ROYAL HOLLOWAY UNIVERSITY OF LONDON

BSRG Sedimentary Research

Abstract Volume
Egham, 13th – 17th December 2019

British Sedimentological Research Group

58th Annual General Meeting

Royal Holloway, University of London

THE DRIFTERS RESEARCH GROUP
BOTTOM CURRENTS & DEEP-WATER SEDIMENTATION

CSI
clastic sedimentology investigation

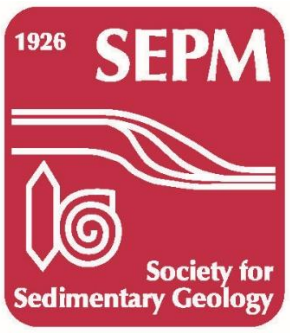
SEARG
SOUTHEAST ASIA RESEARCH GROUP

Convenors:

Javier Hernández-Molina
Domenico Chiarella
Amy Gough
Dan Bosence
Nicola Scarselli

The 58th British Sedimentological Research Group
Annual General Meeting
is dedicated to Harold Reading and Ken Glennie
for their contributions to sedimentology

The workshop has been sponsored by



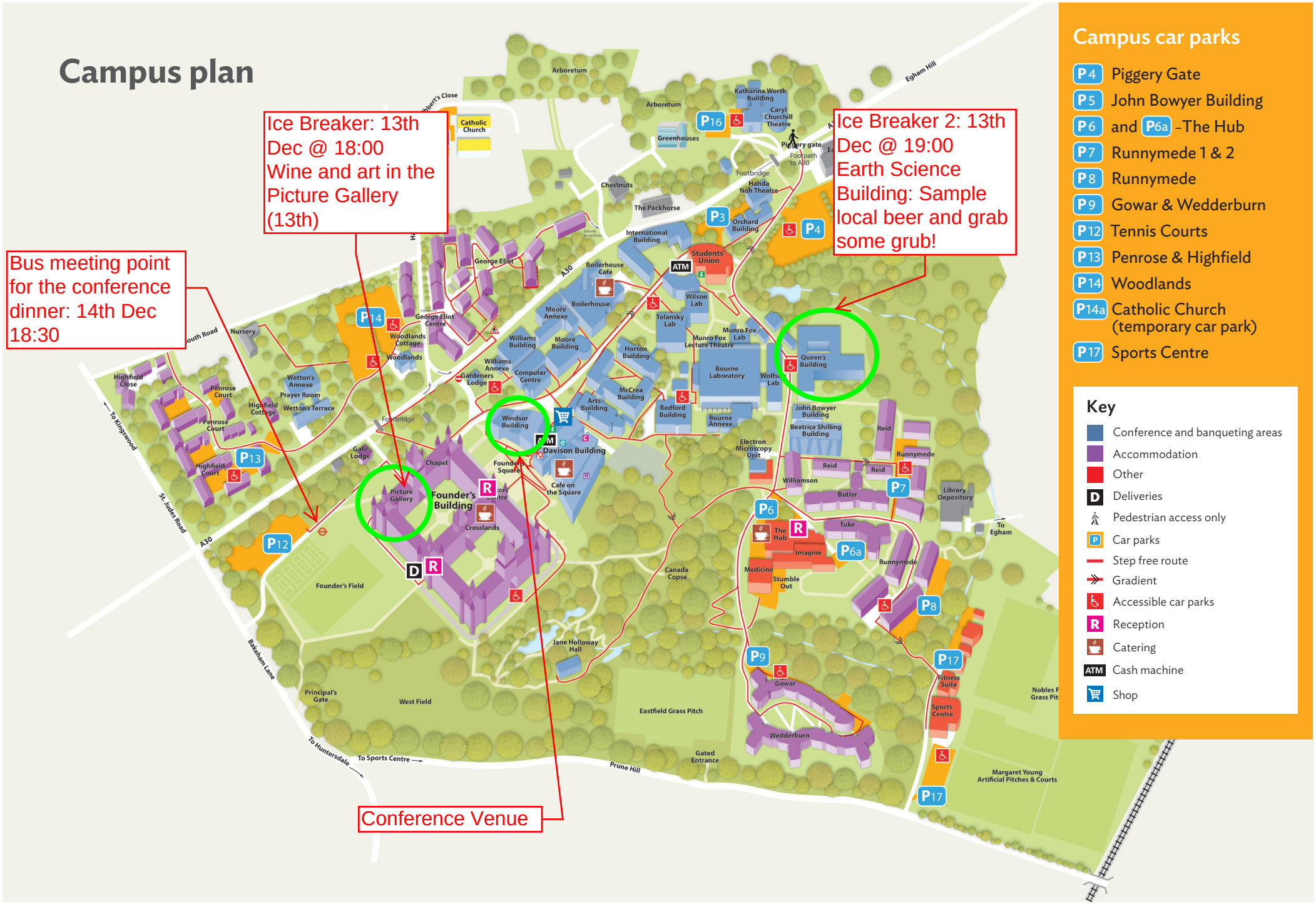
14th December 2019: Day One of the BSRG Annual General Meeting

8:30 – 9:00	Registration: Windsor Building					
9:00 – 9:15	**Welcome to the 58th BSRG at Royal Holloway – Windsor Auditorium**					
9:15 – 9:45	*Keynote: **Dave Hodgson**: Perce Allen Award Winner – Windsor Auditorium*					
9:45 – 10:15	Posters (room 1-02 and 1-03) and Refreshment Break					
	Windsor Auditorium		***Room 0-02 and 0-03***		***Room 0-05***	
10:15 – 10:30	*Session 1:* **Deep Water Processes**	Ben Tindal	*Session 2:* **Tectonics and Sedimentation**	Jon Noad	*Session 3:* **Numerical Sedimentology**	Eoin O'Donnell
10:30 – 10:45		Daniela Vendettuoli		Tim Cullen		James Mullins
10:45 – 11:00		Arne Fuhrmann		James Hunt	*Session 4:* **Tight Sandstones and Mudrocks**	Sophie Behrendsen
11:00 – 11:15		Hannah Brooks		Donald Christie		Xinyu Zhong
11:15 – 11:30		Maria Azpiroz		Miquel Poyatos-More		Jie He
11:30 – 11:45		Laura Buehrig		Andrew Procter		Enrica Battara
11:45 – 12:00		Jefferey Peakall		Chris Elders		Ziyuan Meng
12:00 – 13:00	Lunch					
13:00 – 13:30	*Keynote: **Amanda Owen** (SEARG sponsored) – Windsor Auditorium*					
	Windsor Auditorium		***Room 0-02 and 0-03***		***Room 0-05***	
13:30 – 13:45	*Session 5:* **Contourites and Reworked Turbidites**	F Javier Hernandez Molina	*Session 6:* **Source to Sink**	Mike Blum	*Session 7:* **Reservoir Quality of Clastic and Carbonate Rocks**	Laura Fielding
13:45 – 14:00		William Bailey		Jonathon Rotzien		Robert Waltham
14:00 – 14:15		Zhi Lin Ng		Conor McMillan		Jian Shi
14:15 – 14:30		Dorrik Stow		Kimberley Johnson		Laura Bastianini
14:30 – 14:45		Wouter de Weger		Ikenna Okwara		Luke Wooldridge
14:45 – 15:00						Dimitrios Charlaftis
						15:00 – 15:15 Valentin Zuchuat
15:00 – 15:30	Posters (room 1-02 and 1-03) and Refreshment Break					
15:30 – 16:00	*Keynote**: Joe Cartwright**: a Tribute to Harold Reading – Windsor Auditorium*					
16:00 – 17:00	**BSRG AGM (Business Meeting) – Windsor Auditorium**					
17:00 – 18:30	Poster Session and Awards Ceremony (room 1-02 and 1-03)					
18:30	*Coaches leave from Founders Tennis Courts for the conference dinner at Dorney Lake*					

15th December 2019: Day Two of the BSRG Annual General Meeting

8:45 – 9:15	*Keynote:* ***Karyna Rodriguez*** *(The Drifters Sponsored) – Windsor Auditorium*						
	Windsor Auditorium		***Room 0-02 and 0-03***		***Room 0-05***		
9:15 – 9:30	*Session 8:* **Deep Water Processes**	Ashley Ayckbourne	*Session 9:* **Salt-Sediment Interactions**	Zoe Cumberpatch	*Session 10:* **Glaciogeneic and Glacially Related Sediments and Landforms**	Dan Le Heron	
9:30 – 9:45		Jaco H. Baas		Alja Sassnowski		Xiaoshuai Chen	
9:45 – 10: 00		Patricia Buffon		Mareike Henneberg		Christoph Kettler	
10:00 – 10:15		Maarten Heijen		Ian Davison		Kieran Blacker	
10:15 – 10:30		Chi Li		Frank Peel		Bartosz Kurjanski	
10:30 – 10:45		Minru Zhao		Gillian Apps		Stephen Davison	
10:45 – 11:30	Posters (room 1-02 and 1-03) and Refreshment Break						
	Windsor Auditorium		***Room 0-02 and 0-03***		***Room 0-05***		
11:30 – 11:45	*Session 11:* **Tectonics and Sedimentation**	Peter Wooldridge	*Session 12:* **Shallow Marine**		*Session 14:* **Lacustrine and Deep Lacustrine**	Dan Bosence	
11:45 – 12:00		Marco Pizzi		Kelvin Ikenna Chima		Tom Dodd	
12:00 – 12:15		William Mitchell		Richmal Paxton		Pang Jungang	
12:15 – 12:30		Bernard Guest		Matthew Watkinson		Guilherme Bozetti	
12:30 – 12:45		Marcus Duffy	*Session 13:* **Ichnology**	Javier Dorador		Stamatina Makri	
12:45 – 13:00		Alastair Robertson		Francisco Rodriguez-Tovar			
13:00 – 14:00	Lunch						
14:00 – 14:30	*Keynote:* ***Susanne Gier*** *(CMG sponsored) – Windsor Auditorium*						
	Windsor Auditorium		***Room 0-02 and 0-03***		***Room 0-05***		***Room 0-04***
14:30 – 14:45	*Session 15:* **Deep Water Processes**	Euan Soutter	*Session 16:* **Source to Sink**	Kaja Fenn	*Session 17:* **Seds and Society**	Andy Emery	*Session 19:* **Oblique rifting and volcanic processes controlling reservoir distribution along the northern Atlantic margin** Bent Erlend Kjolhamar
14:45 – 15:00		Adriana Crisostomo-Figueroa		Eugene Szymanski		Ian Kane	
15:00 – 15:15		Ross Ferguson		Wiktor Luzinski	*Session 18:* **Microplastics and Pollutants**	Luyao Tu	Sverre Planke
15:15 – 15:30		Megan Baker		Chris Brewer		Michael Clare	
15:30 – 15:45		Joris Eggenhuisen		Gavin Anthony		Yasmin Yonan	
15:45 – 16:00		Zoe Cumberpatch		Pieter Vermeesch		Florian Pohl	
16:00 – 16:30	Posters (room 1-02 and 1-03) and Refreshment Break						
	Windsor Auditorium		***Room 0-02 – 0-03***		***Room 0-05***		
16:30 – 16:45	*Session 20:* **Exploring and Characterising Deep Water**	Mario Andres Gutierrez	*Session 21:* **Fine-grained sedimentary rocks in decarbonisation**	Joe Emmings	*Session 22:* **Sedimentology**	Charlotte Priddy	
16:45 – 17:00		Michael Steventon		Mark Wilkinson		Jonathan Scafidi	
17:00 – 17:15		Timothy Wigan		Andrew Wiseall			
17:15 – 17:30		Grant Wach					
17:30 – 17:45		Jonathon Rotzien					

Campus plan



Campus car parks

- P4 Piggery Gate
- P5 John Bowyer Building
- P6 and P6a –The Hub
- P7 Runnymede 1 & 2
- P8 Runnymede
- P9 Gowar & Wedderburn
- P12 Tennis Courts
- P13 Penrose & Highfield
- P14 Woodlands
- P14a Catholic Church (temporary car park)
- P17 Sports Centre

Key

- Conference and banqueting areas
- Accommodation
- Other
- D Deliveries
- Pedestrian access only
- P Car parks
- Step free route
- Gradient
- Accessible car parks
- R Reception
- Catering
- ATM Cash machine
- Shop

Keynote Abstracts

Harold Reading (1924-2019): A tribute from his students

Delivered by Joseph A. Cartwright (*University of Oxford, UK)*

The life and achievements of one of the founding fathers of sedimentology, Dr Harold G. Reading, will be celebrated on the first day of the 58th BSRG Annual Meeting.

Professor Joseph A. Cartwright, a former student, will lead the BSRG community in acknowledging the pivotal role that Harold played in establishing the concepts of facies analysis and in making sedimentology a mainsteam geological subject.

His achievements and legacy run deep in our subject, including 'the book' (Sedimentary Environments and Facies), the IAS and the BSRG, all of which were driven by Harold in his modest, determined and deeply enduring style.

Please join us in celebrating the life of an exceptional man who devoted his working life to sedimentology.

Clays and mudstones in the hydrocarbon century and beyond

Susanne Gier
Department of Geodynamics and Sedimentology, University of Vienna, 1090 Wien, Austria; susanne.gier@univie.ac.at

Economic and environmental aspects of mudstones are very diverse and are of great importance to modern society. Organic rich mudstones, for example, are multifunctional. They can act as seal, source and more recently also as reservoir rocks for hydrocarbons. Additionally they can host metals like lead, zinc, or copper. Because of their low permeability, mudstones serve as natural and artificial barriers to fluid flow. They provide barriers to leakage of fluids from landfills or from depositories of hazardous and radioactive waste. Carbon capture and storage is another way how mudstones can contribute to decarbonisation.

The great range of uses is a direct consequence of the wide variability of physical and chemical properties of clay minerals. These make mudstones distinctly different from all other rocks. Clay minerals are fine-grained with large surface areas. Some of them are expandable and are able to absorb and exchange ions. Texture, stratification, mineralogy and the petrology of mudstones needs to be understood before applying them.

The second part of the talk presents a mineralogic and petrologic study of the main source rock for oil and gas in the Vienna Basin in Austria, the Malmian mudstones of the Mikulov Formation. These mudstones were evaluated by the Austrian oil company OMV for their shale gas potential. However, because of environmental and societal reasons, no further actions were taken. For this study, 46 core samples from 10 different wells which penetrated the Mikulov Formation over a depth range of 1400 m to 8551 m were available. This gave a unique opportunity to study the diagenetic development within one formation from shallow to deep burial. Special focus was placed on the diagenetic processes and pore development within the matrix of the mudstones.

Bulk and clay mineralogy of the core samples were analyzed with X-ray diffraction and quantified. The microfabrics of the mudstones were studied on argon ion milled samples with a scanning electron microscope (SEM).

The bulk samples contain minor amounts of quartz, plagioclase, pyrite and a high amount of calcite; the clay mineral content of the bulk samples ranges between 14 to 47%. The clay fraction contains a prominent illite-smectite (I-S) mixed-layer mineral, illite, chlorite and kaolinite. The amounts of I-S and kaolinite decrease with depth, illite and chlorite increase with depth. The diagenetic overprint involves a gradual transformation of smectite to illite through mixed-layer I-S intermediates. The illite content in I-S ranges from 25% for the shallowest sample to 90% for the deepest sample. The ordering of the mixed layer I-S changes with increasing depth from R0 to R1 and R3.

The ions resulting from the illitization of smectite in the matrix are considered to be sources for a variety of late diagenetic mineral cements. For example, illitization is assumed to provide Fe and Mg for chlorite formation and ferroan dolomite precipitation. Illitization is also a potential source for Si, which is needed for quartz cementation. During diagenesis also nanometer to micrometer size pores developed. Organic matter pores developed in deeper, thermally mature samples. Phyllosilicate framework pores between harder grains are commonly observed. Diagenetic cements, like quartz overgrowths or carbonate cements occasionally keep pores open. Additionally, pores caused by partial dissolution along carbonate grains are present. From SEM photomicrographs it cannot be observed if these pores are connected, but most likely they do contribute to the effective porosity and gas storage capacity of these rocks.

While mudstones, in their capacities as hydrocarbon source, as reservoir and seal rocks have played a major role in carbonising our world, they will be equally important for decarbonisation.

Laterally Offset Bulbous Elements, and other deep-water acronyms

***David Hodgson*[1]**, *Amandine Prélat*[1], *Yvonne Spychala*[1], *Menno Hofstra*[1], *Aurelia Privat*[1], *Damjan Osterlic*[1], *Ander Donate-Martinez*[2], *Tim Wigan*[3], *Zoe Cumberpatch*[2], *Daivd Lee*[1], *Jeff Peakall*[1], *Chris Stevenson*[4], *Ian Kane*[2], *Chris Jackson*[3], *Stephen Flint*[2]

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[4]*Department of Earth Science, University of Liverpool, UK*

Submarine fans, the largest depositional bodies on the planet, develop at the end of continent-to-ocean sediment routeing systems. Their growth depends on sediment flux from the continent through an associated fluvial (and/or shelf) system, thereby forming archives of environmental change, and are the ultimate sink for vast quantities of organic carbon and anthropogenic pollutants. To unleash the wealth of proxy information associated with past climate, eustatic, and tectonic forcing requires detailed understanding of their stratigraphic evolution, and the process sedimentology of their major component: lobes.

Exhumed ancient fan successions represent an opportunity to study the architecture and sedimentology of stacked lobes at high resolution. Our detailed analysis of the extensive exposures of Permian submarine fans in the Karoo Basin, South Africa, over the last two decades indicate that submarine lobes do not comprise sheets of sandstone; rather flow-deposit interactions lead to a complicated, yet organised, depositional architecture on the basin-floor. Insights from the analysis of the Karoo basin-floor lobes include: the identification of an architectural hierarchy, the quantification of lobe dimensions and stacking patterns, the definition of environments of deposition, the distinction between frontal and lateral lobe fringes, the planform geometry of lobes, the criteria to distinguish between basin-floor channel fills and scour-fills, the characteristics of intraslope lobes, the suite of components that characterise channel-lobe transition zones, the profound effect of even subtle (<1°) intrabasinal slopes on flow behaviour and sandbody pinchout style, and the close association of abrupt sandbody pinchout and injectite complexes. Our ongoing work is focussed on assessing the control that topography has on lobe architecture from fieldwork in the Neuquén Basin, Argentina and new physical experiments of partially confined flows.

The lateral continuity, and high sand volume, of lobe-dominated reservoirs have made them a target for oil and gas exploration worldwide. However, their utility as archives of environmental change has been questioned. The idea that environmental signals are buffered have established a view that these distal sedimentary settings do not preserve useful information about changes in external controls. Reported concentrations of anthropogenic debris in these systems, even during the highstand period, suggest that there remains much scope to use these successions as palaeoenvironmental archives.

Fluvial response to an extreme global warming event?

Amanda Owen[1], Hartley, A.J.[2], Hoey, T. B.[3], Ebinghaus, A.[2], Jolley, D.W.[2] and Weissmann, G.S.[4]

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[2] *Department of Geology and Petroleum Geology, University of Aberdeen, UK*
[3] *Institute of Environment, Brunel University London, UK*
[4] *Department of Earth and Planetary Sciences, University of New Mexico, New Mexico, USA*

As our present climate undergoes rapid anthropogenic induced warming it is imperative to understand how our environments will change. Geological deposits can give important insights into how environments of the past have responded to external forcing, such as changes in climate, helping us better understand the magnitude of change that may occur in the future. The Paleocene-Eocene Thermal Maximum (PETM) occurred ~56 Ma and was a geologically abrupt global warming event in which temperatures increased from 5-8°C over ~200, 000 years due to a global release in carbon, making it a close analogue to today's global warming trends. The PETM has been interrogated at a number of terrestrial and marine localities across the globe, however, the majority of these studies are not placed within a well-defined spatial and depositional systems context, with study often limited to single successions. In addition, they are often only compared with the deposits that lie immediately above and below the PETM giving limited temporal context to the event. It is imperative that background 'normal' conditions are understood for an assessment of response magnitude and extent to be made.

This study examines several PETM locations in the Bighorn Basin where fluvial channel and their associated deposits dominate the stratigraphy. A total of 4,000 m of sedimentary log data was collected over 28 localities within the basin. Sedimentary logs were then tied to published δ13C data to identify where the PETM was located within the measured sections.

