-MTC translated blocks and/or thrusts. This relief causes pinch-outs, onlap and ponding of reservoirs alone the MTC top surface. An understanding of the MTCs relict topography and adjacent stratigraphic geometries is thus critical for understanding stratigraphic trapping opportunities.

The effect of Oxygen Plasma Ashing treatment on the carbonate clumped isotope parameter

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Carbonate clumped isotope is a technique based on multiply-substituted isotopologues of ^{13}C and ^{18}O (Δ_{47}) and is used for paleothermometry. The application of this technique has been applied to a range of geological problems, which led to a variety in the types of samples used, including organic-rich carbonate samples. High concentration of volatile organic compounds in the CO_2 during the purification process may produce isobaric effect on mass 47, and a static Porapak^{tm} Q (PPQ) trap may not be sufficient to remove heavy organic material.

Oxygen plasma ashing (OPA) is a method known to remove organic matter from samples based on using ionized oxygen in vacuum-plasma system. This method performed at temperature below 100˚C and should not lead to mass 47 re-arrangement within the mineral lattice. Previous work on bulk isotopes have also shown no effects of OPA treatment.

Here, we tested the OPA method for carbonate clumped isotopes. We used two internal standards, IOL (Imperial Oamaru Limestone) and JMF-6A (Oman calcite vein) and treated both on a Henniker^{tm} Plasma HPT-100 with 46 sccm gas flow rate. The initial value of both samples are 0.720±0.028‰ for IOL and 0.629±0.020‰ for JMF-6A. Both samples were exposed to 30, 20 and 10 minute oxygen plasma ashing before being processed through our CO_2 vacuum cryogenic purification line and measured on the mass spectrometer. The result shows a positive correlation between the Δ_{47} offset and exposure time to plasma. The result of the 30 minute exposure shows a significant increase in Δ_{47} with a 0.055‰ positive offset on IOL and 0.027‰ on JMF-6A. The result for 20 minute exposure shows the reduction of this positive offset to 0.017‰ (IOL) and 0.030‰ (JMF-6A). Finally, the 10 minute OPA treatment yields the best results, which final clumped values consistent with the initial value. This result has provided the specific time information for OPA procedure on carbonate clumped isotope samples, particularly for organic rich carbonate samples.

The Structure and Architecture of the Tjörnes Group, NE Iceland.

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The Tjörnes Peninsula in NE Iceland contains a thick sedimentary sequence bounded by basaltic lava flows. The Pliocene sediments (4.4 to 2.6 Ma) comprise of terrestrial sandstones and lignites, marine sandstones, siltstones and conglomerates, and several intercalated lavas. Several palaeoclimate studies have focused on using marine archives from the sequence, including mollusc and dinoflagellate records, to examine palaeoceanographic and palaeoclimatic change in the North Atlantic region. 3D outcrop modelling and UAV photogrammetry have uncovered extensive basinward faulting and mass movement within the Tjörnes section, and fence mapping has highlighted significant lateral sedimentological variability and indicates the classic stratigraphic column, used in many palaeoclimate studies, may be incomplete and is not representative of the whole sequence. Here, we present a revised stratigraphic column for the Tjörnes section, alongside new outcrop maps, which account for the structural and geological complexities observed and reveal a greater insight into the sedimentary architecture of the sequence; ultimately, such refinements are fundamental for developing a reliable stratigraphic framework for future Tjörnes palaeoclimate studies, including our upcoming br-GDGT terrestrial temperature reconstructions.

Photograph of sedimentary structures (cross/trough bedding and channel structures) exposed in a road cut in the Tjörnes Group.

Characterisation of sedimentation in the fluvial-to-marine transition zone: examples from the Dhruma Formation, Rub' Alkhali, Saudi Arabia

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Discerning the roles of autogenic and allogenic controls on the accumulation and preservation of sedimentary successions requires characterisation at multiple scales. This is especially true in fluvial-to-marine transition zone (FMTZ) settings, for which the preserved stratigraphic record is complicated by spatial and temporal interplay of fluvial, wave, tidal and shallow-marine processes that give rise to a broad range of sub-environments. Within the FMTZ, there typically exists a downstream transition from fluvial dominance to marine dominance, but this transition is typically expressed in the geologic record as a complex mosaic of facies trends and patterns, principally because adjacent and co-existent sub-environments undertook lateral shifts in position due to both autogenic processes (e.g. channel avulsion, delta-lobe switching, growth and filling of interdistributary bays) and allogenic controls (e.g. transgression associated with relative sea-level rise, shoreline regression associated with a rate of sediment delivery that outpaced accommodation generation).

This study presents a workflow for the construction of depositional models to account for stratigraphic complexity inherent in a FMTZ succession. The approach integrates techniques in lithofacies analysis, ichnology and sequence stratigraphy based on analysis of subsurface data from 15 wells that penetrate the Middle Jurassic, Lower Dhruma Sand Member of the Dhruma Formation, Rub' Alkhali Basin, Saudi Arabia. The data set includes facies descriptions of ~500 m of core, 77 representative core thin sections, 5 image logs and a series of 2D seismic lines. A specific objective of this study is to predict the nature of juxtaposition of geobodies of various types and to investigate their expected lateral continuity, thereby demonstrating the presence of a range of depositional sub-environments and establishing a sequence stratigraphic framework. Lithofacies cycles revealed in core record amalgamated upward-fining sandstone successions with coarse- to very fine-sized sandstones, lenticular to flaser bedded heterolithic sandstone and mudstone, medium to heavily bioturbated sandstone, cross-bedded sandstone and mudstone. Cores also record the presence of bioturbated very fine sandstone and siltstone with rootlets, thin beds of coal and organic debris. Pyrite nodules are present in the succession in association with mudstone and coal. Associations of these facies are interpreted as tidally influenced fluvial (up-dip settings), coastal plain, mouth bar, and shoreface (down-dip) sub-environments. Facies transitions observed vertically in core record the presence of progradational and retrogradational parasequence sets indicative of multiple transgressive-regressive cycles.

Controls of mass wasting on sedimentation processes and heterogeneity in slope mudstone reservoirs: an example from the Ainsa Basin, Southern Pyrenees

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Slope mudstones can comprise the largest volume of prograding shelf successions and are economically important as unconventional reservoirs and conventional plays as source rocks and seals. Despite this, our understanding of mud transport and deposition rates and processes, lags considerably behind that for coarser-grained depositional systems. This work uses the Fosado slope system (Eocene Hecho Group) of the Ainsa Basin, as a case study focussing on controls of heterogeneity in slope mudstone reservoirs.

During the Eocene, the Ainsa Basin was a piggyback depocentre located to the south of the Pyrenean Orogen which formed as a result of the collision of Iberia with Europe. It was bounded to the north and south by south verging orogenic thrusts, and to the east and west by west-verging blind lateral-ramp thrusts associated with the Mediano and Boltana structures, respectively. The Mediano structure maintained a long-lasting tectonic slope which separated deposition on the shelf to the east from the basin floor the west. The initiation of this slope, its subsequent progradation, the distribution of mudstone lithofacies down and across slope profile are the focus of this study.

Four mudstone litho facies have been identified: 1) Mass transport deposits of slumps, slides and debrites up to 10m thick composed of folded to disaggregated mudstones containing olistoliths of shelf and slope sediments; 2) Low-density turbidites ranging in thickness from 1-10cm; 3) Thin low-density turbidites of less than 1cm; 4) Up to 10cm thick inverse to normally graded beds separated by erosional contacts interpreted as hyperpycnites. Facies 1 typically overlies large-scale scours. Facies 2 and 3 dominate, healing topography above scours draped by Facies 1, and commonly syn-depositionally deformed into folds and onlapping against normal faults. Facies 4, shows a similar architectural features to Facies 2 and 3, but is restricted to the SE of the study area, in an area interpreted as close to a shelf-edge sediment source that was feeding sediment directly to the slope.

Normal faults and folds associated with soft sediment transport occur at scales from sub metre to 100s m. Their mapped orientations reveal a change in slope orientation of over 90° over a distance of c. 10km. The size and abundance of these structures increases with proximity to thrusts which are interpreted to have been active at the time of deposition. Architectural analysis suggests that these structures “creep” slowly over time, rather than failing catastrophically, and generated progressive accommodation and topography on the slope that was filled or bypassed syn-depositionally.

A 3-dymensional model of a low density turbidity current in the deep ocean: understanding turbidity currents (time) step by (time) step

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Turbidity currents are submarine density flows that move vast amounts of sediment towards the deep-sea basins. They reshape the seafloor through erosion and deposition of the sediment in suspension within the flows, and form the largest sediment accumulations on Earth. They control the distribution of hydrocarbon reservoirs and organisms that interact with the superficial seabed sediment. They are, however, still poorly understood mainly because measuring and characterise them is extremely challenging. Studies on turbidity currents have used different approaches, from numerical and experimental modelling to direct monitoring, to enhance our knowledge of these density flows. Among them, numerical models provide the finest temporal and spatial resolution in the analysis of turbidity currents and their deposits. Numerical models compute the calculations based on the parametrization of the processes that occur in the density flow-seafloor system. Defining adequate parameter values is key to obtaining efficient model results that support or reject hypotheses postulated on the turbidity currents behaviour.

In this work we use Delft3D, which is a numerical model widely used in fluvial and shallow water applications, to model a low density turbidity current in the deep ocean. We show the sensitivity of the model to several parameters, such as depth, time steps, turbulence and boundary conditions, and a detailed view of the flow and seafloor morphodynamics. The validation of this model in Delft3D with experimental and field measurements of turbidity currents is the next step forwards towards testing conceptual models that have been previously suggested. The validated model will represent an excellent tool to provide insights into turbidity current and seafloor interaction, and into the morphological changes of the seafloor that can be expected in spatial and temporal scales.

Provenance of Lower Cretaceous quartz arenites from the northern Indian Plate: tropical weathering or a multi-cycled sediment source?

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Lower Cretaceous sediments of the northwestern Indian Plate margin that were deposited in the Barmer, Cambay, Narmada, Kachchh and Jaisalmer basins of the West Indian Rift System (WIRS) and the Lower and Middle Indus Basins (LMIB) are dominated by mature quartz arenites. Such extreme quartz-rich detrital mineralogy is surprising given that the local highs flanking the WIRS and provide long-distance sediment supply to the LMIB comprise a variety of Precambrian basement rocks including: Malani Igneous Suite, Delhi Supergroup, Aravalli Belt and the Bundelkhand Craton. Most published studies assume that the provenance is the Aravalli Mountain Range although there is little palaeogeographical or mineralogical evidence to support this. Presented here are new mineralogical data for the fluvial Ghaggar-Hakra Formation of the Barmer Basin and a compilation of published detrital mineralogies of sandstones across the WIRS and LMIB, aiming to constrain the provenance.

For the Ghaggar-Hakra Formation 99 thin sections from both outcrop and core were point-counted. Virtually all the samples are quartz-arenites or sublithic arenites with almost no detrital feldspar. Published data for the WIRS indicates that the sandstones are predominantly quartz-arenites or sub-lithic arenites, apart from in the Kachchh Basin which has an arkosic detrital composition. The LMIB sandstones are mineralogically sub-lithic arenites. Studies indicate that these sediments have been affected by diagenesis and to provide understanding of the source provenance we need to reconstruct the original detrital mineralogy. This is accomplished by: 1. Adding oversized pores, grain-replacive calcite cement and authigenic kaolinite together to recalculate the original feldspar content, and; 2. Adding authigenic chlorite, smectite, opaque minerals and iron-replaced grains to the lithic total.

These calculations indicate that the sandstones from the Barmer, Cambay, Narmada and Jasimaler basins remain within the quartz-arenite and sub-lithic arenite ranges. The sandstones in the Kachchh Basin are arkosic and the LMIB are within both the lithic arkose and feldspathic arenite ranges.

Major differences in the detrital mineralogy indicate that widespread development of quartz arenites cannot be the result of deep tropical weathering, as previous authors have reported. Rather, the mineralogical differences are likely to reflect variation in provenance. Using well established sandstone provenance triangular plots, these sandstones appear to be composed of mineralogies that fall within the quartzose recycled, dissected arc and transitional continental provenance ranges. Detailed palaeogeographical reconstruction of the northern Indian Plate margin in-conjunction with the recalculated QFL mineralogical diagrams suggests the sediments of the Kachchh and LMIB are probably derived from local highs, whilst the sandstones of the WIRS (minus the Kachchh Basin) are likely to be derived from the late Precambrian Marwar Supergroup sandstones as they are at least second generation quartz detritus that have travelled far.

An integrated study on the formation and dispersal of contourites.

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We apply an integrated GIS, numerical modelling and outcrop approach to define and quantify the controls on the deposition and spatial distribution of contourites. We do this by linking observed contourite deposits identified in the Global Contourite Atlas (Rebesco, et al. 2014) with a variety of oceanographic parameters obtained from satellite measurements and numerical ocean models. These parameters include: Surface currents, bottom current velocity, year-round storm activity, ocean turbidity and tidal amplitude. Our results show that the spatial distribution of contourites is dominantly controlled by ocean turbidity and bottom drag; a parameterization of the friction between the ocean floor and ocean bottom currents (Trossman et al. 2016). We then combine these dominant parameters to quantify boundary conditions for the formation of various types of contourite. We also map the lateral extent and boundaries of Moroccan fossil contourites at the surface with the aim to link our derived boundary conditions to paleoenvironmental settings inferred from outcrop. This study will enhance our ability to predict the dispersal and sedimentary character of various types of contourites.

Submarine fan systems: proximal to distal reservoir quality controls

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Understanding the reservoir quality evolution of mature turbidite systems in proximal to distal settings of submarine fan systems is important to guide exploration of complex turbidite systems, especially in deep-water plays. Clay mineral content and diagenesis has been recognised as a first-order control on reservoir quality of deep-water turbidites and fan systems. This study aims to identify and quantify the variability of clay types and distribution of heterolithic facies in turbidite channel complexes in order to assess their impact upon porosity and permeability distributions from a proximal to distal submarine fans depositional setting. Five facies were identified based on core description of the Palaeocene Forties Sandstone Member, Forties fan, North Sea. A total of 14 wells in seven (7) proximal to distal oil and gas fields have been chosen. These facies include: (1) amalgamated sandstone, (2) channel margin, (3) sand-prone heterolithic, (4) mud-prone heterolithic, and (5) mudstone facies. Two hundred and five (205) thin-section were selected from the Forties Sandstones and light microscopy, SEM, SEM-EDX and XRD analyses have been undertaken. The Forties sandstones are fine to medium grained, poorly to moderately well sorted, and are classified as arkose, subarkose and quartz arenites. The study preliminarily demonstrates that the reservoir quality of the sandstones is controlled by depositional facies, detrital composition (e.g. grain dissolution) and diagenetic processes. Diagenetic modifications and reservoir quality evolution of the sandstones have been achieved during eo- and meso- diagenesis. Primary intergranular porosity was partially to pervasively occluded during eodiagenesis due to mechanical compaction and precipitation of kaolinite, chlorite, calcite, siderite, quartz cements and pyrites. Mesogenetic alterations include conversion of eogenetic kaolinite and smectite to illite, formation of pore-filling chlorite, dissolution of unstable feldspars and mica grains, precipitation of ferroan calcite, and mechanical compaction. Chlorites occur mainly as pore-filling cements and, locally, as pore-lining cements. The pore-lining chlorites, where well developed, appeared to have locally prevented the formation of quartz overgrowths thereby preserving reservoir quality. Based on the preliminary overall assessment of the impact of diagenesis on reservoir quality of the sandstones, it was revealed that there is no single diagenetic alteration that solely controlled the pattern of porosity evolution in the sandstones. As a result, it appears that the major cement types (calcite, siderite, kaolinite, illite-smectite, illite and quarzt overgrowth) as well as mechanical compaction have collectively controlled the reservoir quality evolution of the Forties Sandstones. Mechanical compaction and cementation was more extensive and intense in the distal portion of the fan. This is due to the increase in abundace of ductile detrital grains and mud intraclasts that facilitated compaction and cementation in the distal fan facies. Secondary porosity due to dissolution of unstable feldspar and mica grains appears to have contributed greatly to the overall effective porosity of the sandstones.

Understanding Mg^{2+} sources and patterns of hydrothermal dolomitisation: insights from 3-D Reactive Transport Modelling of geothermal convection

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Fault-controlled hydrothermal dolomites and associated leached limestones are of considerable economic importance as they significantly impact hydrocarbon producing reservoirs. Hydrothermal dolomites, formed at elevated temperatures, are commonly suggested to have formed from fluids derived from a deep aquifer and focussed into overlying limestones by discharge along extensional or trans-tensional fault and fracture systems. However, significant uncertainties remain about the source of sufficient volumes of Mg-rich fluids to account for observed volumes of hydrothermal dolomites.

Over the last 15 years Reactive Transport Model (RTM) simulations have been developed to better understand carbonate diagenesis. We report preliminary results of a 3-D RTM study exploring the controls on dolomitisation within a single transmissive fault system embedded within a porous and permeable carbonate reservoir. Simulations were conducted under different scenarios using TOUGHREACT, a non-isothermal RTM capable of simulating multiphase fluid flow, heat and solute transport with physical and chemical heterogeneity, to investigate the pattern of fluid flow and temperature in the system, as well as resulting water-rock interaction. Simulations show an open pass convection system develops, with areas where hot water ascends to discharge at the surface separated by zones within which Mg-rich seawater is drawn into the descending limbs of the convection cells. Steady convection is largely confined within the plane of the fault for simulations where the permeability of the fault zone is at least 3 orders magnitude greater than that of the matrix. The rate of dolomitisation appears to be primarily controlled by permeability within the fault damage zone, coupled with the Mg/Ca ratio of the seawater that provides the principle source of Mg2+ for dolomitisation. RTM simulations are starting to provide an improved understanding of mechanisms controlling dolomitisation within faulted and fractured systems, and the geometry and spatial distribution of the resulting geobodies.

The stratigraphic architecture and sequence stratigraphy of the Lower Limestone Coal Formation, Spireslack, Scotland.

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Incised valley-fill (IVF) successions are strongly associated with allocyclic controls and often correspond to base-level falls. They are becoming increasingly recognised within the Carboniferous succession of the UK. From an exploration perspective, they also have the potential to form stratigraphical traps and their locations and positions within the stratigraphical record are typically examined using seismic imaging. The Lower Limestone Coal Formation, as exposed at Spireslack Opencast Surface Mine, provides insights into IVF locations within the sequence stratigraphic framework of the Namurian succession.

This work details the stratigraphic architecture of the Brigantian to Pendleian Lower Limestone and Limestone Coal formations, and their sequence stratigraphical context. The study utilises UAV photogrammetry of key sections, in combination with detailed sedimentary logging of ~150 m of strata. A facies analysis is carried out to identify marine successions comprising limestone and coal bearing strata, the resulting successions have been placed in a sequence stratigraphical context.

The sedimentary architecture of the succession is complex and includes shelf and shoreface margin sands, large-scale fluvial barform geometries, and decimetre-scale tidal barforms. Sequence stratigraphical analysis reveals several parasequence-scale cycles that are dominated by flaser-bedded sandstones, grading upwards into more continental coal-bearing facies. Near the top of the logged succession, palaeosol facies show significant maturity indicating a period of limited aggradation and sediment bypass of the shelf. These are erosionally overlain by the Spireslack Sandstone, which represents the strata of a high sediment load, low-sinuosity, fluvial system grading into more heterolithic fluvial strata and tidally dominated transgressive deposits. This fluvial system retrogrades developing evidence of a tidal influence, such retrogradation relative to the surrounding succession suggests IVF strata.

Further work will characterise Namurian incised valley-fill deposits in terms of their internal sedimentary architecture and utilise the Spireslack IVF succession as an analogue for interpreting successions of the onshore and offshore Namurian strata of the UK. This work will have implications for predicting the sub-seismic internal geometries within the underexplored Carboniferous IVF successions of the Southern and Central North Sea, offshore. Future work should also utilise borehole and suitable outcrop data across the Scotland and Northern England to test the interpretation of the Spireslack Sandstone as IVF.

Stratigraphy and architecture of a coarse-grained deep-water system within the Cretaceous Cerro Toro Formation, Silla Syncline Area, southern Chile

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The Upper Cretaceous Cerro Toro Formation, southern Chile, is characterised by thin-bedded turbidites that envelope a series of coarse-grained, confined slope complex systems, interpreted as part of the Lago Sofia Member. This deep-water slope system overlies basin floor sheets of the Punta Barrosa Formation, and is overlain by the sand-filled slope channels of the Tres Pasos Formation.

Particularly distinctive beds, known as TEDs (transitional event deposits), are up to 40 m thick, laterally extensive, have prominent fluted bases, and have a vertical fabric starting with (1) a thin, inversely-graded, clast-supported base; then (2) a normally-graded and clast-supported interval; (3) an increasingly sand and clay matrix-supported conglomerate, with (4) a progressive upwards increase in matrix and normally grading, both in the floating gravel clast and matrix grain sizes, towards the top; and (5) a co-genetic sandstone on top. In the Cerro Toro formation, these TEDs tend to occur as multiple beds in the initial phases of deposition of each channel complex system. The TEDs are highly aggradational, slightly more amalgamated in the channel-axis, and more layered towards the margins. The fabric of these spectacular event beds is described in some detail from measured sections, combined with petrographic analysis and high-resolution field mapping.

The 4 km x 200 m channel systems are contained within topographically irregular bathymetric lows that formed sediment pathways, interpreted to be either the result of slope deformation, or contained by poorly preserved, tectonically disrupted or slumped external levee. Syn-sedimentary tectonism is interpreted to be responsible for sharp changes in the system's architecture from channels to ponds, marked by a sharp change in lithofacies from dominantly conglomerates to dominantly sandstones. A refined architectural analysis is proposed, focusing on the recurrent pattern of at least 5 cycles of conglomerate-filled channel systems – ponded sheet sandstones.

Semi-automated permeability modelling of mudrock thin-sections, using scanning electron microscopy (SEM), image analysis, pore architecture reconstructing (PAR) and pore network modelling (PNM)

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Mudrocks are recognised as highly heterogeneous in character, in terms of parameters such as inorganic detrital composition, biological content and composition, clay mineralogy, organic content, colour, porosity and permeability; with variability on the sub-millimetre to metre scale. Through the use of polished thin sections, scanning electron microscopy (SEM) is ideally suited to investigating variability at the micron to centimetre scale within mudrocks, with rich and continuing development over the last decade for extracting a range of data. The current work outlines a new novel workflow for the modelling of permeability within mudrocks, through 2D backscattered (BSE) imaging of a series of image tiles across polished thin-sections, to 3D reconstructing of the pore architectures revealed, to generating pore network models (PNM) of the 3D models reconstructed, and up to network simulating of permeability. Image acquisition is an automated task over a defined grid across the thin-section, and can be used to collect hundreds or thousands of images (tiles), in a time frame of minutes, hours, or several days. Using convenient image processing software such as ImageJ, such images can then be batched processed, thresholded and binarized to capture morphological information such as pore size distribution. Binarized images are then batch processed to reconstruct 3D stochastic models via in-house 2D to 3D reconstruction software (PAR), and analyzed by pore network software. A pilot project examining a contourite sample from the Bay of Cadiz (IODP 1387), based on 800 discrete BSE images, has been successfully processed, with data being used to construct plots of porosity versus permeability, as well as producing contoured permeability plots to graphically illustrate variability in permeability. The 3D models are produced by a voxel-based optimization algorithm for complex rocks, and the results from PNM appear to be within the bounds of reality. Nevertheless it would be simple matter to tweak the workflow and further test modelled data. This technique therefore offers a rapid technique to generate realistic models and permeability values that can be used to populate larger models used in predicting flow within mudrock (and other geological materials), for upscaling at the well bore, bed or block scale. In addition, the construction of contoured maps, offers insight into the spatial variability of permeability within mudrocks at the millimetre scale, which is not possible using other current methodologies. Future work will involve the investigation and permeability modelling of other deep-water mudstones, including contourites, turbidites and hemi-pelagites.

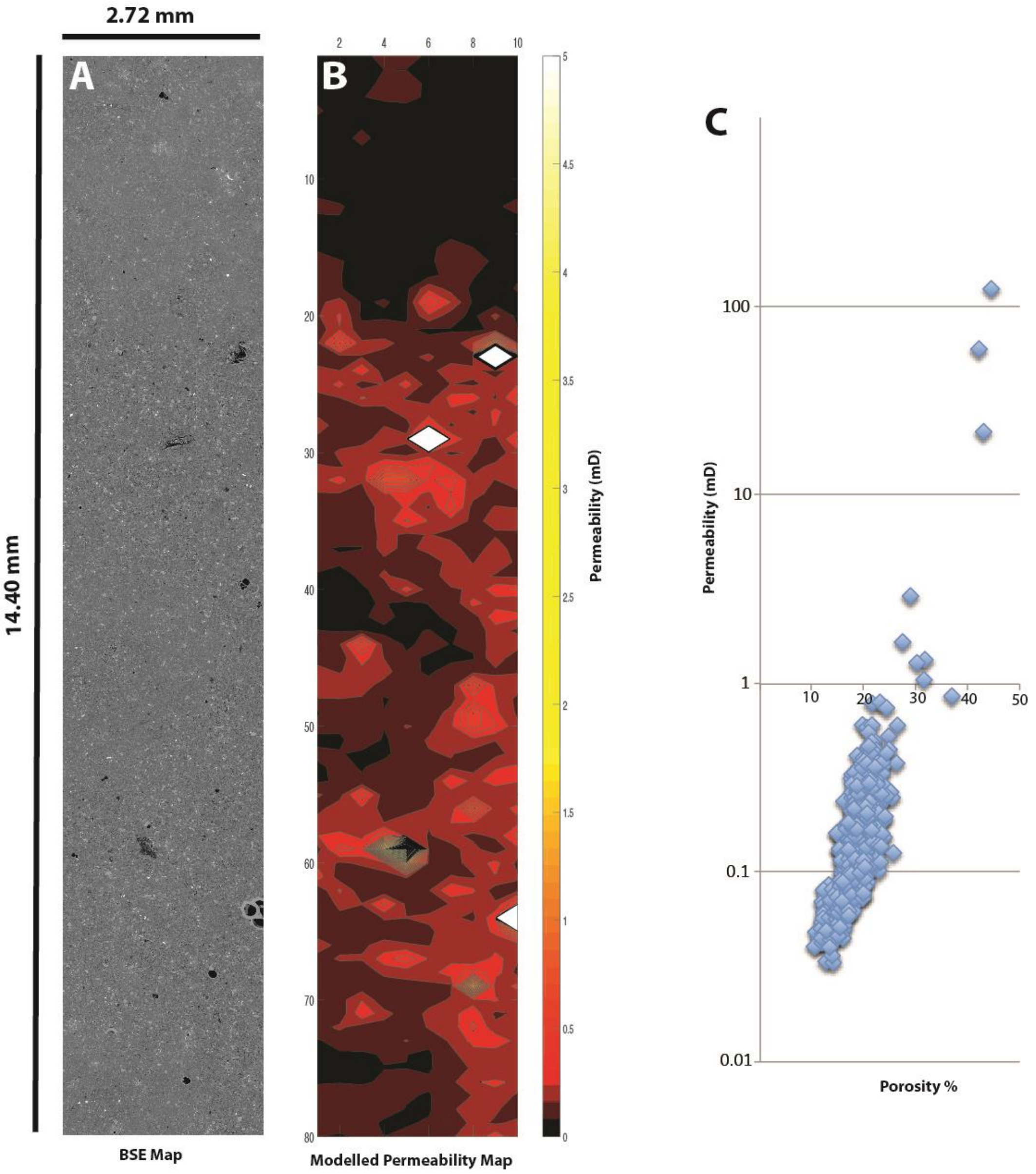

Figure 1. Image and poro-permeability data based on polished thin-section of contourite sample (IODP 1387, Bay of Cadiz). A) Backscattered (BSE) image montage constructed from 800 image tiles. B) Permeability map from same area as in (A), based on pore network models (PNM) from the 800 tiled images. C) Porosity-permeability plot of data derived from analysis of (A).