The presented sedimentological model of the basin shows that during the Paleocene and Eocene a series of alluvial fans, large and small distributive fluvial systems and a large axial system was present, giving essential depositional context to the basin. Sedimentological observations from each PETM site are then made and compared; a) across single outcrop belts; and b) across the basin to establish how consistent sedimentary response is. Initial analyses showed the deposits located in the PETM varied not only across single outcrop belts but across the depositional basin, with deposits ranging in moisture content and paleosol maturity at the 100's m scale. Channel data (storey and channel body thickness data) was quantitatively analysed, comparing channel deposits across the PETM to those within a cross-section in the axial system, across those whole axial system and then to all recorded channel deposits (n = >200) across the basin. This analysis shows that the channel deposits across the

PETM are not statistically significantly different from those outside (above or below) the climate event. Theoretically modelling was also undertaken to understand what magnitude of change in precipitation is needed in order to produce a statistically significant deposit. This study demonstrates that geological responses to climatic forcing may not be spatially synchronous, and that the magnitude of these responses depends on the sensitivity of the system.

Source Rock Characterization to Evaluate Hydrocarbon Potential in Frontier Basins

Karyna Rodriguez, Neil Hodgson and David Eastwell

TGS

Petroleum system analysis in frontier basins should begin by evaluating the presence of a source rock, followed by understanding its quality, distribution and maturity. The challenge is identifying potential source rocks in the absence of well data or onshore outcrop analogues and often with only 2D seismic data available.

This study describes an integrated process developed for the identification of source rocks on seismic data. The first step is to establish a geological model for the deposition and preservation of a source rock. Secondly, a source rock characterization methodology (modified from Loseth et al., 2011) is undertaken. This involves analyzing the acoustic impedance contrast at the top and base of the potential source rock interval, as well as the AVO response (expected to be Class IV at the top). This is complemented by an interval frequency and amplitude variation analysis (expected to be related to TOC %). Finally, these steps are integrated with non-seismic based DHIs such as satellite derived seep studies.

This methodology was first applied in the Orange Basin, offshore Namibia, as a proof of concept and has since been applied in various frontier basins at a global scale. In one example it was used to identify and de-risk a proposed but unproven Paleocene-Eocene source rock in the Eastern Mediterranean.

The presence of a marine Aptian shale, often referred to as "Kudu shale", has been proven in the Namibian portion of the Orange Basin. The workflow was developed using the Kudu shale as it is an established marine source rock in a frontier basin but with the advantage of having well calibration and sufficient thickness and TOC % for adequate assessment using seismic data.

The Eastern Mediterranean has seen significant biogenic gas exploration success in giant fields such as Leviathan and more recently Zohr. In the North Levant Basin offshore Lebanon, the Early Tertiary is buried 1 to 1.5 km deeper. The sequence underlying the Miocene displays marine shale source rock characteristics, with opaque low frequency character, horizontal bedding and a top and a base with decrease and increase in acoustic impedance respectively. This interval is interpreted to represent a Paleocene-Eocene source deposited during the initial clastic flooding and downward flexure of the North African Margin at this time.

An integrated analysis has identified on seismic an Early Tertiary (Eocene) oil source rock capable of charging significant Early Miocene structures offshore Lebanon. Some evidence for the efficacy of the petroleum system can be found in the higher liquid contents of the fields drilled closest to the North Levant Basin, from which thermogenic oil production is reported.

The methodology has also been applied successfully in other basins such as the Argentina Basin, MSGBC and Somalia.

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Oral Presentation Abstracts

Source to sink history of the Neogene sedimentary rocks of the Miri Zone in Sarawak, NW Borneo using provenance tools

Gavin Anthony[1], Juliane Hennig-Breitfeld[1], Tim Breitfeld[1], Robert Hall[1], Nils Keno Lünsdorf[2]

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[2]*Department of Sedimentology and Environmental Geology, Centre of Geosciences, Georg-August University, Göttingen, Germany*

Borneo is the third largest island in the world, yet due to issues with accessibility relatively few studies have concentrated on this mountainous and highly vegetated region. The northwestern part of Borneo is divided into the Kuching Zone (Late Cretaceous to Eocene terrestrial sediments), Sibu Zone (Late Cretaceous to Eocene deep marine turbidites and debrites of the Rajang Group) and the Miri Zone, representing the youngest zone, which include Miocene fluvial to shallow marine sediments. The basement of the Miri Zone is composed of the marine Setap Shale Formation and the fluvio-deltaic Nyalau Formation which rest unconformably on top of the Rajang Group.
The youngest formations of the Miri Zone are represented by the Miocene fluvial to shallow marine Belait, Lambir, Miri and Tukau Formations which are unconformably above the Nyalau/Setap Shale formations. Their ages and stratigraphic relations are still poorly known due to limited paleontological data and field observations. The provenance tools used for this study will integrate fieldwork data with U-Pb zircon dating, biostratigraphy, light and heavy minerals to correlate ages and provenance to existing data from equivalent formations to the north and south of the research area. This will include identification of potential sources and improvement of stratigraphic positions, as well as sediment drainage reconstructions. The Neogene sedimentary deposits in the Miri Zone extend into the offshore region which contains major hydrocarbon reservoirs. This might be useful as an on-land analogue for those sediments.

Sediment transport over complex salt topography: fill and spill revisited

Gillian Apps[1], Frank Peel[1,2], Oliver B. Duffy[1], Naiara Fernandez[1] and Stan Stanbrook[3]

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[3]*Murphy Exploration & Production Co., 9805 Katy Freeway, Houston, TX77024*

Existing published models for fill & spill focus on the depositional sequence in a single 2D structural section along the perceived sediment transport fairway. However, in many salt provinces and deepwater fold and thrust belts, the fill & spill occurs within a strongly 3-dimensional structural topography, and the spill points change through time. This paleotopographic issue, combined with the evolution of the sedimentary deepwater sequence through time, creates a 4-dimensional challenge to predict the vertical and lateral arrangement of facies associations in a single well, in different parts of a single minibasin or across a region; and, in turn, where the best quality and better-connected sands will be found (commonly in the growth phase of a sequence in deepwater, Gardner et al, 2000).

An example of this problem will be presented from a Pleistocene-age sequence (50-100m thick), developed in a set of minibasins within a salt-detached foldbelt at the compressional toe of the Sigsbee salt canopy in the Northern Gulf of Mexico. Sediment entering the foldbelt is ultimately destined for the continental rise in front of the Sigsbee. A linked series of similar scale minibasins developed in a deepwater foldbelt in the S.W. Alps will be used as an analogue to illustrate the facies associations developed in different parts of the system.

The early sand-rich part of the depositional sequence is limited (in space) to regions where structural topography can develop, and (in time) to the topographic healing phase. As the sediment flux increases, and the structural topography is overwhelmed, it evolves into an erosional, then aggradational channel complex which breaks across the region, capturing all the drainage. This channel is not spatially coincident with the early sand-rich depositional region. This evolution happens rapidly in an active fairway with high sediment flux, and therefore the major aggradational channel systems (with their levees, overbanks and associated MTCs) tend to dominate the Pleistocene stratigraphic record on this margin, obscuring, and in places eroding, the earlier stages of sequence development, which commonly contain the best-connected sand-rich reservoirs.

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Mechanisms of mass transport emplacement, accommodation generation and infill in creeping slope successions (Eocene Ainsa Basin, Spain)

Ashley Ayckbourne[1*], Rhodri Jerrett[1], Miquel Poyatos-More[2], Matthew Watkinson[3], Ian Kane[1], Kevin Taylor[1]

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Mass transport deposits (MTDs) are common in progradational basin margin successions, and their emplacement is related to some of the largest sediment transport events on Earth. The topography generated by these events may form depocentres 100s of metres deep and several kilometres wide, trapping sediment gravity flows (SGFs) and resulting coarse-grained deposits on the slope, which would otherwise bypass the area and accumulate on the basin floor. The processes by which MTDs generate slope topography have been well studied, and morphologies after their emplacement include evacuation scars, folds, normal and thrust faults. Implicit to these models, is the passive subsequent on-lap of the seafloor topography by later deposits. Although syn-depositional creep is frequently observed in slope successions, the impact of this process on sediment routing and deposition remains understudied. The research presented here aims to use an outcrop analogue study to better understand heterogeneity in mobile mass transport complexes and processes by which they generate sinks for trapping coarse sediment, with implications for the prediction of reservoir quality, morphology and distribution. To do this, an extensive field study of an MTD-prone slope succession was conducted in Eocene deposits of the South-Pyrenean Foreland Basin (Spain). This has allowed us to obtain an 800m cm-scale sedimentary logged sections, further complemented by palaeocurrent data (n=77) and UAV photography. A detailed facies analysis has allowed us to subdivide the succession into 11 facies, further grouped in 6 facies associations, which relate to a wide spectrum of deep-water depositional elements. These facies associations stack cyclically to form eight distinctive packages, with a repeated and thus predictable pattern. The study shows that accommodation space generated by MTDs was mostly due to 'creep', following emplacement of the MTD. This mechanism leads to the formation of a characteristic vertical sequence: (1) catastrophic emplacement of a debrite on an evacuation surface; (2) coarsening-up and thickening-up packages of low-density turbidite sandstones interbedded with mudstones; these are often folded, exhibiting growth strata and incorporated into stage 1 deposits; (3) high-density turbidites which may form thick, amalgamated sandstone deposits; (4) thinning and fining-up succession of low density turbidites interbedded with mudstones. Stages 2 to 3 are interpreted as 'syn-creep' filling of accommodation space that becomes increasingly confined as the substrate (stage 1) mobilises. Finally, stage 4 deposits are interpreted as 'fill and spill' sequences once the substrate becomes immobilised and no new topography is generated. The eight packages composed of stages 1-4 observed in the 800 m-thick slope succession are likely to be identifiable in subsurface geophysical data such as wireline logs. Results of this study therefore suggest the existence of an autocyclic arrangement of mass-transport emplacement and turbidite deposits filling the resulting intra-slope topography, even in tectonically-active margins. Because these discrete packages can be over 100 m thick, and still fall below biostratigraphic resolution, they may be miss-correlated or even miss-interpreted to be the result of larger-scale allocyclic processes, with important implications for basin evolution models.

Numerical simulation of multiple turbidity currents to analyse the flow-seafloor inter-relation evolution

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Turbidity currents are powerful submarine density flows that travel towards the deep-sea carrying huge amounts of suspended sediment. Keeping sediment suspended in turbidity currents controls the flow duration, which can last from minutes to days. Sediment in turbidity currents is entrained when the flows are triggered, or when the flows erode the seafloor and suspend additional sediment in their downslope path. Eventually, suspended sediment settles to form deposits on the seafloor. Therefore, the composition of the seafloor after the passage of turbidity current passage depends on the initial composition of the seafloor and the erosion, reworking and deposition of the flow-entrained sediment. Can the comparison of seafloor before and after turbidity currents provide information about the initial flow and seafloor parameters? Can the seafloor composition after a turbidity current passage modify next flow behaviour and until what extent?

We set up numerical models of multiple consecutive turbidity currents in Delft3D-Flow to study the evolution of both the flows themselves as well as their interaction with the seafloor. We identify changes in the flow structure and analyse the sensitivity of stratal end-products to pre-exiting topography and substrate. The aim of this work is enhancing the knowledge on the evolution of both flows and seafloor. The combination of the findings of these numerical models with field and experimental measurements and interpretations add to the prediction of the characteristics of turbidity currents and the distribution of the flow sediment.

First evidence of flow-type driven sole marks and their distribution in a mixed sand–mud submarine system

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SUMMARY – Comprehensive field data from the Aberarth section in the Aberystwyth Grits Group (West Wales) show that the type of sole mark below mixed sand–mud gravity flow deposits is closely related to the inferred turbulent, transitional and laminar properties of these flows. Moreover, facies associations interpreted as submarine channel fill, channel levee, channel–lobe transition zone, and proximal and distal lobe have unique suites of sole marks. These observations help in the interpretation of sedimentary process and depositional environment in other deep-marine successions.

DETAILED INFORMATION – Sole marks are common below sediment gravity flow deposits in deep-marine sedimentary successions. Flute marks, groove marks, and other types of scour and tool mark have been used extensively for measuring palaeoflow directions, but there are strong reasons why these sole marks could also be valuable as flow type indicators, in a similar way to other current-generated sedimentary structures, e.g. ripples and dunes. In order to test predictable relationships between type and size of sole mark and the properties of deposits formed by turbulent, transitional and laminar flows, comprehensive sedimentological fieldwork was conducted in the Aberarth section of the deep-marine Aberystwyth Grits Group (West Wales). This location has a rich variety of sole marks combined with ample evidence for the formation of turbidites, hybrid event beds, and debrites by mixed sand–mud flows of different cohesive strength. Based on high-resolution sedimentary logging, detailed sole mark descriptions, drone imagery, and 3D laser scanning, we found that the deposits of turbulent flows, i.e. turbidites, are dominated by flute marks and that groove marks dominate the deposits of laminar flows, i.e. debrites. Transitional flow deposits, which include hybrid event beds, show a variety of sole marks, but groove marks and discontinuous tool marks, e.g. prod marks and skim marks, are most common. These observations support the notion that turbulent flow is needed to form regular scour marks, whereas groove marks mainly form below laminar flows, in which tools are not able to rotate around their axes while dragged along the muddy sea bed. Facies associations in the Aberarth section of the Aberystwyth Grits Group were interpreted as submarine channel fill, channel levee, channel–lobe transition zone, proximal lobe, and distal lobe. The channel fill, levee, and distal lobe successions display almost exclusively scour marks, mainly parabolic and spindle flutes. In contrast, the channel–lobe transition and proximal lobe successions mostly show groove marks, with subordinate occurrences of flute marks. These observations agree well with the dominance of turbidites in channel fill, levee, and distal lobe successions, and transient turbulent flow deposits in the channel–lobe transition and proximal lobe successions. Further measurements show that flutes, discontinuous tool marks, and groove marks generally occur below progressively thicker beds. Moreover, the width, depth, and length of parabolic flutes decrease with increasing downstream distance, which may indicate a progressive decrease in erosive capacity as the flows travelled from the channel to the distal lobe. Although specific to the studied field site, the above observations may aid the interpretation of depositional process and environment from sole marks in other deep-marine systems.

Distribution of contourite drifts on convergent margins: examples from the Hikurangi subduction margin of NZ

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Contourite drift systems form a significant component of the marine clastic sedimentary record. Although contourites are known to form in all tectonic settings, relatively few studies have focused on their development along convergent margins. This study is the first to document contourite drift development along the convergent Hikurangi subduction margin of New Zealand. Six classes of drift are recognised to form around the Hikurangi subduction wedge, occurring in three principal associations: (1) an upper slope drift association of giant elongate mounded (c.150 km long, 50 km wide, and up to 1100 metres thick) and slope-plastered drifts (c. 300 km long, 8 km wide and < 600 m thick), which occurs upon and inboard of a major intrabasinal thrust-cored high, whose long axis parallels the coast; shallow bottom currents disperse sub-parallel to this axis; (2) a spatiotemporally discontinuous association of mixed drifts (c. 500 m long, < 2 km wide, and up to 500 m thick) that occurs along the mid-toouter slope domain of the wedge, recording the interaction of along-slope and downslope currents within trench-slope basins, and (3) a base-of-slope assemblage (c. up to 100 km long, < 30 km wide, and up to 1 km thick), which records the interaction of abyssal bottom currents with turbidity current overspilling from the trench-axial Hikurangi Channel. The presence of contourites along this margin appears to depend on the orientation and strength of oceanographic bottom currents; however, drift type and evolution varies depending on the slope gradient and the presence of irregular seafloor topography. The documented drifts are generally smaller, less continuous, and develop more intermittently than similar styles of drifts documented on passive margins; this mode of occurrence may be characteristic of contourite development on convergent margins.

Can sand promote the cohesive forces in high-density clay-laden sediment gravity flows?

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Adding clay to non-cohesive sediment gravity flows (SGFs) has been observed to produce complex transitional flow deposits and hybrid event beds. However, little work has been done on how adding minor amounts of sand to high-density cohesive SGFs changes the dynamic balance between turbulent and cohesive forces, and hence the flow behaviour and deposit properties.

Lock-exchange experiments were conducted to investigate how increasing the volume concentration of bentonite-laden cohesive SGFs by 25% from adding fine sand changed the flow behaviour. Two flows classified as high-density turbidity currents and containing 14.4% and 16% bentonite were selected as the pure clay controls to which 3.6% and 4% of fine sand were added. The flume experiments recorded the run-out distance, head velocity, and deposit geometry of the SGFs. In addition, dam break experiments were conducted to determine the initial yield stress of samples of the same composition as the laboratory flows.

The dam break experiments found that increasing the volume concentration by adding 25% sand increases the yield stress of the 14.4% and 16% bentonite suspensions by a factor of 2.8 and 2.6, respectively. The increase in the yield stress of the pure-clay suspensions from the addition of sand was matched by a reduction in the run-out distance by a factor of 1.3 for the 14.4% bentonite flow and 2.5 for the 16% bentonite flow. The head velocity profiles of the bentonite-sand flows were slower compared to the original pure-bentonite flows.

The theoretical mechanisms by which sand can increase the yield stress of pure clay suspensions are poorly understood. Of all the mechanisms, hydrodynamic interactions are argued to have had the largest influence on the sand-bentonite flows in the present experiments. However, there is a disconnect between the yield stress of a suspension and the flow behaviour of that suspension, since rheology experiments use a fixed volume and natural flows can expand by entraining water. It is hypothesised that sand can only increase the yield stress of the suspension and reduce the flow mobility if it can be held in the plug region of a flow by matrix strength. If the sand cannot be held in the cohesive plug it is likely to promote turbulence mixing within the flow and thus increase the flow mobility.

These results highlight that the yield stress of natural cohesive SGFs containing sand and silt cannot be considered only in terms of the clay concentration and that the changes in the yield stress from the addition of sand can considerably alter the flow behaviour and deposit properties. This has important implications for flow transformation, especially in the distal region of mud-rich submarine fans where the SGFs are decelerating and cohesive forces are likely to control the flow behaviour.

What causes carbonates to form "shrubby" morphologies? An Anthropocene limestone case study

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The South Atlantic Aptian "Pre-Salt" shrubby carbonate successions offshore Brazil and Angola are of major interest due to their potential hydrocarbon accumulations. Although the general sedimentology of these deposits is widely recognised to be within saline, alkaline lakes in rift volcanic settings, the specific genesis of shrubby carbonate morphologies remains unclear. This study reports the first petrographically comparable shrubby carbonates amongst other carbonate microfacies from an Anthropocene limestone formed under hyperalkaline (pH 9-12) and hypersaline (conductivity 425-3200µS) conditions at ambient temperature (12.5-13 oC) (Consett, UK). This discovery allows us to capitalise on exceptional long-term hydrochemical monitoring efforts from the site, demonstrating that shrubby carbonates occur uniquely within the waters richest in calcium (~240mg/L) and with highest pH (~12) and consequently with very high levels of supersaturation. However, the physical distribution of shrubs is more comparable with estimated local kinetic precipitation rate than it is to thermodynamic saturation, indicating that the fundamental control on shrub formation arises from crystal surface processes. The shrubby carbonate we report grows in the presence of significant diatomaceous and cyanobacterial biofilms, despite the highly alkaline conditions. These biofilms are lost from the deposited material early due to the high solubility of organic and silica within hyperalkaline settings, and this loss contributes to very high intercrystalline porosity. Despite the presence of these microbes, few if any of the fabrics we report would be considered as "boundstones" despite it being clear that most fabrics are being deposited in the presence of abundant extra-cellular polymeric substances. We are aware of no previous petrographic work on anthropogenic carbonates of this type, and recommend further investigation to capitalise on what can be learned from these "accidental laboratories".