Recognition of Carboniferous microboring within shelly substrates, through charge contrast imaging (CCI): significance for the Hosie (McDonald) Limestone, Spireslack, Ayrshire, Scotland

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Spireslack is a Scottish Carboniferous research park (SCARP), located in Ayrshire, based around an open cast coal mining site ('Spireslack Canyon'). It exposes a sequence of limestones, sandstones, shales and coal measures within the Clackmannan Group (Fig. 1a), which along with its industrial heritage is being preserved by the Scottish Mines Restoration Trust (SMRT). The Hosie (McDonald) Limestone is extensively exposed along the length of the 'canyon' as a steeply dipping limestone pavement, the upper surface of which displays clear signs of bioturbation. A range of body fossils are also present, although these have not to date been studied systematically.

Charge contrast imaging (CCI), a scanning electron microscope technique that produces results similar to that of cathodoluminescence (Buckman et al., 2016), and when applied to polished thin-sections of the Top Hosie Limestone, illustrates an abundance of micro-bored shelly material, which are extensively fragmented, with fragments as short as 30 microns. Microborings are typically in the order of 1 - 10 microns wide, and occur in a range of morphologies, with both vertical and horizontal elements. Microborings originate from both external and internal surfaces, although the former is more predominant, and tiering is in many cases clearly developed (Fig. 1b). Microborings are likely to have a range of origins, with horizontal elements produced by 'fungal' activity, and more vertically inclined elements having an 'algal' origin.

The exact environmental significance of the Hosie Limestone, its associated fauna and ichnofauna are uncertain. The recognition of the high degree of microboring and the highly fragmentary nature of the shelly debris, suggests that the Top Hosie Limestone was reworked by wave or storm activity and that water-depth was at least partly within the photic zone. The degree of fragmentation and microboring suggest the possibility of an extended period of hiatus.

Similar shell hosted microborings, also revealed through the CCI technique, within a partially dolomitized Carboniferous limestone from the east coast of Scotland (Barns Ness, East Lothian), suggests that microborings within such Carboniferous limestones may not be uncommon. As such they are worthy of further detailed research into their ethological and environmental significance. The Barns Ness limestones are environmentally interesting as they often contain well developed coral communities (fully marine) but are closely associated (interbedded) with paleo soils, (?)fossil forests and coal deposits.

The recognition of the occurrence of complex microboring associations within the shelly substrates of such Carboniferous limestones, will with future research, further aid in palaeoenvironmental reconstruction.

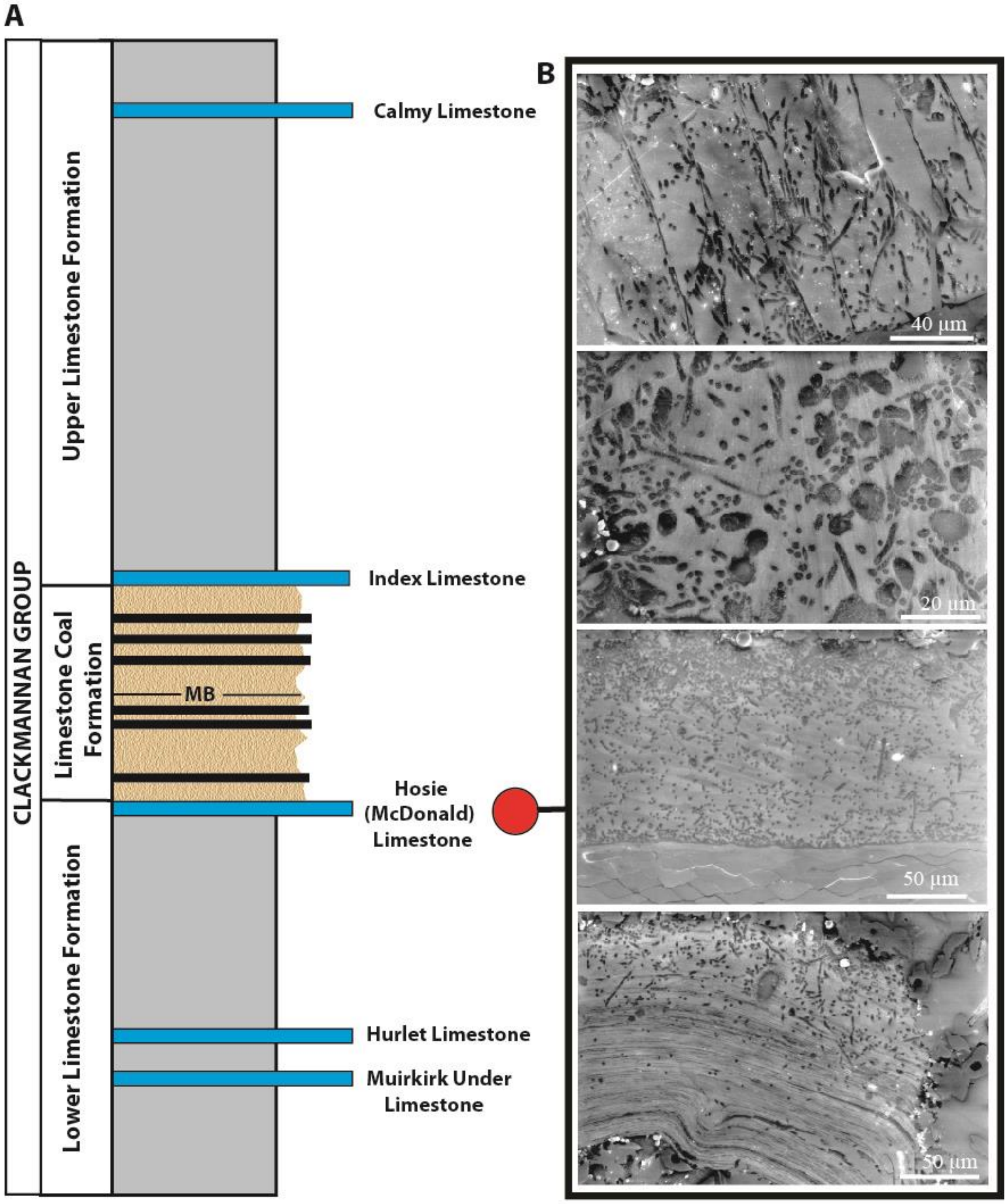

Figure 1. **A)** Simplified representation of the Carboniferous succession at Spireslack, Scotland; illustrating the position of the Hosie (McDonald) Limestone. **B)** Examples of scanning electron microscope (SEM), charge contrast imaging (CCI) images, illustrating the occurrence and nature of microborings in shelly substrates within the Top Hosie (McDonald) Limestone.

References:

Buckman, J.O, Corbett, P.W.M, & Mitchel, L. 2016. Charge Contrast Imaging (CCI): Revealing enhanced diagenetic features of a coquina limestone. *Journal of Sedimentary Research*, 86: 734-748

Correlation and Paleo-environmental reconstruction of the Central North Sea: New insights using palynology

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The Triassic continental successions of the Central North Sea (CNS) a can be divided into two; the early-mid Triassic Smith Bank Formation and the mid-late Triassic Skagerrak Formation. The Smith Bank Formation is thought to represent a predominantly distal aeolian environment whilst the Skagerrak Formation is dominated primarily by fluvial deposits comprising a succession of alternating sandstone and mudstone members. The alternation of mudstone and sandstone members has previously thought to be climatically driven.

In recent years there has been a renewed interest in theses Triassic successions owing in part to the mature status of the North Sea Basin, with these HPHT reservoirs becoming more attractive production targets. However hydrocarbon extraction in the past has been hindered by a lack of knowledge regarding stratigraphy at a basinal, sub-basinal and field scale.

Palynology is powerful tool for well correlation, age assessment and environmental reconstruction and is routinely used within the Petroleum industry. Previous palynological analysis of Triassic sediments within the CNS however, has been limited by poor recovery due to a combination of PDC drilling techniques, oil based muds, poor palynomorph preservation and the heavily oxidised nature of Triassic sediments. Through the use of refined palynology processing techniques it has been possible to obtain an updated palynomorph data set from which a robust biostratigraphic zonation scheme has been established to provide a chronostratigraphic framework across the basin. The use of multivariate statistical techniques, such as de-trended correspondence analysis (DCA), have also been applied to this updated palynomorph data set to quantitatively reconstruct paleo-environments. The resultant relative climate trends across the basin show that the relationship between climate and individual members is perhaps not a simple as first indicated by existing models, e.g. a non-definitive link between mudstone deposition and climate.

The focus of this study is on Quads 22, 29 & 30 from the UKCS and Quads 7, 15 and 16 of the Norwegian sector with results providing a better regional understanding of the Triassic successions of the CNS further aiding hydrocarbon exploration and exploitation.

Syn-kinematic deposition influences structural evolution in emergent thrust belts

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The dynamics of orogenic wedges are highly sensitive to the surface processes of deposition and erosion acting upon them. The most complete records of these settings are provided by submarine thrust systems where stratigraphy, with high temporal resolution, can chart deformation rates and the evolution of structural geometry. But these deposits influence thrust belt evolution. Deposition on the thrust belt itself, concentrated in thrust-top basins, dampens uplift of synclines and promotes amplification of anticlines. Deposition ahead of the active thrust front effectively continually resets the elevation of the free surface to which the thrust trajectory is attracted. Thus, at emergent thrust fronts, thrust trajectories climb progressively, forming syn-kinematic ramps: emergent thrusts only form upper thrust flats (detachments) when depositional rates at the thrust front are very low. The pattern of deposition at these two locations (supra-wedge and thrust front) combine to exert first-order controls the geometry and evolution of the thrust system that in turn influence sediment routing.

The Mio-Pliocene systems orogenic systems of the Apennines and Sicilian Mahgrebides offer ideal sites to examine the consequences of deposition on thrust belt evolution. In Sicily the frontal thrust structures (so-called Gela Nappe) over-run the foreland (Hyblean plateau) for at least 15 km, gliding on Pliocene strata. Deposition rates in the early Pliocene at the thrust front and on the Hyblean foreland were exceptionally low so that the thrust follows a low-angle detachment. It only climbs section when deposition rates increase dramatically in the early Pleistocene. In contrast, deformation in the thrust wedge is marked by spaced anticlines that amplify together in an array, with individual structures active for at least 6 million years. The shortening across the structures in the thrust wedge is rather low (a few km) in contrast to the displacements on the base of the wedge. This pattern of strain partitioning (strongly localised on the sediment-starved thrust front) is in marked contrast with the temporally coeval thrust systems of the northern Apennines. Here the thrust belt is entirely swamped by sediment sourced principally from the nearby Alps. The northern Apennines system is marked by spaced, synchronously active, imbricate thrusts. The frontal thrust does not show excessive displacement – there is no differential displacement partitioning.

In Sicily, partitioning of displacement in the orogenic wedge has fed back into the routing and accumulation of syn-kinematic sediment. The early Miocene turbidite systems (laterally-derived Numidian) were routing through structurally-confined corridors on the thrust wedge, leaving the palaeo-foredeep under-supplied. Sedimentation from the fledging orogen (later turbidites) ponded in thrust top-basins, again leaving the palaeo-foredeep under-supplied. The effect was to keep displacements focussed on the thrust front with slow amplification of intra-wedge structures that in turn ponded further sediment. This behaviour evolved only once significant sediment could reach the foredeep and the thrust front – temporarily in the late Tortonian and again in the Pleistocene.

Understanding the interactions between deposition and deformation is important for understanding not only the structural style in thrust systems – which impacts on reducing uncertainty in subsurface interpretation – but also in deducing sediment routing across fold-thrust belts. After all, it is these tectonic settings that provide many of the World's outcrop analogues for submarine depositional systems.

New insights on the progradation of the West of Shetland continental margin from 3D seismic data.

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The West of Shetland (WOS) continental margin has been extensively investigated by academia and oil and gas industry since the early 1980s. Although detailed chronostratigraphic and palaeo-geographic reconstructions are available for “commercial” intervals, less is known about the evolution of the shallower section due to limited dating control points. This work focuses on the post-Eocene succession, aiming to partially fill this gap in the knowledge of the margin. The study area extends over the WOS Slope and the Faroe-Shetland Channel (FSC), within the Cambo field in water depths ranging between 731 m and 1125 m. The data available consist of a high-resolution 3D seismic cube with a dominant frequency of 45-60 Hz, and a series of exploration wells that have been mainly used to constrain the Mid Eocene (Top Lutetian) Rothbury sandstone member, below the interval of interest of the present study. The modern-day seafloor is characterised by a glacial basin floor fan, and by erosional and depositional bedforms generated by the bottom current circulation probably during the Late Pleistocene-Holocene (FStocker and Varming, 2011; Stewart and Long, 2012). The basin floor glacial fan, accumulated during the Last Glacial Maximum (Stocker and Varming, 2011, Stewart and Long, 2012), represents the distal continuation of the Foula wedge, a large trough–mouth fan reflecting the repeated extensive glaciations since approximately 0.44 Ma (Stocker and Varming, 2011). In the study area, the glacial fan extends over 137 km_2 and is characterised by an irregular surface showing high seismic reflectivity and seabed gradients up to 5°. Seismic data reveal that the fan is up to 85 m thick. Time slices highlight that the fan has a complex pattern of erosive features, often associated with terminal blocks with different flow directions, indicating the presence of multiple stacked basin fan deposits. Below this unit, in the south-eastern corner of the study area, the 3D seismic data reveal a ca. 400 ms thick wedge consisting of a series of prograding sigmoidal reflections packages, reflecting the outbuilding of the margin. The foreset of each body is made of low to high amplitude reflections, laterally continuous often showing v-shaped incisions; these are observed at the base of chaotic seismic units (probably associated to slope debris flow deposits, Line B). With the exception of the younger package, this facies changes into a more complex one towards the basin, made of at least three lenticular shaped bodies exhibiting moderate to high discontinues reflections progressively stepping out basinward, which have been interpreted as basin fans. U-shaped incisions are observed within these bodies showing a transparent to chaotic infill. In map view, each package shows a basal surface cut by straight channel incisions on the slope that distally, towards the basin, evolves into a distributary channel network associated to a basin floor fan 3D amplitude time slices at different levels within the submarine staked fans and the dip of maximum similarity attribute calculated near the base of the seabed floor fan show the internal geometry of these units. The results of this study highlight that there is clear evidence of transport of shelf-derived sediments to the FSC across the Cambo area occurred multiple times before the onset of Quaternary glaciations. Although lack of detailed chronological constraints in the study area and seismic tie-lines, a stratigraphic framework is proposed based on indirect correlation with the results of previous studies (Stocker and Varming, 2011; Stoker et al., 2013). The bulk of the prograding wedge could be as old as upper Middle to Upper Eocene, overlaid by a possible Miocene low stand wedge and separated from the Plio-Pleistocene Foula wedge units by a regional erosional unconformity. The variability in fan morphology and internal architecture observed between the seafloor fan system and the older basin floor fan deposits implies different mechanisms of sediment delivery and paleo-environment, with the younger reflecting a glacially-influenced slope and the older reflecting deposition of an established marine environment.

The mechanism of mass transport deposits in the Southern South China implication from fault and carbonate structure analysis

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Massive submarine failures can generate catastrophic tsunamis and are a threat to people living in the coastal area. Mass movements occurring around islands could be more dangerous than those occurring on continental margins because of their short travel time to coastlines, which do not allow time for an effective warning to be issued. In the southern South China Sea, scattered substantial islands of carbonate occur. Since 2014, four marine cruises have collected at least 30 seismic reflection data around here where numerous mass transport deposits (MTD) have been identified in the formation from top to bottom. To resolve the kind of geological process that contributed to this MTD setup, we analyze the fault and carbonate structures in the southern South China Sea. Based on our observations, even though substantial faults develop in the formation, the failure mass did not deposit along fault planes. Most of the faults formed after the MTD had deposited and then cut through them. This result implies that the growth of faults may not be the primary cause of submarine mass failure here. The carbonate structures, on the contrary, suggest a possible forming mechanism of those MTD. Wide-ranging drowning, upward migration pinnacle, and isolated carbonate structures in the southern South China Sea indicate a relatively fast sea level rise after the continental breakup. This fast changed sea level could destabilize the submarine slope and ultimately produce substantial mass failures in the southern South China Sea.

Assessing HPHT sandstone reservoir quality: Identifying the reality

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Quartz cementation is typically one of the most important cements governing reservoir quality in sandstone reservoirs. It is a major cause of porosity loss and affects permeability by constricting pore throats and reducing pore size. The presence of clay minerals and diagenetically-formed microcrystalline quartz coatings play a crucial role in preserving anomalous high porosity in deeply buried sandstones by inhibiting porosity-occluding macroquartz cementation. Authigenic chlorite is the most important and effective grain-coating clay mineral in terms of inhibiting extensive quartz cementation in sandstones. This is in a large part due to the strong tendency of chlorite to form continuous coatings on quartz and feldspar grains and significantly restrict macroquartz precipitation even in deeply buried HPHT reservoirs.

Previous laboratory experiments and modelling have identified the role played by high temperatures (>100°C) in controlling authigenic clay coatings on detrital quartz grains. It is evident that for higher temperature reservoirs, more robust and greater grain coating coverage is required to preserve significant amounts of porosity. However, the role played by pore fluid pressure in overpressured reservoirs has been identified as significant for preserving anomalously high porosities. Overpressures (low vertical effective stress) can limit and/or prevent quartz cementation by forestalling the onset of intergranular pressure solution. In this study, a series of hydrothermal reactor experiments have been undertaken to simulate quartz cementation and grain coatings, particularly chlorite and microquartz, with different temperature, pore fluid chemistry and pore fluid pressures to mimic the conditions of deeply buried reservoirs.

The experiments were performed in a Parker Autoclave Engineers self-sealing reactor vessel rated to 350 MPa and operating temperatures up to 350$_{o}$C. Quartz crystals, clean quartz sand with no clay coatings or detrital grain components and naturally-occurring sandstone from the Lower Jurassic Cook Formation of the Oseberg Field (Norway, Well 30/6-17R), were used as starting material. Pre-existing berthierine, an aluminous Fe_{2+} rich clay which can act as a precursor for chlorite has been identified in the Cook formation and is of particular importance for the experimental procedure of this study. A variety of artificial solutions mimicking natural formation waters and a source of silica gel maintaining silica supersaturation during all experimental runs were used to elucidate this problem. Both starting material and end-products were inspected using light microscopy, SEM, SEM-EDS, X-Ray Tomography and QEMSCAN mineralogical mapping and petrography of new mineral precipitates. The hydrothermal reactor experiments have revealed that quartz cementation can be achieved in the laboratory under controlled physico-chemical conditions, and that quartz surface topography likely affects quartz cementation. The patchy amorphous berthierine clays transformed to crystalline grain coating Fe-chlorite cements facilitating better grain coat coverage. Changes in thickness and morphology of chlorite are also observed. However, any breaks in chlorite coat coverage can be detrimental to reservoir quality resulting in macroquartz growth.

Assessing and Monitoring the UK Shale Gas Landscape

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Hydraulic fracturing (fracking) for shale gas is a controversial issue in the United Kingdom (UK), with many concerns and uncertainties surrounding the potential environmental, social, economic and political impacts. Thus in October 2018, the Natural Environmental Research Council (NERC) and the Economic and Social Research Council (ESRC), funded the evolving shale gas landscape (UKSGL) project. The UKSGL project aims to provide a cross-cutting consortium to establish the current and future status of the shale gas landscape (SGL) in the UK. The main objective of the UKSGL project is to provide evidence on the current status of the SGL, monitor changes over the next four years, and identify knowledge gaps. Specifically, the UKSGL project will benchmark the current status of UK shale gas resources; the existing knowledge of the potential environmental impacts of shale gas; the social, political and economic dimensions of shale gas development in the UK; and its regulatory and legal framework. Where knowledge gaps are identified researchers from the UKSGL Interdisciplinary Research Team will be funded to address these gaps. Overtime the benchmarking and gap analyses will feed into the development of a heuristic model of the UK shale gas landscape.

The UKSGL project also supports and coordinates the delivery of the NERC-ESRC-funded interdisciplinary research programme on Unconventional Hydrocarbons in the UK Energy System (UKUH). The UKUH programme is a multi-institutional consortium addressing the following for key areas: (1) the shale resource potential in the UK; (2) transportation of the shale gas from reservoir to surface; (3) potential contamination pathways; and (4) the socio-economic impacts of fracking.

To ensure unbiased research and impartiality the UKSGL project and the UKUH programme is accountable to a Programme Advisory Board (PAB). The PAB comprises of representatives from the key stakeholder groups including policy makers, operators, environmental NGOs and professional organisations. The programme is also accountable to NERC-ESRC Programme Executive Board (PEB).

The project has been co-created with key stakeholder groups, including policy makers, operators, environmental NGOs and professional organisations. Through a series of thematic workshops and conferences we will innovate through engagement to ensure that the project delivers impact beyond the 4 years of research.

Evolution of a hypertidal meandering channel in Mont Saint Michel Bay (France) through LiDAR time-series and core analysis

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The morphodynamic of tidal meanders is determined by a number of interrelated factors (e.g. tidal prism, tidal asymmetry, residual current pattern, sediment texture, vegetation, etc.). In a hypertidal setting, interaction among these factors is combined with a significant tidal range (>6 m), which contributes to make erosional and depositional processes extremely dynamic. Beyond the development of heterolithic, laterally-accreting sedimentary bodies (i.e. tidal point bars), spatial facies distribution arising from the morphodynamic evolution of tidal meanders is still matter of investigation. The present study aims at improving our understanding of the relationship between planform evolution of tidal meander bends and the related sedimentary products in a hypertidal environment, focusing on a tidal meander located in the Bay of Mont Saint Michel (France). The bay is subjected to a semidiurnal hypertidal regime which can reach 15.4 m during spring tides. The study channel shows a high spatio-temporal variability in the width, shows a radius of curvature of about 85 m and is 3 m deep at bankfull stage. Elevation of the channel base is about 4 m above Mean Sea Level (MSL), approximately 1 m below Mean High Water Level (MHWL), hence the channel empties out twice per day during spring tides.

We used a dataset of 38 LiDAR surveys (both terrestrial and airborne), previously acquired between July 2009 and January 2017, integrated with sedimentological data from 13 cores. To understand planform evolution of the bend, along with spatial and temporal distribution of erosive and depositional processes, different surveys where compared. Furthermore, each survey was merged with all the following ones allowing to develop a 'virtual stratigraphy' of the point bar. Virtual stratigraphy was used to detect where depositional or bypass processes were recorded in the point bar.

Between 2009 and 2017, in the bend apex zone, the outer bank retreated ca. 26 m. Comparison between LiDAR surveys shows that landward and seaward sides of the bend were affected by different mobility, which led to an alternation between expansional and translational planform transformations. These changes caused a remarkable variability in the spatial distribution of depositional and bypass processes. It also emerges that the lower bar zone was affected by alternation between erosional and depositional processes, whereas the upper bar was characterized by deposition, which was locally promoted by the growth of a pioneering halophytic vegetation. Preliminary core data show that preservation of tidal deposits is strongly controlled by the temporal and spatial distribution of depositional and bypass processes.

Deepwater sediment bypass potential in a modern intra-slope system, East Coast Basin, New Zealand: implications for reservoir distribution and stratigraphic trap development.

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The analysis of modern sediment dispersal pathways has shown great potential to support subsurface interpretations of deepwater depositional systems. Particularly, to aid predictions of petroleum reservoir distribution and character in structurally complex shelf-to-slope basin profiles (e.g. the Sinú Accretionary Prism, offshore Colombia). The East Coast Basin (ECB), located on the convergent eastern portion of the North Island, New Zealand, exhibits a stepped seafloor morphology where elongate fault-controlled ridges play a major role in the distribution of delivery pathways and sites of terminal deposition. Furthermore, a combination of previous outcrop studies, bathymetric analyses and seismic interpretation in the ECB highlighted the importance of detached deepwater canyons for supplying sediment into the basin, for their potential to form up-dip stratigraphic pinch-out traps and as sediment bypass conduits. Here we performed a drainage and gradient analysis using bathymetry from the ECB to identify the factors that might control net deposition versus bypass zones across the slope profile. We identified the main sediment dispersal pathways and determined the location, limits and depth of zones of intra-slope accommodation. Two pathways starting from the canyon heads, deliver sediment into the Porangahau and Akitio Troughs. A third pathway potentially bypass sediment through the intra-slope canyons. The geometry of the pathways and local changes in the seafloor gradient due to ridge-like morphologies are likely to control zones of sediment bypass and the depositional character of potential reservoir sands. This analysis provides insights regarding areas of accommodation that may be starved or well supplied with reservoir grade sandstone and areas where bypass-related stratigraphic trapping might occur. Furthermore, the calculation of slope and flow size values along the inferred delivery pathways will allow us to perform a quantitative estimation of sediment bypass through numerical flow modelling.

Internal architecture and external geometry of sediment waves offshore Senegal

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Deepwater sedimentology has been a focus of the geoscience community for several decades, with progress driven largely by the needs of the oil and gas industry. In recent years, the focus has moved towards bedforms that have previously gone unrecognised and are poorly understood. Sediment waves are an example of this. Sediment waves are large-scale undulating, depositional bedforms that are generated beneath currents flowing at, or close to, the seafloor (Wynn et al. 2000). Currently, there are no published examples in the literature of sediment waves in a petroleum reservoir.

This project aims to better understand the extent and character of the sediment waves present in the SNE field, offshore Senegal. Discovered by Cairn Energy and partners in 2014, the field has since been appraised by a further seven wells. An extensive subsurface dataset is available for this study, including 3D seismic, well logs and cores. Analogues from both the modern-day seabed and from outcrop are being utilised to fill in the resolution gap that exists in the subsurface dataset.

The reservoir sands are believed to be Early Albian in age and were deposited in a pro-delta environment. Current findings from the reservoir cores suggest that the sediment waves were deposited by a series of turbidity flow event beds, which may have been influenced by the existing bathymetry. Seismic analysis of the reservoir shows undulating basin-ward stepping reflectors. When mapped, these linear features orientate north-south and are interpreted as sediment wave crests.

Sediment waves also exist on the modern-day seabed in Senegal, providing a useful analogue for a variety of geometries; crescentic, sinuous and linear. These sediment waves occur in water depths between 700m to 1700m. They exist both on the upper slope in channel overbank settings and along a subtle terrace in the mid-slope. They orientate north-south, perpendicular to the probable downslope flow direction. High-frequency shallow 'sparker' seismic lines highlight an antidune architecture where the sediment waves migrate upslope as deposits accumulate. Outcrop examples of sediment waves from the Fish Creek-Vallecito Basin in Southern California have also been studied as analogues. Although these are significantly coarser than the reservoirs of the SNE field, these Upper Miocene turbidites provide excellent exposures of multiple bedforms, interpreted as subtle antidunes that migrate up-slope against the palaeo-flow.

The final goal of this project is to integrate findings from the varied dataset in order to build a reservoir model that is geologically representative of the SNE sediment wave reservoir.

Reference:

Wynn, Russell B., Douglas G. Masson, Dorrik A. V. Stow, and Philip P.E. Weaver. 2000. "Turbidity Current Sediment Waves on the Submarine Slopes of the Western Canary Islands." *Marine Geology*, no. 163: 185–98.