Carbonate depositional environments and their impact on reservoir properties: examples from Central Mediterranean hydrocarbon fields

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Carbonate reservoirs usually show complexities that result in strong characteristics variability, significantly affecting their performance and economic viability. Primary facies distribution and properties, sequence stratigraphic framework, diagenesis and fracturing are amongst the main factors that exert important controls on reservoir properties. In the complex carbonates reservoirs, the interaction between matrix characteristics and fractures characteristics invariably controls fluid flow by enhancing or imparting primary reservoir properties. The porosity loss of the carbonates increases with depth, as a result of the interplay between mechanical compaction, physical-chemical compaction and cementation. This porosity loss with depth is less predictable than in siliciclastic rocks; the porosity range is produced by strongly variable grain shapes which often contain micro and/or macro-pores, and is mainly controlled by the texture and fabrics of the rock. Consequently, the carbonates depositional environments have a strong impact on the matrix-related petrophysical properties of the reservoirs, influencing the primary porosity and guiding the diagenetic modifications. It is possible to observe and discuss this impact in Central Mediterranean area, where the Mesozoic to Cenozoic geological history saw the existence of platform to basinal settings with predominant carbonate deposition, that currently host several hydrocarbon fields. These carbonates developed in different depositional environments and with different geometry, textures and internal architecture. Inner platform deposits of the Apulian Platform, characterised mainly by mud-dominated lithologies, are one of the principal reservoirs in Southern Italy fields (e.g. Val D'Agri fields). Here, the matrix porosity is extremely low and matrix permeability is in the order of few millidarcies, so the reservoir properties of these tight carbonates almost completely rely on the occurrence of fractures (Bona et al., 2001). Basinal carbonates, composed of pelagic mudstone to wackestones are also proven reservoirs, like for instance in Albania onshore (Shpiragu area); here, the matrix porosity is negligible and the reservoir properties are entirely connected with the fault and fracture network. At the transition between the Apulian platform and the Adriatic basin domains, the toe of the slope deposits that carry hydrocarbons in Aquila field (offshore Adriatic Sea) are composed essentially by carbonate debris, breccias and turbidites with primary porosity up to 23% and permeability up to 1800 mD (Aquila-3 well; Cazzini et al., 2015; Di Cuia and Riva, 2016). Ramp carbonates also could be good reservoirs, as testified by the Miocene bioclastic packstone-grainstone of the Nilde Oil Field (offshore Sicily); here, the petrophysical properties of the reservoir are quite complex with a wide range of matrix porosity values. Matrix properties are good (5-20% of porosity), but the fracture network and the paleokarst system are thought to have given the main contribution to production in this field.

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Sedimentological controls on fluid flow in deeply buried aeolian gas reservoirs

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Aeolian reservoirs are often considered to be homogeneous sand "tanks" which lack significant heterogeneities linked to their sedimentological architecture. However, production characteristics from deeply buried aeolian reservoirs show the presence of heterogeneities that can dictate subsurface fluid flow. These have been associated with the presence of finer grained laminae around the edges of trough bedforms in the dune deposits which produce a specific production profile termed the "slow gas effect" (Mullins et al. 2019). The slow gas effect is characterised by high initial flow rates from the dune core facies in the centre of troughs which are penetrated by the well, followed by an extended production tail, as gas slowly passes through the lower permeability dune plinth facies that encase the troughs. Production is therefore heavily controlled by bedform architecture and predicting dune geometry from well data in the subsurface is a key step in the reservoir modelling workflow.

Romain and Mountney (2014) provided a methodology for reconstructing dune geometry from 1-D well data. This method was applied to a series of wells from a deeply buried aeolian gas reservoir. The dataset included cores, wireline and FMI logs. In addition to the cross-bed angle, and cross-bed set thickness, data were also collected on grainflow proportion and thickness. These data were used to reconstruct the dune body dimensions and estimate the reservoir volumes in the troughs adjacent to the well and from that estimate trough dimensions. These trough dimensions were then compared to outcrop analogue examples from the Page and Entrada Sandstones in Arizona and Utah.

The consolidation properties of the glacial sediments of the Dogger Bank Tranche A – evidence for multiple ice-sheet advance and retreat

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The Dogger Bank is a large shallow topographic feature in the Central North Sea with water depths of 18 – 63m. As one of the proposed round 3 windfarm licence areas an extensive site-investigation was undertaken during 2010 and 2011 across Tranche A including extensive 2D-ultra high resolution reflection seismic surveys, 70 geotechnical and wireline boreholes and over 120 CPT tests. An analysis of the geotechnical and consolidation properties of the Dogger Bank sediments indicates a complex history of at least two phases of direct glacial loading, periodic glaciotectonisation and subaerial exposure evidenced in desiccation surfaces.

By deconstructing the complex loading history and linking one-dimensional consolidation profiles to landforms identified in the seismic data it is possible to identify distinct patterns of vertical loading directly due to ice-sheet loading and a number of desiccated sediment 'crusts' with high shear strength and overconsolidation ratios. These desiccation surfaces represent ice-free periods of subaerial exposure, but are themselves contained within intervals of vertically loaded, glaciotectonised and deformed sediments. This suggests that there were multiple phases of ice-sheet retreat and re-advance, each associated with a cycle of vertical loading, glacioteconism and subaerial exposure – we can firmly identify at least two of these cycles with high confidence but the complex geology present at the Dogger Bank suggests that there may have been up to four such cycles.

It is possible to use geotechnical data, seismic-stratigraphy and relative-age stratigraphic relationships to estimate the minimum-vertical thickness of ice present at the Dogger Bank within a 6-15 kyr time period. We find this agrees with recently published dates of the Dogger Bank sediments (Emery et al., 2019, Roberts et al., 2018) allowing the full consolidation of the sediments by an ice-sheet within this time period.

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Fingerprints of Tectonics and Climate Change in the Detrital-Zircon U-Pb Record of the Deep-Sea Bengal Fan?

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The Himalayan-sourced Ganges-Brahmaputra river system and the deep-sea Bengal Fan represent Earth's largest sediment-dispersal system. Bengal Fan sediments integrate the record of tectonic and climatic forcing within a system that is a "one-of-a-kind" source-tosink system in its own right, as well as a globally significant CO2 sink. IODP Expedition 354 (Spring 2015) drilled a 7-site transect in the middle Bengal Fan, ~1400 km south of the shelf margin, so as to expand the record of source-to-sink sediment routing from the Himalaya to the deep sea: the 1.7 km of recovered core includes turbidite sand and silt deposited from ~18-0 Ma. Recent work has developed a detrital-zircon (DZ) U-Pb provenance record from cores collected during IODP Expedition 354. This dataset consists of 25 DZ samples (~7200 U-Pb ages) from Early Miocene to Middle Pleistocene medium- to fine-grained turbidite sand, and samples from modern sand bars of the Ganges and Brahmaputra Rivers, which serve as benchmarks against which the older record can be compared. At the first order, turbidites record the strong tectonic and climatic forcing associated with, and inherent to, the Himalayas and Ganges-Brahmaputra system. First, continued NNE motion of India relative to Asia means the IODP 354 drill site locations were ~800 km and ~400 km farther south with respect to the GB delta at ca. 20 and 10 Ma, respectively: (a) prior to ca. 18 Ma, this location was too far away to be reached bysignificant volumes of clastic sediment, (b) from 18-10 Ma, fan deposition was mostly turbidite mud with thin sands, and (c) after ~10 Ma, this location was within the limits of deposition of thick sandrich turbidites. Second, after up to 2500 km of river transport, and >1400 km of transport by turbidity currents, the DZ U-Pb record faithfully represents Himalayan and Tibetan sources. We also detect possible signals of climate change within the Plio-Pleistocene part of the record. Most importantly, present-day sediment transfer to the land-sea boundary is closely coupled to Asian monsoon rains. However, delivery of sand to the deep sea does not occur during interglacial highstands like that of the present, and the sand-rich turbidite record instead reflects glacial periods when rivers extended across the shelf in response to sea-level fall, and connected directly with slope canyons. Moreover, sandy Bengal Fan turbidites display the same DZ U-Pb age populations and peaks that are present in modern river samples, but their proportions are significantly different, especially after the Plio-Pleistocene transition between 3 and 2.5 Ma. Pleistocene Bengal Fan samples include (a) higher proportions of the <300 Ma population from Tibet, (b) higher proportions of the ca. 400-600 Ma population, which can be derived from Tibet and/or the Greater Himalaya, and (c) lower proportions from the Lesser Himalaya and/or peninsular India. We speculate these differences reflect contrasts in the loci of sediment production in the modern interglacial climate with strong monsoon rains, vs. glacial climates where monsoon strength is reduced and erosion is closely coupled to higher-elevation cold-climate and glacial processes.

Bumps in the Bay; Did carbonate mounds form the large, circular sea-floor structures in Weymouth Bay, Dorset, UK?

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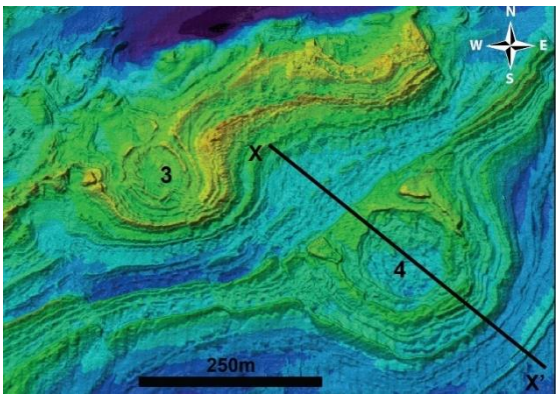
The remarkable seafloor images of Weymouth Bay obtained by the Dorset Wildlife Trust's DORIS project provide new insights into the geology of Dorset's Jurassic Coast. Large (30-150 m diameter) circular structures have been discovered on seafloor images of Purbeck limestones that have not previously been seen in any of the coastal exposures or quarries from Durlston Bay to the Isle of Portland, despite over a hundred and fifty years of geological research. Many geological processes can generate circular arrangements of strata such as meteorite impacts, dolines, gas chimneys, volcanoes, carbonate mounds, Philip structures and salt diapirs. The morphology of the structures is imaged from multibeam echo sounding data (below) indicating that these are sections eroded through SE-dipping, dome-shaped structures. Strong tidal currents in the bay keep the eroded rock ledges essentially sediment free. Diver-collected sampling in 2019 confirms that the structures are developed in the mid to upper parts of the Purbeck Limestone Gp. and, for the most part, represent typical lithologies from this unit. The structures occur within a restricted band on the southern limb of the Purbeck Anticline. Apparent onlapping geometries on the flanks of the structures together with truncation by presumed Alpine faults bracket their age as Late Jurassic to early Cenozoic. Serious contenders for the origin of the circular structures are periclinal folds, salt diapirs and carbonate mounds. Periclinal folds generate similar plan-view shaped inversion folds in these rocks, but are considered an unlikely origin as such structures are only developed on the steeply dipping northern limb of the Purbeck Anticline. Salt diapirs, are also considered unlikely as the Purbeck salts are sulphate-rich and not halite. In addition the structures are small for diapirs and die out to the east while the salts thicken to the east. No diapirs are seen on seismic sections arising from Triassic salts. Tufa mounds, have analogues in the lower Purbeck Caps, could have a restricted (depth-related) distribution in the Purbeck lake and conform to the morphology and size range of the structures. If proven, this would add a significant new component to Purbeck palaeogeography in its type area and provide an additional analogue for south Atlantic, Presalt carbonate plays.



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FIELD EVIDENCE OF DEEP-LACUSTRINE SLOPE CHANNELS IN THE TRIASSIC YANCHANG FORMATION, ORDOS BASIN, NORTHERN CHINA

Guilherme Bozetti

SUSTech - China

The continuous increase in publications on outcrops of marine systems, especially in slope to basin floor environments, contrasts with the scarce number of studies, at least in the English language, on ancient deep-lacustrine systems, which is an important hydrocarbon play worldwide, particularly in the pre-salt rift basins of West Africa and intracratonic basins in Asia. This research presents preliminary data from the PetroChina funded project that aims to understand sedimentary processes and architectural elements of the deep-lacustrine deposits of the Triassic Yanchang formation in Ordos Basin, China, which covers an area of 2.5×10^5 km² across 5 Provinces and is the second largest hydrocarbon producer in China. Sedimentary processes in ancient deep-lacustrine systems in China have for many years been interpreted as dominated by sandy debris flows, with subordinated influence of turbidity currents. In the proposed model, large portions of the lake deltaic sediments initially deposited in shallow water detach and due to gravity move to deeper portions of the basin, evolving into a hyperconcentrated density flow and a turbidity flow. This model has been established to explain thick sandstone deposits, previously interpreted as individual beds, interbedded with thin-bedded sandstones and mudstone, surrounded by black mudstone interpreted as hemi-limnic deposits. Alternative interpretation for sand-prone slope deposits of the Yanchang formation uses small scale erosional surfaces as evidence for channelizing, proposing four different types of hyperpycnal channel morphologies, which range between 3 to 10 metres in width and 0.8 and 2 metres in depth. Based on detailed lithofacies analysis of the deep-lacustrine deposits of the Yanchang formation three main architectural elements are recognised: i) slope channel, which are composed of amalgamated sandstone interbedded with non-amalgamated sandstone and mudstone couplets, all confined into large composite erosional surface (500 to 700 m wide and 8 to 18 m thick), with common scours at the base of the sandstone beds and mud clasts in the sandstones, common parallel and ripple cross-lamination, sharp grain-size breaks, and absence of mudstone overlying some graded sandstone beds; ii) levee, which although poorly and discontinuously exposed is composed of thinly bedded graded sandstone to mudstone with common parallel and ripple cross-lamination (70-90%), and medium sandstone beds (20 – 60 cm); and iii) frontal splay or lobe, composed of laterally continuous (traceable for few kilometres) interbedded sandstone and mudstone, dominantly thinly to medium bedded, with scarce sediment bypass features such as scours and mud clasts, and uncommon parallel and ripple cross-lamination (20-30 %). The slope channel-levee theory proposed in this research has a large impact for hydrocarbon exploration in the deep-lacustrine of the Ordos Basin. Although substantially smaller than the equivalent in marine systems (usually 4 to 7 km wide and 200 – 400 m thick), lacustrine slope channels are low topographic relief on the lake floor that act as conduits for gravity driven flows to transport sediments from shallow to deeper water, generating important accumulations of sand-rich deposits on the basin floor with hydrocarbon reservoir potential substantially greater than previously interpreted sandy debris flow deposits. The future of this work consists of mapping out the channel-levee deposits recognisable in outcrop, combining with some of the more than 12900 cored wells (670,000 metres) to generate sandstone fairway maps and test the efficiency of the slope channels.

Grain size fractionation and sediment mass balance: The keys to unlocking the stratigraphic archive in Source-to-Sink systems

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Presence and volume of reservoir facies are a key risk in the exploration workflow. Frontier regions often have sparse data and limited seismic imaging, leading to large uncertainties in the presence of the reservoir within a petroleum system. Our research combines conventional analysis of stratigraphic architecture with sediment mass balance to develop a predictive approach to characterising sediment volumes and grain-size distributions in sediment routing systems. The approach is tested using the data-rich Early Eocene Dornoch-Hermod sediment routing system of the East Shetland Platform, Northern North Sea, UK. This system comprises the deltaic deposits of the Dornoch Formation and coeval slope to basin-floor deposits of the Hermod Formation. Prior work on these deposits has defined their gross stratigraphic framework and palaeogeography but not the specific sediment input points to the basin, sediment dispersal patterns across the shelf and slope, or individual basin-floor fans. Using high-resolution 3D seismic data and 55 wells we have delineated the sediment fairway of the Dornoch and Hermod Member. This detailed work will show two of the five distinct sediment routing systems within the study area mapped from the alluvial domain to the basin floor. Each system has a separate erosional catchment that represents its sediment generating source region. The Dornoch Delta forms a near linear deltaic shoreline in plan view, implying strong sediment transport along the shoreline. Thus, the Dornoch-Hermod sediment routing systems are presumed to not be closed and there would have been sediment transfer between the adjacent “leaky” sediment routing systems. The volumes of alluvial, coastal plain, shelf, slope and basin floor deposits have been accurately calculated from seismic mapping and well data for each Dornoch-Hermod sediment routing system, and the erosional source tied to the corresponding depositional sink for each system. Grain-size distributions in the sediment volumes for each sediment routing system have been characterised using core, cuttings and wireline-log data. Integration of grain-size data into the volumetric framework allows the sediment mass balance and downsystem-fining trends to be linked, allowing the position of grain-size “fronts” (e.g. downsystem limit of sandstone) to be highlighted and measured. Such downsystem trends in grain size can be normalised relative to accommodation space to give generic, predictive trends. In the Dornoch-Hermod sediment routing systems, downstream-fining rates are lower than expected for closed systems, which emphasises the role of sediment transfer between “leaky” systems along the shoreline and also implies that tilt and clay may have been transported beyond the limit of the seismically mapped volumes.

Quantifying lateral and distal variability in clasts and matrix size within hybrid beds, case studies from Central and Northern Italy

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Hybrid beds or linked debrites are deposits that form under bi- or tri-partite flow conditions, involving both turbulent and laminar flow conditions. Often, hybrid beds occur with distal or lateral flow transformation following significant entrainment of a muddy substrate and/or declining turbulent energy (e.g. Haughton et al., 2003, 2009; Amy and Talling, 2006; Hodgson, 2009). Hybrid beds have been noted to make up significant proportions of deposits within basin floor setting worldwide, most commonly within the distal fringes of lobe systems (Haughton et al., 2003; Hodgson, 2009; Spychala et al., 2017). The aims of this study are to establish the changes within clasts size, dimensions, concentration and distribution, along with lateral and down-dip grain size changes within hybrid beds. A detailed study of these changes within the targeted deposits will help to establish how flow processes varied laterally and down-dip. Through quantifying the amount of mud within the matrix and clasts at any one time within the flow it may be possible to characterise how and when turbidites and hybrid beds erode and incorporate sediment from underlying substrate.

Detailed mapping of the Marnoso Arenacea (Ricci Lucchi and Valmori, 1980; Amy and Talling, 2006), Castagnola (Southern et al., 2015; Marini et al., 2016) and Gottero (Fonnesu et al., 2016; 2018) formations, deposited within three different basins, allowed detailed logging and sampling to be undertaken within well-constrained palaeogeographic frameworks. Sections within these systems were selected where hybrid beds could be traced out laterally or down-dip for several metres to several 10's of kilometres. In total 407 samples were collected to be used for grain-size analysis. Samples were selected through beds at 20 cm intervals and across/ down-dip at 10's of metre to several km intervals. The primary method of grainsize analysis involves the disaggregation of samples using a SELFRAG and an ultrasonic bath, followed by laser diffraction analysis using a Mastersizer 3000. Thin sections will be used for comparison with these results in order to check that the disaggregation process is successful. Here we present preliminary result from the disaggregation and grain-size analysis processes. Recent studies have shown that disaggregation and grain-size measurement through laser diffraction can be a useful and more time efficient tool in ancient sand-rich sediments (Maithel et al., 2009) where the fines have been removed, but this can be more complex with finer samples or debrites.

A global database-informed investigation of submarine-canyon formation and evolution in a source-to-sink context

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Submarine canyons constitute important large-scale conduits for the distribution of sediment, organic matter, nutrients and pollutants to the deep-marine environment, exerting significant control on its sedimentary systems and ecosystems. Moreover, submarine canyons pose a potential geohazard due to intra-canyon slope failures triggering tsunamis and to canyon morphology influencing tsunami propagation. Furthermore, their sediment fill and linkage with sand-prone submarine-fan and contourite drift systems has made them important targets for hydrocarbon exploration. Despite representing a key area of interest in both academia and industry, and being extensively studied, the factors and controls affecting submarine canyon-formation and long-term evolution are still not well understood. Previous global-scale canyon studies are few in number and limited in scope, with the focus on one or a small number of study parameters and with limited consideration of the multiplicity of controls on canyon evolution. As a consequence, conceptual models for submarine-canyon evolution have been largely derived from individual or regional studies of submarine canyons in areas influenced by specific environmental conditions. Thus, the universal validity and applicability of these models has to be questioned. A database-informed statistical analysis of 200+ globally distributed late-Quaternary submarine canyons has been undertaken with the aim of investigating the role of canyon self-organisation and external forcing on submarine canyon evolution. Utilising literature-derived, high-resolution bathymetric and seismic datasets from seabed and subsurface studies presented in 300+ publications, canyon geomorphology (e.g. dimensions, cross-sectional and planview shape, canyon sidewall steepness, canyon sinuosity, axial thalweg gradient) and physiography (e.g. location of the canyon head relative to catchment and shelf edge, water depth range, proximal and distal transitions to other architectural elements, connection to sediment sources) have been investigated in a source-to-sink context. Geomorphologic and physiographic parameters of the catchment, shelf and slope segments (e.g. dimensions, gradient, process regime), as well as external controls such as tectonic setting, latitudinal position, structural influence and climate, have been analysed. The data show the variability in influence of autogenic and allogenic controls on canyon evolution and how spatial configuration of submarine canyons can be related to source-to-sink system configuration and external controls. Canyon evolution is more differentiated and complex than hitherto depicted in published models. The following novel results arise: (i) groupings of submarine canyons with specific geomorphic configuration and physiographic setting can be established on the basis of source-to-sink settings and external controls; and (ii) boundary conditions for the significance of influence of control parameters on canyon development can now be defined. Findings of this study will aid in the reconstruction of canyon configuration in ancient canyon systems and prediction of canyon evolution in modern canyon systems.