Sedimentological context of a large *Arthropleura* fossil from the middle Carboniferous Stainmore Formation, Northumberland

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A newly-discovered partial arthropod body fossil, 80 cm in length and at least 35 cm in width, is here attributed to *Arthropleura*: the giant Carboniferous myriapod more commonly known from its trace fossil record. The fossil was discovered within a fluvial channel sandstone of the Lower Pennsylvanian Stainmore Formation of Northumberland, NE England. The purpose of this poster is to offer a preliminary description of the fossil and its sedimentary and palaeoenvironmental context. *Arthropleura* fossils of similar dimensions and completeness are extremely rare in the global rock record, meaning that the Northumberland specimen may shed new light onto an archetypal Carboniferous organism and the sedimentary environments that it inhabited.

Turbulent-laminar transitions in flows laden with cohesive sediment

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Clays and fine silts are transported by flows of variable concentration in a wide range of sedimentary environments. Common higher concentration flows are rivers with high suspended sediment concentrations, fluid muds in estuaries and deep-ocean density currents. Such flows have significantly different fluid-dynamic characteristics to clear water or low-density flows, including: i) the dominant mechanism for sediment suspension and transport; ii) the exchange of sediment between bed and flow, resulting in important differences in depositional properties; and iii) shear velocity and turbulence distribution within the flows. As driven by environmental setting, and/or inherent flow processes, flow turbulence is of critical importance. For example, suspended sediment load and flow turbulence influence both the geohazard risk posed to infrastructure and also landscape evolution.

Due to the cohesive properties of clay, particles attract each other forming clay flocs or gels. With increasing clay concentration flow properties change from Newtonian to Non-Newtonian. Relatively small percentages of clay can damp fluid turbulence and result in transitional flow conditions. Previously, different flow types have been distinguished with increasing clay concentration: turbulent flow, turbulent-enhanced transitional flow, lower and upper transitional plug flow and quasi-laminar plug flow. However, the mechanisms via which flows evolve from one state to another are poorly constrained.

To address this shortcoming, a new research project will conduct physical experiments to investigate the role of cohesive sediment on turbulent – laminar flow transitions. Experiments will be conducted in a custom-built, progressively expanding channel, housed in the Cohen fluid dynamics laboratory at the University of Hull. The channel design will enable controlled spatial changes in the flow velocity and thus turbulence in otherwise steady non-uniform flow. The character of local spatial, and temporal persistence of, variation in flow turbulence will be tied to clay concentration to yield insight into flow transformation in prototype environments.

ANCIENT SANDY CONTOURITES AND THEIR SEDIMENTOLOGICAL CRITERIA – CASE STUDY FROM UPPER MIOCENE OUTCROPS IN THE SOUTHERN RIFFIAN CORRIDOR, MOROCCO.

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Numerous bottom current controlled depositional and erosional features have been recognized in both modern and ancient sedimentary records along many continental margins and in abyssal plains. The recognition criteria for these deposits are mainly well established in present-day systems, and, as morphological features in seismic. However, despite the scientific and economic importance, these bottom current deposits and their diagnostic sedimentological criteria are not well understood.

In this combined sedimentological and ichnological based study we investigate three upper Miocene sandy contourite outcrops from the southern Riffian Corridor (Morocco). Our aim is to increase understanding of the processes, products and characteristics of sandy contourite depositional features. Furthermore, by studying these particular outcrops we hope to improve our understanding of the oceanographic processes resulting from gateway closure, which in this case led to the onset of the Mediterranean Salinity Crisis.

The marine upper Tortonian to lower Messinian Riffian Corridor deposits can be divided in 4 main lithofacies associations: hemipelagites; gravitational deposits; contourites; and shallow marine carbonates. Within the contourite exposures several depositional settings can be distinguished, but our main focus is on the sandy deposits. We find that the majority of sand units are deposited as laterally migrating channelized bodies consisting of upward decreasing bed-set thicknesses within hemipelagic background sedimentation. The initiation of bottom current dominated sedimentation shows a direct relation with increased gravitational processes. The upward shallowing nature of the system shows an increase in tidal influence and a reduction of bottom-current velocity.

The ichnological study allowed us to define a paleoenvironmental reconstruction. Changes in the trace fossil communities reflect a shallowing trend throughout the corridor, passing from the deeper *Cruziana* to the shallower Skolithos ichnofacies. Furthermore, within the sandy contourite bodies, different ichnological assemblages can be identified which are associated to different morphological parts of the channel (e.g., axis, flanks, proximal or distal).

This work improves our understanding of sandy contourites and their conceptual and economic implications for hydrocarbon exploration.

Sedimentology and depositional environments of the Sentosa Group, Singapore: a fluvial to marine transition in a mature volcanic arc

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The bedrock geology of Singapore records the evolution of a complex Palaeotethyan forearc basin in which sedimentation was strongly influenced by contemporaneous arc magmatism. Subsequent closure of this basin resulted in folding and thrusting of this terrestrial to marine sedimentary succession, followed by its fragmentation and dispersal by trans-tensional strike-slip tectonics. The lack of surface outcrop makes understanding the geology of Singapore extremely challenging. The recent detailed study undertaken by the BGS has focused on the interpretation of *c.* 20,000 m of newly acquired borehole data, resulting in the construction of an ICS-compliant lithostratigraphical framework for the subsurface geology of Singapore. The Palaeotethyan forearc sedimentary successions, including the Upper Triassic to lowermost Jurassic Sentosa Group, form a major component of this new framework. Sediments of the Sentosa Group can be found exposed on the Southern Islands of Singapore (Sentosa, Pulau Tekukkor, St. Johns Island and Pulau Jong). It comprises two formations, the lower-most Tanjong Rimau Formation and the overlying Fort Siloso Formation. Detailed sedimentary logging (1:10 cm scale of 466 m of outcrop data), along with facies analysis, has revealed that the Tanjong Rimau Formation is characterised by a succession of fine- to very coarse-grained sandstones and conglomerates deposited in a braided-to-meandering fluvial environment. The increasing occurrence of hummocky and herringbone cross-stratification, as well as flaser lamination and marine ichnofacies, upwards through the Tanjong Rimau Formation provides evidence of an increased marine influence on this predominantly terrestrial succession. The typically fine-grained sandstones and interbedded siltstones of the overlying Fort Siloso Formation were deposited in a marginal-marine environment. Consequently, the transition from the Tanjong Rimau Formation into the Fort Siloso Formation records a major marine transgression during Sentosa Group times, which has implications for regional-scale palaeogeographical reconstructions of South East Asia during the Triassic and lowermost Jurassic.

Turbidity Currents: underwater rivers or seafloor jet streams?

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Seafloor gravity, and turbidity, currents are flows generated by a density difference from the ambient ocean. Arising from variations in heat and salinity, gravity currents, or suspended-sediment, turbidity currents, density-driven-flows can travel for thousands of kilometres; with multiple flows building some of the largest sedimentary landforms on the planet. Despite this, the dynamics of these flows are enigmatic and our understanding of them as an environment shaping process is poorly understood. This is predominately due to a lack of observational data to motivate theoretical, and experimental, models of fluid dynamics.

Stratification, i.e. the vertical variation of flow velocity and density, of gravity currents is fundamental to the long run-out of flows on the shallow slopes of real-world ocean basins. Despite its importance, and unlike open-channel flow, there exists no unified model for velocity and density stratification of gravity currents. Existing models suggests that, diffusion based random turbulent mixing, flow velocity follows a standard logarithmic law of the wall before decaying slowly above some internal velocity maximum. However, such theory is based on limited time- and length-scale experimental and numerical models. Here flow velocity and density are presented from direct observations of a saline gravity current in the Black Sea, which contradict this standard theory. Moreover, saline and sediment laden gravity current laboratory experiments show that expected small-scale diffusive mixing does not dominate turbulent fluctuations in gravity currents. The high-resolution field and experimental data, that was obtained over a large range of time- and length-scales, instead shows that turbulent mixing is organised by coherent structures. The organisation of turbulence results in anti-diffusive radiation stresses that determine the evolution of flow dynamics.

With analogy to models atmospheric jet-streams, anti-diffusive mixing is recognised as turbulence – internal-gravity-wave interaction; an inherent and naturally occurring phenomena in stratified flow. Over long time- and length-scales, internal-gravity-waves drive systematic correlation of the small-scale diffusive turbulent fluid motion resulting in otherwise unexpected self-organization in stratified flow dynamics. Self-organisation influences, and is postulated to be the ultimate control on, the run-out of long-duration gravity currents.

Evolution of Neogene basins in the Northern Gulf of Cádiz, SW Iberian Margin: Impacts of Tectonics and Diapirism on the Contourite Depositional Systems

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The development of the Gulf of Cádiz since the Late Miocene is a result of the intricate interplay between tectonic, sedimentary and palaeoceanographic processes. It has undergone complex tectonic evolution related to the Betic-Rif orogenic arc and related forland basins towards the east and its proximity to the Eurasian (Iberia)–African (Nubia) plate boundary.. More recent evolution of this region is marked by intense halokinesis, fluid migration and escape processes, related to the emplacement of Gulf of Cádiz accretionary wedge (GCAW). Analysis on these Neogene basins (Algarve, Doñana, Sanlucar and Cádiz basins) is crucial to understand the complexity of the evolution in this region. The aim of this work is to comprehend how tectonism and inherited margin structure affected the development of the SW Iberian Margin (SWIM) since the Late Miocene, controling the overall evolution of the contourite depositional systems. This is being carried out based on seismic analysis on regional high quality multichannel seismic reflection profiles. The Deep Algarve Basin is a foredeep basin developed on top of an older Mesozoic rift and a Paleogene inverted basin. Its sedimentary infill, composed of Pliocene-Quaternary contourite drift deposits developed under the persistent influence of the Mediterranean Outflow Water (MOW) and relatively thin to absent Late-Miocene deposits, are only affected locally by upward movements of salt bodies. At the SE limit of the basin, the sedimentary cover is folded, dipping towards NNW. This was caused by the uplift of the Guadalquivir Bank structural high and the emplacement of GCAW, indicating that these processes were active during the Quaternary. Whereas, the Doñana, Sanlucar and Cádiz basins, separated from the Algarve Basin by the Gualdalquivir Bank, developed as wedge-top piggyback basins bounded by several diapiric ridges. These basins developed on top of the advancing orogenic wedge, where diapirism occurred as a result of compression of pre-existing salt and shale structures, and sedimentary loading. Evolution of these basins were controlled by various phases of diapiric growth, that led to the formation of sub-basins (or intra-diapiric basins) and the continuous NW migration of the Betic-Riffian Arc front. Their Late-Miocene to Quaternary sedimentary infill presents a more complex architecture, with folding and tilting. Differential folding can be observed in these basins indicating various pulses of diapiric growth and or basin subsidence. The diapiric features have a direct control on the evolution of the MOW pathway within these basins, influencing the distribution of bottom-current erosional and depositional features. The Guadalquivir Bank, squeezed between the structural high and the Betic-Rif orogenic front, acted as a barrier to the advancement of the GCAW. The continuous migration of the orogenic front led to regional shortening, with increased deformation towards the SE of the structural high. This work supports the control of inherited margin structures on the difference of deformation in the Neogene basins as a major factor on sedimentary architecture and the regional evolution of the SWIM. The evolution of these structures has conditioned the MOW circulation in the Gulf of Cadiz and consequently the development of the contourite depositional systems and their sedimentary stacking pattern.

Palaeoenvironmental change in response to glacial/interglacial cycles: Middle and Upper Pleistocene stratigraphy of the southern North Sea

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The Middle to Late Pleistocene (MIS19 to MIS2) period is characterised by considerable global climatic instability, with repeated cycles of glaciation and high amplitude relative sea-level changes. The offshore stratigraphic record of ice-sheet advance and retreat is highly fragmented, and controversial. However, recently acquired high resolution seismic, core, and geotechnical data from the southern North Sea basin from the offshore renewable energy industry form a valuable archive of mid-latitude palaeoenvironmental change during this period. Three major stratigraphic units have been identified and characterized using seismic mapping, seismic facies analysis, core logging and interpretation of cone penetration test (CPT) data. The lowermost stratigraphic unit (approximately MIS19 to MIS13) is predominantly fluviatile and overlies the marine deltaic successions that characterize the Early Pleistocene. Channel-fills within this unit are orientated approximately north-south and northeast-southwest, display variable channel fill architecture, and provide direct evidence for large-scale Middle Pleistocene fluvial networks North of 52° in the southern North Sea. These fluvial networks are interpreted to be a consequence of the evolution and increasing influence of mainland European and British river systems in response to glaciation and resulting relative sea-level fluctuations. A series of north-south trending tunnel valley-fills, provide evidence for subglacial conditions at this location, and are thought to have formed during the Anglian Stage glaciation (MIS12), incise the Middle to Late Pleistocene stratigraphy (maximum depth ~165 m). Analysis of seismic facies within the valleys reveals a single fill of likely glaciofluvial origin that correspond to the lowermost fill found in Anglian stage tunnel valley-fills north of the survey area. Marine transgressive sediments dominate the survey area between MIS12 and approximately MIS4. The transgressive deposits are predominantly sheet-like and composed of silts and clays with indications of iron sulphide and marine shells supporting a low energy, restricted marine environment. Seismic facies analysis indicates isolated coarse-grained marine sediments overlying the transgressive surface, formed during early stage marine inundation. Dune-scale bedforms and variation in the geomechanical properties of the transgressive fill provide evidence for fluctuations and/or a hiatus in the rate of transgression and late stage evolution of the transgressive depositional environment.

The interpretation of the Middle to Late Pleistocene stratigraphy reveal a highly dynamic and constantly evolving landscape in response to climatic fluctuations. High resolution analysis and interpretation of the southern North Sea Quaternary stratigraphy provides critical information informing ice sheet extent, the landscape response to glacial/interglacial cycles and the resulting regional sea-level fluctuations, and the sedimentary process feedback to those environmental changes.

Climatically Influenced Progradation of a Deep-Water Turbidite Fan, Late Pliocene Syn-Rift Succession, Corinth Rift, Greece

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The structural, sedimentary and climatic evolution of a rift basin and its associated catchment area is reflected in its deposits, but deconvolving primary controls on stratigraphic evolution is often problematic. Here we present results from an integrated sedimentological, palaeoenvironmental and structural study of the Corinth Rift to investigate the role of basin tectonics and climatic variations on deep-water depositional processes in a highly active rift setting.

Northward migration of active faulting in the Corinth Rift during Early Pleistocene times resulted in uplift of early syn-rift deposits on the northern Peloponnese peninsula. We focus on the Late Pliocene to earliest Pleistocene deep-water deposits of the Rethi-Dendro Formation (RDF) that are spectacularly exposed in the central part of the rift. In general, the RDF consists of coarse grained siliciclastic sediments emplaced as mass transport deposits, channel complexes and channelised lobes, and fine grained intervals consisting of thinly bedded turbidites and hemipelagic mudstones.

Sedimentology and sequence stratigraphy of the RDF has been analysed using traditional field methods tied to terrestrial LiDAR and AUV photogrammetry, together with continuously cored shallow research boreholes. This integrated dataset allows for sedimentary observations at a variety of scales, from mm-scale sedimentary structures to seismic-scale geobodies. To supplement our sedimentological observations, detailed palynological analysis has been undertaken to identify changes in hinterland vegetation as a result of climate change. Focus has been placed on a 80 m interval that is characterised by an abrupt change in depositional style from a thick unit of dominantly hemipelagic mudstones sharply overlain by laterally extensive, amalgamated and channelised sandstone and conglomerate bodies that are consecutively replaced by hemipelagic mudstones. The change in depositional style is contemporaneous to changes in the pollen and spore assemblage suggesting that a shift to drier and colder conditions aids to the delivery of coarse grained sediment into the deeper parts of the basin. This study highlights how climate change in the hinterland can have a major impact on the timing of deep-water reservoir development, even in highly active basins.

Sedimentological variability within the Lower Jurassic Redcar Mudstone Formation, Cleveland Basin: Implications for Mudstone Depositional Conditions

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Although mudstones are the most abundant sedimentary rocks, they are the most poorly understood rocks type. Mudstones were used to be described as homogenous rocks that were deposited out of suspension in energetically quiet environments; however, recent studies reveal that mudstones show wide variety in micro-texture which means it can be transported and deposited under energetic conditions that also deposits sand. This study aims to understand the vertical and lateral variability in the early Jurassic mudstones of Cleveland basin and identify which sedimentological and depositional processes are responsible for this variation. We collected data from previously undescribed core from the Cleveland basin, UK. , as well as outcrops on the Yorkshire coast. Detailed microfacies characteristics have been defined using optical microscopy, high resolution SEM images, and TOC analysis. Six mudstone microfacies have been identified within the examined Redcar Mudstones from Robin hood’s Bay at Yorkshire coast and from the Felxikirk and Brown Moor Boreholes: (A) Homogeneous, Argillaceous, Mudstone, (B) Homogeneous, Calcareous, Mudstone, (C) Graded bedding, biogenic rich, Argillaceous, Mudstone (D) Cross laminated, Siliceous, Mudstones (E) Planar laminated, Argillaceous, Mudstones (F) Lenticular, Silt-rich, Carbonaceous, Mudstones . At the millimetre to centimetre-scale, these facies include fine- and medium-mudstones that are composed of different proportions of argillaceous, calcareous, and siliceous minerals whose depositional fabrics have been variably affected by burrowing and diagenesis. This study suggests that the structural setting and relative sea level controlled the accommodation space for sedimentation of Redcar mudstone Formation. We found that the mineralogic composition and sedimentological texture, as well as the organic content of Redcar mudstones, vary predictably as a function of shelf processes linked to relative sea-level change and tectonic activity.

Inherited topographic controls on barrier retreat and preservation: an example from Dogger Bank, North Sea

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Barrier retreat can occur due to in-place drowning, overstepping or rollover, depending on the interplay of controls such as sea-level rise, sediment supply, coastal hydrodynamic regime and antecedent topography. The timescale and well-constrained rate of sea-level rise during the Holocene provides a useful analogue for investigation of marine transgression preserved in the geological record. Offshore sedimentary archives of barriers active during Holocene rapid sea-level rise are vital to mitigate projected relative sea-level rise, and more effective prediction and planning for coastal realignment. This study analyses the sedimentary archive at Dogger Bank, which is a formerly-glaciated area in the North Sea. Dogger Bank experienced marine transgression due to Early Holocene rapid relative sea-level rise. Using an integrated dataset of vibrocores and high-resolution seismic reflection data permit a stratigraphic framework to be established, which reveals the coastal geomorphology of the southern Dogger Bank for the first time. A transgressive stratigraphy was identified, comprising a subglacial and terrestrial basement, two phases of barrier and tidal mudflat retreat, and shallow marine sediments. Barrier phase A was a recurved barrier drowned in place, and discontinuously overstepped to barrier phase B, which experienced continuous overstepping. By linking barrier elevations to well-constrained relative sea-level curves from literature, the timing of each barrier phase was established. Both barrier phases retreated during periods of rapid sea-level rise with abundant sediment supply. Coastal hydrodynamics (increasing wave energy) and steepening antecedent topography with variable accommodation morphology are therefore suggested to be the main reason for differing retreat mechanisms, as opposed to the rate of sea-level rise.

Understanding the Origin of Mud Intraclasts in a Mississippian Black Shale

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The Mississippian Bowland Shale Formation is a target for unconventional hydrocarbon exploration in the UK and across Europe, including the age-equivalent Geverik Member (Epen Formation) and Upper Alum Shale Formation. Despite this interest, the sedimentological and biogeochemical processes that operated in epicontinental seaways, such as the Mississippian Rheic-Tethys, are poorly understood. Sedimentological, palynological and geochemical data were integrated from three time-equivalent sites in the Craven Basin (Lancashire, UK), a basin with ongoing unconventional hydrocarbon exploration, in order to develop a holistic understanding of the Bowland Shale. The Bowland Shale at these sites is a highly heterogeneous succession comprising carbonate-rich, siliceous, and siliciclastic, argillaceous organic-rich mudstones. These facies developed in response to a combination of fourth-order sea level cyclicity, fault activity at the basin margins and linkage with the prograding Pendle delta system.

Mud export from the Pendle delta system to the Craven Basin was fast, despite the intrabasinal complexity, likely an order of magnitude higher than contemporaneous successions deposited in the UK and North America. Taking 100 m of uncompacted pelagic/hemipelagic sediment (assuming 55% compaction) and assuming this was deposited over ~333 kyrs (i.e., spanning three ‘marine bands’) yields an estimated ~30 cm/kyr mean sediment accumulation rate (mSAR). This compares with 1.4 cm/kyr for the contemporaneous Barnett Shale, and 0.2-0.9 cm/kyr for North American Late Pennsylvanian Midcontinent Seaway cyclothems.

This high ‘deltaic-type’ mSAR is supported by widespread evidence for sediment deposition from turbulent, laminar and hybrid flows, particularly during periods of reduced basin accommodation. In addition, a ‘lenticular’ texture is observed in most sedimentary facies. This is defined as a fine to medium-mud sized matrix which hosts coarse-mud to *gravel*-sized mud lenses. The geometry of the mud lenses suggests these represent partially consolidated mud rip-up intraclasts transported in bedload, rather than faecal pellets or burrows. Combining interpretations of the sedimentology and palynology with palaeoredox proxies, such as Fe-speciation, redox-sensitive trace elements and $\delta^{34}S_{py}$ indicates the most pervasive lenticular textures are associated with changing bottom water redox conditions and changes in the type of amorphous organic matter (AOM) preserved. Based on the observed associations, we conclude that mud rip-up intraclasts in the Bowland Shale were potentially sourced from areas of biostabilised muds at or just beneath the seawater-seabed boundary. Intersection between the water column chemocline and seabed apparently promoted biostabilisation, perhaps via sulphide-oxidising microbial mats that colonised the seabed. The rapid accumulation of mud onto areas of seabed associated with a high redox gradient at seabed was potentially a key mechanism for mud stabilisation and therefore generation of intraclasts, in the Craven Basin, and perhaps in other similar basins.

The Variability of Reservoir Quality in Submarine Slope Channel Complexes: Insights from an Outcrop Analogue, Tres Pasos Formation, Chilean Patagonia

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Submarine slope channel complexes are important, but heterogeneous exploration targets. Owing to the sub-seismic nature of most heterogeneities, reservoir quality and connectivity prediction can be challenging. Outcrop-based architectural studies augmented with detailed bed-scale observations can be used to bridge the gap between seismic data and detailed reservoir models. This study investigates the stratigraphic evolution of two seismic-scale slope channel complexes from the Tres Pasos Formation, southern Chile. Architectural differences between an early phase of lateral channel migration and a late phase dominated by aggradation of vertically aligned channels are investigated. Sedimentary logging, petrographic analysis and quantification of sedimentological characteristics were used to understand reservoir quality at different stratigraphic hierarchical orders (i.e., channel elements, complexes).

From channel element axis to margin, bedding changes from amalgamated to non-amalgamated, laminated and ripple dominated sandstones and thin bedded turbidites. Abundant mudstone intraclast lags overlie erosion surfaces, which are commonly mantled by mudstone drapes. The lower channel complex (min. 500 m wide and 40 m thick) is composed of channel elements deposited during several lateral cut and fill cycles, which makes a distinction of each element complicated. Towards the top, a thinner element (10-15 m thick; up to 400 m wide) has an asymmetrical fill and a thick mudstone drape (up to 1.4 m) overlying its basal surface. The overlying vertically aggrading channel complex is 80 m thick and separated from the underlying channel complex by MTDs. Channel elements are 15 to 20 m thick, up to 400 m wide, and characterized by symmetrical fill with mudstone-draped basal erosion surfaces.

The early stage slope channel complex was subject to multiple cut and fill phases instead of constant lateral migration, resulting in a high degree of facies heterogeneity due to prevalent mudstone drapes and intraclast lags (i.e., potential flow barriers and baffles). Channel element morphologies tend to be more variable with apparently thinner, asymmetrical fill at the top, recording development of high sinuosity. This variability leads to a more complicated distribution of reservoir facies compared to the overlying, vertically aggraded channel complex. Our study allows refinement of reservoir models for submarine slope channel systems, reducing risk and uncertainty in these challenging targets.

SEQUENCE BOUNDARIES OR AUTOGENIC EROSIONAL SCOURS? SCALING BACKWATER HYDRODYNAMICS IN FLUVIO-DELTAIC STRATIGRAPHY

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Sequence stratigraphy relies on the identification of unconformity-bound sedimentary packages to understand variations in sediment supply, subsidence, and eustasy. Erosional surfaces that demarcate genetically-related sedimentary packages set the architecture of fluvio-deltaic stratigraphy, and they have classically been interpreted in terms of changes in boundary conditions such as climate, tectonics, and base level (allogenic forces). Intrinsic dynamics of sedimentary systems (autogenic dynamics) can also create a rich stratigraphic architecture, and a major knowledge gap exists in parsing the relative roles of autogenic versus allogenic processes. Emerging theoretical and experimental work suggests that backwater hydrodynamics play an important role in driving transient channel incision in river deltas, even those experiencing net aggradation. Here, we identify and quantify two autogenically generated mechanisms that produce broad erosional surfaces within fluvio-deltaic stratigraphy, namely, floods and avulsions. Using a simple mass-balance model, we show that flood-induced scours initiate near the shoreline, and avulsion-induced scours initiate at the avulsion site, and both propagate upstream over a distance that scales with the backwater length. We also develop scaling relationships for the maximum scour depths arising from these mechanisms, which are functions of characteristic flow depth and formative flood variability. Theoretical predictions were validated using a flume experiment of river delta evolution governed by persistent backwater hydrodynamics under constant relative sea-level. Results indicate that autogenic dynamics of backwater-mediated deltas under conditions of constant base level and constant ratios of water to sediment discharge can result in stratigraphic surfaces and shoreline trajectories similar to those often interpreted to represent multiple sea-level cycles. Finally, we reinterpret outcrop scale observations within the Castlegate Sandstone, Utah—type example for fluvial sequence stratigraphy—and show that field observations are consistent with scours resulting from floods, avulsions and backwater hydrodynamics alone. Our work provides a quantitative framework to decouple autogenic and allogenic controls on erosional surfaces preserved within fluvio-deltaic stratigraphy.

A multi-scaled approach towards weak layer characterisation, the AFEN submarine landslide complex (UK)

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Submarine landslides are common on continental slopes worldwide. They can pose a hazard to seafloor infrastructure and may generate tsunamis that can cause substantial coastal damage and loss of life. Despite their importance, it is still unclear what governs the depth at which submarine landslides initiate. Two key controlling mechanisms have been proposed. The first is the generation of excess pore pressures (i.e. above hydrostatic pressure) at subsurface permeability interfaces. This rise in pore pressure reduces the vertical effective stress, which in turn decreases the shear strength of the sediment and reduces slope stability. The second is the presence of mechanically weak layers within the stratigraphy. Such interfaces of contrasting strength can be a focal zone for shearing, and hence enhance the formation of a basal failure plane. Although understanding permeability interfaces and/or weak layers is key to understanding how submarine landslides initiate, little is known about their composition and nature because the slide movement usually removes or remoulds them. There is thus a pressing need to sample, test and characterise zones of such mechanical contrast.

Here, we present a detailed characterisation of a weak layer based on core material from the AFEN (Atlantic Frontier Environmental Network) submarine landslide complex. The AFEN slide is a four-stage retrogressive landslide, located offshore the Shetland Islands (UK), which lies on a slope between 0.7 and 2.5°. This study places detailed constraints on the main weak layer of the AFEN submarine landslide complex. The setting provides a unique opportunity to identify and characterise the weak layer, because cores seem to have penetrated both the upper glide plane and the main failure plane traced in the undisturbed sedimentary sequence. Here we use multiple scales of data to delineate and characterise the weak layer, ranging from seismic profiles, non-destructive core scanning (MSCL), geochemical (XRF) data, as well as grain size analysis and geotechnical tests, including undrained shear tests and water content measurements. We use micro-CT scans to image grain-scale structures, which are coupled with direct shear and oedometer tests, to explain the geomechanical behaviour of the weak layer. We assume that the weak layer of the AFEN slide coincides with a prominent sand layer, embedded between clayey layers. We observe a sharp increase in water content, and a decrease in bulk density and undrained shear strength at the interface between this sand layer and the underlying clayey layer. This detailed study of a weak layer that spans from continental slope to grain-scale provides new insights into the important role of these geomechanical interfaces.