The Effect of the 2004 Indian Ocean Tsunami and Subsequent Beach Recovery On the West Coast of Aceh

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Figure 1. Field photo of study site in Glee Bruk. Large concrete blocks which are remains of buildings can be seen both on the surface and partially buried.

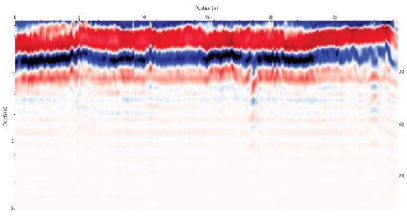

Figure 2. GPR profile from site in fig 1.

The 2004 Indian Ocean tsunami was the result of a 9.2M_w subduction zone megathrust earthquake. This resulted in a tsunami that inundated 14 countries and killing over 200,000 people and leaving 1 million homeless (Grilli, S. et al., 2007) almost two thirds of these fatalities occurred in Aceh Province, Indonesia (Meilianda, E. et al., 2010). Ground penetrating radar (GPR) was used to investigate the sedimentological impact of the tsunami in two locations, Glee Bruk and Meulaboh, on the west coast of Aceh with mixed results. In Glee Bruk the site chosen had been used as a paddy field before the tsunami but is currently uncultivated. The field contains parts of buildings that had been destroyed in the 2004 tsunami, figure 1. However high levels of salt water and/or clay minerals in the ground resulted in a high attenuation rate of the electromagnetic waves produced by the GPR and therefore poor quality data, figure 2. At Meulaboh a profile was taken near the beach, figure 3. This site showed a strong erosional layer which corresponds with a ridge on the surface, figure 4. This layer represents the extent of the 2004 tsunami. There is also a series of beach progrades both before and after the tsunami erosional layer showing the beach growth and recovery.

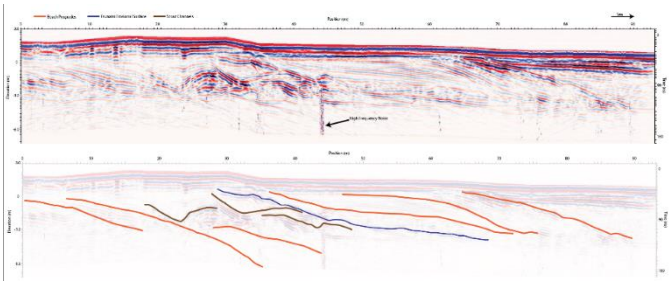

Figure 3. GPR profile taken in Meulaboh

Below the tsunami erosion layer there are three channel features. These could be related to the local river channel system or are potentially the remains of previous tsunamis. Understanding how the coast is effected by these events and the subsequent recovery is important in understanding how protection measures can be best put in place and hopefully reduce fatalities in the future.

Figure 4. Field photo of site in Meulaboh

Contribution of turbidity currents triggered by jets to sediment management in water reservoirs

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Reservoir sedimentation critically affects reservoir water storage, which is vital for human and animal supply, irrigation, energy production, and flood control. In addition, sediment trapping in reservoirs affects fluvial and coastal morphology and aquatic ecosystems downstream of a dam. The current scenario of climate change, population increasing and limited capacity of regulating rivers increase the necessity of promoting sustainability of dams, which demands efficient sediment management techniques, ideally able to promote sediment continuity through these barriers. While turbidity currents - a type of buoyancy-driven flow - naturally occur in deep-water systems transporting sediments to distal areas, in dredging applications they are triggered artificially (for instance: by means of water injection) to move sediments from one site to another using the transport capacity of these flows. The goal of this research is quantitatively describing the physical processes related to turbidity currents triggered by jets, a technique that can contribute to a strategy for sediment management in water reservoirs. An experimental investigation will be conducted at the Environmental Fluid Mechanics Laboratory of the Delft University of Technology (TU Delft) using an existing experimental setup - 4 meters long, 2 meters high, and 22 centimeters wide - which will be adapted for the purposes of this research. In the end, numerical modelling and upscaling of the results will be applied to improve knowledge transfer to prototype applications.

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Quantification of grain coatings in sandstone reservoirs

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Quartz cementation is one of the most important cements governing reservoir quality in sandstones. The presence of clay coatings plays a crucial role in preserving anomalous high porosity in deeply buried sandstones by inhibiting porosity-occluding macroquartz cementation. 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. In this study, a series of hydrothermal reactor experiments have been undertaken to simulate quartz cementation and grain coatings, particularly chlorite, at specific temperature steps to mimic the conditions of deeply buried reservoirs and develop predictive models for clay-coat-controlled reservoir quality in such settings. The experiments were performed in a Parker Autoclave Engineers self-sealing reactor with operating temperatures up to 350 °C. Sandstone samples from the Lower Jurassic Cook Formation of the Oseberg Field (Norway), were used in this study. Pre-existing berthierine, an aluminous Fe2+ rich clay which can act as a precursor for chlorite, and siderite grain coating cement have been identified in the Cook Formation and are of particular importance for the experimental procedure of this study. An artificial solution and a source of silica gel maintaining silica supersaturation during all experimental runs was used. Both starting material and end-products were inspected using, SEM/SEM-EDS, Micro-CT and automated mineralogical imaging and petrography of new mineral precipitates. Helium pycnometry was used to evaluate the porosity evolution of the samples. This research presents a new methodology capable of quantifying grain coat volume change in the 3D domain and assess the subsequent influence on reservoir quality. Results show that the patchy amorphous berthierine clay transforms to crystalline robust grain coating Fe-chlorite cements facilitating better grain coat coverage. Porosity maintenance correlates directly to chlorite grain coating volume increase at temperatures higher than 175 °C. This provides the early framework to construct a robust predictive capability of chlorite grain coats for reservoir quality in ancient deep and hot sandstones.

Subglacial landforms formed by an Ediacaran ice sheet in west Henan, North China

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The Gaskiers glaciation of mid-Ediacaran (ca. 580 Ma) is often considered to represent the youngest ice age recorded in the Precambrian. However, diamictites of late Ediacaran age are widespread across Southeast–Central Asia. Along the southern margin of the North China craton, this diamictite corresponds to the Luoquan Formation, which crops out in high quality sections. Its basal unconformity exhibits striations and p-forms, interpreted to have been produced subglacially, and which were cut into Mesoproterozoic basement (Fig. 1). Integrating new observations on the basal unconformity with the stratigraphy and sedimentary succession of the Luoquan Formation, an unequivocal glacial origin is demonstrated. The succession evolves from massive or stratified diamictite to laminated fine-siltstone with dropstones upward, and is capped by siltstone with or without dropstones on the top. These lithological combinations represent a glacial sedimentary succession evolved from land to shallow sea, indicating a paleogeographic background of a continental ice sheet in the southern margin of North China. Based on multiple paleoflow measurements, data from 7 new measured sections, and facies analysis, a new paleogeographic model is proposed: this model envisages the expansion of a large continental ice sheet from the land in the north to the shallow sea in the south at the southern flank of the North China craton. The continental ice sheet of Ediacaran period in Southeast–Central Asia appears to have developed in the context of a global greenhouse climate.

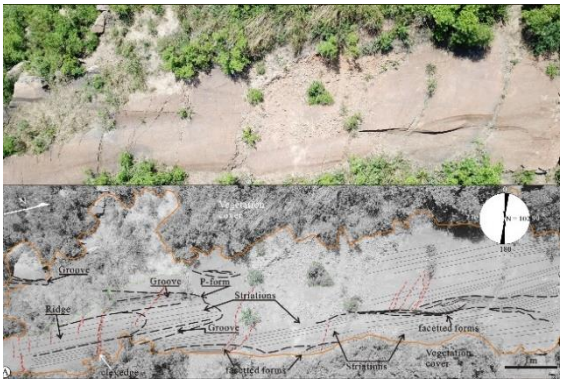

Fig1. The pavement in Shimengou, West Henan

Pliocene and Pleistocene stratigraphic evolution of the western Niger Delta: A record of glacioeustatic and autogenic forcing

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Despite the plethora of publication on the Pliocene and Pleistocene sedimentary records of the Niger Delta, no study has investigated sequence cyclicity, which may be related to obliquity and eccentricity forcing. This aim is achieved in this study by integrating detailed seismic stratigraphy and 3D geomorphological analysis of a high-resolution 3D seismic data. Our results show that the Pliocene and the early Pleistocene are dominated by 4^{th}-order sequences of 0.3-0.4 Ma duration, while the middle Pleistocene and present-day are dominated by 5^{th}-order sequences of 0.11 Ma duration. Correlation of seismic markers with the high-frequency sea-level and oxygen isotope ($\delta^{18}O$) curves, suggests that stratigraphic records of the western Niger Delta evolved from obliquity-dominated sequences of 400 ky periodicity between the early Pliocene and the early Pleistocene but switched to eccentricity-dominated sequences of 100 ky periodicity from the middle Pleistocene to present-day. Depositional elements comprise erosional channels, confined meandering channel levee complexes (CLCs), MTDs and hemipelagites that respectively document late forced regressive, lowstand normal regressive/early transgressive and late transgressive/highstand transits of the shoreline. The change of these architectural elements across the inferred obliquity-dominated to the eccentricity-dominated sequences, also suggests a complex interplay between allogenic (glacioeustatic) forcing and autogenic (syn-sedimentary faulting, shale tectonics and inferred delta lobe migration). This pioneer seismic stratigraphic study demonstrates for the first time, sequence cyclicity associated with obliquity and eccentricity forcing in the intraslope-basins and serves as a useful analogue for further Pliocene and Pleistocene studies in the Niger Delta, Gulf of Guinea and the equatorial Atlantic.

Simulation of Stratal Architecture in Deep Marine Mini-basins: Making it Realistic is Easy – Making it Exactly Right is not

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Simulation of the stratal architecture using numerical forward modelling can provide insights into how basins develop. For example, simulation of the stratal architecture in salt-floored mini-basins in continental slope settings can elucidate the interplay between salt movement and sediment supply.

There are several modelling approaches, which include: process-based methods (that numerically simulate gravity currents and their consequent deposits); and geometric methods (that use simple equations to model deposits without modelling the processes that form them). We have developed a geometric model (Onlapse) which is appropriate in typical exploration settings, with limited constraining data. Onlapse uses a small number of physical input parameters (starting sea floor topography, background sedimentation rate, structural growth rate and profile, and a variable rate of rise of a clastic-limiting surface), and combines these inputs using simple rules to create geologically realistic looking basin architectures.

Previous studies have used similar geometric approaches to create generic basins to understand the general principles. We go one step further, recreate the detailed geometries of real-world mini-basins of the US Gulf of Mexico, using a simple iterative process. Our first target was an apparently simple near symmetrical mini-basin. The first-pass model matched the general form of the basin but not the detailed thicknesses and stratal geometries. We progressively tuned the model inputs to reduce the mismatch; and have optimized the model output.

The closest fit was achieved by combining: 1) Multiple structural growth rates; 2) highly episodic sediment supply; 3) long periods of depositional hiatus; and 4) brief periods of rapid deposition. Matching the geometries of some intervals requires extremely fast rates of sedimentation; these appear to correspond to mass-transport complexes. Best fit also required the use of two subtly different structural profiles, indicating a progressive evolution of structural controls.

A good match was achieved for most of the basin infill. However, for some key intervals it is impossible to create a perfect match using simple simulation. These appear to correspond to extrinsic events (such as collision with adjacent mini-basins, and interaction with the base of the salt).

Deep-sea circulation creates seafloor microplastic hotspots

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An estimated 8.3 billion tonnes of non-biodegradable plastic has been produced over the last 65 years. Much of this is not recycled or effectively disposed of, has a long environmental residence time, and accumulates in sedimentary systems worldwide; often in the form of microplastics, which pose a threat to important ecosystems and potentially human health. While microplastics are known to pervade the global seafloor, the processes that control their dispersal and concentration in the deep sea remain unknown. We present an analysis of seafloor, sediment and microplastics data from the Tyrrhenian Sea to show that thermohaline-driven currents, which create extensive contourite drifts, also control the seafloor distribution of microplastics. Our findings indicate that contourite drifts may be globally important repositories for microplastics, with higher concentrations than other better-known microplastic hotspots, such as canyons and deep-sea trenches. Several previous studies propose that microplastics are transported to the seafloor by vertical settling from surface accumulations. Instead, using numerical modelling, we demonstrate that the spatial distribution and ultimate fate of microplastics is strongly controlled by the same near-bed currents that supply oxygen and nutrients to a range of deep sea benthos. Our findings suggest that deep sea biodiversity hotspots are also likely to be microplastic hotspots, thus compounding the threats already faced by such vulnerable, but globally important biological communities.

Numerical modelling of equilibrium conditions for turbidity currents: examples using submarine channels of the East Coast Basin, New Zealand.

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Whether turbidity currents are in an erosional, depositional or equilibrium state is a key control on where sediment is distributed into deepwater systems. Therefore, being able to predict the flow state – and in particular that of equilibrium flow, which is balanced between erosion and deposition – may enable prediction of turbidite reservoir presence and that of upslope stratigraphic pinch-out traps (through formation of sand bodies that are disconnected from up-dip feeder systems). However, because most sediment transport models do not jointly consider capacity, competence and particle size distribution to estimate the equilibrium condition, their predictive power is limited, and consequently, it is still difficult to predict whether any sectors of a flow pathway are subject to non-deposition. This study adopts a modelling approach that incorporates each of these factors to better understand the occurrence of non-deposition, and hence the development of upslope pinch-out traps. To this end we used morphometric data extracted from the Madden Channel (located in the central portion of the East Coast Basin) to estimate paleaohydraulic conditions using the flow super-elevation method. We then applied the Flow-Power Flux-Balance model to estimate erosion, deposition or equilibrium conditions for turbidity currents, incorporating different grain size distributions in the flow as a function of the slope gradient. We show that: 1) equilibrium flow conditions in the Madden Channel are controlled by local changes in the seafloor gradient (here predominantly related to the presence of tectonic structures), by flow height and by the grain size distribution in suspension; 2) the deposition of very fine sand in bathymetric lows is more likely to occur when turbidity currents transport narrower particle size distributions in suspension (i.e. when the sediment carried by the flows is well sorted); 3) axial profiles showing zones of bypass across steeper slope sections juxtaposed with lower gradient zones of deposition represent ideal conditions to allow up-dip stratigraphic trapping. The immediate results may allow prediction of stratigraphic trap presence and location in the local subsurface and the general approach may find application more widely.

Research and application of petrophysical facies in low permeability reservoirs—a case study of Chang 6 reservoir of Jiyuan Oilfield in Ordos Basin

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At this stage, China's key development targets are low-permeability and ultra-low permeability reservoirs which are poor in physical properties, strongly modified by later diagenesis, and complex in microscopic pore structure. Therefore, a comprehensive study of such reservoirs is of great significance. Petrophysical facies, which has been widely developed in recent years, is a research method for the effects of comprehensive sedimentation, diagenesis and later modification on reservoir performance. Its advantage is that it avoids the use of a single means to study the reservoir.

In this paper, logging data, drilling data and core flake are used to study the sedimentary facies, diagenetic facies and fracture facies of the Chang 6 reservoir in the Jiyuan Oilfield, Ordos Basin. On this basis, the types of petrophysical facies in the study area are determined by superimposing the above three. Using the experimental data such as RQI value, high pressure mercury injection, nuclear magnetic resonance, and real sandstone simulated displacement experiment, the microscopic pore structure characteristics of the petrophysical facies are evaluated. Finally, the favorable pore infiltration development zone is predicted based on the actual production data. The research indicates that Sedimentary microfacies in the study area include subaqueous distributary channels and subaqueous diversion bays; Diagenesis is divided into constructive and destructive; Tectonic effect is reflected as locally developed and high angle oblique crack. Combining the above three, the three petrophysical facies types are summarized and the corresponding RQI values of each petrophysical facies are calculated, so that the single well is evaluated longitudinally. Finally, two small layers of the Chang 6 reservoir are taken as research objects, and the prediction of distribution of favorable pore infiltration zone in the study area is completed by dividing the plane distribution of the petrophysical facies and determining the distribution of the favorable petrophysical facies (PF1).

Structural and palaeoclimatic controls on deep-water syn-rift depositional systems

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Deep-water syn-rift systems respond to interactions between multiple sedimentary inputs, fault-related topography, and hinterland drainage over short spatial and temporal scales. This results in a complicated stratigraphic architecture, which can be challenging to characterise and predict with limited datasets. As a result, existing conceptual models have struggled to address stratigraphic variability at small spatial (10s of metres to 5-kilometre distances) and high-order temporal (10^5 years) scales. Outcrop investigations provide an appropriate scale to address this scale gap. However, exhumed systems are rare or complicated by inversion tectonics. The West Xylokastro Fault Block (Corinth Rift, Greece) provides an Early-Mid Pleistocene, exhumed ~35 km^2 syn-rift depocenter. This depocenter received contemporaneous axial supply from a Gilbert delta-fed deep-water system at the fault tip, and a transverse supply from a fault-scarp apron. Here, we integrate geological mapping, 3D outcrop models, and an onshore research borehole to examine the controls on, and character of, stratigraphic architecture within the West Xylokastro Fault Block. The borehole permits the generation of a chronostratigraphic model supported by palaeomagnetic and palynological data to constrain temporal changes in climate and vegetation. Extensive (100-500 m long) cliff sections in dip and strike orientations, show stratigraphic variability at sub-regional scales and highlight short-scale (<1 km) changes from proximal chute-, channel- and scour-fills and small (20 m x 150 m) conglomeratic base of foreset lobes to more extensive and heterolithic,conglomerate- and sandstone-rich, channelised lobes (15 m x 1.5 km). Minor intra-basinal structures and a competing transverse fault-scarp apron, force this axial system ~3 km from the immediate hanging wall of the West Xylokastro Fault, and complicate the distribution of depositional elements. For example, conglomerate-rich lobes are localised in minor fault-controlled topographical lows, and prolonged channel development is restricted to intra-basinal relays and hanging wall synclines. Coarse-grained supply is interrupted by rare, regionally extensive mudstones. The chronostratigraphy and palynology from the borehole highlights that these deposits occur during major transgressions, which are accompanied by rapid expansion of forest cover in the hinterland. Following the initial phase of large transgressions, semi-arid interglacials can promote the return of sediment supply into the deeper basin. The exposures of the West Xylokastro Fault Block provide a superb example of the stratigraphic architecture of deep-water syn-rift systems. Synthesis with other deep-water syn-rift systems has permitted the generation of new conceptual models for the range of depositional settings and stratigraphic architectures within deep-water syn-rift settings, and how these are influenced by structural domain and palaeoclimate.

Halokinetic modulation of allogenic sedimentation; insights from numerical models and outcrop and subsurface analogues

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Understanding the stratigraphic architecture of syn-diapiric deposits at the salt-sediment interface is important for predicting hydrocarbon and carbon capture and storage reservoir distribution around salt bodies. This interface is difficult to image in subsurface seismic data due to the often steep to overturned bedding, rapid bed-thickness changes, and sharp lithological contrasts; accordingly deposits in salt-influenced mini-basins are different from those deposited in unconfined settings. Integrating observations from subsurface and outcrop datasets into a Discrete Element Model (DEM) provides a very efficient and inexpensive tool to analyse onlap geometry and sedimentary system evolution adjacent to a growing salt body. A DEM has been developed to investigate the interplay between extensional active-passive diapirism and deep-water sedimentation. Model input parameters are taken from the Bakio diapir, Basque Cantabrian Basin, northern Spain and the Pierce diapirs, eastern Central Graben, UK North Sea and their adjacent, halokinetically influenced deep-marine successions. Six experiments were run, lasting for a total of 4.6 Myr. After a 2.2 Myr calibration period sediment was added to the model over three 800,000 year stages: 1) 2.2-3 Myr, 2) 3-3.8 Myr 3) 3.8-4.6 Myr. Sedimentation rate was varied to study the effects of sedimentation on mini-basin individualisation, extent of halokinetic modulation, deformation styles and thickness and facies variability. The six experiments represent: no sedimentation, slow, intermediate and fast aggradation, progradation and retrogradation. Results show that diapir growth is greater with increased sedimentation, in agreement with models of passive diapirism by sediment loading. Slow aggradation results in sedimentation restricted to mini-basins while all other configurations experience sedimentation on the roof of the diapir. In all models, sediment, at least initially, thins towards the diapir crest, often pinching out as deposits approach the flanks. Deposits would likely experience facies changes towards the pinch out, as is observed in the Aptian-Cenomanian succession around the Bakio diapir. Pseudo-well creation highlights that on a field scale heterogeneity around a diapir is high and therefore successions could easily be mis-interpreted as entirely allogenically controlled, despite the obvious halokinetic influence. However, our results suggest that there is a zone of halokinetic modulation, which equates to 4-5 of the diapirs width, within which sediments are primarily controlled by halokinesis. Outside of this zone salt-related influence is probably minimal. Findings suggest that the best stratigraphic traps are formed where deposits onlap diapirs (i.e. close to the diapir). However, best reservoir quality exists further from the diapir, where flows have not interacted with topography and thus deposits are clean, thick sandstones with limited debrites. The models therefore highlight a trade-off between reservoir quality and trap integrity that is also evidenced in the Cabo Matxixako succession of the Basque Cantabrian Basin. Our innovative, iterative approach is capable of improving current understanding of the variables influencing reservoir distribution and stratigraphic trap configuration around extensional-passive diapirs. The findings of our model may help hydrocarbon exploration and production in salt-bearing sedimentary basins, especially in frontier settings where data coverage is minimal and/or of limited quality.