Downstream facies changes in fluvial meanders: upstream vs. downstream sedimentary facies from a mixed gravel and sand point bar of the Ombrone River (Southern Tuscany, Italy)

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Fluvial meander bends are known to be characterized by progressive downstream decrease in sediment grain size. Nevertheless, the most popular sedimentary facies models depict point-bar deposits along 2D sections parallel to the bar axis, where the classical large-scale inclined beds (i.e. epsilon cross bedding) and vertical decrease in sediment grain size can be easily detected. Although these sections can be quite diagnostic for point bar bodies, they are not representative for downstream grain size and facies changes occurring within them.
The present work contributes to fill this gap of knowledge focusing on a modern point bar of the Ombrone River (southern Tuscany, Italy), which drains from the Chianti Mts. to the Tyrrhenian Sea over a distance of ca. 160 km. The averaged discharge of the Ombrone River at its mouth is $32m^3$/sec. At ca. 30 km from the mouth, the Ombrone River is 60-80 m wide and carries gravel and sand forming serval bends, which show a sinuosity ranging between 1.5 to 3. In 2017, one of these bends has been artificially cutoff in order to prevent local flooding. The artificial cut went from the upstream to the downstream riffle of the bend and exposed the whole point bar deposits along a ~450 m long and ~3.5 m high cliff. This cliff exposure allows a detailed comparison between upstream and downstream point bar deposits. Upvalley-dipping (3°-5°), plane-parallel stratified pebbles and cobbles form the upstream bar deposits. Gravels are clast-supported with a variable amount of sandy matrix, which can be locally missing (open framework texture). Upstream bar gravels cover a channel lag made of cobbles and large pebbles, and do not show any clear vertical grain size trend. Downvalley-dipping (5-10°) beds of sand form the downstream bar deposits. Sand ranges from coarse to fine and is ripple-cross laminated and plane-parallel stratified. Sandy beds range in thickness from 5 to 20 cm. Isolated mud drapes (1-5 cm thick) can occur in the upper part of the section. Downstream bar deposits overlay a basal channel lag made of coarse pebbles and show a clear fining-upward grains size trend. Transition between gravelly and sandy facies is located at about 150 m from downstream termination of the cliff exposure, and occurs over a distance of about 15-20 m. This study highlights a remarkable grain size and facies contrast between upstream and downstream point-bar deposits, which record different flow configurations and sedimentary processes occurring in these two areas. These differences are not commonly assessed by classical facies models, but should be considered, and possibly quantified, defining new fluvial facies models and trying to interpret the origin of fluvial bars in the fossil record.

A Quantitative Sedimentological Analysis of Preserved Fluvial Architecture, Wealden Formation, Isle of Wight

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The Wealden Formation, Isle of Wight has seen little to no detailed sedimentological analysis since Stewart in 1981. By considering fluvial architecture and associated heterogeneity, the lateral variability of sandstone bodies in the system can be better understood, in turn contributing to a better understanding of the quality and extent of preserved fluvial systems where they form hydrocarbon reservoirs. The Wealden formation was deposited in the Berriasian Age (198.8-145Ma) to Barremian (125 – 129.4 Ma) during the Early Cretaceous. The overall thickness of the Wealdon Formation in the Wealden basin is 850 m, though it thins in basin marginal areas. The lower boundary is conformable, resting on the calcareous mudstones and limestones of the Purbeck Group whilst the upper boundary is unconformable, with a sharp contact, on the Isle of Wight, between the Vectis Formation and the Atherfield Clay Formation. The Wealdon Formation is a recognised fluvial succession but lacks modern studies, with palaeontology being the primary studied aspect in recent years. This study focuses on the better understanding of fluvial architecture and will benefit petroleum reservoir studies.

The studied exposure is a 1.8 km sea-facing cliff face up to 13 m in height. Several data sets were collected for this study: i) high-resolution 3D drone imagery of the cliff section; ii) six detailed sedimentary logs (total length – 16.11 m); three sketch logs (total length – 2.8m; iii) five field sketches; iv) sixty three palaeocurrent readings from planar cross bedding, trough cross bedding, lateral accretion surfaces, and ripples; v) lithological data such as clast size and distribution, as well as length and distribution of laminations; and vi) a suite of photographs that complement a detailed facies analysis. Field analysis (ii-vi) was used to identify facies and ground truth the drone data (i).
Nine facies, and thirteen sub-facies, have been derived that are based on the Miall (1978) classification. These facies include i) silt grain sized mudstone with fine lamination and small ripples (Fl), silt grain sized mudstone with bioturbation (Fcf), silt grain sized mudstone with lamination (Fsc), medium sandstone with horizontal lamination (Sh), fine grained sandstone with scours (Ss), medium to coarse sandstone with trough cross-beds (St), medium to coarse sandstone with planar cross bedding (Sp), gravel beds with planar cross-beds present (Gp) and bedded gravel (Gm). The sub-facies are determined with variations of colour and structures being defined by a change in clasts grain size or type of clasts.

So far, there has been a justification of a lateral point bar, associated with the increasing compartmentalisation of the sandstone bodies by the mud draping increasing vertically to the hypothetical bar top. This interpretation assumes that the mud drapes are not from marine advancement. The colour changes in the silt and clay have also been related to two different processes: bioturbation causing the change in ferrous ions and pedogenesis which can cause the extensive colour mottling. However, the interpretation is not extensive at this point.
Future work includes determining the large scale fluvial architecture of the locality in order to reconstruct the fluvial palaeoenvironment. The model will then be compared to active fluvial reaches, and heterogeneity variations in the outcrop will be used to estimate fluid flow pathways where these rocks may form a hydrocarbon reservoir.

THE IMPACT OF HYDROCARBON EMPLACEMENT ON CARBONATE RESERVOIR DIAGENESIS

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Diagenesis is one of the major factors affecting the quality of petroleum reservoirs. This primarily impacts on the nature and evolution of porosity and permeability, as well as their distribution. Diagenesis involves an array of different processes, including cementation, dissolution, and recrystallization, occurring from early deposition to the late and deep burial stage, which create the final reservoir rock. The rate of these processes is driven mainly by the nature of the pore fluids like brine and hydrocarbons, as well as their level of saturations in the pore spaces, but geochemical models focus more on brine/rock interaction and the exact role of hydrocarbon emplacement on the rate of cementation is not well defined.

A few previous studies, have highlighted the dynamics of cementation in the presence of oil emplacement, establishing the conditions and factors that make oil emplacement to inhibit cementation and preserve porosity. But these studies have largely been qualitative and based on petrographic analysis of the final reservoir rock properties. Paleo fluid-rock interactions and exact paleo fluid geochemistry has not been reconstructed and matched with porosity and permeability preservation.

This research is an attempt, to produce an empirical evidence for the impact of hydrocarbon emplacement on cementation through experimental studies, the aim is to produce a geochemical pore scale model, that will quantitatively demonstrate this impact on petrophysical properties.
This will be done by flowing calcium supersaturated solution into rock cores along with hydrocarbon, using a core flooding system. The pore scale dynamics of the cementation will be investigated using X-ray computed micro tomography technique, which enables capturing 3D images of the samples at micro-scale resolution. Calcite cementation is investigated in this study as the starting point for the understanding of the factors affecting cementation during oil emplacement. The choice of this mineral is based on the confidence with which it can be precipitated under laboratory conditions. The plan is to then apply the defined controls also on mixed carbonates-silicates and silicate reservoirs.

Exploring carbonate platform heterogeneity: what is a depositional geobody and what controls geobody geometry

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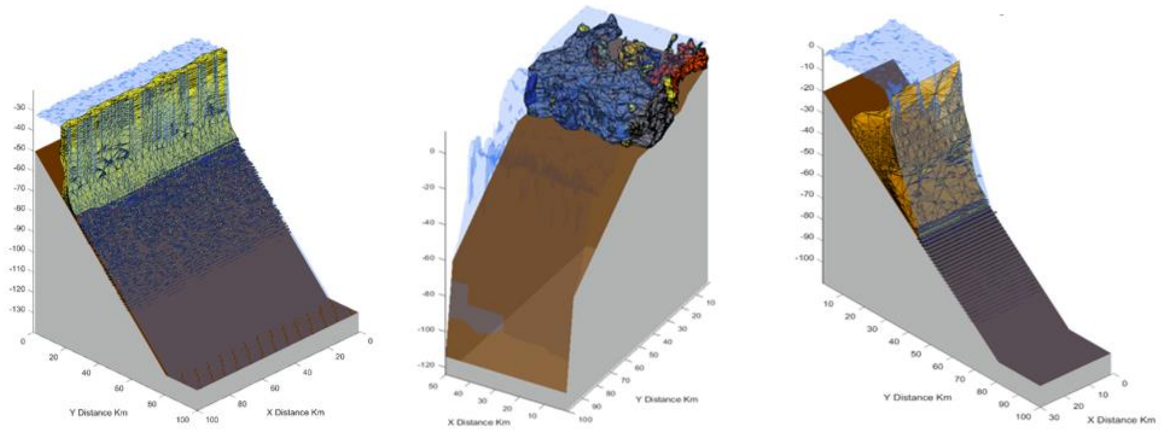
The term ‘geobody’ is commonly used, but poorly defined in carbonate stratigraphy, and is therefore perhaps less useful than it could be. From analysis of numerical forward model stratal geometries, we define depositional geobody as mappable, connected, volumes of strata with a particular lithofacies distinguished by specific physical characteristics, including porosity and permeability. An extended definition can also include the bounding surfaces of geobodies, based on the observation that in seismic data, carbonate geobodies are often mapped as bounded by high-amplitude low-impedance stratigraphic surfaces.
In this study, we identify and extract geobodies produced in CarboCAT stratigraphic forward model runs (Burgess, 2013; Antonatos et al, in prep). CarboCAT consists of various key geological processes, such as tectonic subsidence, eustatic oscillation, in-situ production facies heterogeneity, and complex sediment transport. It produces fully quantitative three-dimensional models that can replicate and predict carbonate stratal geometries formed under predefined input conditions.
Very simply initial numerical experiments suggest that in an aggradational sequence, where the rates of relative sea level rise matches sediment production rate, geobodies composed of marginal reef facies will grow vertically, with very limited horizontal extent of migration. In a progradational platform setting, where production and transport rate exceed rate of relative sea-level rise, geobodies of marginal facies are very likely to grow both horizontally and vertically with a more complex wedge shape. If the relative sea level is sinusoid with periodic subaerial exposures, spatial distribution of geobodies will be more complex still, forming relatively small, isolated geobodies. These initial results suggest that we should be able to characterise the horizontal and vertical structure and continuity of geobodies in carbonate platforms, controlled by the factors described above, and perhaps being to better predict the degree to which the hydrocarbon reservoirs are horizontally versus vertically compartmentalized during production and sequestration.



Vertical geobodies of marginal facies | Isolated geobodies of marginal facies | Prograding geobodies of marginal facies

Figure 1: Examples of three different types of geobody geometry. Note the degree of lateral versus vertical connectivity.

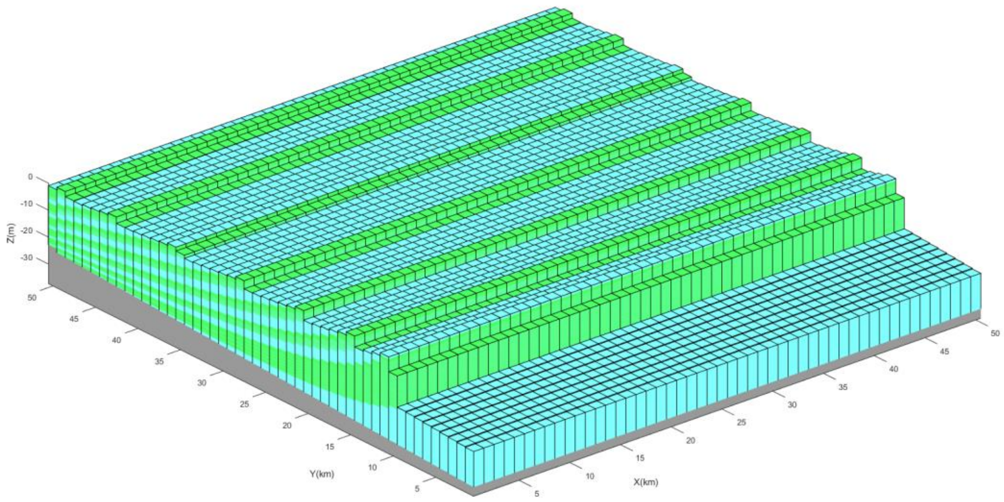


Figure 2: Example of autocycles generated by repetitive landward transport of sediment from subtidal source areas, and accretion to the shoreline, island progradation, subsidence on the sediment-starved leeward side of the prograding shoreline, island detaches and form a new subtidal area.

The

Neogene evolution of the NE Atlantic Basin

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During the last 8 million years the NE Atlantic basin has witnessed profound changes in seafloor bathymetry, ocean circulation and climate change. Short term (1–10 Ma) uplift and subsidence (100s of metres) of the Greenland-Scotland Ridge associated with variations in Icelandic plume activity during this period, is considered to have modified deep water circulation and influenced knock-on climatic effects, including high-latitudinal warming during the mid-Pliocene (3.3–3 Ma) and the onset of the Northern Hemisphere glaciation. Here we present new $\delta^{13}C$ records, used as a nutrient water mass tracer, to ratify pre-existing compilations and temporal and spatial isotopic changes in order to reevaluate potential interactions between tectonic activity and ocean circulation processes. A unique and significant $\delta^{13}C$ shift north of Iceland is observed between 6−3 Ma contemporaneous with inferred ridge subsidence; this excursion is unexpected and contradicts our present understanding of regional palaeoceanography during the Pliocene. Several biological and physical mechanisms are suggested to explain this observed isotopic shift, and additional experimental stages are proposed to clarify the oceanic processes during this time. Preliminary palaeotemperature records generated from sedimentary biomarkers are also presented, alongside current work analysing Icelandic lignites to create the first North Atlantic land surface temperature record for the Pliocene; these temperatures will ultimately be integrated with our other proxy data to assess whether tectonically-induced changes in ocean circulation influenced regional climate.

Machine Learning for capturing uncertainty in facies classification – a North Falkland Basin study

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Facies classification is paramount for characterising the depositional environment and determining those aspects that impact on fluid flow in a reservoir. Uncertainty in facies classification in hydrocarbon exploration may be due to the sparse and incomplete core data, as well as various biases including preferential well placement and interpretational bias. Interpretational uncertainty often has the largest impact on the subsequent development decisions and should be considered early during the reservoir modelling process.

This contribution proposes a novel way to account for interpretational uncertainty in a quantitative data-driven way and demonstrates the capability of machine learning for facies classification in deep-water deposits in the North Falkland Basin. A machine learning algorithm, Random Forest (RF), was applied to classify facies based on the combination of conventional wireline logs and additional geological features that are used by a petrophysicist. The RF classifier, with additional derived features, helps to more accurately capture the facies distribution and achieved between 70-100% classification accuracy on a blind test well. The log-derived features – porosity and resistivity difference – appeared to be the most important features for classification in conjunction with the gamma ray (GR) response.

This method helped to differentiate between two alternative aspects of turbidite depositional scenarios – high density turbidite and hybrid event beds (HEB) (see Fig. 1) – based on the wireline logs. This differentiation is achieved by varying the combination of training/validation well data configuration. The classification outcome depends on which well data are used for training (fitting the model to) and which are kept for validation – tuning the parameters of the classifier. The possibility of HEB has been identified in four out of five available wells in 1 out of 4 considered training/validation data configurations (see Fig. 2). Further uncertainty analysis using entropy quantified the probability of each scenario's occurrence along the blind test well (see Fig. 3). Validation with core interpretation confirmed that high entropy corresponded to the intervals of geological complexity, e.g HEB, Intermediate facies.

The proposed workflow was applied to the data from the North Falkland basin and the above results demonstrated a very encouraging perspective for more holistic application of the machine learning methods to support more comprehensive quantitative understanding of uncertainty in facies interpretation and integration of different types of data (logs, core, seismic, etc.) into modelling.

Reference

Thomas J. H. Dodd, Dave J. McCarthy, Philip C. Richards (2018)_ *A depositional model for deep-lacustrine, partially confined, turbidite fans: Early Cretaceous, North Falkland Basin*, Sedimentology, doi: 10.1111/sed.12483.

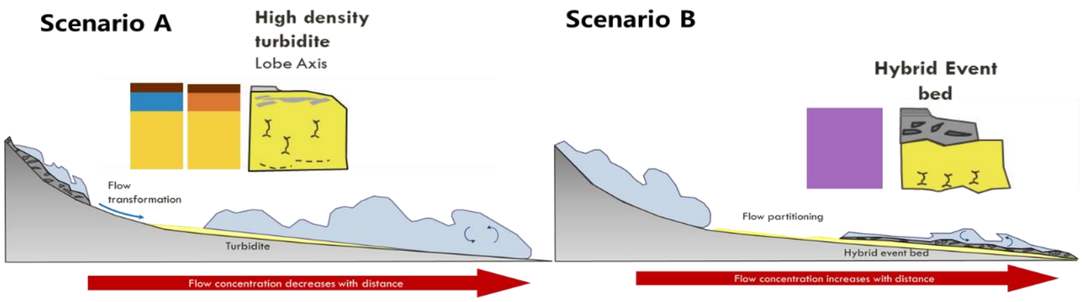

Figure 1. Two possible alternative turbidity deposit scenarios: high density turbidite (left) and hybrid event bed (HEB) (right).

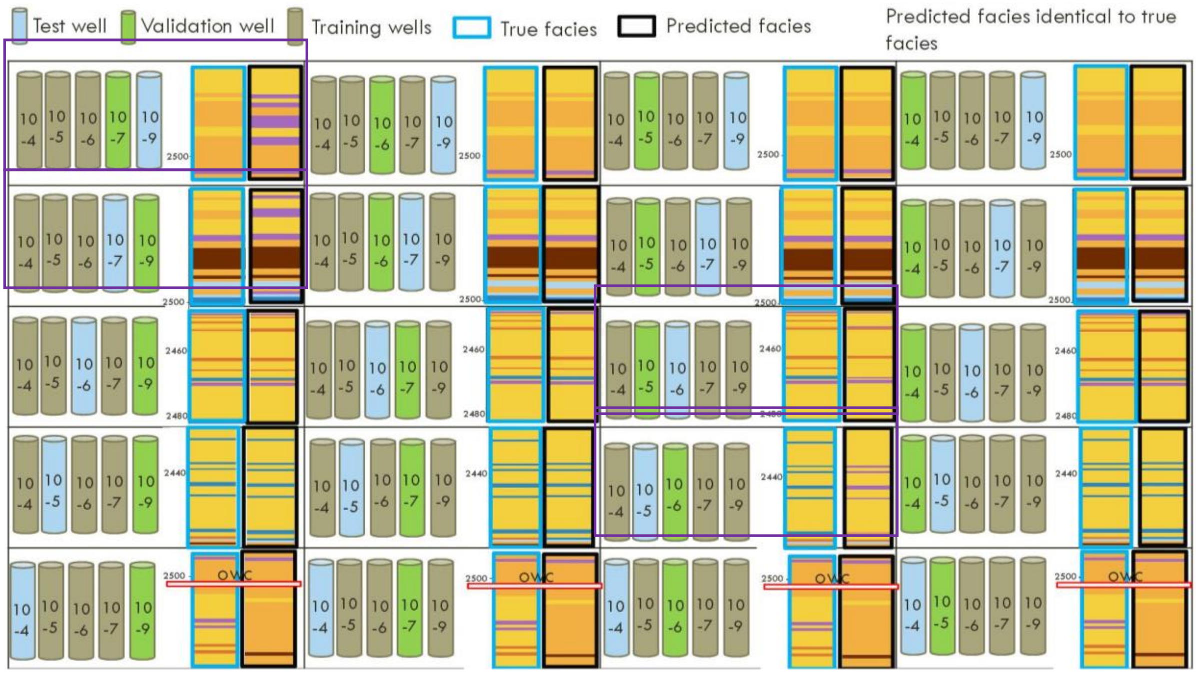

Figure 2. RF sample prediction interval vs the true facies interpretation from core: Scenario A: prediction identical to true facies, similar to the ones by Dodd et al (2018); Scenario B (purple boxes): 4 combinations predict an alternative depositional scenario

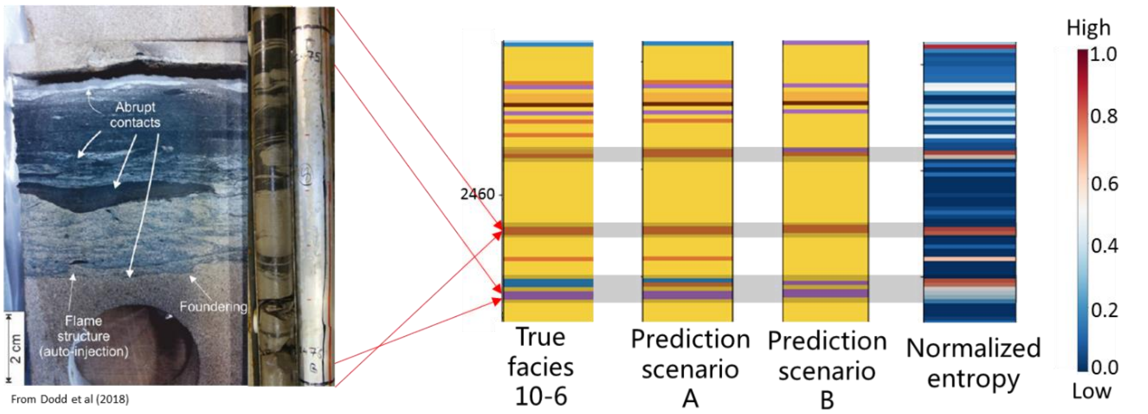

Figure 3. Uncertainty in RF facies classification represented by entropy – high entropy is related to geological complexities such as a lithology of interbedded mudstones and sandstones. Picture from Dodd et al (2018) shows a hybrid event bed, comprising the fab1 to fab3 facies succession and underlying structureless sandstone.

Local-scale sedimentological, intraparasequence and parasequence variability in a mudstone-dominated shelf succession, Book Cliffs, Utah.

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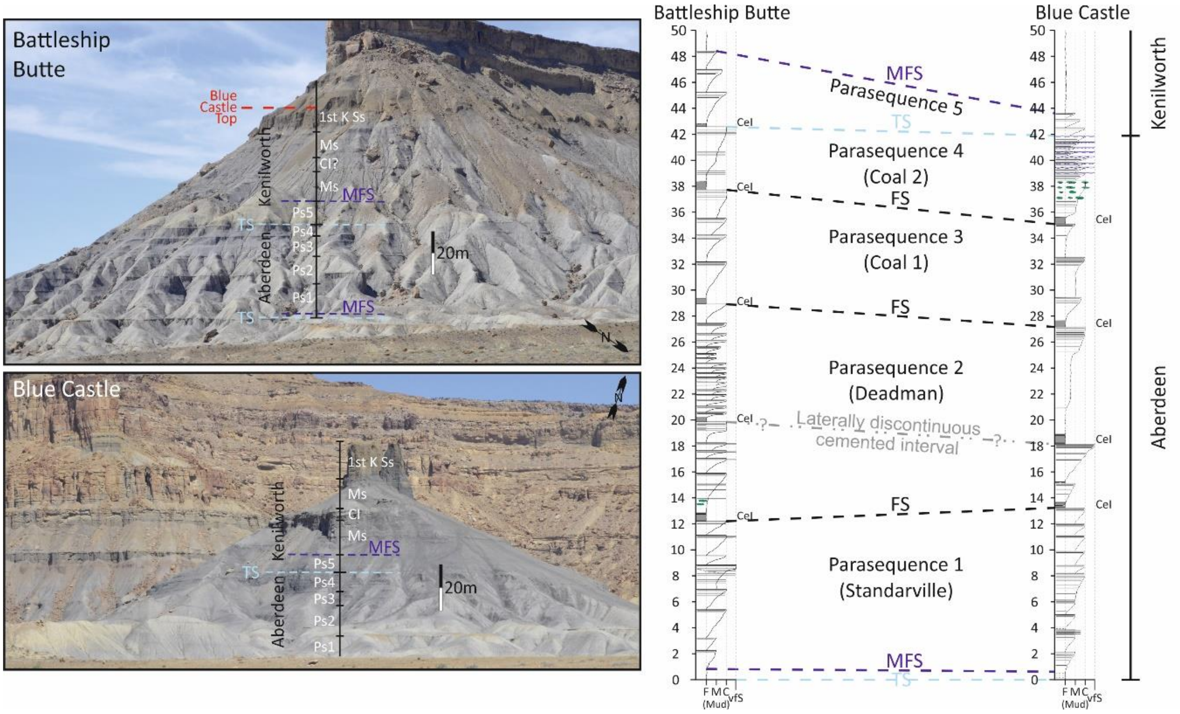
Core-based mudstone studies, which form the larger part of recent mudstone research, give very limited insights into local-scale lateral variability in mudstone facies and depositional processes. So whilst regional sedimentology, intraparasequence and parasequence variability is generally well understood, smaller scale, local variability is not. This study aims to characterize the local-scale along-shelf variability in facies, depositional processes and facies stacking patterns in a mudstone-dominated shelf succession.

This study focused on strata deposited in the Western Interior Seaway during the Campanian (80Ma), specifically the offshore deposits of the Aberdeen Member (Blackhawk Formation) in the Book Cliffs (Utah). Comprehensive sedimentological analysis was completed on two ~45m stratigraphic successions north of Green River, approximately 1.5km apart and oriented parallel to the palaeoshoreline. Samples were collected at 2m intervals with half the samples from each measured section manufactured into thin sections.

The two logged successions are characterised by 0.5m to 2m thick coarsening upward bedsets that stack to form 5m – 12m parasequences. The basal parts of bedsets consist of heavily-bioturbated homogenous fine-mudstone with sporadic bed relics that thicken and coarsen upward into less-bioturbated well-preserved coarse-mudstone beds. This is interpreted to reflect a change from occasional current-deposited beds with depositional breaks allowing fauna to inhabit and disturb surface sediment to more frequent varying energetic conditions with relatively shorter to non-existent hiatuses. Thin-section analysis revealed offshore deposits of the Aberdeen Member is dominated by extremely thin fining-up and bi-gradational event-beds (<0.5cm). The fining-up event-beds are interpreted to represent turbidites and WESGFs with the bi-gradational event-beds interpreted to represent hyperpycnites, this indicates the depositional system was almost always active during this time-period. Facies variation is particularly common within thin-sections as hyperpycnite and turbidite deposits appear interbedded within 0.5cm intervals and bioturbation can differ from 1/2 to 4/5 across a 0.5cm interval.

The two measured sections exhibit varying intraparasequence and parasequence stacking patterns indicating mudstone-dominated shelf settings vary at local scales. For example, bedset quantity and parasequence thickness differs across the measured sections and the interbedded, small-scale turbidite and hyperpycnite deposits provide subtle insights into processes acting upon the shelf. Local topography and/or wider palaeogeographic influences such as river discharge and delta-slope instability may result in the stacking pattern and depositional process variability resulting in highly heterogeneous mudstone successions.