Evolution of a mixed siliciclastic-carbonate system on an unstable margin: the Cretaceous of the Eastern Greater Caucasus, Azerbaijan

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Mixed siliciclastic-carbonate deep water systems, herein termed 'mixed systems', are less well documented than their silicicilastic-dominated counterparts, but may be common globally, and misinterpreted as transition zones. The well-exposed Upper Cretaceous mixed-system of the Buduq Trough, Eastern Greater Caucasus (ECG), Azerbaijan, provides an opportunity to study the interaction between contemporaneous siliciclastic and carbonate deep-marine deposition. The Buduq Trough represents a topographically-complicated deep-marine sub-basin formed within the larger unstable post-rift margin of the ECG. Qualitative and quantitative facies analysis reveals that Upper Cretaceous stratigraphy of the Buduq Trough comprises a Cenomanian-Turonian siliciclastic submarine channel complex, which abruptly transitions into a Coniacian-Maastrichtian mixed-lobe succession. The Cenomanian – Turonian channels are shown to be entrenched in lows on the palaeo-seafloor, with the sequence entirely absent 10 km toward the west, where a persistent Lower Cretaceous high, formed by an extensive mass-transport complex, is suggested to have prevented deposition. This is consistent with palaeocurrent measurements, regional palaeogeographies and thickness maps. By the Campanian this topography was largely healed, allowing deposition of the mixed-deep marine lobe succession across the Trough. Evidence for topography remains, however, in the form of opposing palaeocurrents, major slope failures and mega-clast emplacement. The overall sequence is interpreted to represent abrupt Cenomanian-Turonian siliciclastic progradation , followed by a ~Coniacian retrogradation before a more gradual progradation in the Santonian-Maastrichtian. This deep-marine siliciclastic system interfingers with a calcareous system from the Coniacian onwards, leading to the development of 'mixed' events beds in addition to siliciclastic dominated beds. These beds stack to form mixed lobe complexes which are different to siliciclastic-dominated systems in that they contain both siliciclastic and calcareous lobe elements. These commonly represent different lobe sub-environments making classification of distal and proximal lobe using conventional terminology difficult. Convolution between the two systems in the mixed system has made stacking patterns, and therefore precise system evolution, difficult to decipher. Findings are compared to other topographically controlled analogues, both in outcrop and the subsurface and provide insight into the processes operating in mixed, confined deep-marine sedimentary systems globally.

Some remarks on unconformities developed around salt bodies

Ian Davison

These remarks on unconformities are based on field outcrops around salt domes in Nova Scotia and Portugal.

Giles and Rowan (2012) described J-hook unconformities from the La Popa diapir where the debris flows systematically lie above the angular unconformity, cusp are developed at the salt sediment interface where a J-hook unconformity intersects the diapir wall, and slip has taken place along the J-Hook unconformity. There is no evidence of slip along the unconformities in Portugal or Nova Scotia; nor is there any special reason for slip to occur at J-Hook unconformity, because this will often be an irregular erosion surface filled in by coarse sediment debris. Significant topography can still be present after diapir roof and flank collapse, so that angular unconformities can occur at the base and top of the debris flow.

High- angle flap-onlap unconformities occur where an upturned flap (either a perched or a basal mega flap protrudes at the sediment surface by ca. 100m in extensional and passive diapirs and up to ca. 1 km around compressional diapirs. If there is no collapse of the cohesive sediment in the upturned flap and rotation occurs rapidly then a high-angle (> 30°) unconformity can be developed which is buried by later low-angle onlapping sediment. The stability of the upturned strata will determine whether the bedding can be rotated and elevated to a significant height above the regional sediment depositional surface; or whether the upturned flank collapses into debris flows deposited at a J-hook unconformity.

Low-angle wedge unconformities

Tapered halokinetic sequences with wedge-shaped geometries are often imaged on seismic data, but the actual mechanism of wedge generation is often not clear due to lack of resolution. Stratal onlap thinning, offdome sliding producing downslope thickening, or tectonic thinning after deposition could all create the wedge effect. There is no evidence of tectonic thinning with normal faulting or bedding plane slip or slope sliding with soft wedging in the Lusitanain examples. Instead wedging is mainly caused by many low-angle unconformities of 1- 3° with subtle onlap surfaces developed. This indicates that the salt diapirs have grown unsurprisingly with subtle but pulsed variations in salt flow /sedimentation rate over time.

Dropstones, slime and ice; re-advancing glacigenic interpretation in the Proterozoic Stoer Group (Torridonian) of NW Scotland

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The Proterozoic Stoer Group is a 1.2Ga sequence of clastic red-beds of predominantly fluvial origin, which lies unconformably upon an ancient land surface developed on the 2.8Ga Lewisian Gneiss in NW Scotland. Within the basal part of the sequence, where it lies in close proximity to the underlying basement gneiss, there are a series of poorly sorted cobble deposits, microbial limestones and carbonate cemented laminites. These rocks and the associated features have previously been interpreted as the product of an arid, possibly hot, continental setting comprising alluvial fans and ephemeral lakes[1]. The lowermost part of the sequence has previously, and controversially, been interpreted to have a glacial or glacially influenced origin[2]. More recently, a section of the lowermost Stoer Group has been interpreted as a meteorite impact deposit. The most recent work seeks to cast doubt on the microbial origin of the limestones and re-interpret them as re-worked Palaeoproterozoic deposits that were re-deposited as clasts and cemented at depth[3]. A combination of new analyses, field observations and unpublished legacy data shows that features in the Stoer Group, such as ragged and chemically altered gneiss surfaces, clast-supported conglomerates and desiccation cracks, which were previously cited as evidence precluding a glacigenic origin, have close analogies within unequivocal Quaternary and modern glacial deposits. In addition, new examples of possible glacigenic features including isolated outsize clasts deposited in an aquatic setting, support the presence of ice in the lowermost part of the sequence. New evidence of a microbial origin of the limestones, sedimentary structures and comparisons with recent examples of microbial mats in glacial settings, reiterates the original interpretation of the limestone and supports the previously published, low temperature interpretation of oxygen isotope data. The microbial material recovered from the limestones may represent some of the oldest multicellular microbes yet found in the UK, adding to the importance of these rare and relatively under-studied outcrops.

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Ancient contourite channels and their sedimentological criteria – case study from Upper Miocene deposits in the southern Rifian 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 their scientific and economic importance, these bottom current deposits and their diagnostic sedimentological criteria are not well understood.

In this study we investigate four 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 outcrops we improve the understanding in the effects of Late Miocene Mediterranean overflow on oceanographic processes and climate.

The marine upper Tortonian to lower Messinian Riffian Corridor deposits are 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 focus is on the newly recognized set of three large vertically stacked sandy contourite channel deposits. We find that these 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.

Sedimentological analysis allowed us to better constrain the different morphological parts of the channel (e.g., axis, flanks, proximal or distal) as well as the long-term paleoenvironmental changes, which reflect a shallowing trend throughout the corridor from the Tortonian to the Messinian.

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

A Depositional model for deep-lacustrine turbidite fans: examples from the North Falkland Basin

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The controls, and their relative level of influence, on sedimentary fill in deep-lacustrine basins versus that of their deep-marine counterparts remains an interesting and potentially under-appreciated topic in the literature. Despite there being comparable controls on sedimentation in both settings, such as the influence of tectonics on sediment delivery and overall structural configuration, there are many differences. For example, in deep-marine settings eustatic sea level variation imparts a strong control on sedimentary processes and resultant deposits, whereas in deep-lacustrine settings, climate and climatic variability (regional and local) are more relevant. The different controls potentially lead to the formation of contrasting sedimentary deposits in deep-lacustrine basins, compared to marine counterparts. In deep-lacustrine settings, sub-aqueous sediment gravity flows (e.g. turbidity currents) are the principal delivery mechanism of coarse(r) grained material from the margins into the deepwater areas. The resultant deposits (principally deep-lacustrine turbidite fans in this study) have the greatest potential to document and record the variability in sedimentary processes occurring in deep-lacustrine basins. The early Cretaceous-aged Sea Lion Fan represents an interesting and complex sand-rich deep-lacustrine turbidite fan, deposited in the North Falkland Basin of the Falkland Islands. The Sea Lion Fan comprises three lobes, including (from oldest to youngest): Sea Lion 20, Sea Lion 15, and Sea Lion 10. Internally, the lobes display a series of intricate seismic architectures observed in 3D seismic data, including feeder systems, sinuous lobe axis deposits, flow deflection, stranded lobe fringe areas and terminal mouth lobes. Analysis of core data collected from across the Sea Lion Fan confirms a complex sedimentary system, comprising high-density turbidites, low-density turbidites, hybrid event beds and hemi-limnic background sedimentation. Seismic mapping and core analysis are combined to produce a depositional model of the Sea Lion Fan, and by association deep-lacustrine fan systems in general. From examination of Sea Lion Fan cores, and by comparison to deep-marine systems characterised in the literature, deepwater sedimentation in both lacustrine and marine settings appears to form a similar suite of sediments, from high-density to low density turbidite deposits, through to hybrid event beds and background deposition. One key difference between these two environments may be an affinity for turbidite fan and lobe elongation in deep-lacustrine settings. Sea Lion's fan morphology appears constrained to linear belts, along which the internal lobes display an elongate geometry. Internally, the lobes are characterised by sinuous lobe axis deposits, which form parallel to the overall elongation of the fan. Fan/lobe elongation is interpreted to be influenced by a combination of: the size of the flow entering the basin compared to pre-existing palaeobathymetry; a critical difference between the rheology and characteristics of flows entering the fresh–brackish water (lacustrine) basin; and flows that were likely highly efficient, probably by virtue of high sediment volumes. Studying deep-lacustrine turbidite fans is important as they often form relatively isolated sand-rich successions surrounded by thick encasing hemi-limnic mudstones, and therefore have the potential to form effective reservoir bodies in the subsurface. Consequently, these systems are becoming a globally recognised focus for hydrocarbon exploration, and they could be considered valuable for other applications of subsurface fluid storage such as carbon capture and sequestration or natural gas storage in the future.

Core bottom currents affecting ichnological signature within a muddy contourite drift: a case study from the NW Iberian Margin

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Ichnological analysis is a powerful tool for sedimentary basin research due to the palaeoenvironmental information provided by trace fossils. For this reason, bioturbation has been proposed by some researchers as a potential criterion to differentiate contourites from associated deposits, which is not, sometimes, an easy matter (Rodríguez-Tovar and Hernández-Molina, 2018 for a recent review). During the last years, some detailed studies about ichnological signature of contourites deposits have been published (e.g., Miguez-Salas and Rodríguez-Tovar, 2019; Rodríguez-Tovar et al., 2019), but the research is still in the first stage. Thus, some aspects, as the lateral variations in the ichnological features along a contourite drift have not been explored yet. Here we analyse contourite deposits from gravitational cores retrieved across a Quaternary muddy contourite drift in the NW Iberian Margin (Mena et al., 2018). The ichnological data show spatial differences from sites close to the core bottom current to more distal settings. A higher sedimentation rate and more organic matter availability is registered in zones closer to the core bottom current, allowing the bloom of *Palaeophycus* producers. Opposite, both values are lower in distal settings, favouring the development of *Zoophycos* trace makers. These observations reveal that the trace maker community is significantly affected by the distance to the core bottom current, demonstrating an impactful application of ichnological analysis in contourite research. Ichnological content can be used to differentiate contourites from associated deposits as it is pointed by some researcher, but also, in a new approach, to differentiate areas within a contourite drift based on the distance to the core bottom current.

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Evolution of sandstone reservoir quality due to mineral alteration in proximity to igneous intrusions

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Igneous intrusions are common features within rifted sedimentary basins. With advances in technology, exploration has progressed into more complicated petroleum systems where sediments are segmented and altered by networks of dykes and sills. Magmatism within sedimentary basins leads to an increase in temperature and fluid pressure and subsequent movement of mineral-rich hot fluids. These hot fluids pass through pores and fractures altering the original mineralogy by mobilizing and redistributing minerals. However, few studies have addressed the quantitative impact that intrusions have on sedimentary host rocks as a result of dissolution and mineralisation and subsequent impacts on reservoir quality. A combination of core plug porosity and permeability, microscopy, SEM and cathodoluminescence have helped give further insight into mineralogical and petrophysical changes to sandstones within thermal aureoles. The general assumption of only decreasing petrophysical profile toward igneous bodies should not necessary be considered the go to 'rule of thumb'. From our analyses of two intruded sandstones, reservoir quality was found to be altered both positively and negatively by (1) remobilisation of carbonate cements within a calcareous sandstone and (2) Illitisation of pre-existing kaolinite clays and quartz precipitation within a clay-rich sandstone. This study has shown that intruded sediments can have a wide range of reactions and effects on reservoir quality need to be studied on a case-by-case basis. Understanding how sediments are affected by intrusions has significant implications for reservoir quality and migration in magma-rich sedimentary basins.

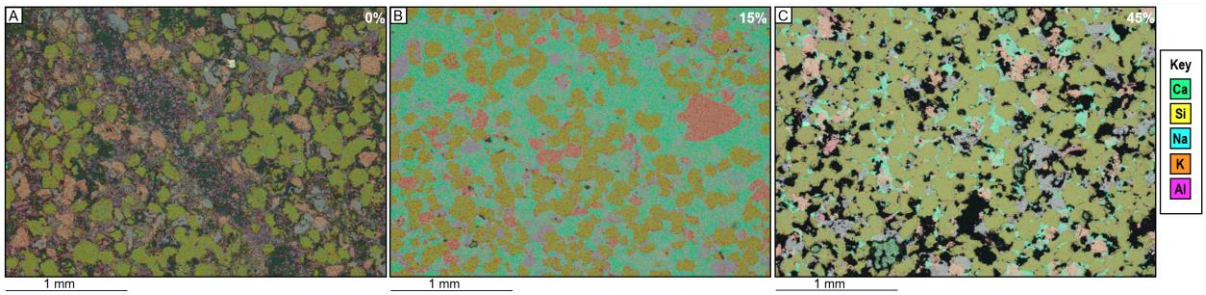

Fig 1. Calcareous sst, EDS maps-Selected elements showing chemical composition of host rock with distance in % intrusion thickness from sill. Calcite represented by green, yellow- quartz grains, orange- potassium feldspar, blue- plagioclase feldspars, black- porosity. (A) contact zone, high porosity 38% no carbonate (green) material present (B) Reduced zone 7-35 % i.t., calcite material (allochems and cements) fill significant portion of the rock, core plug porosity c. 1-2%. (C) from 35-60% i.t. distance from intrusion, porosity increases up to 10% seen as black with reduction in carbonate material.

A critical appraisal of the Rouse equation as a simplified model for particle suspension in turbidity currents

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The margins of submarine channels are characterized by deposits that fine away from the channel thalweg. This grain-size trend is thought to reflect upward fining trends in the currents that formed the channels. This assumption enables reconstruction of turbidity currents from the geologic record, thereby providing insights into the overall sediment load of the system. It is common to assume that the grainsize and concentration distribution inside a turbidity current can be modelled with simple diffusion models, such as the Rouse equation. Yet the Rouse equation was developed to describe how particles should be distributed through the water-column in open-channel flows such as rivers, which fundamentally differ from turbidity currents in terms of their flow structure. Consequently, a rigorous appraisal of the Rouse model in deep-marine settings is needed to validate the aforementioned flow reconstructions.

In this presentation we provide a robust evaluation of the Rouse model's predictions of vertical particle segregation in two experimental turbidity currents that differ only in terms of their initial bed slopes (4° versus 8°). The concentration profiles of the coarsest sediment, which is suspended predominantly in the lower part of the flow, is accurately reproduced by the Rouse equations. The equations can thus be applied for flux estimates of fine grained and coarser sands that are predominantly transported in the lower sections of submarine channels. Significant mismatches appear, however, in the concentration of finer grained sediment, especially towards the top of the flow. This problem is caused by the mixing with clear water at the top of turbidity currents, which is not included in the derivation of the Rouse equation. Caution is especially advised in applying a Rouse model to levee overspill and levee-crest deposits. Also, sediment with a very-fine grained particle sizes and silt are problematic. For these grainsizes, the so-called Rouse number appears not to be a parameter that characterises the shape of the concentration profile, such as commonly assumed. This is especially significant since the Rouse number is now showing up in analyses of fluxes of microplastics, terrigenous organic matter, and pollutants adhered to silt and clay, which all behave hydrodynamically similar to muddy sediments, and are thus poorly represented by the Rouse equation. We therefor call for fundamental research into the suspension and transport of particulate matter in turbidity currents in response to the rapidly diversifying array of research question asked of deep-water sedimentologists.

Middle Jurassic "syn-rift" sedimentary systems in the Northern Carnarvon and Roebuck Basins of the NW Shelf of Australia

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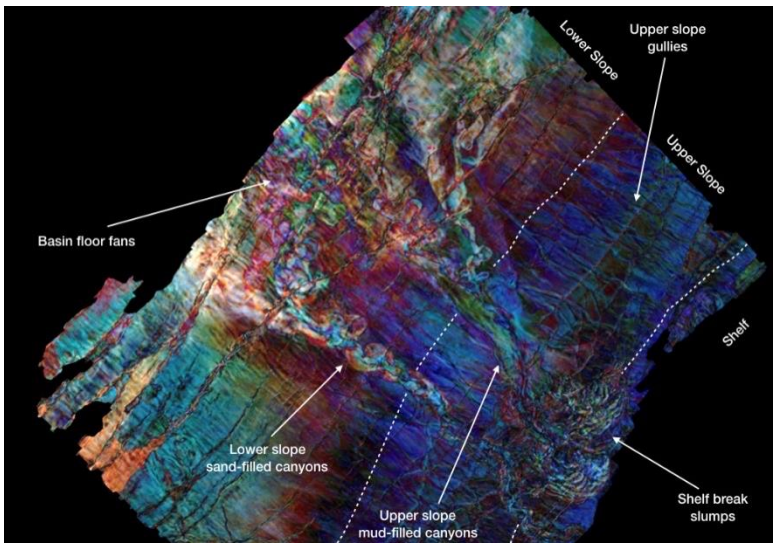
There are two widely recognised phases of Mesozoic extension on the North West Shelf of Australia. The first started in the latest Triassic and continued until the Middle Jurassic, and is often associated with rifting that resulted in the formation of the Argo Abyssal Plain at 155 Ma. The second started in the Upper Jurassic and continued until the Valanginian, when Greater India and Australia separated, forming the Gascoyne and Cuvier Abyssal Plains at c. 135 Ma. However, there is little agreement as to the precise timing of these events – the North West Shelf covers a vast area and recent work has shown many events in the evolution of the margin are diachronous. Mesozoic rifting is a case in point. Rifting clearly initiated in the western part of the Northern Carnarvon Basin in the latest Triassic, in central parts of the basin in the early Jurassic, and was not active until the Callovian in the eastern part of the basin. Indeed, at this time, the boundary between the Northern Carnarvon and the adjacent Roebuck Basin does not appear to have been a significant geological feature. Seismic facies analysis shows fluvial systems belonging to the Legendre Delta in the Roebuck Basin were feeding shelf and shelf edge systems in the eastern part of the Northern Carnarvon Basin, where there was little fault activity. There is a dramatic reduction in sediment thicknesses west of the shelf edge, with sediments presumably being diverted into the emerging marginal basins, and condensed Jurassic sequences onlapping onto rotated fault blocks in the western Exmouth Plateau. The Middle Jurassic sedimentary systems are clearly responding to the evolving rift system, but the timing of fault activity, and the orientation of many of the faults, does not sit easily with existing tectonic reconstructions.