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Ps4
Ps3
Ps2
Ps1
Aberdeen
20m
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Battleship Butte
Blue Castle
MFS
Parasequence 5
TS
Parasequence 4
(Coal 2)
FS
Parasequence 3
(Coal 1)
FS
Parasequence 2
(Deadman)
Laterally discontinuous
cemented interval
FS
Parasequence 1
(Standarville)
MFS
TS
Cel
Kenilworth
Aberdeen
F M C vfS
(Mud)

The study of a complex sedimentological succession in a foreshore setting using a drone

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The use of unmanned aerial vehicles (UAVs or drones) has increased in recent years for a range of geological studies, in both academia and industry. Their most common use is for the mapping and/or monitoring of structural features, such as faults, folds or neotectonic movements in hazardous or inaccessible locations or where an aerial vantage point is needed. Their deployment with sensors, to sample volcanic gases for instance, is also becoming more common-place. The employment of drones in sedimentological studies is less well reported. We present a high-resolution drone survey of a 5 km long and c. 200 m wide section of the Helmsdale Boulder Beds succession, exposed on the foreshore in NE Scotland. Close up images of sections that are inaccessible on foot, large-scale orthomosaic photographs and digital elevation models produced using structure-from-motion photogrammetry methods have been produced. These provide additional data and new perspectives on the succession, aiding the interpretation of depositional processes. Capturing such imagery in a tidal location requires careful planning and a series of trade-offs relating to the time of day, month and year chosen for the survey.

Stratigraphic Transition from Deep-marine to Shallow-marine in a Single Clinothem

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The topset-to-bottomset depositional architecture of basin margin clinothems provide important palaeoenvironmental archives to investigate controls on the timing of basinward sediment transfer. Typically, the shallow-marine process regime in the topsets is separated spatially and stratigraphically from the deep-marine process record in the bottomsets. The exhumed Permian Unit 5 system (Skoorsteenberg Formation, Tanqua depocentre, Karoo Basin, South Africa) thickens-then-thins basinward, demonstrating a clinoform geometry, and provides a rare example where the stratigraphic transition from a deep- to shallow-marine environment permits these process interactions to be investigated.
Sedimentary logs and palaeocurrent measurements collected from Unit 5 are complemented by two research boreholes across a 55km^2 area. Sedimentary facies analysis, thickness variations and correlation panels allowed identification of four evolutionary stages within Unit 5 in the most proximal outcrops. Stage 1 (~60m thick) is characterised by deep-marine architectural elements including sandstone-rich channel complexes with multiple incisional surfaces; fining-upward thin-bedded turbidite successions interpreted as external levees; and proximal lobe deposits comprising tabular climbing ripple laminated sandstone beds intercalated with thin-bedded turbidite deposits. Stage 2 (<35m thick) is marked by soft sediment deformation with evidence of downslope movement, typically accompanied by thickening upward packages of rippled sandstone beds, and an upward increase in hummocky cross stratification and symmetric ripples on bed surfaces, suggesting shallow-marine processes. Stage 3 (<4m) is characterised by highly bioturbated fining upward sandstone interpreted as a minor transgressive deposit. Stage 4 comprises <5-35m thick thickening- and thinning-upward packages of thin-bedded turbidites capped with a regional mudstone marking a regional relative sea-level rise.
That shallow-marine deposits overlie deep-marine deposits in a single clinothem points to a shallow water depth at the time of deposition (~100 m). The presence of underlying point sourced submarine fans, and overlying clinothems, indicates Unit 5 is an important record of the stratigraphic change from bypass- to accretion-dominated slope processes.

Upstream-migrating knickpoints and their control on submarine channel evolution

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Submarine flows called turbidity currents form spectacular seafloor channels, whose scale rivals rivers on land. These underwater channels are much less well understood, however. Turbidity currents pose a hazard to important seafloor infrastructure, and their associated deposits form archives of Earth's history and major hydrocarbon reservoirs. Therefore, understanding how submarine channels form and develop is important. We present the most extensive timelapse monitoring yet for any submarine channel, which provides new insights into the controls on channel evolution. We analyse a decade of repeat seafloor surveys from a river-fed submarine channel in Bute Inlet, British Columbia, Canada. Past studies suggested that meander bend erosion, levee deposition, or trains of scours control submarine channel growth. We show for the first time that exceptionally rapid (100–400 m/year) upstream migration of 5–30 m-high knickpoints can dominate submarine channel development over the entire length of the system. Sediment volumes eroded and deposited during knickpoint migration significantly exceeds that supplied by the inputting rivers, and that associated with outer-bank erosion at meander bends. Knickpoints are a well-known feature in rivers where they result from external factors, such as tectonic uplift, bedrock layers, or base-level change; however, they are not regarded as a dominant morphodynamic process, since they migrate upstream at much slower rates. While meandering primarily controls river morphology, we find that knickpoints formed by internal processes are the dominant control on the morphologic evolution of the submarine channel; capable of completely altering channel geometry, initiating channels and controlling meander-bend growth. Knickpoints also exert a major control on the preservation potential of individual events and may strongly control sediment delivery to the terminal lobe. Similar knickpoints have been identified in many submarine channels worldwide; hence we suggest that they are of global importance.

Investigation of Microbial Activity using Clumped Isotope Thermometry along Carbonate Vein in Granite Host Rock

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Several investigations confirm that microorganisms thrive in oligotrophic fracture systems, surviving by consuming and producing methane. Methanogenesis induces a fractionation or kinetic isotopic effect of carbon (expressed in $\delta^{13}C_{VPDB}$). In our study area (Laxemar, Götemar and Forsmark, Sweden), microbial activity have caused carbon depletion, with $\delta^{13}C_{VPDB}$ in the range from -7.5‰ to -24.8‰ due to anaerobic oxidation processes.

Here we apply a relatively new technique, carbonate clumped isotope thermometry to measure the $\delta^{13}C$, $\delta^{18}O$, and clumped isotope-derived temperature of the precipitating carbonate vein in granitic host rock. The method is based on measuring the, clumping of ^{13}C-^{18}O bonds in the carbonate lattice (indicated as Δ_{47}). The abundance of Δ_{47} of CO_2 relative to a stochastic distribution depends only on the temperature of the fluid. The CO_2 purification processes for our measurements were done using two methods, a manual line and an automated line (called Imperial Batch Extraction System or IBEX).

We also compare the result to fluid inclusion results to investigate the precise temperature of fluid within the fracture. We show that the fracture systems were at temperatures ranging from 45°C to 94°C, the lower end of this being a perfect environment to support microbial or thermophile activity.

Our work demonstrates that the clumped isotope approach significantly reduces uncertainties and increases our ability to constrain temperature and fluid source related to microbial activity within the fracture system. This is especially true at temperatures <80˚C where fluid inclusions are difficult to apply.

Categorising the Petroleum Play of the Miocene Deposits within the Salin Sub Basin, Myanmar

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The Central Myanmar Basin (CMB) contains most of the onshore petroleum plays in South East Asia, and exports much of its reserves to nearby countries such as China and Thailand. Exploration has been ongoing in the country since the mid-1800s, with some of the first wells still producing today. With hopes of the petroleum helping the country's economic growth, many of the once illegal artisanal oil fields have become fully established production wells.

The petroleum plays in the Central Myanmar Basin occur in the Miocene Formations: the Pyawbwe, Kyaukkok and the Obogon. In one of the main oil fields, the 'Yenangyaung' (the literal Burmese translation being "stream of oil"), most of the production is from the clean, porous sandstones of the Kyaukkok Formation. Much of the Miocene succession (and the Cenozoic as a whole) has undergone post-depositional compressional tectonics, causing a large synclinal fold to form within the CMB, acting as a very effective structural trap. Hydrocarbons are such a common feature within the area, that oil seeps at the surface are a regular occurrence.

This research into the Miocene deposits are based on a month-long field season completed in October 2018, with the intention to further classify the nature of these formations. The basal Miocene formation, the Pyawbwe, contains organic rich mudstones and siltstones, with some marginal marine ichnofacies, interpreted to have been deposited in a muddy deltaic setting. The TOC and the presence of petroleum in the mudstones are apparent in the modern-day deposits from the Minbu mud volcanoes, located NW of Magway, which are sourced from the fine-grained sediments of the Pyawbwe Formation. The overlying Kyaukkok Formation is formed primarily from interbedded channelised sandstones and siltstones, interpreted to represent predominantly a shallow marine environment. The youngest Miocene formation, the Obogon, is again predominately formed from interbedded sands and silts. Heavily bioturbated horizons are also present, with inchofacies indicating largely deltaic settings with fluvial influence in the north. On average, the palaeocurrents taken from the Miocene formations suggest a southerly flowing fluvial and deltaic systems.

Decoding the evolution of the Carboniferous fluvial system using onshore-offshore correlation

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Understanding the evolution of the Carboniferous fluvial system in the UK offshore sector has historically been hampered by differences in stratigraphic nomenclature in the areas surrounding the Mid North Sea High and onshore. This has hindered the systematic regional understanding of the timing and controls on stacked source and reservoir rock intervals.
The joint industry-government 21st Century Exploration Roadmap Project, aimed at rejuvenating the exploration from the Central North Sea/Mid North Sea High to the East Orkney Basin, has provided the opportunity for a comprehensive re-evaluation of Carboniferous onshore-offshore UK stratigraphy. Over 130 well reinterpretations, tied to seismic interpretations, provide evidence of the inception and extent of the delta system.
This has allowed the identifications of the extent and inception of the Carboniferous delta systems and the basins in which the deposited into. Also how facies architecture evolved through the Carboniferous in response to tectonic events and sea-level change. We created palaeo-geographic maps which show times slices from the Tournaisian to Namurian. These show the geographic relationships between fluvial, fluvio-deltaic, platform carbonate and shale-dominated basins and how they evolve through the period.
This will lead to a better understanding of how facies and palaeogeography influence Palaeozoic petroleum system and help to identify new targets for exploration.

Late Cretaceous contourite features on the West Iberian margin: implications for palaeoceanography and hydrocarbon exploration

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In recent years, contourite research has accelerated and the economic significance of bottom-current controlled sedimentation is being re-evaluated. One reason for this is frontier hydrocarbon exploration. As industry moves further offshore to the continental slope and deep marine environment, contourite features become increasingly prominent and therefore warrant a better understanding. Whilst this is the case, the processes and mechanisms required for their formation are still poorly understood, relative to other deep marine processes. In this study, 2D seismic profiles and Deep Sea Drilling Project (DSDP) data from the West Iberian margin has been used, alongside published literature, to define the morphology and seismic facies of some large contourite features, categorise their geometries, compare them to non-contourite deposits and better understand the late Cretaceous oceanographic setting in which they formed. Both depositional and erosional features were identified and have been considered as elements in a conceptual hydrocarbon system. The presence of large palaeo-drifts and erosional features on the margin at this time, coupled with examples from literature, is evidence for persistent moderate to strong bottom current activity, within the North Atlantic basin during the late Cretaceous. Large deposits have been observed on the lower slope in a confined seaway, where faulted blocks formed margin-parallel palaeo-seafloor highs. This increased bottom current velocities by restricting flow, to the point where they could be capable of reworking coarse-grained sediments and mass-transport deposits (MTDs) that were deposited earlier. Based on 2D seismic profiles, two post-Cenomanian drifts were identified, the internal seismic character and external geometries of which, suggested potential as a reservoir, seal and trap simultaneously, in a petroleum system. Thus strengthening the argument for the significance of contourite deposits in hydrocarbon exploration. The work achieved in this project is highly relevant for developments in research on the prospectivity of (palaeo-) contourite features, as well as bottom current influenced sedimentation during the late Cretaceous, on North Atlantic passive margins.

Flood variability and the origin of a preferential avulsion node on lowland river deltas

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River deltas are built by cycles of lobe growth and abrupt channel shifts, or avulsions, that often occur within the backwater zone of coastal rivers. Here I summarize our recent work on the necessary conditions to produce persistent, backwater-scaled avulsion nodes, including flume experiments and a numerical model of delta growth that includes backwater effects, cycles of lobe growth and abandonment, relative sea-level rise, and variable flood regimes. We find that under the common assumption of an initial uniform bed slope, avulsion location in the numerical model scales with the backwater length regardless of flood variability due to a geometric artifact. For more realistic scenarios of lobe reoccupation, discharge variability is required to produce persistent backwater-scaled avulsion nodes, consistent with flume experiments. Our findings hold over a wide range of relative sea-level rise and fall rates, and suggest flood variability is a fundamental control on coastal river morphodynamics and delta stratigraphic architecture.

Constraining basin-floor lobe architectures using well log data and artificial neural network models: Tanqua depocentre, Karoo Basin, South Africa

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In the Tanqua-Karoo Basin, a number of research wells have been fully cored and geophysically logged to investigate the subsurface expression of sand-rich basin-floor fans and associated mud-rich inter-fan successions. The resultant integrated dataset permits the analysis of well log responses that can be used to constrain stratigraphic architectures within lobe-dominated basin-floor fans from their wireline signature. Distinct lobe environments related to depositional environments within basin-floor lobes have been identified: i) lobe axis; ii) lobe off-axis; iii) fringe; iv) distal fringe; v) inter-fan mud-rich background sedimentation. The lobe environments, determined by sedimentary logging of the core and extensive investigation of nearby outcrop exposures, are characterised based on facies associations present and bed thicknesses.

Through calibration of the high resolution well log data with the core, the petrophysical characteristics (gamma, density, neutron porosity, sonic velocity, and resistivity) of the previously defined lobe environments were used to generate a suite of electrofacies. The electrofacies were used to train artificial neural networks (ANN) to facilitate the prediction of stratigraphic architectures from the well log data. Facies associations and architectural lobe elements were positively identified in more than 80 % and 70 % of cases respectively using the trained ANN when tested against the known stratigraphy of nearby validation wells. Erroneous predictions in the modelling results is primarily observed in lobe fringe environments and is attributed to the presence and variability of mud- and organic-rich components in sand-rich hybrid beds commonly observed in these depositional environments. It is shown that the approach adopted here can be employed to reduce uncertainty in the identification of lobe environments in non-cored wells and help constrain the extent and architectural characterisation of basin-floor lobe deposits.

A frosty Cambrian Dawn?

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The biotic radiation associated with the onset of the Cambrian Period is one of the most intensely studied periods in the evolution of life and understanding the environmental context of this biotic revolution is essential. In the aftermath of extreme glaciations of the Cryogenian Period and multiple, perhaps more regional, glaciations of the Ediacaran, the Cambrian is universally considered a warmer period in which there is no conclusive evidence for icy conditions. Challenging this consensus we present data from an ongoing project from the North China Craton, which may indicate permafrost conditions at mid-palaeolatitudes during the early Cambrian. We have observed ice wedge casts incising into the uppermost surface of the Ediacaran-aged glaciogenic Luoquan Formation. These are filled exclusively with sediments of an overlying unit mapped as the Xinji Formation, which elsewhere trilobites and small shelly fossils have placed within Series 2 of the Cambrian. The geometry of these wedges is such that they would represent a perfect sediment trap, likely to trap the first available material even during net sediment bypass. However, this trap would not be sprung until the original ice within the wedge had thawed, meaning that the depositional age of the sediments filling the wedge is likely penecontemporaneous with the end of permafrost conditions i.e. permafrost persisting well into the Cambrian period. Although this is an exciting prospect, the very considerable challenge facing this ongoing project is whether the unit overlying and infilling the wedges truly is the Xinji Formation and Cambrian in age or whether it represents subaerial exposure within the Ediacaran Period.

CO_2 mineral trapping in natural analogues – case studies from the Southern North Sea (UK) and the South China Sea (China)

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Mineral trapping of CO_2 by precipitation of carbonate minerals is seen as the most permanent and secure mechanism of CO_2 storage. A common problem is to connect carbonate mineral precipitation to high CO_2 concentration compared to 'ordinary' diagenetic carbonate minerals often present in reservoir formations. The study of natural analogues, where the geochemistry of CO_2-rich reservoirs are compared with low-CO_2 reservoirs of similar initial mineralogy, can reveal the impact of high CO_2 concentration on the geochemical equilibrium. We have investigated mineral trapping in CO_2-rich siliciclastic reservoirs of upper Miocene age in the Yinggehai Basin (South China Sea) and used nearby CO_2-poor reservoirs of similar age as benchmarks for the analysis. Within the reservoir, the CO_2 has triggered the reaction from calcite and chlorite to ankerite, a magnesium bearing carbonate mineral, and kaolinite. Geochemical modelling shows that the total amount of permanently trapped CO_2 is approximately one half of the CO_2 in the newly formed ankerite. The Fizzy discovery, a high-CO_2 gas accumulation reservoir of Rotliegend age located in the Southern North Sea (UK), probably does not provide the necessary geochemical environment for effective mineral trapping. With only minor dawsonite present (an Al-carbonate), the dominant carbonate mineral is dolomite, both in-situ dolomite cement and dolomite precipitated due to a later increase of the CO_2 concentration (Heinemann et al., 2013). Although our results show that up to 22% of the dolomite in the Fizzy discovery precipitated due to the high CO_2 concentration, a certain amount of dissolution of in-situ dolomite might be assumed because the overall amount of dolomite is lower than a low-CO_2 equivalent reservoir, the Orwell Field (Wilkinson et al., 2009). Our results show that effective mineral trapping is only guaranteed when the in-situ reservoir rock provides the required geochemistry.

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What palaeohydrologists and geomorphologists get wrong about megafloods

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Megafloods, loosely defined as high-magnitude, low-frequency catastrophic floods involving the sudden release of water, are significant geomorphic events, capable of releasing as much energy as major volcanic eruptions or earthquakes, altering planetary scale patterns of water and sediment delivery to the oceans, and even impacting the global thermocline circulation pattern that controls the Earth's climate. Although such events occur in a range of settings with a diverse set of triggers they are most often associated with the termination of the Last Glacial Maximum, when huge fluxes of water from land to sea were associated with disruption and break-up of continental ice sheets in North America and Eurasia. Some of these floods released hundreds of thousands of km^3 of water, at discharges estimated in millions of m^3/s, and producing spectacular landscapes such as the Channelled Scablands in the NW United States.

However, since megafloods almost by definition involve flows of water much larger than any that have been observed during historical times, they are studied largely on the basis of the large-scale erosional and depositional landforms that they produce, coupled with palaeohydraulic reconstructions based on computer-modelling. This gives rise to a critical problem: the preserved channel geometry is not representative of the actual, *evolving* channel geometry that carried the flood *during* the flow. Consequently, palaeofloods are typically modelled as being (i) bank-full flood events, i.e. at peak discharge the flow fills the channel from its modern base to the highest observed palaeostage indicator, channel rim, or other high-water mark, and (ii) as having fixed channel boundaries (a requirement of current computational codes). Collectively these ignore the facts that megaflood channels are demonstrably highly erosive (e.g. the spectacular erosional landforms, the huge volumes of distally deposited material eroded from the channels etc.); and that environments such as the Channelled Scabland were eroded by multiple (as many as 25-60) outbreak events that would each have progressively deepened the channels. This thinking results in automatically (subconsciously?) underestimating the erosional capacity of megafloods and overestimating the energy expenditure required to produce erosional features.

Recent studies have challenged these oversimplifications. Transport-limited bedrock erosion models and progressive incision are a better fit to the geometry of Scabland channels and reduce required peak discharges by a factor of ten[1], while the erosional capacity of even relatively modest modern floods has been demonstrated by the Canyon Lake Gorge event in 2002[2], and the 2007 Crater Lake break-out at Ruapehu[3]. Further work is needed on the development of mechanistic transport-limited erosion models based on incipient motion thresholds, calibrated from single-flood events where peak discharge, total flow volume, and net erosion can be well-constrained.

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Contrasting mud-rich and mud-poor submarine lobes and their architecture in a post-rift setting

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Deep-water lobes are formed by deposition of sediment transported by gravity flows. Lobe systems that developed on rifted margins during the post-rift stage are typically deeply buried, and constraining the architecture and facies distribution of lobes in subsurface data is hindered by variable seismic resolution and limited core coverage. Typically, to bridge the gap between seismic resolution and well data, outcrop analogues can be used. However, exhumed post-rift lobe systems are rarely well-preserved due to deformation during basin inversion. The Early Jurassic Los Molles Formation, Neuquén Basin, Argentina, is a rare exhumed example where the syn- to post-rift transition is well-preserved. In the Chachil depocentre, the onset of the early-post rift stage is recorded by the drowning and deepening of a carbonate system and the consequent development of a deep-water lobe system. This field-based study will involve correlation of detailed logs and field observations, with emphasis on grain size and textural changes across depositional systems form axial to margin environments. The lobes show a stratigraphic evolution from an argillaceous to a sandier nature. The observed evolution could be interpreted as the progradation of the depositional system, where sand-rich lobe deposits evolve in down-dip direction to mud-rich deposits. However, it has been observed that the sandy lobes pinch-out without any significant transitional to argillaceous deposits, which suggests either the source of the sediment is changing, or that the flows do not transform in the same manner. The working hypothesis is that high-density flows tend to terminate more abruptly against confining slopes, whereas lower-density flows have the tendency to produce strong facies variability and to be less influenced by the interaction with intra-basinal topography. Furthermore, the mud-poor lobes are closely associated with extensive clastic injections, whereas injectites are not observed with the mud-rich lobes, suggesting that the depositional porosity and permeability is an important control on post-depositional injection processes. The study of lobe and facies architecture in post-rift settings where subtle topography affects sediment gravity flows will be a useful comparison to existing models from unconfined and fully-confined settings, and will give new insights into these systems as reservoirs, aquifers, and sites of carbon capture and storage.

Constraining the thermal histories of the Carboniferous Midland Valley of Scotland: a potential resource for unconventional gas and shale oil?

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Situated between the Southern Uplands and the Highland Boundary fault, the Midland Valley of Scotland has a history of oil and gas exploration that dates back to the 1850's and the birth of the hydrocarbon industry. Economic exploitation of oil-shale units continued through the 20th century until the price of oil and gas left further exploration uneconomical and the focus of the hydrocarbon industry migrated to the offshore North Sea prospects.

The economical units of the Midland Valley of Scotland were deposited in a series of Late Devonian and Carboniferous sedimentary basins which formed in the foreland of the Variscan orogen. Such is the complexity of the geological history of the Midland Valley that several very different regional tectonic models have been proposed, all of which express the need for major switches in tectonic regime to satisfy the geological observations. Alongside the complex tectonic history, the Midland Valley has also experienced widespread volcanic activity throughout the Carboniferous and into the Permian.

Despite this complex geological history, the Midland Valley may still be considered a potential resource for unconventional oil and gas. However, little work has been done to quantify the thermal history of the basins and therefore the maturity of the organic matter cannot be constrained with great confidence. It is the aim of this project to constrain the time-temperature pathway of the Carboniferous rocks of the Midland Valley using low temperature thermochronology, primarily apatite fission track (AFT) and Uranium-Thorium/Helium in zircon (U-Th/He). The time-temperature pathway, will provide robust, quantitative constraints on the maturity of the organic matter and on the exhumation histories of the evolving sedimentary basins. This will be the pioneering thermochronological study in the University of Glasgow using Laser Ablation on the recently acquired Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS). This technique provides rapid data acquisition, removes the need for neutron irradiation of samples in a nuclear reactor and enables multi-element analysis, delivering fission track, uranium-lead and rare earth element data with a single ablation.

Sedimentary provenance and depositional environments from the Oligocene formations in the north of the Salin sub-basin, onshore Myanmar

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Due to political instability, accessibility to scientific research in Myanmar was limited until 2012. Since then, there has been a steady increase in interest into the geology of the country, mainly driven by the numerous proven resources of Myanmar. This study looks at the petroleum-bearing Oligocene Shwezetaw, Padaung, and Okhmintaung Formations in the CMB, which sits between the accretionary wedge of the Indo-Burman Ranges in the west and the Sino-Burman Ranges in the east. The CMB itself is split into a westerly and an easterly strand, separated by the high of the Wuntho-Popa magmatic arc. This work specifically focuses on the Salin sub-basin that sits in the middle of the western strand. Around 4 km of sediment accumulated in the basin during the Oligocene, but the source region for these deposits is contested between the Himalayan Foreland or more localised highs, such as the basin bounding ranges or the central magmatic arc.

Sedimentary logs, panel diagrams, and samples for further processing were collected during a month-long field season in October 2018. The deposits in the Shwezetaw are formed from interbedded sandstone and dark silts. Towards the south, the sandstone contains abundant bioclastic conglomerate horizons with intermittent calcarenites. Analysis of the sedimentary logs suggest that the Shwezetaw was predominately deposited in fluvial environments in the north of the basin, grading into possible deltaics towards the south. The overlying Padaung Formation is composed of mudstones and siltstones with occasional thick channelised sandstone packages, more common in the north. Towards the south, heavily bioturbated horizons are common. The deposits are interpreted as having been deposited in northern fluvial systems that graded rapidly into deltaic and shallow marine environments towards the south. The deposits of the Okhmintaung Formation are formed from thick packages of sandy channels interbedded with thin silts. At certain locations towards the south of the basin, heavily bioturbated horizons occur. These deposits are interpreted as a deltaic- to shallow marine transgression. Overall, the Oligocene was dominated by a transitional marine environment with intermittent fluvial and marine processes.

Recent previous studies have challenged the interpretation that the majority of the sediment was sourced from the Himalayan region, instead suggesting more localised source areas. An ongoing sedimentary provenance study will add data to this new interpretation through light mineral analysis, heavy mineral analysis using optical point counting and Raman Spectroscopy, and U-Pb dating of detrital zircons using LA-ICP-MS.

Quantifying the relationship between structural deformation and the morphology of submarine channels from shelf-edge to deep water: Case studies from the Niger Delta system

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The processes and deposits of deep-water submarine channels are known to be influenced by a wide variety of controlling factors, both allocyclic and autocyclic. However, unlike their fluvial counterparts whose dynamics are well-studied, the factors that control the long-term behaviour of submarine channels, particularly on slopes undergoing active deformation, remain poorly understood. We combine seismic techniques with concepts from landscape dynamics to investigate quantitatively how the growth of gravitational-collapse structures at or near the seabed in the Niger Delta have influenced the morphology of submarine channels along their entire length from the shelf edge to their termination in deep water.

From a 3D, time-migrated seismic reflection volume, which extends over 120 km from the shelf edge to the base of slope, we mapped the present-day geomorphic expression of several submarine channels and active structures at the seabed, and created a Digital-Elevation Model (DEM). A second geomorphic surface and DEM raster—interpreted to closer approximate the most recent active channel geometries—was created through removing the thickness of hemipelagic drape across the study area. Elevations within the DEM rasters were used to establish flow networks, enabling the longitudinal profiles of the channel systems to be extracted. We evaluate the evolution of channel widths, depths and slopes at fixed intervals downslope as the channel systems interact with growing structures. Results show the channel long profiles have a relatively linear form with only localised steepening associated with seabed structures. We demonstrate that channel morphologies and their constituent architectural elements are sensitive to active seafloor deformation, and we use the geomorphic data to infer a likely distribution of bed shear stresses and flow velocities from the shelf edge to deep water. Our results give new insights into the erosional dynamics of submarine channels, allow us to quantify the extent to which submarine channels can keep pace with growing structures, and help us constrain the delivery and distribution of sediment to deep water settings.

Depositionally-conditioned training images for fluvial sandsheet reservoir models

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The recovery of petroleum reserves in fluvial reservoirs is typically low, especially when considering the high net-to-gross nature of fluvial sandsheet reservoirs. This has been attributed to a lack of geological realism within current 3D reservoir models. Training images, typically generated from outcrop analogue data, are commonly used to populate 3D reservoir models. However, such data are usually biased, either by the outcrop size/scale or by its specific sedimentary depositional environment.
This study shows how to generate newly proposed depositionally-conditioned training images that use logical depositional rules, which subsequently populate Multi-Point Statistics (MPS) reservoir models that are more geologically realistic. The technique is under used due to its reliance upon traditionally generated training images and its inherent complexity. The more commonly utilised sequential indicator simulation (SIS) models, are also generated as a comparison to the connectivity and geological realism of the newly developed depositionally-conditioned MPS models.
Sedimentary architectures and palaeocurrent data from both an outcrop analogue of the Upper Cretaceous Lower Castlegate Sandstone at Tuscher Canyon, Utah, USA, and modern-day Jamuna River, northern India, were used to generate the logical rules for the depositionally-conditioned training images. Results evidence that the depositionally-conditioned training image reservoir models represent a more realistic representation of architectural distribution within a fluvial sandsheet reservoir, enabling a more reliable and efficient production mechanism to be invoked. Initial results from net-connectivity analysis show similar net-connectivity statistics for the two modelling techniques. This shows that with the newly proposed, geologically realistic approach, significantly simplifies the under-utilised MPS reservoir modelling technique. Study implications suggest using a newly generated reservoir model building workflow will provide more geologically realistic reservoir models, with regards to baffle-bearing sedimentary architecture. Thereby, reducing uncertainty surrounding secondary and tertiary phases of production, which are commonly more susceptible to the influences of sedimentary heterogeneity. Future work will expand into object-based simulations to further test the application of depositionally-conditioned MPS reservoir model development.

Source to sink analysis of Cretaceous sediments along the Atlantic margin, Senegal

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During the Cretaceous, the continued separation of South America and Africa, following break-up of the Gondwana supercontinent, lead to the formation of the proto-Atlantic oceanic basin; comprising several large offshore sedimentary basins along the continental margins. Provenance of the sedimentary fill is poorly constrained. This study aims to investigate sediment distribution from the erosional hinterland potential catchment areas in Senegal to the offshore MSGBC basins; to better constrain the processes controlling sediment delivery into passive margin basins. The results will improve constraint on the prolific offshore petroleum-reservoir systems and further develop our understanding of the paleogeography of the NW African passive margin during the Cretaceous. This project involves petrographic and mineralogical characterisation and heavy mineral analysis of outcrop and subsurface core and cuttings data from exploration wells.

The examination and characterisation of sediments delivered into the Senegal Basin is part of a larger study being undertaken by the North African Research Group (NARG) as part of a regional study to examine the relationships of the Cretaceous depositional systems along this entire margin, including a regional thermogeochronolgy study of the Maurinitides and improved biostratigraphic dating of the entire Cretaceous sequence in the Central Atlantic basins.

Experimental investigation of sand production from the deep water sediments of the Daini Atsumi Knoll hydrate reservoir, Nankai Trough, Offshore Japan.

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Sand production is the unintended production of sand particles along with reservoir fluid from a wellbore. It is a known problem for conventional petroleum production and has been a significant challenge in viable commercial production of natural gas from gas hydrate reservoirs. The sand can fill the wellbore, cause wellbore instability and casing collapse, clog production equipment and erode facilities. Catastrophic sand production terminated the 2013 Japan Oil, Gas and Metals National Corporation (JOGMEC) gas hydrate production trial at Daini Atsumi Knoll, Nankai Trough, offshore Japan. Over 30 cubic meters of sand was produced from a production interval across deep water submarine fan sediments of the Middle Pleistocene Ogasa group. This study investigated whether the reservoir heterogeneity of the deepwater sediments, particularly the layering and grainsize, could have contributed to this catastrophic sand production.
A custom designed sand production test apparatus was designed and manufactured at the Cambridge University Department of Engineering Mechanics Laboratory as part of the MH21 research program. The apparatus designed to simulate and visualise a plane-strain case of sand production in the openhole gravel packed AT1-P hydrate production test well in the 2013 JOGMEC trial. Collecting data from a deep water hydrate reservoir is challenging and it is unclear if the available wireline log data at the trial site was able to capture the scale of the patterns in the sand and mud layers. To predict reservoir grainsize and layering scales analogue outcrops of deep water sediments in the Aberystwyth Grits, the Bude Formation and the Myall Syncline were compared with the wireline data from the Daini-Atsumi Knoll reservoir. Based on this analysis, two scenarios were created in the sand production apparatus. The scenarios consisted of a massive fine sand layer representing the base of the Bouma et al. (1962) sequence topped with a graded fine to very fine sand layer and then a silt layer.

The results of these sand production experiments suggested that the layering and grain size of the turbidites encourages sanding. Even small weaknesses in sand production controls will lead to catastrophic sand inflow. The sand production is also likely to preferentially come from specific layers in the turbidite sequence. The finer sands were moved more easily than the coarser sands. As a result of shear induced negative excess pore pressure, the silt behaved as a stiff layer during sand production. This created a slab effect which encouraged the creation of a high permeability zone at the top of the graded layer. The increase in permeability and fluid flow velocity in this zone increased the capacity of the fluid flow and in turn the sand production.

Interrelations of petrophysical and microstructural properties of el Gueria reservoir (ypresian, tunisia)

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Carbonate reservoirs are characterized by a large heterogeneity in their internal structure due to the variation of sedimentary and diagenetic processes that affect this type of rock. This micro-textural heterogeneity is responsible for heterogeneity and anisotropy of petrophysical parameters. El Gueria Formation (Ypresian) in Tunisia represents a nummulitic carbonate reservoir and has generated a great deal of research. The sedimentological study of El Gueria nummulitic reservoir (Ypresian) allows us to subdivide it into two members and 7 facies (F1 to F7) which evolved between supratidal to subtidal ramp. This reservoir shows microstructural and petrophysical heterogeneities. We have carried out a detailed sedimentological and petrophysical studies of this nummulitic limestones in order to: a) understand the heterogeneity of this reservoir, b) subdivide this formation into petrophysical levels and c) determine the relations between the microstructural, sedimentological and petrophysical parameters. Microstructural observations were made on thin sections under optical and scanning electron microscopy (SEM). Porosity has been measured by the triple weight method and estimated from the optical microscopy and SEM observation using JMicrovision and Image j software. The different facies are characterized by different types of porosity due to their microstructural heterogeneity. The variation of microstructural characteristics controls the petrophysical parameters of this reservoir. Four parameters have been determined when studying the electrical conductivity (surface conductivity, formation factor, Tortuosity and cementation exponent). The results obtained for these electrical parameters show heterogeneity in the pore connectivity and in the arrangement of mineral crystals, particles and pores. The electrical properties allow us to determine the internal architecture of pore spaces. The study of the anisotropy of magnetic susceptibility permits to differentiate several sedimentary and tectonic phases that affected El Gueria Formation during its deposit steps. The acoustic measurements results show that acoustic velocity depends of the diagenetic evolution and the internal microstructure of each facies of the El Gueria Formation. The combination between sedimentological and petrophysical studies allow the definition of two members within El Gueria Formation. This formation evolved from isotropic material with sedimentary fabric in the lower member (F1 and F2) to anisotropic material with deformation fabric and cementation in the upper member (from F3 to F7).

Effects of Latest Miocene changes of the Mediterranean-Atlantic Gateway Exchange and the Messinian Salinity Crisis on the Neogene basins around the Gulf of Cádiz.

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The Messinian Salinity Crisis (MSC) is an established event of the precipitation of more than 1 million km^3 of salt, equivalent to 5-6% of total dissolved oceanic salt globally, in the Mediterranean Sea during the latest Miocene (5.97-5.33 Ma). The conditions of the isolation from the Atlantic Ocean that led to the deposition of these evaporitic deposits within the Mediterranean Sea is still widely debated. However, restriction of the Mediterranean Outflow Water (MOW) is one of the prerequisites for the hypersaline conditions to deposit the MSC evaporites. Prior to the MSC, the circulation of the MOW during the Late Miocene was active through a Mediterranean-Atlantic exchange of Betic and Riffian, and possibly the Gibraltar gateways. This connection is thought to have ceased or reduced between 5.97-5.33 Ma with the deposition of evaporites. Coevally to the MSC within the Neogene Basins of the Atlantic margins surrounding the Gulf of Cadiz, seismic interpretation shows transparent and very weak seismic facies underlying the regional M reflector (Miocene-Pliocene boundary) separating the uppermost Miocene unit from the Pliocene-Quaternary sequences. This transparent unit is divided into two packages and could also be found in the Guadalquivir and Gharb basins. Biostratigraphic dating shows equivalent age of the upper package with the MSC sequence, while the lower package predates the MSC. Distribution of the transparent unit implicates dominant deposition of hemipelagic / pelagic deposits whose top was drilled during the IODP Expedition 339. These sediments were deposited in relation to a period of quiescence in the Atlantic margins subsequent to the disconnection of the MOW from Late Miocene until Early Pliocene. This suggests that the onset of the weakening or cut-off of intermediate bottom currents of the Mediterranean-Atlantic connection through the Betic-Gibraltar-Riffian paleo-gateways was earlier than the onset of the deposition of the MSC evaporites. This work is crucial for the understanding of sedimentary, paleoceanography and climatic effects for the Late Miocene in the Atlantic margins.

Keywords: Messinian Salinity Crisis, Mediterranean-Atlantic gateway exchange, Neogene basins, Latest Miocene, seismic facies

Geopareidolia: the world's best rock faces

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Humans seem programmed to see patterns in random data, with one of the most celebrated examples being that of seeing faces in rocks. Once thought to be related to psychosis, it is now recognized as being perfectly healthy. Famous examples of geopareidolia include faces, such as the Man in the Moon, the Face on Mars and the Old Man of New Hampshire (sadly no longer with us). They also include a variety of animals such as elephants, lions, dogs and sheep, as well as many random objects including Noah's Ark. It is worth noting that most of these "work" as recognizable images only when viewed from just the right angle.

Almost any rock outcrop is in danger of being identified as a mythical animal, person or object, particularly where this would help to draw punters to such tourist attractions as Wookey Hole, Red Rocks Provincial Park, Mexican Hat or a random outcrop in an entrepreneur's backyard. Most natural attractions or landscapes with outcropping rocks are liable to have some kind of image delineated in the rocks. Indeed it is fair to say that the number of examples of geopareidolia is really limited only by your imagination.

Rock outcrops have therefore become natural Rorschach inkblot tests (much like clouds), but the question remains as to which rocks make the best faces? An analysis of more than 100 well known examples of "rock faces that rock" allows us to pinpoint the most popular sedimentary rocks, including aeolian sandstone and dolomitized limestone, as well as igneous rocks like granite. This data provides us with templates to go out and find more and better examples of faces in the rocks. Judging by the embarrassingly poor quality of the human forms and faces currently on show around the world, there is a desperate need for more convincing examples.

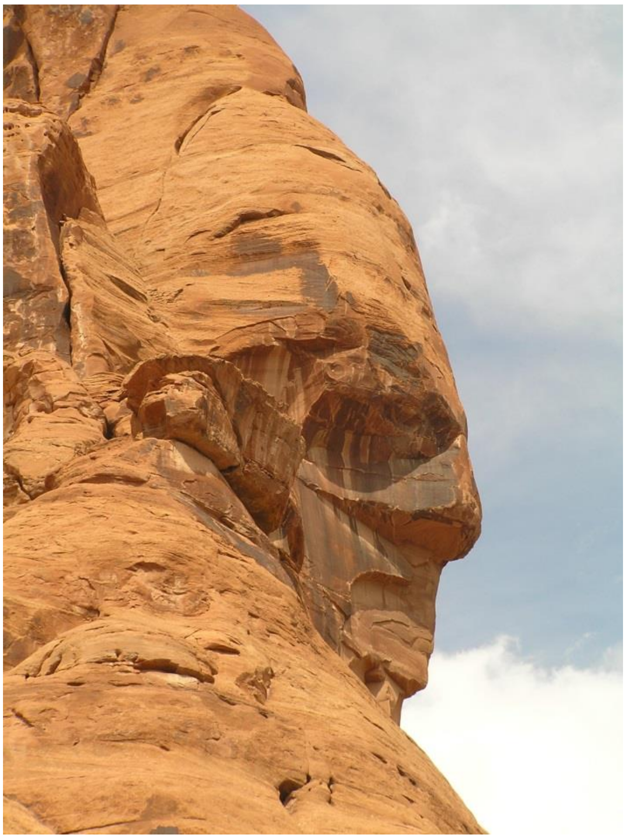

Figure 1. Indigenous native American, Colorado River

Figure 2. Elephant, Valley of Fire State Park, Nevada

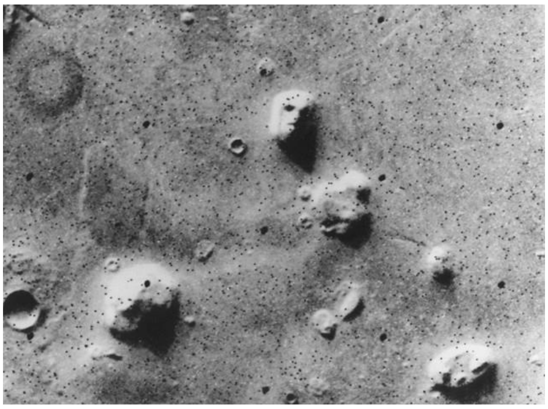

Figure 3. Martian Face, Cydonia, Mars (NASA)

Kinematics of mass-transport complex (MTC) emplacement: evidence for intra-flow cells and shear from 3D seismic reflection data, Exmouth Plateau, offshore NW Australia

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The degradation of submarine slopes drives emplacement of large mass-transport complexes (MTCs). MTCs imaged in 3D seismic reflection data are typically interpreted as the deposit of a single flow that has minimal intra-flow shear, resulting to a classic tripartite morphology, with extensional, translational, and compressional domains. Although intra-flow shears encased within a larger, first-order flow, have been documented from outcrops, their full 3D geometry is poorly-understood. Here, we use five, exceptionally high-quality, post-stack time migrated (PSTM) 3D seismic reflection surveys to investigate the kinematics of MTC transport and emplacement on the Exmouth Plateau, offshore NW Australia. We focus on a large (>65 km long, up to 20 km wide, 500 km^3) MTC that thickens downslope to a maximum of 300 m. The MTC is characterised by dominantly transparent and chaotic seismic facies. The MTC originated from a 30 km wide, NE-trending headwall scarp (at 200-700 m water depth) that dips steeply (30^o) seaward. Kinematic indicators identified on the basal shear surface include: [1] dip-oriented, downslope-converging grooves (>10 km-long), [2] large remnant blocks (c. 4 km-long and 1 km-wide), [3] ramps (with both parallel and perpendicular to MTCs transport direction), and [4] progressively deepening erosional lateral margin (i.e. from c. 150 m in translation to a maximum of 300 m in toe domains). These kinematic indicators suggest the MTC was transported northwestwards, with downslope-converging grooves suggesting transport and emplacement was influenced by pre-existing topography. The top surface of the MTC (i.e. seabed) contains: [1] high-relief (c. 30 m), NW-SE trending longitudinal shears that express the underlying erosional lateral margin, and [2] sinuous, NE-SW trending shear fabrics that terminate at the longitudinal shears. These kinematic indicators suggest the MTC was defined by two separate flow bodies or 'cells' despite being characterised by relatively uniform seismic facies, which flowed basinward at different speeds. This shows the importance of the top surface to understand the kinematics of MTC transport and emplacement, which are not recorded in the internal seismic facies and/or along the basal shear surface.

Reconstructing Dimensions of Ancient Source-to-Sink Systems through First-Order Scaling Relationships

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Source-to-sink (S2S) systems describe the fate of sediment from hinterland erosion to basin deposition. Reconstructing the sediment routing pathways of ancient sedimentary successions is imperative to define controls on the likely location and volume of sediment input that determines extent and character of depositional environments. However, a majority of the preserved ancient S2S system is incomplete and/or fragmented by uplift and erosion through Earths history. Hence, scaling relationships derived from analogous modern sedimentary systems are typically applied as a first-order prediction of ancient S2S system scale.

In this study, we revisit morphological scaling relationships used to define dimensions of ancient S2S segments of the hinterland catchment, continental shelf, continental slope and submarine fan size based on 52 modern S2S examples. The results reaffirm previous scaling relationships between size and sediment load of the hinterland catchment and their submarine fan dimensions with an r^2 above 0.6. However, caution should be exercised in the application of continental shelf and slope scaling relationships that were found to be significantly influenced by both tectonic and sedimentological factors. Rather morphological scaling relationships to reconstruct ancient S2S systems should be restricted to only unconfined sedimentary systems and to predict proximal to distal properties.

Testing the ability of forward stratigraphic modelling to replicate tectono-sedimentary interactions in rift basins

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Tectonics plays a key role in controlling regional and local surface gradients, drainage patterns, sediment entry points, depocentre locations and across-rift asymmetry. Modern rift basins, ancient examples and both physical and numerical models have all contributed to understanding the interplay between tectonics, climate and sedimentation. Forward stratigraphic modelling is also increasingly used to assess the depositional response to variable subsidence, sediment supply and base level and can potentially help predict lithology where this is poorly constrained in the subsurface. However, it is important to verify that the forward models can replicate the behaviour of natural systems. One way to do this is to test the extent to which numerical simulations can reproduce the stratigraphy generated in scaled physical experiments where all the inputs are known. Many of the experiments in subsiding tanks have focussed on changing base level combined with subsidence in the form of simple hinging, but Kim et al. (2010) and Straub et al. (2014) introduced a pair of faults separated by a relay zone and showed that local fault-related uplift and subsidence could steer channels and divert them via a relay into a rapidly subsiding hanging wall depocentre. They showed that the ratio of the timescale needed for tectonic tilting to produce a lateral slope comparable to the main fluvial slope and the timescale required for channels to visit a significant fraction of the basin surface determined whether or not channels were steered. This was termed the timescale ratio.

A set of numerical simulations were run duplicating the experimental setup, the input sediment flux and the location, rates and pattern of subsidence, the latter including both a regional tilt and superimposed fault-related uplift and subsidence. The forward stratigraphic models recreate the variable timescale ratio explored in the empirical models. The channel mobility is decreased by changing the sediment and water discharge at prescribed time intervals during the model run. As a result the timescale ratio is increased which results in a greater influence of the tectonic steering and an increase in the duration of cyclicity noted in the experimental models. The cyclicity consists of cross system channel steering around the fault tip alternating with periods of footwall trenching and transverse supply to the hanging wall. This pattern is replicated in the forward stratigraphic models increasing from 27 hrs to 34 hrs to 71 hrs matching the cycle durations in the physical model. This increased cycle interval time has implications for the stratigraphy in the hanging wall depocentre. Trenching across the uplifted footwall delivers coarse sediment transversely, creating a fan. When the channel is steered away and around the uplifting footwall, finer sediment is deposited into the deepest part of the depocentre as a prodelta with coarse sediment close to the fault tip where an axial delta forms. Slicing of the stratigraphy shows both models generate comparable geometries with coarse grained hanging-wall sandbodies separated by fine grained packages. It appears the forward stratigraphic models capture many of the key aspects of the physical model.

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Oil charging, diagenesis and varied hydraulic properties in the Dunlin Reservoir Sandstones, East Shetland Basin, North Sea

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Porosity and permeability are hydraulic properties that are heavily influenced by diagenesis. It has often been noticed that these hydraulic properties and also diagenetic history vary between oil-saturated reservoirs and water-legs within the same field. In many cases, it can be shown that the oil-saturated reservoir has better hydraulic properties than corresponding water legs. Such a situation exists for the Dunlin field where porosity and permeability within the oil-bearing formation is 11-30 % and 1.3-4200 mD, whereas, within the water leg, it is 8-27 % and 1-50 mD. Previous work in other settings has suggested that pore-blocking diagenetic reactions are inhibited within an oil-bearing formation by the physical presence of oil, which occludes nucleation sites and prevents the growth of secondary mineral phases. Thus, the pore-blocking diagenetic processes that are observed within the water leg are inhibited in the oil-saturated zones resulting in higher porosity and permeability values. Within the Dunlin field sandstones, quartz overgrowths can be found within both the oil-saturated reservoir and the water leg. Within the water leg quartz overgrowths, where they partially surround a clast are found alongside illite-bearing surfaces coating the native clast surface. Within the oil-bearing reservoir partial formation of overgrowths is associated within both illite and oil on the native clast surfaces. Extractable oil and porosity have a positive correlation, but there is no correlation (positive or negative as might be expected) between quartz overgrowth cements and hydrocarbon content. Furthermore, it was observed that oil phases are interstitial between pores, and not trapped beneath overgrowths. Thus while oil charging was subsequent to quartz overgrowth formation, its effect within the oil-saturated reservoir was to inhibit phyllosilicate formation, rather the formation of quartz overgrowths.

Sediment mass-balance constraints for the Middle Jurassic "Brent Delta" sediment routing system, Northern North Sea

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A first-order quantification of the influence of sediment supply and accommodation generation on stratigraphic architecture, and associated tectonic and climatic signals, can be assessed by sediment mass-balance methods. In this study, we investigate the controls on the Middle Jurassic "Brent Delta" sediment routing system in the Northern North Sea Basin, offshore UK and Norway, using sediment mass-balance analyses and downsystem grain-size fractionation.

Published sequence stratigraphic studies are synthesized to provide an age-constrained framework of the "Brent Delta" system over a depositional length of c. 350 km. The framework consists of four chronostratigraphic intervals, each of duration 2 – 8 Myr, and that together span 179 – 157 Ma. Unit 1 corresponds to coeval eastward and westward progradation of basin-margin deltas, sourced from the Shetland Platform and Norwegian Landmass, respectively. Units 2 and 3 correspond to the relatively rapid northward progradation and subsequent aggradation of the main Brent Delta along the basin axis, sourced from the uplifted Mid-North Sea Dome to the south, with contributions from the western and eastern basin margins. Unit 4 records the drowning of the "Brent Delta" in response to the onset of active rifting within the basin.

We present data of sediment grain size and facies proportions, constrained by sedimentological analysis of cores and well logs. We derive isopach maps for the four time units from well log data and published palaeogeographic maps, and use this to quantify sediment volumes and fluxes for the Brent Delta system in a mass-balance framework. Our initial results show that the proportions of depositional facies (coastal plain, shoreface and shallow marine shelf sediments) change significantly through the four depositional time units. Moreover, we demonstrate that this occurs concurrently with changing sediment supply, with the sediment accumulation rate between units, varying by up to a factor of four. Our results suggest that a mass-balance framework is useful for understanding the behaviour of ancient sediment routing systems, and we consider the drivers of this variation in sediment supply. These results provide quantitative parameters that can be used to calibrate and test basin filling models of the Brent Delta system.

Bed termination styles and hummock-like bedforms at onlaps in a post-rift setting

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Submarine lobe deposits, formed by sediment density flows, are of interest as archives of Earth's climate and the transfer of terrigenous material from land to deep-ocean; they form important hydrocarbon reservoirs as well as being potential locations for carbon capture and storage. Knowing how these deposits record Earth's climate and predicting how they behave as reservoirs requires an understanding of their detailed stratigraphic architecture. Their depositional architecture is well defined in unconfined basin-floor settings, but less so in topographically confined settings where flows interact with, and pinchout against, intrabasinal topography. The exhumed Early Jurassic Los Molles Formation in the Chachil depocentre, Neuquén Basin, western Argentina, presents an opportunity to study the deposits formed by these interactions in a post-rift setting, in which a range of flow types were confined by inherited syn-rift topography. The Chachil depocentre outcrops permit detailed documentation of pinchouts from bed- to lobe-scale within a well-constrained post-rift basin-fill. Lobes are intercalated with metres-thick debrites, which add additional topographic complexity. The characterisation of termination styles in the onlapping lobe deposits, and their rates of thinning and facies variability towards the confining slope, indicate the role of flow rheology. Hybrid beds and high concentration turbidites change thickness and facies more abruptly than low concentration turbidites. Evidence of interaction between flows and seabed topography include palaeocurrent patterns, with tool marks at a high angle to ripple lamination, and hummock-like deposits at the pinchout of lobes. These distinctive bedforms form from combined flows generated by deflection, and a morphometric analysis including dimensions, angles of cross-lamination within them, and lateral/vertical grain size changes, has been documented for the first time. Their size ranges from 30 to 70 cm in width and 4 to 11 cm in height, and angles of lamination from 2° to 24° with average values of 46.5 cm, 6.75 cm, and 9°, respectively. Asymmetry of lamination angles, across the bedform, is possible, and they are normally graded. These quantitative bed- and bedform-scale data can help to better constrain the architecture of lobe deposits in confined settings, and support the recognition of subtle onlap in subsurface datasets.

Contourite facies and cyclicity: a geostatistical approach

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The contourite depositional systems can vary widely in both composition and textures. Notable lithofacies changes from muds, through silts and sands then to silts and muds again are typified by the term bi-gradational sequences (sediment cycles). These sequences are described within the contourite depositional systems of Gulf of Cadiz with distribution patterns unique to each stage of the drift evolution.
This research focuses on the cyclicity patterns of the contourite sediments, as expressed by their lithological facies' changes. Cores from Sites U1386 and U1387 were logged and sampled for their facies and mineralogical characteristics.
Clustering and geostatistical analyses including autocorrelation, cross-correlation and frequency analysis were applied to assess Site-to-Site correlation as well as connection to the Marine Isotope Stages (MIS), wirelog data and downhole magnetic susceptibility measurements. Significant changes to these the contourite cyclicity were triggered by major climatic events, such as warm and cold periods during the past million years.

Palaeoenvironmental Reconstruction using Sedimentary Analysis of North-Eastern Iceland's Tjörnes Sequence

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The Tjörnes sequence in northeast Iceland records significant evidence to interpret changeable palaeoenvironments and climatic events in the North Atlantic region from the late to early Pliocene (4.4 to 2.6 Ma). The Tjörnes sequence is one of the thickest sedimentary successions on Iceland, with more than 700 m of dominantly terrestrial, littoral and shallow marine deposits, with minor intercalated lavas. The Tjörnes peninsula represents a unique and accessible site for palaeodepositional analysis, containing abundant well-preserved molluscan fossils, organic-rich lignites and sedimentary structures, including well-defined trough cross-bedding and wave ripples. Here we present the preliminary results from a recent field study to develop the first sedimentological and palaeoenvironmental reconstructions for the section to support and refine our existing understanding of palaeodepositional systems, and the wider influences and interactions between tectonic, oceanic and climatic processes within the region. Our findings indicate previous studies have misinterpreted fundamental lithostratigraphic and sedimentological relationships, have unaccounted for subtle and lateral lithological changes, and suggest the existing benchmark stratigraphic column is incomplete. Consequently, we present a revised lithostratigraphic column which incorporates our sedimentological data collected during fieldwork, and is informed by our palaeodepositional reconstructions. Future analyses of br-GDGTs and Ar-Ar dating of basalts are planned to investigate other challenges, including ambiguities associated with the Tjörnes age model and palaeotemperature estimates derived from the sequence.

Grain-Scale Heterogeneity in Deep Water Massive Sands – Implications for Depositional Processes and Reservoir Quality.

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Deep water massive sands are ubiquitous in the deep-marine record and form excellent reservoirs for hydrocarbons. At the bed-scale, the sedimentologically homogenous nature of these sands has been the root cause of the controversy concerning their emplacing mechanism(s). However, sedimentary deposits are intrinsically heterogeneous at a variety of scales. This heterogeneity can be investigated to shed light on the very mechanism(s) responsible for depositing massive sands, as well as assessing the reservoir quality within the beds. To this end, vertical grain-scale heterogeneity (grain size, sorting and fabric) within six massive beds from the Grés de Peïra Cava (SE France) and the Numidian Flysch (northern Tunisia) was investigated in back-scatter electron images using digital image analysis. Images parallel to the bedding plane and perpendicular to the apparent grain long-axis orientation were acquired to minimise the uncertainty in the grain size and fabric, and increase the statistical significance of the data. Hypothesis testing was employed to reduce the subjectivity in assigning vertical trends within each bed. Results show that the majority of the massive sands contain statistically significant vertical variation in grain size and fabric (p-values <0.01). A vertically diverging followed by converging grain size profile involving the coarse- (90^{th}) and fine-tail (10^{th}) components is seen three of the beds. The remaining beds reveal an anomalous 'undulating' or statistically ungraded trend across the various percentiles. Grain fabric in the bedding parallel sections show a consistently flow-oblique trend with an average azimuthal deviation of 47°, but becoming increasingly flow aligned at the top of most beds. However, there is little consistency in the mean vector rotation about the palaeocurrent direction. All bedding perpendicular sections show imbrication angles greater than 15°, with an average imbrication angle relative to the horizontal of 80°. Both up- and down-current imbrication polarities were observed in equal abundance. These grain-scale heterogeneities are interpreted as a product of differential impact of near-bed sedimentation processes that are controlled by sediment fallout rates from a concentrated, but turbulent sediment gravity flow. The resulting geometric character of the grains can be used as a tool to determine high porosity-permeability zones at the bed-scale, and ultimately as predictive inputs during the development phase.