Middle Jurassic shelf edge sedimentary systems, NE Exmouth Plateau

Sedimentary and stratigraphic archives of Late Pleistocene terrestrial drainage network evolution at Dogger Bank

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Dogger Bank, in the Southern North Sea, was covered by the British-Irish Ice Sheet prior to its deglaciation by approximately 23 ka BP. Subsequently, it was exposed subaerially, before marine transgression at approximately 8.5 ka BP. During this window of subaerial exposure, the Dogger Bank area experienced climatic warming after deglaciation, which may have altered the sedimentary environments and drainage basin characteristics. The vulnerability of drainage networks to changes in the palaeoclimate may provide insight into future hydrological changes under projected climate warming. Investigation of an integrated dataset of high-resolution seismic reflection data and Cone Penetration Tests, acquired for windfarm site investigation, has revealed a channel network, incising glacial and proglacial lake sediments, which sits below coastal and shallow marine sediments. These channel-fills are interpreted to represent terrestrial drainage networks. When mapped out, the morphology and sinuosity of the channel forms reveal two distinct sets of channels. The first set comprises two straight, wide (400 m) channels that contain macroforms interpreted to be braid and side bars. The long profile of these channels show flow direction was from north to south in one channel, and west to east in the other channel. These channels are interpreted to be proglacial rivers, draining the ice sheet margin to the north. The second set of channels are more sinuous and all have heads within the study area. These channels form a tributive subdendritic network that flows into to the proglacial rivers. These channels are interpreted to have formed later, based on their differing morphology and channel long profiles that incise down towards the proglacial channels. The timing of channel formation lacks direct constraint. However, the first set of channels, the proglacial rivers, must have formed as the ice sheet was still on Dogger Bank, before 23 ka, to supply meltwater to the rivers, but after the filling of the proglacial lake basin with fine-grained lake sediments. Palaeoclimate modelling was used to generate precipitation profiles for Dogger Bank, and this shows a cold and dry period after the ice sheet retreat and until 17 ka. After this, precipitation increased, which would have allowed the second set of channels to form, draining precipitation from the land surface. These rivers were then active until marine transgression at around 8 ka. This landscape evolution provides unique insights into the changes in drainage of the North Sea Basin during climate warming.

Investigating the sedimentary rock record using text mining

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Here we demonstrate the application of text mining interfaced with a stratigraphic database in order to understand deep-time geological processes. This presentation will describe use of the GeoDeepDive digital library and machine reading system in order to delineate geological events through time. At time of analysis, the GeoDeepDive library contained ca. 11 million published documents, including most content from publishers such as Elsevier and Wiley. We executed an algorithm in order to decompose sentences into speech and linguistic components using Stanford natural language processing (CoreNLP).

The redox state of the oceans exerted a key control the evolution and diversity of life, and the distribution of black shale resources (including roles in mineral systems) through time. Therefore we utilize the changing proportion of pyrite-bearing sedimentary rocks as a proxy for key ocean redox events. Target phrases extracted from the digital library, such as 'pyrite framboids' and 'pyrite concretions', were linked via an application programming interface (API) to sedimentary stratigraphic packages recorded in the Macrostrat database. The pyrite record delineates the widely recognised key redox events, such as; the Great Oxidation Event; onset of ferruginous global ocean conditions at the start of the Neoproterozoic, and; Phanerozoic 'ocean anoxic events' (OAEs), for example during the Permian-Triassic transition and Early Toarcian (Jurassic) OAE. The ratio of pyrite concretion/nodule-bearing rocks versus framboid-bearing rocks may delineate fundamental changes to element cycling (trace metals) in the marine environment. Ultimately this can be used to improve our understanding of the controls on basin/belt hydrocarbon and sedimentary mineral system fertility.

The provenance of loess-palaeosol sequences along the Middle and Lower Danube

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Sediment provenance is a powerful tool in understanding sediment system dynamics, and through them climate. Yet detailed provenance investigations are not very widespread in loess research. Investigations of loess-palaeosol sequences can provide unique insights into sediment dynamics, production, transport and deposition over various time- and spatial- scales, from local to continental. However, provenance information needs to be examined alongside high resolution absolute chronologies, to identify drivers of the process, link with other archives and quantify rates of process over the longer term.

Great advances in understating provenance of loess deposits on the Chinese Loess Plateau (c.f. Nie et al., 2015) have been made by moving away from bulk sample analysis to single grain resolution of analysis, in particular U-Pb dating of detrital zircons. Comparatively limited single-grain work has been done in Europe to date. Here we present the results of provenance analysis from three loess-palaeosol sequences along the Danube, in Croatia, Serbia, and Bulgaria. For the first time in loess provenance research, U-Pb dating was combined with Hf isotopes from single grain zircons in a systematic manner, to investigate multiple loess-palaeosol units at high resolution. The results of the single-grain zircon analysis are compared with existing published potential source records to explore the primary sediment sources and sediment transport pathways on a source to sink scale. We demonstrate that geomorphological source for loess deposits are alluvial floodplains, while the Alps and Carpathians are identified as main primary source. Additionally, we identify several smaller sources which haven't been explored showing that production mechanisms for loess sediment must be revisited.

Spatial and temporal variability in the stratigraphic evolution of muddy and unstable continental slopes: an example from the Shannon Basin, western Ireland

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Muddy, steep-sided continental slopes with high sedimentation rates can lead to slope instability and mass wasting. This *en masse* remobilization of the ocean floor can create local topography, resulting in complicated sediment routing and ponding of gravity-flow deposits. The Shannon Basin of County Clare, Ireland, provides a record of one such muddy and unstable slope; the Namurian Gull Island Formation. This 200 m thick succession has been investigated at Killard and Doonbeg using drone photography, sedimentary logging, and facies analysis, to reconstruct the basin fill history. Steeply dipping strata associated with a broadly E-W trending anticline reveal an upwards transition from a basal mass transport complex (MTC) to a ~30 m thick laterally continuous (~2.5 km exposed) sandstone succession that exhibits evidence of channelization. Above this is another ~150 m of muddy MTC exposed at four locations across the study area with pronounced variation in lithofacies between each locality. At Location (1) sandstone packages are rare and occur within a mostly homogenous sheared mudstone. At location (2) there are frequent sandstone 'balls' that occur within distinct, but discontinuous layers. At location (3) large rafts of sandstone up to 5 m thick and 50 m long are observed along shear surfaces that indicate slumping in a westerly direction. Finally, location (4) features a thick 20 m scoured, compensationally stacked sandstone section. The lower laterally continuous sandstone is interpreted to represent ponding of turbidites within earlier MTC topography and records channel propagation through a channel to lobe transition zone. In the upper MTC, we propose that the thick scoured sandstone section present in location (4), but progressively less so in locations 3-1, documents a major remobilization event that has stripped away most of this succession and presumably deposited it further down the slope towards the basin floor. These findings support previous interpretations that the Gull Island Formation is the expression of a muddy and unstable slope in the ancient Shannon Basin. Mass movement in multiple directions is indicative of local slope variability. This results in difficulty reconstructing the orientation of the ancient regional slope based off this single study area. Highly variable paleoflow directions recorded in turbidite beds are interpreted to again reflect the local topographic variability which induced pronounced flow deflection in ponded intraslope deposits. This study demonstrates the intermittent nature of channel propagation through muddy unstable slope systems, and how this slope instability can consequently reorganise the stratigraphy. These findings can be applied to larger subsurface datasets to aid reconstruction of mass movements and support predictions on where thicker sandstones may be in depositionally unstable and locally variable continental slopes.

Diagenetic control on mineralogical suites in sand, silt, and mud (Cenozoic Nile Delta): Implications for reservoir quality

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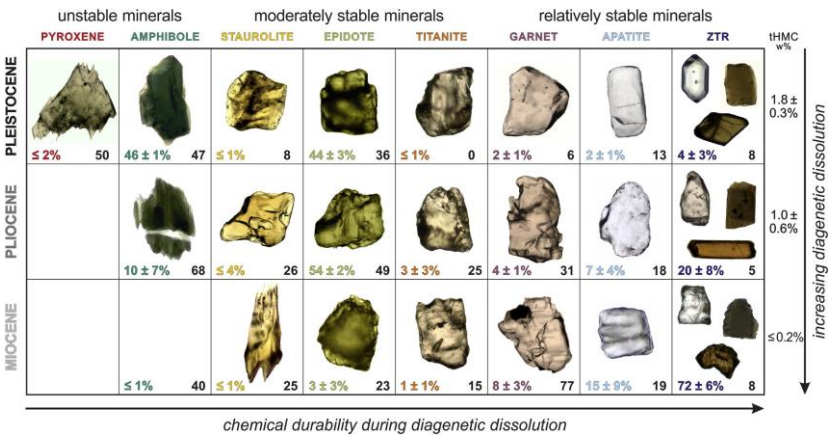
This Nile Delta case study provides quantitative information on a process that we must understand and consider in full before attempting provenance interpretation of ancient clastic wedges. Petrographic and heavy-mineral data on partly lithified sand, silt, and mud samples cored from the up to 8.5 km-thick post-Eocene succession of the offshore Nile Delta document systematic unidirectional trends. With increasing age and burial depth, quartz increases at the expense of feldspars and especially of mafic volcanic rock fragments. Heavy-mineral concentration decreases drastically, transparent heavy minerals represent progressively lower percentages of the heavy fraction, and zircon, tourmaline, rutile, apatite, monazite, and Cr-spinel relatively increase at the expense mainly of amphibole in Pliocene sediments and of epidote in Miocene sediments. Recent studies have shown that the entire succession of the Nile Delta was deposited by a long drainage system connected with the Ethiopian volcanic highlands similar to the modern Nile since the lower Oligocene. The original mineralogy should thus have resembled that of modern Delta sand much more closely than the present quartzose residue containing only chemically durable heavy minerals. Stratigraphic compositional trends, although controlled by a complex interplay of different factors, document a selective exponential decay of non-durable species through the cored succession that explains up to 95% of the observed mineralogical variability. Our calculations suggest that heavy minerals may not represent >20% of the original assemblage in sediments buried less than ~1.5 km, >5% in sediments buried between 1.5 and 2.5 km, and >1% for sediments buried >4.5 km. No remarkable difference is detected in the intensity of mineral dissolution in mud, silt, and sand samples, which argues against the widely held idea that unstable minerals are prone to be preserved better in finer-grained and therefore presumably less permeable layers. Intrastratal dissolution, acting through long periods of time at the progressively higher temperatures reached during burial, can modify very drastically the relative abundance of detrital components in sedimentary rocks. Failure to recognize such a fundamental diagenetic bias leads to grossly mistaken paleogeographic reconstructions, as documented paradigmatically by previous provenance studies of ancient Nile sediments.



Bottom current modification of turbidite lobe complexes

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Seafloor topography affects the distribution and sedimentological characteristics of deep-marine sedimentary systems and is prevalent in active tectonic margins or diapirism. However, recent work showed that bottom current influenced margins comprise a complicated topography caused by erosion or deposition of fine-grained drift deposits as well as the potential for complex interactions of margin parallel bottom currents with sediment gravity flows. Understanding these interactions is crucial to correctly interpret the stratigraphic record and the distribution of coarse grained sedimentary systems. This study assesses how terminal turbidite lobes are affected by bottom currents and their deposits by incorporating high resolution 3D seismic and core data from the East African Margin augmented. Lobe complexes in the Upper Cretaceous were deposited in the topographic lows associated with fine grained, up-slope migrating drift deposits and large sediment waves. The shape of the drift deposits governs the large scale shape of the deposits that ranges from crescent shaped to elongated and asymmetrical lobes. Core data reveal thick, massive, high density turbidites (HDTs) in the lobe axis position with steepening cross bedding and pervasive dewatering towards the top, which indicates rapid deposition. At the lobe off-axis and fringes, low density turbidites (parallel laminated and ripple-laminated) are inter-bedded with bioturbated, muddy siltstones that show starved ripples, and streaks of up to fine sandstone, which are interpreted to represent bottom current reworking. This facies distribution reflects temporal and rheological differences of the two interacting flow processes. “Quasi steady bottom currents” build drifts and sediment waves along the lower slopes over a long period of time, which act as focal points for shorter duration, highly energetic sediment laden gravity flows. During periods of high sediment availability, lobe complexes develop in a fill and spill fashion, similar to confined mini-basins with increased flow velocities and rapid deposition of HDTs. Dilute turbulent flows towards the lobe off-axis and fringes may directly interact with the bottom currents and be laterally re-distributed. When sediment input is limited (i.e. a lower frequency of sediment gravity flows) or the system is less confined, individual turbidite bed are reworked and interbedded with fine grained drift deposits. Mixed turbidite and contourite systems cause a strong modification of the overall shape and run-out distance of sediment gravity flows due to the highly mobile and complex relief and a direct modification of lobe fringes due to direct flow interactions. It is therefore crucial to take both processes into account to correctly interpret the evolution of bottom current influenced margins.

Sandstone provenance and tectonics using detrital zircon metamorphic rim U-Pb dating

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The Late Cretaceous paleogeographic position of the Insular Superterrane of the western North American Cordillera is disputed. The consensus view has been that the Insular Superterrane was accreted close to its present position on the southwestern Canadian margin, despite paleomagnetic evidence to the contrary. The paleomagnetic evidence, and more recently, several detrital zircon datasets, require that the Insular Superterrane was accreted at the latitude of southernmost California. Cretaceous strata of the Nanaimo forearc basin exposed on Vancouver Island, provide an important independent test of the Late Cretaceous paleogeographic position for the basin and associated terranes. Zircon rims are ubiquitous on Proterozoic detrital zircon populations in the basin and provide a record of metamorphism and magmatism in the source region. Here we use depth-profiling to measure the ages of these overgrowths and compare this to tectono-magmatic events in southwestern Laurentia. Cathodoluminescence imaging and U/Th ratios were used to classify zircon rim growth as metamorphic or magmatic. Grains with high U/Th ratio rims indicate metamorphism in the source region mostly between 100 Ma and 66 Ma with a peak at 86 Ma. Low U/Th ratio rims indicate magmatism in the source region mostly between 110 Ma and 64 Ma with a peak at 80 Ma. Core age populations (peaks at 1698 and 1388 Ma) are similar for grains with rims of metamorphic or magmatic affinity, suggesting the source region underwent metamorphism and partial melting in the Late Cretaceous. The timing of metamorphism and magmatism in the extra-regional source area are a good fit to tectonic events in the Mojave-Sonoran Region. Specifically, metamorphism and partial melting of the Pelona-Orocopia-Rand (POR) schists of southern California closely match to timing of rim growth in the source region for the Nanaimo Basin, supporting a southerly paleoposition for the Insular Superterrane. In addition to the above, metamorphic rim data from Cretaceous forearc basins like the Nanaimo Basin and exhumed schist complexes with froearc sediment protoliths in southern California and on the Insular Superterrane (e.g. Swakane Gneiss) provide evidence for rapid cycling in the Cretaceous forearc. For example, the youngest metamorphic rims in Nanaimo Basin samples are, on average, only 5 m.y. older than the depositional age of the sample indicating that exhumation of the metasedimentary source rock for the Nanaimo Basin was rapid following metamorphism and began before 84 Ma when the first grains with rims occur in the Nanaimo Basin. Exhumation of the metasedimentary source rock for the Nanaimo Basin predates deposition and underplating of parts of the POR schists and the Swakane Gneiss (a schist complex on the Insular Superterrane that is very similar to the POR schists), indicating that underplating and exhumation of metasedimentary rocks was contemporaneous in the Cordillera and probably part of a cyclical process involving, sediment subduction, metamorphism, underplating, exhumation, erosion and redeposition along the Southwestern margin of North America in the Late Cretaceous.

Impacts of early diagenesis of organic-rich mudstones: an example from the Morridge Formation, the Widmerpool Gulf, UK.

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An understanding of the diagenetic processes impacting organic-rich basinal mudstones lays a good foundation for studying the nature of fluids that have circulated within the basin. Of particular interest are the sources of silica and aluminium during the early diagenesis. The Widmerpool Gulf, one of the Carboniferous basins in northern England, has been selected for this study due to the presence of sub-surface core material. This research utilizes the petrographic and mineralogical data from mudstones from the Morridge Formation in the Carsington Dam Reconstruction C4 borehole to investigate above questions. The total organic content of the studied samples ranges from 1.3 to 4.3 wt%. Whole rock XRD analysis shows that the studied samples are composed of muscovite, quartz, carbonates (calcite, dolomite and siderite), kaolinite and chlorite. Muscovite and chlorite are detrial in origin. Early diagenetic products include authigenic calcite, kaolinite, non-ferroan and ferroan dolomite, siderite, quartz and pyrite. There are three textures of pyrite, namely framboidal, anhedral and euhedral pyrite. Framboidal pyrite is trapped in the kaolinite cement and considered to be the first product formed during the early diagenesis. Kaolinite mainly filled in the intraskeletal pores with a vermiform habit. Most kaolinite cements are associated with pyrite and quartz. Anhedral pyrite was formed at the rim of a kaolinite assemblage indicating its formation postdates the latter. In some cases, the calcite cement is present with the kaolinite cement in the same shelter porosity and they appear to have precipitated approximately simultaneously. Based on the inclusive relationship between pyrite and dolomite, euhedral pyrite was formed following anhedral pyrite but before the precipitation of dolomite. Ferroan dolomite commonly occurs as the rim of non-ferroan dolomite and is surrounded by siderite in some cases. Quartz is a late product in the early diagenesis and present as a cement surrounding clay-mineral assemblages and pyrite. No smectite and illite was detected in the studied samples. Therefore, amorphous silica is a possible source for authigenic quartz. Aluminium released during the maturation of organic matter is a likely source for the kaolinite cement and its mobility is significantly increased by organic acids. This indicates that the mobility of dissolved silica and Al plays an important role during the diagenesis. The widespread occurrence of kaolinite cements also reveals the presence of organic-rich fluids during the early diagenesis of mudstones.

Reservoir Characteristics and Evaluation of Tight Sandstone of Chang 8 Member in Zhenbei Oil Field, Ordos Basin

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Abstract: Zhen 218 well area is the main oil producing area of tight sandstone of Chang 8 member in southwest Zhenbei Oil Field. However, the single well production is low and the productivity varies greatly. The petrological characteristics, diagenesis physical properties, pore structure and seepage characteristics of reservoir were studied and evaluated by using data of cast thin sections, scanning electron microscope, cathodoluminescence, high-pressure mercury injection, petrophysical analysis, nuclear magnetic resonance, gas-water relative permeability experiment and gas test, and the relationship between reservoirs type and natural gas productivity was discussed. The results show that the reservoir rocks of Chang 8 member in the study area are mainly lithic feldspar sandstone. The fillings are basically cements which are mainly illite, siliceous and calcareous. Digenesis are mainly compaction-pressure solution, cementation and dissolution. The pore types are mainly secondary pores such as debris dissolved pores and intercrystalline pores, and the pore structure mainly consists of fine pore-small throat. The saturation of movable fluid varies greatly, which is closely related to physical properties and increases with the improvement of physical properties. Based on the characteristics of reservoir physical properties, pore structure, sedimentary facies zone and sand body distribution, the reservoir of Chang 8 member in the study area was divided into four types. The productivity of natural is obviously controlled by reservoir types, and with the decline of reservoir type, the natural production gradually decreases. The research results can provide reference for the effective development of tight sandstone reservoirs.