Allocyclic Controls upon Clastic/Evaporitic Interactions in Arid Continental Settings: Examples from the Cedar Mesa Sandstone

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Arid continental settings deposit and preserve complex interactions between aeolian, alluvial, lacustrine, fluvial and sabkha sediments. While the distribution and preservation of different facies associations within any one of these environments are reasonably well constrained, the relationships between deposits of coeval environments and their temporal evolution have, until recently, received comparatively little attention despite their potential to affect both basin-scale fluid migration and reservoir quality.
These interactions are influenced strongly by complex relationships between autocyclic and allocyclic processes, including climate, however within arid continental settings these signatures are often difficult to detect within the sediments preserved.
We present results from the margin of the Cedar Mesa erg of the Paradox Basin which preserves complex interactions of clastic and evaporitic sediments. Studies are based upon extensive regional fieldwork examining the sedimentology, geometries, and interactions, complimented with outcrop gamma ray data. The sedimentology shows large variations spatially and temporally which grade through aeolian, sabkha and lacustrine settings with complex interactions occurring where these sediments transition. Interactions occur at multiple scales. Facies scale interactions occur as two main trends: aeolian-sabkha interactions and fluvio-lacustrine-sabkha interactions. Aeolian-sabkha interactions are characterised by highly altered gypsiferous dune deposits with an absence of large evaporite deposits, whereas fluvio-lacustrine-sabkha interactions comprise large bedded gypsum deposits, enterolithic growth in surrounding sediment and lack large scale dune development. Larger scale temporal interactions preserve distinct sedimentology relating to a changing climatic regime, however, laterally a rapid switch in the dominant depositional environment occurs only preserving the facies-scale interactions.
The results have been developed into idealised models and recognisable log signatures which characterise and assess their impact on reservoir quality. Wetting or drying climatic cyclic trends, on various orders of magnitude, have also been identified, which govern both temporal and spatial facies changes. Identification of these allows for basin wide correlation and prediction of where facies will occur in space and time.
This work will be applied to subsurface data from the arid Permian basins of the North Sea, in order to better predict facies shifts and to characterise basin-scale fluid migration and reservoir.

Carbonate Microfacies of the Cedar Mesa Sandstone: Examples from a Mixed Clastic/Evaporitic Continental Sabkha.

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Arid continental environments are typically dominated by aeolian, alluvial and fluvial deposits. Despite being commonly recognised, carbonate deposits within these environments are often overlooked, yet they can provide vital insight into the depositional history, climatic and tectonic controls of a basin. This work presents the first microfacies analysis of the carbonates found within the Cedar Mesa Sandstone Formation of the Western USA.

The Cedar Mesa Sandstone Formation is a predominantly aeolian succession of early Permian age, exposed across much of the Colorado Plateau of southern Utah and northern Arizona. The formation is dominantly clastic erg deposits, which transition into a mixed sediment sequence, with carbonate and evaporitic horizons interspersed throughout which are interpreted as sabkha or sabkha-like deposits.

Whilst many authors have worked within the aeolian dominant facies and proposed various facies schemes for the siliciclastic components, comparatively little attention has been paid to the mixed evaporitic/clastic/carbonate aeolian sabkha transition zone. This work details a microfacies analysis of the carbonates present within the Cedar Mesa Sandstone, in order to: (i) develop an appreciation of the carbonate components; (ii) suggest formational mechanisms and (iii) identify evolutionary trends within the environmental system, which stand alongside the formations clastic depositional story. Six microfacies are presented: MF1) Clastic Influenced Carbonate Wackestone; MF2) Carbonate Packstone; MF3) Microbial Bioclastic-Bindstone; MF4) Carbonate Mudstone; MF5) Bioclastic-Ostracod- Wackestone and MF6) Microcrystaline Chert.

The microfacies have been interpreted to document the development of carbonate interdune and sabkha environments juxtaposed across a wetting and drying climatic cycle (which is also observed throughout the formations dominantly clastic sections). The carbonates exhibit excellent preservation and potentially some structures of additional interest, namely – wavey microbial laminations and stromatactis-like cavities.

Using deepwater sandstones to unravel basin configuration: a Numidian system (early Miocene, southern Italy) case of study

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Turbidite systems of the central Mediterranean region are commonly used as analogues for a variety of worldwide deep-water hydrocarbons reservoirs. Understanding whether the system is unconfined and deposited on relatively unstructured basin floor or confined by actively deformed basins is important for predicting the sand distribution and therefore the applicability of analogues. This study considers the Numidian turbidite system (early Miocene) of Sicily and southern Italy - for many the type example of massive submarine sandstones. The tectonostratigraphic setting of the Numidian is analogous to sand systems of the southern Caribbean and associated ultra-deep water exploration. This study is based on field mapping, sedimentological/structural fieldwork, and biostratigraphy (foraminifera, nannofossils). These new data not only challenges conventional ideas on its depositional setting, but also highlight implications for the current central Mediterranean paleogeography. Rather than having being deposited within an unstructured foredeep by relatively unconfined flows, we show that Numidian deposition was strongly confined by active structures. There is no architectural evidence for major incisional channel systems in the outcrops but there is erosional products derived from local substrate incorporation of pre-Numidian strata, presumably being sourced from the local submarine slopes. Thrust-top basins filled diachronously implying a large scale tectonic control both on sand fairways and facies variations along their margins. Existing models suggest that facies variations between adjacent outcrops on Sicily (and elsewhere) result from long-range stratigraphic variations being juxtaposed by later large-displacement thrusts. This research reveals a much simpler tectonic structure but a more complex stratigraphic arrangement for the Numidian of southern Italy - a characteristic of confined turbidite systems.

Erosive structures, sedimentary facies, and paleoflow distribution in an ancient channel-lobe transition zone: from bed-scale to a 500 m long mega scour.

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Turbidity currents are subaqueous gravity flows that transport sediment from the continents into the deep ocean. They flow down channels where they dominantly bypass their sediment load, transporting similar volumes of sediment as terrestrial rivers. Downstream of the channel termination, turbidity currents lose their capability to transport sediment, resulting in deposition of sediment lobes, which represent the biggest sediment accumulations of earth. Bathymetric surveys have revealed that the area separating the channels from the lobes, the channel-lobe transition zone (CLTZ), is characterised by enhanced erosion and scour formation. The flow processes explaining the observed erosion are poorly understood and a much-debated. Detailed outcrop studies on ancient CLTZs may provide new insights into the sedimentary structures and the morphodynamic evolution of CLTZs. However, the erosive character of CLTZs make their identification in outcrop is rather difficult and rare.

Here we present a detailed outcrop study of the sedimentary structures and bed-scale depositional architecture in a previously recognised CLTZ in the Karoo Basin, South Africa. The exceptional study area allows us to investigate the ancient sea floor along a 5 km long outcrop that is aligned with the paleoflow direction. The outcrop reveals the erosive patterns in the CLTZ and the deposits of the associated sediment lobe farther downstream. Sedimentary structures in the CLTZ are predominantly marked by rip-up of the ocean floor sediments, injection of sand into the substrate, and scour formation, but also by deposition of mud-clast breccias and sand. In addition, GPS data revealed the presence of a 500 m long and 25 m deep mega scour, which was located at the downstream end of the CLTZ, in close proximity to the associated lobe deposits. The scour is partially filled with massive and structureless sands, indicating rapid sediment fallout from the turbidity currents. Furthermore, paleoflow direction in the CLTZ showed a larger spread in direction than observed in the associated lobe farther downstream. We think that the turbidity currents in the CLTZ were steered by ocean floor scours. This in contrast to the plane surface on the sediment lobe, which results in less paleoflow spreading.

The results provide insights into the sedimentary structures, facies associations and the paleoflow distributions in an ancient CLTZ and the associated lobe. Documentation of the sedimentary characteristics in CLTZs from bed-scale to mega-scour scale, will improve our ability to identify CLTZs in the rock record. Additionally, an increased understanding of the flow processes in the CLTZ is pivotal in advancing out understanding of the evolution of submarine channel-lobe systems.

Conglomerate recycling in the Himalayan foreland basin; implications for river dynamics

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The Siwalik Group form the foothills of the Himalaya and comprise Neogene fluvial sandstones and quartzite-rich conglomerates which were deposited in the Indo-Gangetic foreland basin and later exhumed by thin-skinned tectonics. Rapid erosion recycles these conglomerates adding an additional flux of rounded quartzite cobbles to the bedload of rivers sourced from both the high mountains and the front ranges of the Himalaya. The addition of conglomeratic bedload into the rivers as they emerge from the mountain front has implications for the morphology and behaviour of the channels, and the position of the gravel-sand transition (GST) in the basin. In the Ganga Plain, differential basin subsidence is currently thought to control the position of the GST (Dingle et al., 2016); However, variation in the amount of conglomerate recycling along the Himalayan front requires consideration.

Here, we use mass balance calculations which suggest that the recycling of the Upper Siwalik conglomerates may contribute more than half of all gravel exported into the Himalayan foreland basin. To explore the impacts of sediment recycling three Himalayan catchments have been selected: The Karnali River, which passes through approximately 100 km of Siwalik conglomerates, the Kosi river which has no Siwalik conglomerate and the Mohand River which drains exclusively Siwalik sandstones and conglomerates. For each catchment pebble shape, size and lithology on exposed gravel bars from the Main Boundary Thrust (pre-recycling) down to the GST is documented. Pebble lithology and grain size of the Siwalik conglomerates is also recorded.

The results indicate that where rivers pass through the Siwalik conglomerates, the grain-size and volume of bedload is significantly modified, becoming enriched in rounded quartzite cobbles. In contrast, in rivers such as the Kosi, the bedload comprises more varied bedload lithologies and grainsizes, and more angular clasts. The implications for river dynamics is considered.

Influence of multiple flood events on river morphology and sediment transport

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Flood events induce significant sediment transport, which in turn dramatically influences the morphology of the channel through bed erosion and deposition processes. Several studies, based on laboratory flume experiments, have been carried out on the river channel response to a single flood event. The current study deals with the response of the channel to multi-peak unsteady hydrographs. The main focus of this study is to investigate river channel morphology evolution during a series of flood events as very few studies have observed, measured or described the bed form due to the technical difficulties in obtaining data on bed features at grain scale. With recent advancements in laser scanning technology, sharpened examinations of bed evolution and bed form are now possible during flume experiments. In this study a high resolution laser scanner is employed to study the impact of flood events on the morphodynamics of a sand bed. A series of experiments are being conducted considering the variable durations, flow rates and intervals between two simulated hydrograph peaks:

(a) to quantify significant parameters affecting the bed load transport and yield over the hydrographs

(b) to understand the bed evolution in detail and

(c) to establish any linkages between hydrograph characteristics and channel response.

Early results show that successive hydrographs increase sediment transport rates, consequently higher sediment yields during the falling limb of hydrographs are found. This is more evident during the second peak of a two peak storm. A high water level is observed during the second hydrograph, particularly in the downstream section of the flume which is a result of the bed formation developed during the first hydrograph.

BOTTOM CURRENT-CONTROLLED QUATERNARY SEDIMENTATION AT THE BASE OF THE MALTA ESCARPMENT

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The influence of bottom-water circulation in deep-sea sedimentation is still poorly understood, but the perception of its importance is steadily increasing. New findings of contourites - sediments deposited or substantially reworked by the persistent action of bottom currents - have been discovered in many different settings in every ocean basin and even in lakes. Bottom currents, predominantly unidirectional water currents that are in contact with the sea-floor of a sidewall, are in fact pervasive and observed at all latitudes. Such currents, which are affected by tides, eddies, internal waves, tsunamis and turbidity-currents are focused against continental slopes and escarpments. They are capable of actively eroding, transporting and depositing sediments on the seafloor, as well as generating bedforms and reliefs. For this reason, bottom currents may pose a risk to deep-sea infrastructures, such as pipelines and telecommunication cables, or scientific observatories. The study of contourites is also crucial for hydrocarbon exploration, as well as palaeoclimatological and palaeoceanography reconstructions.

In the nineties, large-scale asymmetric, climbing bedforms were identified at the base of the Malta Escarpment only on the basis of single-channel Sparker seismic reflection profiles. These bedforms were tentatively ascribed to the action of focused bottom currents. We now describe these bedforms on the basis of recently acquired multi-channel seismic, sub-bottom echosounder and multi-beam bathymetry data, and discuss their origin by integrating these with available and hydrographic information. These bedforms, lying at 2500 m water depth, have a height of ~30-50 m, a steeper (by about 2°) southern side, and are elongated along an ENE-WSW trend. The regular northward migration of these bedforms is roughly assumed to have begun at 650 Ka, in association with the Mid Pleistocene Transition, which may have led to a strengthening of the bottom currents.

The few existing currentmeter data in the area, show a predominant direction of motion towards SSW, even if a certain variability is observed. The variability of abyssal currents in the Ionian sea has been attributed to the mesoscale vortices probably due to baroclinic instability of the order of 10 km in the horizontal dimension. Furthermore, an estimate of the wavelenghts of the sediment waves has been computed according to the hydraulic condition for the generation of such waves, which depends on the density stratification of the bottom waters, the Coriolis parameter and the mean current speed. A good agreement, at least as order of magnitude, has been obtained with the observed bottom feature wavelenghts.

We aim at understanding if these features are still actively migrating and if they are a potential hazard for infrastructures, and at deciphering their origin and their palaeoceanographic significance.

Revisiting the Upper Carboniferous Westward Ho! Formation North Devon: a well-exposed slope system dominated by hyperpycnal underflows, and characterised by small channels interacting with major mass transport complexes

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Some of the first outcrop descriptions of turbidite filled channels were made in the Westward Ho! Formation (Walker 1966; 1970). However, Walker interpreted associated rippled, thin-bedded facies to record "shallow water agitation" (Walker 1969) and became locked in a paradox of interbedded "deep water" turbidites and shallow water ripples. Walker's shallow water interpretation, together with the landmark description of the overlying Bideford Group as the deposits of a large, fluvially-dominated delta (Elliott 1976) influenced Li (1990) to interpret features indicating mass movement as collapse depressions similar to those that form in shallow-water areas of interdistributary bays in the modern Mississippi delta (Coleman 1981).

Visiting the rocks fifty years later three strands suggest a new interpretation, that the Westward Ho! Formation was deposited on a persistent deepwater slope:

(i) the ripple cross-laminated intervals are now readily interpreted as the product of hyperpycnal underflows (Mulder et al 2003) rather "shallow water agitation" (Walker 1969);

(ii) isolated cross-bedded sands are similarly considered as deepwater deposits rather than indicative of abrupt shallowing, and

(iii) large-scale features indicating mass movement are reinterpreted as deepwater, mass transport complexes.

This revised view allows the reconstruction of a slope system over 400m high, dominated by mudstones largely supplied by hyperpycnal underflows, and characterised by slope channels interacting with mass transport complexes. The outcrop is a rare, readily visited deepwater analogue in the south of England. Outstanding issues include (a) placing the slope system in to a sequence stratigraphic framework, and (b) the detailed interpretation of thin-bedded channel associated facies - are they affected by MTC topography, and does hyperpycnal flow result in channel fills that contrast with channels largely filled by turbidity currents?

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Geomechanical analysis of the Captain X Sandstone Member in relation to CO_2 injection

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Global warming, driven primarily by the release of anthropogenic CO_2, is one of the biggest threats facing the planet today. One technology which could reduce these emissions is carbon capture and storage (CCS), whereby CO_2 produced at power stations is captured and injected into subsurface geological formations. The Lower Cretaceous Captain X Sandstone Member, located within the Atlantic Field in the Inner Moray Firth Basin, North Sea, has been identified as a potential CO_2 storage reservoir. A key uncertainty during CO_2 injection is how the resultant pore pressure increase will affect the stability of the host-rock sandstone and pre-existing faults. Therefore, this study focuses on the Captain X Sandstone from three wells within the Atlantic Field, to examine how mineralogy and fabric affect its geomechanical response to a pore pressure increase, with rock strength data also being related to the in-situ reservoir stress conditions. Mineralogical results show that the Captain X Sandstone is subarkose, with minor clay and calcite horizons and little lateral variation between the wells. Geomechanical analysis found the strength differences between the sandstone samples to be controlled primarily by the number and type of grain contacts present. Stress analysis concluded that the tectonic regime is strike-slip, with the host-rock and pre-existing faults being stable at the current reservoir stress state. A 3 and 10 MPa pore pressure increase reduces the likelihood of host-rock failure, although a 3 MPa increase moves pre-existing faults closer to failure, with a 10 MPa increase possibly reactivating pre-existing faults. Future work should focus on other possible CCS reservoirs in the North Sea comprising stronger, more cemented sandstones, to examine their geomechanical response to CO_2 injection.

Sedimentary Model for Mixed Depositional Systems: Conceptual Implications

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Along- and down-slope processes are fairly common processes along continental margins. The aforementioned processes and their interaction can build large mixed / hybrid (turbiditic-contouritic) depositional systems. These systems are characterized by a variability and complexity of features. Globally, several mixed systems have been identified on the Cenozoic, however their representation in the Mesozoic remains severely understated. This issue is aggravated if we consider that the diagnostic criteria for mixed systems is not fully defined and, therefore, not used to improve the examples already described in the literature.

This work aims to contribute to a better understanding of the dynamics between along- and down-slope processes, by identifying significant modifications in physiographic features and stacking architectures, and by discriminating the mechanisms responsible for the formation of each feature and how they operate through time. To approach these objectives, we are studying two key areas: 1) a modern example on the Pacific Margin of the Antarctic Peninsula, characterized by a remarkable depositional system with several contourite mounded drifts and turbidite channels in the continental lower slope and continental rise; and 2) the Cretaceous record on the Argentine Margin, which comprises an extensive mixed system on the continental slope. This study is based on a compilation of swath multibeam bathymetry, high- and low-resolution seismic reflection datasets, well borehole data and sediment cores.

The two examples share similar downslope elongated mounds along the lower slope and rise with asymmetric morphologies, marked by a smooth, aggradational side and a steep, eroded side with signs of mass movements. However, while the Antarctic Peninsula has a dendritic network of gullies and channels on the upper continental slope that converge into single turbidite channels on the lower slope and rise, the Argentine Margin is characterized by individual large channels that start at the continental shelf / upper slope and cut through the topography. The interpretation and integration of these results aims to propose a conceptual model for depositional mixed systems that will clarify the role and influence of bottom currents versus turbidity currents.

Causes, timing and spatial extent of diatom bloom events within a deglacial record from the Anvers-Hugo Trough, western Antarctic Peninsula shelf

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In the modern day we see the retreat and thinning of many ice streams and marine terminating glaciers along the Pacific margin of Antarctica. It is therefore important for us to predict the impacts of deglaciation on regional oceanographic conditions and primary productivity, whose changes may influence ecosystems and nutrient budgets. Reconstructions of palaeoenvironmental conditions and their impacts on diatom assemblages and productivity following the Last Glacial Maximum (LGM; ca. 25-19 ka BP) provide crucial insights into future changes. This study will utilise sediment cores recovered from the Anvers-Hugo Trough, western Antarctic Peninsula shelf, and will aim to (a) reconstruct the palaeoceanographic setting of the Anvers-Hugo Trough during and following the last deglaciation and (b) investigate the cause and spatial extent of diatom bloom production and the controls on diatomaceous ooze deposition and accumulation. Sediment cores were recovered using a gravity corer and were analysed using visual core descriptions, X-radiographs and a multi-proxy approach (water content, shear strength, magnetic susceptibility, density, contents of biogenic opal, Total Organic Carbon (TOC) and CaCO3 and grain size analysis). X-ray fluorescence data was collected at high resolution using an ITRAX XRF scanner, while analysis of quantitative diatom slides provided total diatom abundance and species assemblage data. We observe a thick (1-2 m) unit of laminated diatomaceous ooze within three cores deposited over ~2,000 years, from ~11,200 cal yr BP. These three cores were recovered from bathymetric depressions. Neighbouring cores recovered from shallower and more exposed bathymetric settings also document a peak in biological productivity at this time (i.e., relative increases in diatom abundance, biogenic opal, total organic carbon and $CaCO_3$ contents and Si/Ti ratios); however, only a thin (~10 cm) laminated diatomaceous unit is observed. This suggests that environmental conditions favouring enhanced primary productivity over this period were widespread, whilst the seafloor topography played an important role in accumulating and preserving diatomaceous ooze deposits. Layers of orange/brown diatom ooze within the laminated units are characterised by an increase in both total diatom abundance and the percentage of *Chaetoceros* spp. resting spores and *Corethron pennatum*. The diatom assemblage observed likely results from the formation of a well-stratified water column initiated by melting in the austral spring, followed by nutrient depletion and spore formation.

Shifts in ichnological character during the Late Palaeozoic evolution of the Maritimes Basin, Atlantic Canada

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Certain basin-wide sedimentary successions, such as those of the Maritimes Basin of eastern Canada, have global significance for understanding the record of the colonization of the land by flora and fauna. These successions are often read as a literal historical record of palaeontological changes through stratigraphic time but how might regional basin evolution have skewed, biased or influenced the known record of the colonization of land? Using ichnological and sedimentological characteristics of environmentally-similar units from different stages of the Maritimes Basin's history, we provide an insight into how terrestrial communities developed in relation to a filling basin during the first 120 Ma of the animal colonisation of land.

This poster illustrates the results of a preliminary study of the changing non-marine ichnological signature over the course of the evolution of the Maritimes Basin using data from the Devonian Gaspé Sandstones, Lower Mississippian Horton Group, Middle-Upper Mississippian Mabou Group, and Pennsylvanian Cumberland Group. The changing trace fossil communities are considered alongside the sedimentological evolution of the basin and the broader global record of terrestrialization to attempt to disentangle the respective signals.

Influence of the embankment geometry during breaching failure

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Breaching failure is a type of retrogressive subaqueous slope failure characterized by nearly vertical failure angles, slow and steady retrogressive erosion rates, and production of sustained turbidity currents (You et al., 2012). Such failures can be initiated by triggering events including erosion by tidal flow, local changes in water pressure, or human interventions such as dredging. Breaching failure occurs in medium to densely packed sand and it is associated to very steep slopes. When this densely packed sand is subjected to shear, there is an increase of the pore volume by deformation. This process is called dilatancy and leads to negative pore pressures with respect to the hydrostatic pressure. This underpressure keeps the sand body, temporarily, stable and drives, also, water flow into the sand deposit. When enough water has flowed in and the sand has dilated enough, sand particles rain down the slope producing a turbidity current (Van den Berg et al., 2002).
In the Netherlands, extensive research has been conducted on breaching failures because two thirds of the country is vulnerable to flooding. One of the unknown controls on the severity of breaching failure is the occurrence of so called unstable breaching. It occurs when the slope that forms downstream of the breach face is milder than the upstream slope. The slope formed downstream of the breach face will depend mostly on the interaction between the formed turbidity current and the existing downstream slope. The erosion causes the height of the breach surface to increase with time. It is difficult to predict when an unstable breaching process will occur or end. This phenomenon can threaten the stability of dikes and cause a lot of damage to its surrounding. The present work addresses this topic.

Figure 1: *Breaching failure in Queensland Australia 2014 (https://www.youtube.com/watch?v=ILptlF7P6LI).*

Experiments were performed in the Eurotank Flume Laboratory (Utrecht University) to study the influence of the geometry of the sand deposit and its surroundings during failure. The experiments consist of a submerged column of sand with 0,40x0,80x0,22m (length x height x width) and an initial porosity of 0,44. The sand (median diameter, D_{50}=0,140mm) was deposited in a flume filled with water and constrained with a removable vertical plate on one side. The failures were triggered by removing the confining plate. During the experiments, pore pressure transducers were placed inside the sand body to monitor the pore pressure, and two ultrasonic velocity probes, 10 and 20cm from the front deposit, respectively, to study the retreating velocity of the breaching front (erosion rate) and the velocity of the resulting turbidity current.

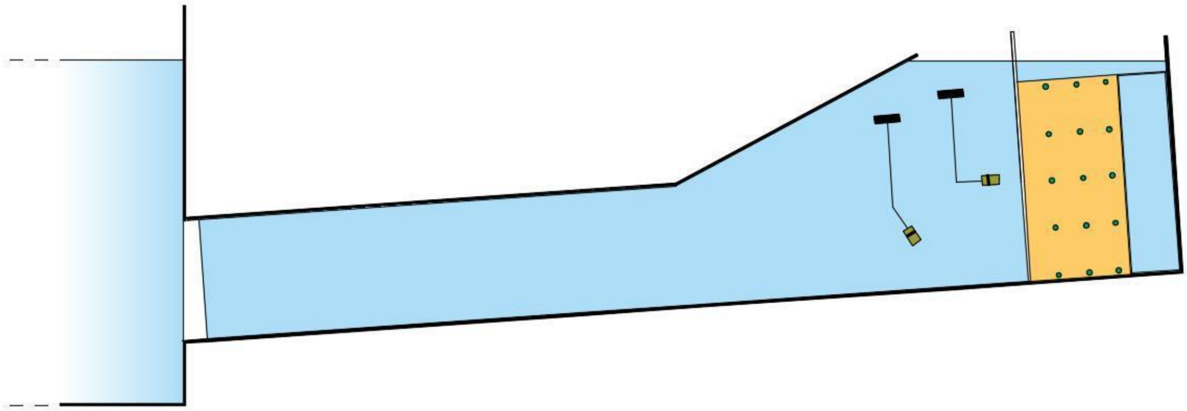

Figure 2: *Schematic overview of the 2D experimental setup and location of the instrumentation used during the experiments.*

Results from the experiments show that, besides the sand grains raining from the deposit, wedges of sediments slide down periodically, causing a drop in pore pressure. Furthermore, when the angle of the flume floor (β) increases from horizontal to 8 degrees, the retreating velocity of the breaching front increases from 2,83mm/s to 3,25mm/s, respectively, indicating a higher rate of erosion. The final deposit thins and elongates with increasing β angle, which means that the slope angle of deposition decreases enhancing the tendency for unstable breaches to occur. These measurable variables during the experiments indicate whether a slope is vulnerable for unstable breaching.

Despite the history of several events, they are not well understood being only noticed after the failure and when it reached the subaerial bank. Therefore, it is essential to understand the mechanics of breaching failures for the safety assessment of flood defences.

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Organic geochemistry of the Early Toarcian Oceanic Anoxic Event recovered in the Sogno Core (Lombardy Basin, northern Italy)

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The Jurassic stratigraphic succession of the Lombardy Basin (Southern Alps) is part of the southern Tethys passive continental margin. A Late Triassic-Early Jurassic rifting phase resulted in regional bathymetric differentiation vis-à-vis deep basins and structural highs. Outcrops of Jurassic sections at Colle di Sogno remain undisturbed, and include Moltrasio Limestone, Domaro Limestone, Sogno Formation, radiolarites and Rosso ad Aptici Formation. An organic matter-rich black shale interval (also called *Fish Level*) corresponds to the sedimentological expression of the Early Toarcian Oceanic Anoxic event (T-OAE). The T-OAE was a geologically short, though extreme, climate warming perturbation that led to a variety of feedback reactions, including oceanic anoxia at global scale.

In 2013, a coring campaign was conducted to recover the T-OAE interval, lowermost Sogno Formation, and the uppermost Domaro Limestone section, since associated Colle di Sogno outcrop is deteriorated in the marly lower portion of the Sogno Formation, hampering high-resolution sampling of the black shale interval. With the core samples, we applied diverse, multi-proxy geochemical investigations on the T-OAE black shale interval, which include coupling: (i) hydrocarbon (*n*-alkane, pristane and phytane) distributions, (ii) the stable carbon isotopic composition of hydrocarbons ($\delta^{13}C$ for alkanes, including phytol derivatives), and (iii) hydrogen isotopic composition of hydrocarbons ($\delta^{2}H$ for *n*-alkanes).

Based on molecular analyses in this study, organic matter input included both marine and terrestrial sources, which resulted in mixed kerogen II/III type. Fluctuating pristane/nC_{17}, phytane/nC_{18} and pristane/phytane ratios (Pr/Ph= 0.5-1.25; 0.5 [reducing] to 3.0 [oxic]) establish firm evidence of a water column that oscillated between reducing and oxic conditions during the T-OAE as recorded in the Sogno Core. Associated $\delta^{13}C$ values of long-chain *n*-alkanes (nC_{27}, nC_{28}, nC_{29} = -29 ‰ to -37 ‰; terrestrial) parallel those of shorter-chain *n*-alkanes (nC_{17}, nC_{18}, nC_{19}= -31 ‰ to -38 ‰; marine and microbial) throughout the core, with both showing a negative carbon-isotopic excursion amid T-OAE. This confirms that the T-OAE at Colle di Sogno was a major carbon cycle perturbation of both the marine and the terrestrial environment, consistent with observations from other locations worldwide. Further, compound-specific alkyl $\delta^{2}H$ values (-72 ‰ to -152 ‰) indicate that hydroclimatic conditions were characterized by a tropical-like environment with high humidity in the studied area, while more arid conditions prevailed before and after the T-OAE event. Although the ultimate triggering mechanisms behind such an extreme global change remains elusive, it is plausible that concomitant physical-chemical-biological perturbations produced the negative carbon isotopic excursion characteristic of the T-OAE.

Sedimentary records of coastal storm surges: Evidence of the 1953 North Sea event

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The expression of storm events in the geological record is poorly understood; therefore, stratigraphic investigations of known events are needed. The 1953 North Sea storm surge was the largest natural disaster for countries bordering the southern North Sea during the twentieth century. We characterize the spatial distribution of a sand deposit from the 1953 storm surge in a salt marsh at Holkham, Norfolk (UK). Radionuclide measurements, core scanning X-ray fluorescence (Itrax), and particle size analyses, were used to date and characterise the deposit. The deposit occurs at the onset of detectable 137Cs - coeval with the first testing of nuclear weapons in the early 1950s. The sand layer is derived from material eroded from beach and dunes on the seaward side of the salt marsh. After the depositional event, accumulation of finer-grained silt and clay materials resumed. This work has important implications for understanding the responses of salt marshes to powerful storms and provides a near-modern analogue of storm surge events for calibration of extreme wave events in the geological record.

Does fan-scale lateral confinement affect sedimentary organisation in deep-water channels?

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Deep-water fans are commonly traversed by channels that supply sediment to terminal deposits up to thousands of kilometres from their feeder canyon. Channel avulsion is the dominant process for the lateral re-direction of sediment to new areas on such fans. The development of depositional topography, which forces a channel or lobe into instability and increases the relative efficiency of a new flow pathway, is the primary driver of avulsion; resultant 'compensational stacking' of multiple hierarchical orders may provide autogenic confinement at many nested scales. Confinement resulting from this phenomenon, and that imposed by independently constructed sedimentary edifices or tectonic effects is often considered at the scale of an individual channel or levee deposit; however, the interaction of autogenic confinement with imposed confinement at scales larger than that of an individual architectural element remains unstudied.

We present a comparative study focused on three deep-water fans which exhibit different scales and styles of confinement: the Congo Fan, which is affected only by autogenic confinement; the Amazon Fan, which is additionally confined in part by mass transport deposits (MTDs) and the Bengal Fan, which is confined by the regional tectonic configuration. The work aims to determine whether lateral confinement at the scale of an entire fan (thousands of km) may, through the compound effects of compensational stacking, affect sedimentary organisation at the scale of an individual channel. A novel methodology allowing the derivation of statistics from geometrical relationships is applied to published maps of channels on large deep-water fans. Specifically, the orientation of channel segments is used as a proxy for flow direction, with the effect of confinement expressed by the angular standard deviation about the vector mean; increasing confinement leads to smaller variability in flow direction.

Confined systems, such as the Bengal and Amazon fans, show a narrower range of channel orientation, and hence flow directions, than their 'unconfined' counterparts, such as the Congo Fan. Modern confinement of the Amazon Fan is imposed by two large MTDs, creating depositional topography with heights similar to those of a typical channel-levee deposit. With progressive aggradation, the Amazon fan is likely to escape its MTD-related confinement, making its effects temporary; fans confined by tectonic features, such as the Bengal Fan, are unlikely to escape their permanent confinement.

Application of image analysis in textural characterisation of sedimentary grains

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Textural analysis of siliciclastic sedimentary grains is an important source of information regarding the processes involved in their formation, transportation and deposition. However, a standardised approach for quantitative grain shape analysis is generally lacking. In this contribution we report on a study where fully automated image analysis techniques were applied to loose sediment samples and lithified samples. Unconsolidated sediment samples were collected from glacial, aeolian, beach and fluvial environments. Sandstone samples of fluvial and aeolian origin were sampled from across Dingle group and Caherbla group of the Dingle basin, Ireland. A range of shape parameters are evaluated for their usefulness in textural characterisation of populations of grains. The data gathered demonstrates a clear progression in textural maturity in terms of roundness, angularity, irregularity, fractal dimension, convexity, solidity and rectangularity. Textural maturity can be readily categorised using automated grain shape parameter analysis. However, absolute discrimination between different depositional environments on the basis of shape parameters alone is less certain. For example, the aeolian environment is quite distinct whereas fluvial, glacial and beach samples are inherently variable and tend to overlap each other in terms of textural maturity. This is most likely due to a collection of similar processes and sources operating within these environments. This study strongly demonstrates the merit of quantitative population-based shape parameter analysis of texture and indicates that it can play a key role in characterising both loose and consolidated sediments.

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Controls on turbidity current flow modes: New insights from direct measurements worldwide

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New technology now enables high-resolution measurement of turbidity currents. New data can answer key questions, such as what flow types exist for field-scale turbidity currents? How important is the trigger in controlling flow behaviour compared to grain size? We analyse direct measurements of turbidity currents from eight locations worldwide (water depths: 65-2300 m). We test whether commonalities in flow mode exist, independent of location, thickness, velocity and duration. Normalised time-velocity plots reveal three distinct flow modes. Type 1 is a rapid temporal increase in velocity (first 5-10% of the flow) followed by an exponential deceleration. Type 2 is a steady increase in velocity (first 30-50% of the flow), followed by a similar rapid waning decline. Like Type 1, Type 3 exhibits a rapid peak in velocity; however, the exponential decline is interrupted by a period of near-constant velocity for c.80% of the flow, followed by declining velocities in the final c.20% of the duration of the flow.

Canyons with coarse axial sediments (<10% mud) and oceanographic-triggers feature Type 1 flows. Canyons directly linked to hyperpycnal rivers feature Type 2 flows, where sediments comprise c.10-40% mud. Type 3 flows are also linked to rivers, but are not directly fed by sediment-laden river water. Unlike Type 1 and 2 flows which are <22 hours long, Type 3 flows last for several days. High mud contents (>60%) permit Type 3 flows to sustain themselves at low velocities (0.2-0.8 m/s). We suggest that triggers and grain size are equally important controls on flow mode, but that the latter is more significant further away from the source.

Low temperature quartz overgrowths in Quaternary glacigenic sediments: an example from North Wales

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A new study of a glacigenic sequence on Anglesey (North Wales) demonstrates the presence of well-formed, euhedral quartz overgrowths (Fig. 1) in fluvioglacial sediments from the Late Quaternary (approx. 15-20,000 years).

The formation of quartz cements and euhedral overgrowths in clastic sediments is a widespread and well-documented process. Accepted theory generally states that - with the exception of opaline silica - quartz cementation begins at burial depths of approx. 1200-1500 m and elevated temperatures of around 70°C, with widespread development taking place below 2000 m and temperatures exceeding 90°C. The quartz overgrowths found on Anglesey (Fig. 1) are therefore highly unusual, because these sediments have never been buried beyond depths of a few 10's of metres and could not have been elevated to temperatures anywhere approaching 70°C.

This indicates two possibilities: either the overgrowths are inherited from an earlier cycle of deposition and burial, or, they are the product of a previously un-reported process of euhedral quartz overgrowth formation that can take place at shallow burial depths and low temperatures in a geologically short amount of time.

Detailed examination of detrital grains with overgrowths, using CL, SEM and automated mineralogy analysis, has shown that the observed overgrowths appear to be in pristine condition and are unlikely to have survived transport within the high energy, fluvioglacial system in which the sediments were deposited (Fig. 1). This suggests that the overgrowths are in-situ rather than inherited.

The apparent possibility to form quartz cement at low temperatures and pressures has crucial and wide-ranging implications for the exploration of fluid-bearing geological reservoirs, since quartz cement can have a strong negative impact on reservoir quality, but early quartz cementation potentially prevents compaction.

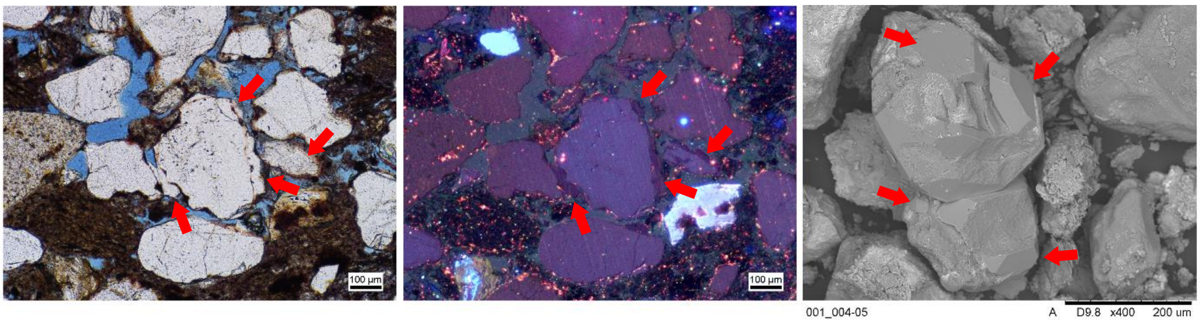

Figure 1: Images from a sample taken from the glacigenic sediments on Anglesey showing images of the same thin section under normal light (a) and CL (b), and an SEM example from the same rock sample (c).Quartz overgrowths are indicated with arrows.

Training image suitability for modelling poorly connected deep marine sequences.

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Many deep marine turbidite reservoirs consist of relatively laterally continuous sandstones interbedded with low permeability shales. Local erosion of the thin bedded shales can lead to amalgamation of the sandstone beds. Vertical compartmentalisation is common in turbidite reservoirs where laterally continuous impermeable shale beds separate sand bodies, and the extent of sandstone amalgamation is often a key control on reservoir performance. Outcrop studies suggest that natural systems have low connectivity at high net sand fraction (Fig 1), a relationship that varies depending on the depositional environment and the turbidite system, which is not reproduced in unconstrained geomodels. It is therefore vital to incorporate the correct degree of sand amalgamations into reservoir geomodels to realistically represent the reservoir connectivity and heterogeneity. The aim of this work is to discuss difficulties associated with producing high net sand reservoir geomodels with low connectivity, representative of what is seen in natural systems.

Multiple-point statistical (MPS) modelling has become a popular geostatistical modelling technique since MPS models easily honours available well data and uses a geologically appealing training image (rather than a variogram) to define the desired geological architecture. A training image represents the heterogeneity deemed to be present in the reservoir, including the geometry of the sand, stacking patterns, facies distributions, depositional architecture and connectivity. Generation of training images is aided by well data, outcrop data, other reservoir studies and geological knowledge, and the creation of realistic training images for subsequent use in MPS modelling has become a common output of many reservoir characterisation studies. It is not widely appreciated, however, that the MPS algorithm, as a general case, is unable to reproduce the desired connectivity even if it is correctly contained in the training image, because of an inherent and unavoidable tendency for sand connectivity in the MPS model to be controlled by its sand fraction, rather than by the sand connectivity of the training image (e.g. Fig 2).

Because the sand connectivity of a geomodel is controlled primarily by the volume fraction of the sand, a geometrically transformed training image can be used to achieve the correct connectivity in an MPS model, but with a lower sand fraction (Fig 3). A second transformation can then be applied to the MPS model, to transform it to one with the target net sand fraction, but low sand connectivity. The new workflow, which is illustrated here using very simple idealised models (Figs 2,3) has been adapted to deal with hierarchical sedimentary staking and multiple conditioning wells in a producing oil-field.

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Database-driven quantitative analysis of the internal facies architecture of incised-valley fills

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Incised valleys are fluvially eroded, elongate palaeotopographic lows developed in shelf and coastal settings during relative sea-level fall, and subsequently inundated and reworked by coastal and marine processes during sea-level rise. They are generally associated with greater sediment accommodation than time-equivalent interfluve areas as sea level rises. Thus, an investigation of the infill of incised valleys could provide key information about earth-surface processes and depositional history. Additionally, they are important reservoir targets and serve as reference for exploration of downdip deep-marine sands. However, the present models for the internal fills of incised valleys are conceptual, descriptive or derived from individual case studies.

Here, an innovative database-informed approach to the synthesis of many known late-Quaternary incised-valley fills (from both outcrop and subsurface) is utilized for the development of a series of quantitative facies models of the internal fills of incised valleys from different physiographic, climatic and tectonic settings, and of sequence-stratigraphic models that account for variations in sedimentary architecture in these environments as functions of a range of geologic controls.

Key results are as follows: (i) the stratigraphic organization of the incised-valley fills are governed by several controlling parameters, such as sea-level change, climate, tectonics, sediment supply, hydrodynamics and valley morphology; (ii) within a wave- and tide-dominated environment, the thickness of the lowstand systems tract is a function of the size of the fluvial drainage basin; lowstand systems tract deposits will be preserved seaward of the estuary mouth if the depth of fluvial incision generated during sea-level fall is deeper than the depth of tidal/wave ravinement associated sea-level rise; (iii) different rates of sediment supply versus sea-level rise could result in significantly different styles of facies architecture; (iv) incised-valley fills developed along tectonically active margins are demonstrated to develop infill architectures that are distinctive from those seen in valley fills hosted on passive margins; evidence of relative sea-level falls (for example due to tectonic uplift), such as transitions from estuarine to fluvial environments, could be seen during periods of time when the eustatic sea level was constantly rising.

Some of these results challenge paradigms embedded in sequence-stratigraphic and facies models regarding the internal fills of incised valleys, and have significant implications for hydrocarbon-reservoir prediction and characterization.

Reconstruction of reservoir quality evolution in tight gas sandstones using x-ray micro tomography

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The Upper Carboniferous sandstones in the Southern North Sea (SNS) have proven gas reserves, however they are characterised by very low permeabilities (<0.1 mD) and are therefore defined as tight gas reservoirs. The best reservoir quality in the Copernicus Discovery, SNS, is preserved within quartz and kaolinite cemented sandstones from multi-storey fluvial channels. Whilst methods such as conventional core analysis enable quantification of porosity and permeability, they do not allow us to understand the 3D pore throat dimensions, pore shapes and pore connectivity that govern fluid flow in such reservoirs.

Mapping of the pore network and quantifying different pore types is therefore an invaluable tool to understand what controls permeability and therefore reservoir quality. Samples from the Copernicus Discovery were imaged using X-Ray Micro Tomography (XMT) with a voxel (3D pixel) resolution of 2.5 µm. The 3D images were used to define the 3D distribution of quartz, kaolinite and porosity, and subdivide the connected and isolated porosity. The 3D models were used to simulate permeability and fluid flow in the reservoir, and compared to porosity measurements from point count analysis and Helium porosity data.

Quantitative analysis of the pore network provides insight into how much extra porosity could be connected by fracking, and to investigate the connectivity of the pore network prior to the precipitation of the quartz overgrowths observed in this unit. After defining 3D maps of quartz and kaolinite distribution, the quartz overgrowths were removed stepwise by numerical erosion of the 3D volume. The gradual increase in pore volume and throat sizes changes permeability, and eventually reconnects isolated pores to the pore network. Even slight, uniformly distributed reductions of quartz cement volume results in a small porosity change but significant change in permeability as the pore throats widen and tortuosity reduces. Small variations in diagenetic style can therefore result in permeability differences of several orders of magnitude over small areas of reservoir. Here we present an assessment of how connectivity and permeability may have evolved through time resulting in the formation of a tight reservoir. The reconstruction of tightening mechanisms is vital for understanding hydrocarbon accumulation history and the assessment of reservoir effectiveness in tight gas reservoirs.

Straight from the source's mouth: controls on sediment export across the Corinth Rift, central Greece

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The volume and characteristics of sediment supplied from catchments controls depositional stratigraphy, and can determine how the sedimentary archive records tectonic and climate forcing. However, to date, few studies have constrained sediment budgets released into tectonically active basins over a regional scale. We address this challenge in the Gulf of Corinth, Greece, one of the most rapidly extending rifts worldwide, where we have excellent constraints on the climatic, tectonic and lithological boundary conditions. We visited the river mouths of 49 catchments feeding into the Gulf, which drain 83% of the rift by area. At each site, we measured channel hydraulic geometries and we characterised the grain-size distribution of sediment exported from these rivers by Wolman point counting and in-situ sieving. In total, we measured ∼17,000 clasts and processed 3 tonnes of sediment. The grain-size distributions show a marked increase from East to West on the southern coast of the gulf. The coarse-fraction grain sizes range from 20 to 110 mm, with 50% of values less than 40 mm. Simple geomorphic parameters such as catchment area and relief have little control on the grain size exported. However, the strong westerly gradient in tectonic extension rate and the type of bedrock lithology cropping out exert a first-order control on the sediment calibre measured. We estimated the bankfull shear stress and transport capacity for each river, and our calculations show that median grain sizes are transported in bedload at bankfull discharge; sand-grade particles are transported as mixed- or suspended-load. Finally, we derived the full Holocene bedload sediment budget for the Gulf by combining our grain size data with catchment sediment flux estimates, calibrated to Holocene sediment volumes in the basin. This is the first time such a budget has been derived, and we demonstrate that sediment export is highly intermittent in time and space.

Morphology and facies distribution in confined deep-water lobes: a seismic review.

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ABSTRACT

Deep-water lobes and lobe complexes are important hydrocarbon reservoirs and offer potential sites for carbon capture and storage, but there is significant uncertainty in how confinement affects lobe morphology and facies distribution. Here we review the morphology observed and facies distributions inferred in confined deep-water lobes, as revealed by high-resolution seismic reflection surveys from the shallow subsurface. By doing this, we aim to of reduce uncertainties surrounding their identification at deeper, economic burial depths, or in more spatially limited outcrops.

We draw on examples from East Corsica, the Niger Delta, and the Brazos-Trinity system in the Gulf of Mexico. Six key seismic facies are recognised in confined-lobes, with distinct internal geometries. The seismic expression of the lobe termination allows us to infer the impact of basin configuration on lobe migration, stacking, and sediment volume. In addition, the effects of erosional flows are observed in confined-lobes in the form of scours in proximal locations that are rarely observed in unconfined settings. These seismic characteristics are used to define lobe morphology and architecture at a scale that is typically below seismic resolution when imaging more deeply buried lobes.

Future work will develop conceptual models for confined lobes established in settings with different styles of topographic configurations. This will improve our ability to predict sub-seismic facies distributions and stacking patterns in confined deep-water lobe complexes, and will therefore enable the recognition of the best-quality reservoir facies in frontier basins, influence production strategies in existing discoveries, and reduce uncertainties in stratigraphic trap plays in mature basins.

Petrophysical properties of basal shear zone of mass-transport complexes (MTCs); implication for hydrocarbon seal potential

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Mass transport complexes (MTCs) are one of the most sedimentologically- and seismically-distinctive architectural elements in deep-water depositional systems. Previous petrophysical studies have focused on determining the bulk lithology of MTCs, yet the petrophysical properties of the basal shear surface, which may control their ability to act as hydrocarbon seals, remain poorly constrained. In this study, we evaluate the seismic reflection characteristics and petrophysical properties of the basal shear zones of three deeply buried (> 2100 m), thick (c. 80-340 m), and areally extensive (c. 90-120 km^2), Pleistocene MTCs in the northern Gulf of Mexico. Using high-quality 3D reflection seismic and borehole data we show that rather than a basal shear surface (BSS) a basal shear zone (BSZ) exists below MTCs. Basal shear zones are characterised by: (i) an increase of amplitude reflection at their base (i.e. when compared to similar mudstone lithology in adjacent undeformed strata); (ii) an anomalously high acoustic velocity (Vp) and density (RT) (i.e. when compared to the overlying body of the main MTC deposit, and the underlying slope sediments); (iii) a mappable thickness that ranges from 15 to 30 m; (iv) velocity (Vp) and Resistivity (RT) vary lateral, which is highest on main body of MTC, and lowest on distal part of the MTCs. We interpret three processes that may cause the characteristics of the BSZ: (1) initially, the shear stress applied to the BSZ causes an increase of fluid pressure, which then allows liquefaction and fluidization to occur; (2) continued shearing on the BSZ causes further pore fluid escape, resulting to additional pore space reduction; (3) the latter stages of fluid escape results in further reduction of pore space, which increases BSZ compaction, density and velocity. This analysis demonstrates that hydrocarbon seal potential of MTC s is internally highly variable, with the BSZ displaying the greatest seal capacity (smallest pore throat diameter and lowest permeability) compared to the main body of the MTC.

Keywords: MTCs, petrophysical properties, basal shear zone

Facies Analysis of the uppermost Devonian to Lower Carboniferous Billefjorden Group of Central Spitsbergen, Svalbard

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In this work we present the results of a detailed sedimentological study conducted in the uppermost Devonian to Lower Carboniferous strata of Central Spitsbergen (Svalbard, Norway). The succession belongs to the Billefjorden Group, which is subdivided into the Hørbybreen and Mumien formations. The up to 1000 m-thick sequence was deposited in a NNW-SSE trending half-graben basin and records both climatic and tectonic changes in a terrestrial depositional environment. The succession is considered a good analogue for the deeply buried Lower Carboniferous rocks of the same group name in the western Barents Shelf, which could be suitable as both source and reservoir rocks.

A framework for facies distribution and depositional architecture in the basin has been established for the Billefjorden area at Birger Johnsonfjellet (key locality), Mumien, Pyramiden, Cowanodden and Carronelva. This information, combined with maceral analysis of coal samples, palaeocurrent measurements and stratigraphic architecture analysis contributes to a better understanding of the depositional environment and sedimentary basin development.

Data interpretation in this project suggests that the Hørbybreen Formation (Famennian-Viséan) consists of conglomeratic alluvial deposits in its lower part and floodplain element deposits in its upper part, recording a change from marginal, steep slopes with rapid flowing rivers to flat, vegetated marshes with laterally migrating rivers. The overlying Mumien Formation (Viséan) shows a similar floodplain environment but with a prominent, widely distributed meandering channel complex. This large-scale change in sediment character is interpreted to reflect a major change from arid to humid climate near the Devonian/Carboniferous boundary along with possible changes in palaeoprovenance, subsidence rate and base-level.

Keywords: Sedimentological study, uppermost Devonian, Lower Carboniferous, Central Spitsbergen, Billefjorden Group

Experimental study on the impact of the Coriolis force on density currents

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The ocean is thermally and salinity, and thus density, stratified. Denser-than-ambient flows, often concentrated in downslope channels that link and act as conduits from the continental shelves to the deep sea, are an important mechanism driving exchange of water between shallow and deep-water environments, resulting in vertical exchange of heat and salinity and the transport of sediments, pollutants and nutrients such as carbon to the deep marine environment. Thus, understanding these mixing and exchange processes are critical to furthering our understanding key ecosystems, the global carbon cycle and climate.

Density differences may be driven by the thermal or saline stratification of seawater, or by differences in suspended sediment concentrations. Natural mixing by waves and tides, along with surface water cooling can also generate downslope gravity currents. Many parameters are known to affect density current dynamics, including density difference, bed roughness, and bottom slope. In addition, at large-scales and in real-world environments, Coriolis forces (that increase with latitude) are also known to be as important as the inertial force of average fluid motion. As such this force also affects flow dynamics.

Here, we outline a PhD project that will investigate the dynamics of gravity currents under the influence of Coriolis forces, exploring latitudinal effects on material transport and mixing processes. The research will utilise unique experimental data of density driven flows measured in the world's largest rotational flume: the 13 m-diameter CORIOLIS II at Laboratoire des Écoulements Géophysiques et Industriels, Grenoble. These experiments explored how the dynamics at the heads of the gravity currents, subject to varying Coriolis forcing, varied in sinuous channels. These data will be supplemented by those collected in small-scale experiments in a custom-built 1m-diameter rotating flume capable of rotating up to 0.5 Hz, where Coriolis effects on the mixing efficiency between topographically confined density-driven flows and ambient-fluid will be considered. Further, we will consider other factors such as surface waves, internal waves and tides that might significantly influence the behaviour of density flows and related mixing processes. It is expected that results will lead to increased understanding of mixing of deep-ocean continental-shelf waters and the development of a new model of density-driven flows.

Synsedimentary hydrothermal dolomites in a lacustrine rift basin: petrographic and geochemical evidence from the Lower Cretaceous Erlian Basin, Northern China

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Dolomites occur extensively in the lower Cretaceous along syn-sedimentary fault zones of the Baiyinchagan Sag, westernmost Erlian Basin, within a predominantly fluvial-lacustrine sedimentary sequence. Four types of dolomite are identified, associated with natrolite, analcime and Fe-bearing magnesite as hydrothermal minerals. The finely-crystalline dolomites consist of anhedral to subhedral crystals (2–10 μm), evenly commixed with terrigenous sediments that occur either as matrix supporting grains (Fd1) or as massive argillaceous dolostone (Fd2). Medium-crystalline (Md) dolomites are composed of subhedral to euhedral crystals aggregates (50–250 μm), and occur in syn-sedimentary deformation laminae/bands. Coarse-crystalline (Cd) dolomites consist of non-planar crystals (mean size >1 mm), and occur as fracture infills crosscutting the other dolomite types. Fd1, Md and Cd dolomites have similar values of $\delta^{18}O$ (−20.5 to −11.0 ‰ VPDB) and $\delta^{13}C$ (+1.4 to +4.5 ‰ VPDB), but Fd2 dolomites are isotopically distinct ($\delta^{18}O$ −8.5 to −2.3‰ VPDB; $\delta^{13}C$ +1.4‰ to +8.6‰ VPDB). The rare earth element content of the dolomites is highly variable (97.24–328.08 ppm) and samples define three groups which differ in LREE vs. HREE enrichment/depletion and significance of Tb, Yb and Dy anomalies. Md dolomite indicate formation from brines at very high temperature, with salinities of 11.8–23.2 eq. wt% NaCl and Th values of 167–283°C. The calculated temperatures of Fd1 and Cd dolomites extend to slightly lower values (141–282°C), while Fd2 dolomites are distinctly cooler (81–124°C).

These results suggest that the dolomites formed from hydrothermal fluid during and/or penecontemporaneous with sediment deposition. The networks of faults and fractures that bound the basin were important conduits through which high-temperature Mg-rich fluids discharged, driven by an abnormally high heat flux associated with local volcanism. It is thought that differing amounts of cooling and degassing of these hydrothermal fluids, and of mixing with lake waters, facilitated the precipitation of dolomite and associated minerals, and resulted in the petrographic and geochemical differences between the dolomites.

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