Key words: Tight sandstone; Reservoir characteristics; Pore structure; Zhenbei Formation; Ordos Basin

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Infrequent large events versus frequent small events: importance for submarine channel evolution

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Turbidity currents carve spectacular canyons and channels in the seafloor, which can extend for thousands of kilometres, rivalling the length of rivers on land. However, turbidity current systems differ from rivers in their large variability in discharge. Subaqueous channels host many small events and more infrequently, large events. How these large and small events contribute to the evolution of submarine channels is currently poorly understood. These canyons and channels are important conduits for sediment, nutrients, pollutants, and organic carbon to the deep-sea. Understanding these systems is important because they can influence marine ecosystems and geochemical cycles. The deposits they create can form valuable hydrocarbon reservoirs, while the flows themselves pose a hazard to seafloor infrastructure including cables that facilitate >95% of global data transfer. The often remote nature of submarine channels, and the powerful episodic flows that occur within them, pose challenges to direct monitoring of active systems; hence, much of our existing understanding is based on ancient systems or scaled-down experiments. Recent developments in technology have enabled direct measurements to be made of turbidity currents in the field. However, the flows that have been measured to date are presumably on the smaller end of a spectrum, and may not be those that fundamentally sculpt seascapes or build seismically-resolvable depositional sequences. Sequences of frequent small 'canyon filling' events followed by an occasional bigger 'canyon flushing' event have been proposed to control sediment transport in these systems. However, smaller flows have been demonstrated to be able to create and cause migration of bedforms, that are hypothesised to be the 'building blocks' of submarine channels. The role of small frequent flows compared to infrequent larger events in channel evolution remains unclear, and competing ideas exist. Here we present time-lapse bathymetry mapping of an extremely active submarine channel in Toba Inlet, British Columbia. Here we can compare the erosional and depositional patterns related to different scales of events. The surveys record the influence of frequent sub-annual turbidity currents, which dominantly promote deposition in the proximal reaches of the channel. Between two of the surveys, a 1,000,000 m^3 submarine slope failure occurred on the prodelta slope. This is the first site ever where we can directly compare the resulting erosion and deposition of these different scale events in a single system. The collapse triggered up to 15 metres of erosion and eroded metres deep into the prodelta, before reaching the main channel. This event affected the channel along its full length, including up to 8 metres of erosion in the most distal part of the channel. This distal part of the system remains inactive between surveys that do not cover this submarine slope failure. Here, our results show that frequent flows create sediment accumulation on the prodelta and promote channel fill in the proximal part of the system; this occurs over short timescales. Instead, infrequent large events control the submarine channel evolution and the ultimate preservation potential of channel fill deposits along the full-length of the channel.

Depositional and erosional contourites features in the Morondava Basin, offshore Madagascar

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Over the last decade, numerous bottom current–controlled (contourites) depositional and erosional features have been recognized in deep-water settings. While most contourite deposits (drifts) are mud dominated, sandy deposits have also been recognized, especially with advances in high-resolution three-dimensional (3-D) seismic data interpretation and implementation of seismic attributes. Deep-water sand deposits are usually interpreted as forming from sediment gravity flows. Some deep-water, sand-rich deposits, however, are interpreted to have formed or been reworked by bottom currents, especially along contourite terraces and channels. A contourite depositional system (CDS) developed during the Paleogene along the Morondova Basin, offshore Madagascar (SW of the Indian Ocean) is presented here for the first time. It was recognized by a detailed seismic analysis using high quality 3D seismic data and seismic attribute calculation from OMV in the Grand Prix Bloc (2800 km^2). Its age control and stratigraphic framework have been estimated by a larger regional geological framework that integrated well data along the continental margin. The main aims of this work is to decode the main stages in the evolution of this CDS, infer the possible occurrence of sandy deposits, evaluate its conceptual recognition criteria and discuss its potential economic implications. The identification of three main seismic units (SU) of the Paleogene deposits has allowed determining three main evolutionary stages in the CDS; *a)* *Onset stage* (SU1)*;* that is initiated by a prominent regional erosional surface overlain by a tabular SU characterised by weak reflections with an aggradational seismic configuration along the lower slope. This SU is interpreted as a *sheeted drift*; *b)* *Drift growth stage* (SU2)*;* during this stage an uniform mounded deposits and adjacent contouritic channels are developing parallel to the slope. These features are migrating up-slope and form a remarkable succession of progressively eastward shift of the channels. These channels are about 2–3 km wide and up to 40 km long. Seismic facies within SU2 are characterised by higher amplitude reflections compared to SU1, especially within the channel where high-amplitude reflections (HARs) are clearly visible. This unit is interpreted as an *elongated, mounded and separated drift* being channels considered as *moats*; and *c)* *Burial stage* (SU3), which is characterised by a regional aggradational and homogeneous seismic unit composed of low-amplitude and weak reflections draping over the underlying drift. Once aggradation surpasses the upper drift surfaces, individual reflections become traceable laterally across the entire margin. We interpreted US3 as dominantly composed by hemipelagic / pelagic deposits fossilizing the CDS. The three identified evolutionary stages on this CDS have been also identified in other drifts along other basins at a different ages, which highlight the common evolution and behavior of water masses over the depositional and erosional features formation on time. The identified HARs along moats are interpreted as the occurrence of extensive sandy deposits, which potentially could have petrophysical characteristics that make them viable targets for future hydrocarbon exploration.

Characteristics of the catastrophic December 22nd 2018 Anak Krakatau flank collapse and tsunami

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Geological and historical records imply that volcanic islands are inherently unstable and their flank collapses can produce tsunamis. Without warning at around 21.30 local time on December 22nd 2018 a tsunami began to impact the coastline of the Sunda Strait in Indonesia. The source was the collapse of the SW flank of the volcanic island Anak Krakatau, representing a modern-day example of this natural hazard. The tsunami resulted in 437 deaths, over 2,750 destroyed buildings and homes, and over 33,700 people displaced. Attempts have been made to calculate the scale of the flank collapse that reduced Anak Krakatau's height from 333 m to 110 m, but models have yielded varying results. Here, for the first time we present new swath bathymetry and seismic reflection profiles of the landslide deposits that show its scale and emplacement mechanisms. Swath bathymetry resolves a large debris field with coherent, hundred-meter scale blocks that travelled up to 1.5 km into the adjacent basin. However, the true scale and complexity of the landslide is only revealed in our new high-resolution seismic reflection data. A staggering 18 m of post-landslide volcaniclastic sediment has buried the landslide in places but also importantly buried a 8 m-thick debris flow that travelled a further 1 km beyond the landslide into the basin. Combining pre- and post- event swath bathymetry and seismic reflection data we provide the landslide volume and identify the likely tsunamigenic volume. We calculate the total landslide volume to be 0.295 km^3; this comprises 0.230 km^3 of proximal tsunamigenic landslide materials and 0.065 km^3 representing the distal debris flow. Using pre- and post-event satellite radar data we determine the extent of the subaerial failure, which combined with a pre-event DEM we calculate a subaerial landslide volume to be 0.098 km^3. Therefore 50-66% of the landslide volume originated from the submarine flank. These new volumetric calculations and landslide characteristics impact upon tsunamigenesis. Our studies also show that Anak Krakatau likely suffered flank collapses (albeit smaller in volume) several times in the past and remains a significant hazard that requires monitoring. Understanding this landslide and its tsunamigenesis will inform future monitoring and mitigation strategies at potentially vulnerable locations; including over 40 global examples of rapidly constructed volcanic cones formed following past caldera collapses.

Sediment Provenance and Routing Pathways of the Miocene Formations of the Salin Sub-Basin, Central Myanmar

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Myanmar sits in an active geological area, with the Indian Plate obliquely subducting under the Myanmar Microplate in the east, and the large-scale dextral strike slip Sagaing Fault dissecting the entire country. Central Myanmar (and the Central Myanmar Basin) sits between the accretionary wedge of the subduction zone to the west and Eastern Myanmar, uplifted due to movement on the Sagaing Fault. Due to inaccessibility, there has been only limited work on the Cenozoic Formations of Central Myanmar. The Central Myanmar Basin is subdivided into several sub-basins, including the Salin Sub-basin. This work considers the approximately 3400 m thick Miocene deposits of the Salin Sub-basin to interpret the depositional environment and provenance of the sediments. This is achieved through a multi-proxy study including fieldwork, light and heavy mineral analysis, and U-Pb dating of detrital zircons using LA-ICP-MS.

Interpretation of the sedimentology shows that all three Miocene Formations; the Pyawbwe, Kyaukkok, and Obogon, share similar depositional environments, with spatially limited fluvial deposits exposed in the north, and deltaic to marine deposits outcropping in the south. Overall, the formations show that the depositional systems were constrained to the west, by the Indo-Myanmar Ranges, and to the east by a structural high that transects the Central Myanmar Basin. The light minerals again show very little variation, with the majority of the samples plotting as 'Recycled Orogen' with some plotting as 'Arc'. The U-Pb zircon ages display peaks in the Cenozoic and Cretaceous, with an overall lack of older zircons. Notably, there is a distinctive lack of Jurassic to Early Cretaceous zircon ages. The heavy minerals show the greatest variety, with a large percentage of Chromite in the older Pyawbwe Formation which almost disappears in the younger formations, replaced by a large proportion of amphiboles. There is a consistent lack of ultra-stable heavy minerals.

This suggests that most of the sediment was sourced from a mixture of high grade detrital metamorphic lithologies from the Indo-Myanmar Ranges with subordinate amounts of mafic-ultramafic material, potentially from the Myanmar Ophiolite Belts. There is also evidence for potential sources from intermediate igneous and contact metamorphic lithologies, which could come from the Central Myanmar Volcanics.

Microplastics across global environments - a challenge for sedimentologists

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Microplastics are an anthropogenic sedimentary particle. Understanding their distribution across the Earth is therefore a problem that sedimentologists are uniquely equipped to investigate. Recent studies have found microplastics at high altitudes, delivered as wind-blown dust, in river systems, in lakes, in coastal areas, on the sea surface, in the sea ice, suspended in the oceanic water column, and, , on the deep seafloor. While definitions differ, we suggest that <1 mm plastics be referred to as microplastics. Microplastic density ranges from lower than that of water, to nearing that of quartz. Microplastics also have a wider range of shapes and surface areas than naturally-occurring minerals; hence, their distribution within geophysical flows and their deposits may differ to that of natural mineral particles. Microplastic fragments are broken-down from larger macroplastics, manufactured microplastics include beads and pellets, but perhaps the dominant microplastic in the environment is microfibres. While 'fresh' microplastics are relatively inert, through time they can accumulate biofilms and various toxins. Due to their bioavailability, these contaminated particles readily enter the trophic web. Based on a number of case studies, we provide insights into the transport of microplastics from source, via river systems and estuaries, through shallow marine environments and into deep-water. We will focus on the deep-marine 'sink' and the role of gravity and thermohaline flows. Using this analysis we identify challenges that sedimentologists can address in terms of microplastic distribution and fate, and how this can be used in conjunction with mitigation efforts to address the environmental microplastic challenge.

Palaeo-ice streams and meltwater channels formed during the decay of a Late Palaeozoic ice sheet in eastern Chad

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Our current state of knowledge about the scale and timing of glaciations during the Late Palaeozoic Ice Age (LPIA) is mostly limited to the southern areas of Gondwana (Isbell et al. 2003). In the northern parts of the supercontinent, a well-defined LPIA ice stream network (Le Heron 2018) occurs alongside spectacular previously undocumented channels on the Ennedi Plateau (Fig. 1A) of eastern Chad and western Sudan. They rest on Devonian and Carboniferous sandstones (Wolff 1964). In this study, we present the mapping results of the significant morphological features utilizing publically available satellite images and DEMs with a 1arcsec resolution to provide further insights into the sedimentary record of the LPIA on the northern continental margin of Gondwana. The entire set of morphological features presented in this talk shares a common regional fracture pattern to surrounding outcrop belts, demonstrating that these features are ancient. On the 300 km wide Ennedi plateau, palaeo-ice streams cover an area of at least 100 km^2, and reach lengths of 75 km. Palaeo-ice stream tracks trend NNW-SSE (Fig. 1B) and contain subparallel ridges, which we interpret as mega-scale glacial lineations (MSGLs) and associated drumlins cut beneath a fast-flowing ice sheet. Furthermore, evidence for crosscutting sets of MSGLs occurs at different stratigraphic levels. These relationships testify to a multiphase glaciation that recorded subtle shifts in ice flow direction with each successive advance. Locally, these are accompanied by a network of anastomosing to meandering channels standing in positive relief and partly crosscutting each other, marking lateral migration over time (Fig. 1C). The positive relief is explained in a model which envisages: (i) initial incision into a muddy substrate, (ii) filling of channels with sand, with subsequent diagenesis and fracture development followed ultimately by (iii) deflation and removal of interchannel / overbank material. Most strikingly, channel belts are unaffected by traces of grounding ice, and are thus interpreted to record the final retreat phase, and establishment of proximal (fluvial) channels that drained northward.

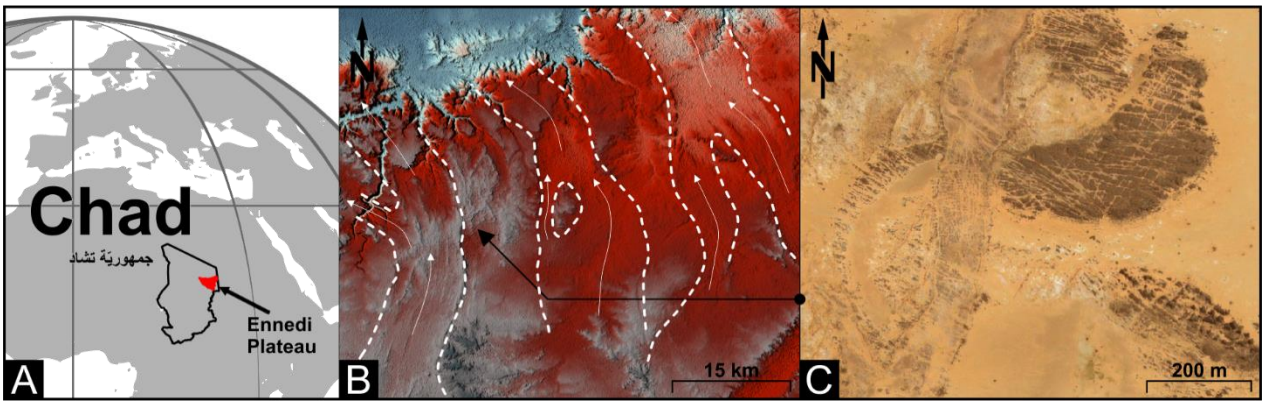

Figure 1: Location of study area (A), Ice stream network and inferred flow direction (B), Anastomosing channel deposits (C)

Isbell, J.L. et al. (2003). https://doi.org/10.1130/0-8137-2370-1.5
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Ice-contact deltas investigation using sedimentology, electrical resistivity tomography (ERT) and ground penetrating radar (GPR), Salpausselka I and II near Lahti, Finland

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In Finland, 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 (Glückert, 1986). They are inferred to be chronologically related to the cold stage known as the Younger Dryas which occurred at the end of the last glaciation. During this time the Baltic ice lobe and the Finnish Lake District ice lobe, constituting a part of the southern margin of the Fennoscandian ice sheet, were grounded in a large proglacial lake, the Baltic ice lake, a predecessor to the modern-day Baltic Sea. The “moraine” ridge is mostly composed of glaciofluvial sands, gravels and boulders rather than diamicton and deposited on crystalline, impermeable bedrock and constitute the only freshwater aquifer in southern and eastern Finland. The average thickness of ice-contact deltas sediments is estimated at between 10 and 60 meters.

Outcrop studies are combined with ERT and GPR profiles to provide insight into the aquifer architecture at different scales and depths of investigation. This study aims to improve our understanding of such deposits in the subsurface, especially about their internal structure, sedimentary facies distribution and potential barriers and/or baffles to fluid flow and poro-perm characteristics.

Complex development of a 300-million-year old subglacial unconformity in southern Namibia

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The existence of ice masses across southern Africa during the Late Palaeozoic Ice Age (LPIA) at about 300 Ma has been recognised in the literature for over a century, including the distribution of upland areas in controlling the configuration of ice masses. In Namibia, increasing attention has focussed on long and deep palaeovalley networks in the north, but comparatively little work has been attempted in the topographically subdued plains of the south. The desert terrain of the Mariental area exposes diamictites of the Dwyka Formation discontinuously over about 300 km, extending further south to the Noordoewer area at the Namibian-South African border along the Orange River. Whilst examined at a stratigraphic level, the nature of the contact between the Dwyka glacial rocks and underlying lithologies has not been systematically investigated. This paper presents some preliminary results from fieldwork in austral winter 2019, in which we describe a highly varying basal contact that records the processes of growth, flow and expansion of ice masses across this part of Gondwana. Subglacially-produced unconformities may exhibit classic glacially-striated pavements at basin margins, which substitute for soft-sediment striated surfaces in comparatively more "basinal" areas. Where these features are absent, additional criteria may be sought. In Mariental, spectacular soft-sediment shear zones exhibit a combination of brittle and ductile end products are recognised, overprinted by shear bands. This type of subglacial unconformity developed over well differentiated, unconsolidated, siliciclastic materials. Where ice advanced over more poorly sorted material or cannibalised pre-existing diamictites, "boulder-pavements" occur, which are recognized as clast-thick boulder-dominated intervals that are facetted and striated in-situ by overriding ice. By integrating measurements of striation orientations, fold vergence and palaeocurrent information, former ice flow pathways can potentially be reconstructed over a wide area, which is suspected to have been dominated by Piedmont glaciers.

Lonestone, interpreted as an ice-rafted dropstone, in laminated siltstones of the basal Dwyka Formation along the Orange River at Noordoewer, Namibia

Influence of Thermal Fluid on Sandstone Carbonate Cement Quality: the Baiyun Sag Study Case (Northern South China Sea)

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Abstract: Baiyun Sag, located in the typical "hot basin", Pearl River Mouth basin, South China Sea, is regarded as one of the vital regions of oil-gas research and deep-water exploration in China. The current geothermal gradient is generally higher than 4.50℃/100m in southern Baiyun Sag and the maximum geothermal gradient in this area is up to 6.67℃/100m. The aim of this study is to analyze the influence of fault and thermal fluid activity on occurrence of carbonate cement in Zhuhai formation in Baiyun Sag, based on a number of analytical methods such as thin section observation, electron microscope scanning, electronic probe analyze and carbon isotope analysis of carbonate minerals.

The average content of carbonate cements (mostly calcite, ferrocalcite and ankerite) in Zhuhai formation is 2.0% and the corrosion ratio is 9.4% in average [corrosion ratio= corrosion value / (current content + corrosion value)]. The result of carbon isotope analysis of carbonate cement in sandstone shows that some of the authigenic carbonate minerals (δ13CPDB: -5.38~ -5.29‰) formed in mesodiagenetic stage are related to deep sources (e.g., mantle-derived δ13CPDB= -5±2‰), which means the thermal fluid may be involved in the formation of the carbonate cement. Under most circumstances in this region, thermal fluid activity is associated with the anomalous high pressure of the stratum. The time of overpressure emancipation coincided with the time of tectonic movement in Baiyun Sag and the hydrothermal genesis minerals in sandstone is located in the zone where gas chimneys and deep faults have been found. Thermal fluid is participated in both the formation and corrosion of carbonate cements, and the secondary dissolution pores (plane porosity from 0% to 0.6%, 0.28% on average) has been generated during this process. Salinity of pore fluid and concentration of CO2 in the strata is relatively increased, and calcite is much easier to be dissolved when the thermal fluid upwelling frequently. Inversely, salinity of pore fluid and concentration of CO2 is relatively decreased, and it is helpful for the precipitation of calcite cement when the frequency of fluid upwelling decreased.

The episodic activity of thermal fluid may be one of the important factors leading to wide distribution, low content and strong dissolution of carbonate cements in Baiyun Sag.

Textural development of sand grains in natural fluidisation

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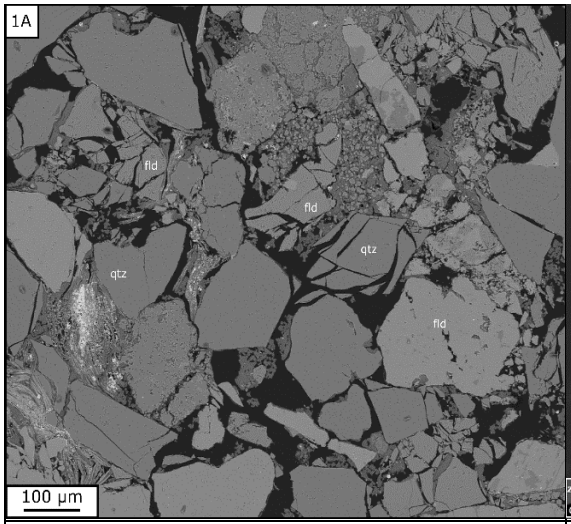
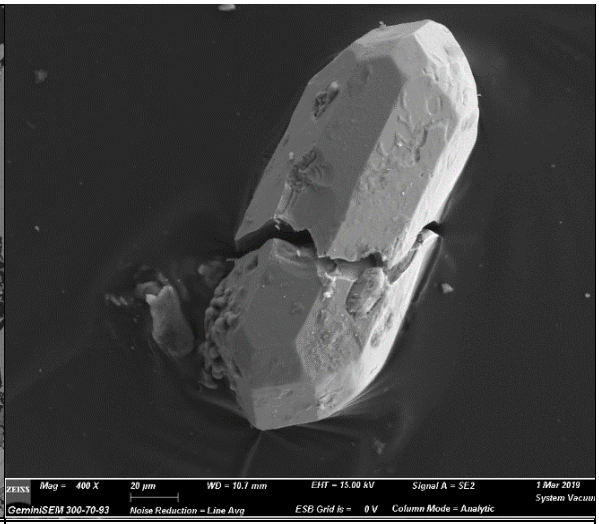
Granular characterisation of sand grains from sandstone intrusions reveals common intra-crystalline micro-fracturing, pervasive mechanically formed surface textures, and some relationships between mechanically and chemically formed surface textures. Framework grains and heavy minerals share the textural characteristics; of particular interest is the micro-fracturing and surface fracturing of ultra-resistant minerals, for example zircon. Micro-fractured grains are ubiquitous in sandstone intrusions and formed by high-velocity intergranular collision during sand fluidisation and injection of dilute granular suspensions in turbulent flow. Textures are autochthonous to sandstone intrusions and probably diagnostic of sand fluidisation and injection. Numerous mechanically formed surface textures are identified. Intense mechanical modification of zircon is remarkable considering its low probability of collisions with similarly hard grains and high mechanical stability (Mohs scale: zircon 7.5, quartz ~7, feldspar ~6-6.5). Zircon fracture records a high number and velocity of intergranular collisions during sand injection. The appearance and size of fractures indicate formation under high-stress, with large fractures far more common than small impact marks and abrasion features. Grain surface characteristics in the sandstone intrusions are indicative of higher intensity impact fracturing than that associated with depositional processes. Paucity of small impact features and abrasion markings shows that the average energy of inter-granular collisions exceeded the minimum energy to fracture grains; apparent abundance of large fracture surfaces relative to the paucity of small fractures is likely to be diagnostic of sand fluidisation and injection; this requires further research with a more quantitative approach. Relationships between chemically and mechanically formed surface textures on heavy mineral grains shows overprinting of surface weathering by later mechanically formed textures. A period of residence in a depositional parent unit, shallow burial and leaching caused partial dissolution of unstable grains that occurred prior to sand fluidisation. Evidence of mineral dissolution is partially obscured by fracturing that occurred during sand injection. This textural association further proves the overall significance of vigorous turbulent flow during the formation of sandstone intrusions.



Micro-fractured quartz and feldspar with pervasive open fractures (BSEM).



Micro-fractured zircon with conchoidal fractures on the zircon surface (SEM).

Late Glacial-Holocene high resolution records of productivity and meromixis from varved lake sediments across Europe: methods and applications

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20th century unprecedented environmental change has put freshwater ecosystems at stake. Human impact combined with accelerated climate change have resulted in adverse ecosystem impacts such as increased productivity and anoxia [1]. However, long-term records of lake eutrophication and altered lake mixing regimes are rare due to extensive time needed for analytical measurements. Here, we review recent developments in novel hyperspectral imaging techniques and discuss applications from lakes across Europe (Switzerland, Greece and Poland). We examine how and when meromixis (incomplete mixing) has developed over the Holocene, and how it has been affected by human activity, such as land use changes and erosion, as well as paleoproductivity. Hyperspectral imaging (HSI) is a nondestructive method to detect diagnostic sedimentary pigments at very high spectral (3 nm) and spatial (40 μm^2 pixel size) resolution. This allows the observation of seasonal patterns of pigment deposition within individual varve years (sub-varve scale). We use hyperspectral indices to infer quantitatively total chlorophyll *a* as a proxy for aquatic productivity and bacteriopheophytin *a* as a proxy for meromixis [2,3]. Spectral indices are calibrated with absolute pigment concentrations of selected samples measured by HPLC, using linear regression models (e.g R typically between 0.87 and 0.95, average RMSEP 10%) [4]. We combined our data with µ-XRF scans and pollen records. Late Glacial-Holocene HSI records provide evidence for naturally occurring meromixis long before any human intervention, mainly driven by climate and productivity changes. In the Mid-Holocene, after the establishment of closed mixed beech forests in Southern Central Europe, meromixis occurs repeatedly for long periods of ca. 300 years and ceases after substantial human disturbance in the catchment (Neolithic and Early Bronze Age land use, deforestation and reforestation) [4,5]. In recent times, human impact refers to increased nutrient inputs and intense eutrophication, when meromixis can become established permanently.

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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 Central Myanmar Basin (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 and sandstone samples were collected for further processing 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 are having been deposited in northerly located 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 studies have challenged the interpretation that most 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 Raman Spectroscopy, and U-Pb dating of detrital zircons using LA-ICP-MS.

Basic to Acid Pyroclasts Deposited in A Sediment-hosted Geothermal System in A Permian Lacustrine Rift Basin: Implications for Ancient Hydrovolcanic Sedimentation

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The sedimentation of pyroclasts formed by sublacustrine volcanic and hydrothermal processes are complex and affected by physical, chemical and biological factors. Once the clasts mixed with lacustrine sediments, they are hardly to be identified and researched. We propose four groups of pyroclasts dominated rocks which are intercalated within fine-grained sedimentary rocks (mainly interlaminated tuffaceous shales with dolomicrite) in Permian Lucaogou Formation in lacustrine Santanghu rift basin, Xinjiang, NW China. Mineralogy and petrology were studied on samples from cores and outcrop to reflect the sedimentary processes and sources. Four lithofacies suggesting basic to acid volcanic origins were observed. They are combinations of magmatic, hydrotherma, and sedimentary minerals, such as dolomite-smectite, diopside- wollastonite, analcime- peralkaline feldspars, and felsic grains-carbonate cements. The former two are thin bedded to laminated with sharp boundaries with adjacent shales. Their grains are massive, poorly sorted, angular, and supported by matrices, indicating a high-density granular deposition originated from basic and peralkaline-alkaline carbonatite and pyroxenite. The latter two are laminated with a sharp bottom and gradually top with adjacent dolomicrite. Their grains are normal graded, moderately sorted, angular (some of them are shard-like), and cemented by micritic dolomite, indicating a turbidity deposition originated from medium to acid analcime phonolite and andesite. These grains have low compositional and textural maturity, which are not common in traditional lacustrine fine-grained sedimentary rocks. Embayed boundaries are common in individual mineral as well as aggregated grains, suggesting multiple episodes of melting and welding under a high temperature condition. These lithofacies are interpreted as sublacustrine hydrovolcanic deposits at the sediment-hosted geothermal system, where the pyroclasts had been altered by syndepositional hydrothermal fluids and mixed with lake deposits. The interpretation is substantiated by abundant cone-shaped stratigraphic buildups on seismic sections in the basin. The different property of volcanic sources may be caused by various depth of volcanisms in a rift basin.

Diagenetic Facies And Their Microscopic Characteristics In Upper Triassic Yanchang Formation Chang 6 Member, Ordos Basin,China

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Abstract:

Diagenetic activities are an important and complicated geological process for oil preservation after deposition in a fluvial–lacustrine siliciclastic sedimentary system. The studied Ordos Basin is located in the western part of the North China craton. And the Yanchang Fm. is an important oil-bearing layer and is composed of interbedded sandstones and mudstones, which are divided into 10 members. And Chang 6 member is sandstone dominated reservoir as the focus of our study. In this work, the basic geological characteristics, diagenesis and pore evolution are studied by using basic physical data, polarizing microscope, SEM and XRD. The characteristics of micro-pore structure and seepage of each diagenetic facies are studied by high pressure and constant velocity mercury intrusion, nuclear magnetic resonance and oil-water phase infiltration experiments.

The sedimentary sub-facies are delta front with microfacies of subaqueous distributary channels, estuary dams, and diversion bays. The lithology is feldspathic sandstone with main cement of carbonate minerals and matrix of clay minerals. The reservoir is a typical low to extra low porosity (8.58% in average) and extra to super low permeability (0.33×10^{-3} μm^2 in average) reservoir. It contains a series of complex diagenetic processes. ① The compaction destroys the physical properties, resulting in a decrease in porosity of 20.14%; ② The cementation includes chlorite, illite, carbonate, and siliceous cementation, resulting in a decrease in porosity of 9.88%; ③The dissolution improved the reservoir properties, resulting in an increase in porosity of 2.84%. The main pore types are intergranular pores and dissolved pores; whereas the main throat types are flaky, curved and bundled. Five types of diagenetic facies are classified: ① chlorite cemented intergranular pore facies, ② feldspar dissolution facies, ③ illite cemented pores-intergranular pore facies, ④ siliceous cemented pores-intergranular pore facies, and ⑤ carbonate intense cemented dense facies. The chlorite cemented intergranular pore facies have the best physical properties with large pore throat radius, good pore throat sorting and connectivity, high movable fluid saturation.

Quantifying the Structural Control on Submarine Channel Stacking Patterns: Case Studies from the Niger Delta

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Over the past two decades, the increased availability of high-resolution three-dimensional (3D) seismic data and its integration with outcrop and numerical modelling studies have enabled the geomorphology and architecture of submarine channel-complexes to be studied in detail. While tectonic activity is recognised as a primary control on the morphology of submarine channels, the temporal and spatial complexity associated with these systems means aspects of channel incision, migration, aggradation, and how these processes result in time-integrated sedimentary architecture, remain poorly understood. For instance, tectonically-driven changes in slope morphology may enhance or diminish a channel's ability to incise, aggrade and migrate, thereby dictating the distribution of composite channel architectures. Here, we combine seismic attribute analysis with the concept of stratigraphic mobility to investigate quantitatively how the growth of gravitational-collapse structures influenced the morphology and stratigraphic architecture of submarine channels, at both complex and channel element scale.

From a 3D, time-migrated seismic reflection volume, we use amplitude extractions, frequency decomposition and RGB blending, combined with reflection termination mapping in seismic section to determine channel stacking patterns and trajectories. We evaluate the evolution of widths, depths, sinuosities, and stratigraphic mobility at fixed intervals downslope as the channels interact with growing structures. Our results demonstrate the sensitivity of channel architectures and stacking patterns to the underlying tectonic template. We show lateral migration to be the dominant form of stratigraphic preservation immediately up-dip of active thrust-folds, while a two-phase evolution—an initial phase of lateral migration followed by a phase of increasing aggradation and decreasing migration—characterises the channel trajectory away from active structures. Our results provide new insights into the dynamics of submarine channels in a setting where the tectonic boundary conditions are well-constrained, and allow us to quantify the extent to which the stacking of successive channel-fills and channel-complex morphology are influenced by growing structures.

Deciphering reservoir complexity of ice-contact deltas using surface analogues

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Glaciogenic sediments form important hydrocarbon reservoirs (including Oman, India, Siberia and China) and aquifer systems (including Europe, Greenland, Russia and North America) (Huuse et al. 2012). They are considered to be notoriously complex with abrupt proximal-distal and lateral facies contrasts. As a result, it is extremely challenging to identify and model reservoir distribution in the subsurface relying only on limited wells and seismic data.

In this study we examine the feasibility of using relatively modern ice-contact deltas as an analogue system to provide input data for a subsurface reservoir model. In Southern Finland, two large "moraine" ridges (Salpausselka I and Salpausselka II) delineated major stillstand/ re-advance positions of the Fennoscandian ice sheet during the last deglaciation (Glückert, 1986). These ridges provide up to 600 km in analogue information.

The resulting 3D reservoir model is conditioned using information derived from the multiple 2D ground penetrating radar (GPR) profiles, modern-day LiDAR topography, producing water wells, electrical resistivity tomography (ERT) and traditional outcrops information. This study presents novel insights on the 3D internal reservoir-scale complexity of glaciogenic systems.

Latest Miocene Mediterranean-Atlantic gateway restriction: The Atlantic's side of the story

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The closure of Late Miocene Mediterranean-Atlantic gateways and the restriction of Mediterranean Outflow Water (MOW) led to the Messinian Salinity Crisis (MSC), the dynamics of which is not well understood. However, restriction of the Mediterranean-Atlantic interchange and the Mediterranean Outflow Water (MOW) is one of the prerequisites to generate hypersaline conditions for evaporitic deposition. During the Late Miocene, MOW circulation was active through a Mediterranean-Atlantic exchange of the Betic, Riffian, and possibly Gibraltar gateways. This connection is thought to have ceased or reduced with the onset of the MSC, before re-establishing through the Gibraltar gateway since the Pliocene to the present. In this study, we define the sedimentary evolution of the Neogene Basins of the Gulf of Cádiz to investigate MOW evolution during the latest Miocene. Seismic interpretation shows an Upper Messinian sedimentary unit of transparent seismic facies. It could also be found in the lower Guadalquivir and Gharb basins, and towards the West Portuguese margin. Biostratigraphic dating indicate an onset of deposition predating the MSC. Distribution of this transparent unit implicates the dominant deposition of hemipelagic/pelagic deposits during a period of quiescence in the Atlantic margins, subsequent to MOW disconnection. This suggests that weakening or cut-off of the intermediate bottom currents of the Mediterranean-Atlantic exchange through the Betic-Gibraltar-Riffian paleo-gateways precedes the onset of MSC evaporites. This work is crucial for the understanding of sedimentary, paleoceanographic and climatic implications of the Latest Miocene Mediterranean isolation in the Atlantic margins.

The Guinness Book of Sedimentology: your guide to the world's largest EVER sedimentary features

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Sedimentary deposits from throughout Earth's geological history have been scoured with a fine toothcomb to find the biggest, the tallest, the deepest and steepest sedimentary structures and landforms. Depositional environments ranging from fluvio-lacustrine and aeolian, tidal and deltaic and a range of marine settings have been studied to identify the record breaking ripples, dunes, bars, channels, deltas, fans, sheet sandbodies and more. Each "giant in its field" is then compared to the largest modern example to get a sense for just how different ancient environments were when stacked up against their recent counterparts.

There is obviously something special about the largest bedforms and landforms ever to grace our planet, but there are also some practical aspects. The results will provide a reality check when you try to interpret unusually sizeable structures in the field. The chance, and degree, of preservation of sedimentary structures and features in each category will be evaluated. Each identified sedimentary behemoth will also be mapped against supercontinent cycles, plate tectonic setting, global sea level and temperature curves to see whether they cluster at certain time intervals. Do certain cyclic events favour the deposition of particular extreme landforms? This data also provides a predictive tool to search for further examples of the world's "greatest" sedimentary features. Join us and find out if your favourites have made the cut.

Testing the impact of fault growth models on syn-rift stratigraphy using forward stratigraphic modelling.

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Tectonics plays a key role in controlling both regional and local surface gradients and hence drainage patterns, sediment entry points and depocentre locations in rift basins. Studies in modern rift basins, ancient examples and both physical and numerical modelling can all contribute to better understanding the complex interplay between tectonics, climate and sediment supply. This study employs forward stratigraphic modelling to investigate how details of the fault system evolution and intrabasinal relay development can impact hanging wall sediment accumulation and stratigraphy. It has been carried out using Sedsim (Stratamod) which uses a hydrodynamic approach to model sediment dispersal based on an approximation of the Navier-Stokes equations (Griffiths et. al, 2004). Intrabasinal transfer zones (relays) have been proposed as likely entry points for larger hinterland supply systems that feed expanded transfer fan systems in the basin. However, relays can arise in different ways dependant on how faults grow. Two contrasting models have been proposed for the development of large faults by growth and linkage of fault segments. The Isolated Growth Model envisages the segments of a fault array initiate as a series of isolated faults. As extension proceeds, the faults systematically increase in both maximum displacement and length until they interact and form relay zones, ultimately becoming connected to form a larger fault. An alternative model recognises that fault length is established rapidly (the Constant Length model) so relay zones between fault segments form under low strains; subsequent fault growth is then achieved by an increase in fault displacement with minimal change in fault length (Walsh et. al, 2002). Numerical models of the different fault growth models have been generated incorporating displacement gradients and uplift and subsidence patterns seen in natural examples. All other inputs (sediment flux, base level) are held constant. Relays that form according to the Isolated Growth Model are seen to act as sediment conduits prior to breaching and feed local, poorly connected hanging-wall depocentres. Concentration of coarse material is seen at the base of the relay ramps. However, although both Isolated and Constant Length models converge once full breached, the early history of the latter involves sediment routing via relay ramps until the integrated uplift across all the fault segments diverts flow around the fault tip at one end of the fault array. Deposition is then focussed as an aggradational axial fan with coarse material closest to the fault tip and finer grained material concentrated at the base of the relay ramps. The uplift and subsidence fields around the faults also impact the trapping efficiency of the depocentres, with more accommodation and better communication between depocentres in the Constant Length model. The accommodation outpaces sediment supply and results in underfilled or starved depocentres distal to the axial entry point. In addition, erosional feeder channels are not backfilled and the sediment entry point is locked in position earlier than in the Isolated Model. The disconnected depocentres of the Isolated Model are filled via the relay ramps and outpace accommodation creation early in the tectonic history allowing bypass. The implication is the fault growth model, and extent to which earlier structures are reactivated, can have an important impact on the early syn-rift stratigraphy.

Effect of early and late oil charges on diagenetic and reservoir quality variation in sandstone reservoirs: An example from the Dunlin Field, East Shetland Basin, UK

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Oil extracts from two blocks of the Dunlin reservoirs have been studied to understand the to examine the role of oil composition on diagenesis, and the factors controlling the variation of oil composition during its charging history. The results of these study has shown that the oil in these two reservoir blocks are genetically related by similarity in source rock based on organic matter, source rock lithofacies, source rock age, and depositional environment. However, variation exist in the degree of their thermal maturity and biodegradation and have been related to two stages of oil emplacement in the field. The early charged oils are less biodegraded, more thermally matured saturate-light oils and dominated the present-day water-leg. The presence of these light oils shows no significant influence on diagenesis. Hence, continued diagenetic reactions precipitated mineral cements in pores, thereby deteriorated porosity. Conversely, the late charged oils are more biodegraded, less thermally matured polar heavy oils dominated the oil leg. These oils inhibited diagenetic reactions thereby preserving porosity. Because diagenesis can also be influenced by the fluid composition as revealed in this study, it is recommended that studies of diagenesis for accurate prediction of subsurface reservoir quality should be holistic involving both the rock and their fluids.

Mass-balance analysis of the Middle Jurassic Brent Delta sediment routing system, Northern North Sea, offshore UK and Norway

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Mass-balance analysis of sediment discharge and its grain-size mix provides key inputs for stratigraphic forward models. However, characterisation of sediment volume and grain-sizes in ancient (subsurface) sediment routing systems remains challenging. In this study, we use the relatively data-rich Middle Jurassic Brent Delta sediment routing system in the proto-Viking Graben, Northern North Sea, to quantify grain-size partitioning and mass-balance between source area and depositional sink. Published sequence stratigraphic studies are synthesised to provide an age-constrained framework of the Brent Delta system. The framework consists of four units that span a total duration of 8.1 Myr. Unit 1 (3.9 Myr) corresponds to coeval transverse progradation of basin-margin deltas, sourced from the Shetland Platform to the west, and the Norwegian Landmass to the east of the basin. Units 2 (1.1 Myr) and 3 (0.9 Myr) correspond to the rapid northward progradation and subsequent aggradation of the Brent Delta along the basin axis, sourced from the uplifted Mid-North Sea High to the south, with contributions from the Shetland Platform and Norwegian Landmass. Unit 4 (2.2 Myr) records the drowning of the Brent Delta in response to the onset of active rifting within the basin. Sediment mass-budget was quantified for the four units, constrained by palaeogeographic reconstructions, isopach maps, and sedimentologic analysis of core and well-log data. Our results show that c. 1.9 ± 0.3 x 10^7 Mt of sediments were deposited over the duration of the mapped Brent Delta system, corresponding to a net-depositional sediment budget of 2.3 ± 0.3 Mt/yr, partitioned into a gravel, sand, and mud budget of 0.01 Mt/yr, 1.4 Mt/yr, and 0.9 Mt/yr, respectively. Temporal variations in the long-term, net-depositional sediment budget were likely driven by changes in tectonic boundary conditions (e.g. due to a transient volcanic plume in the Mid-North Sea High), as there was no major climatic shift during this time period. By comparison, the long-term averaged sediment load from the three source regions, over the same time interval, was quantified by applying a Monte Carlo simulation to the BQART sediment load prediction model, to obtain a total budget of 20 ± 9 Mt/yr, suggesting that the preserved source-to-sink sediment budget of the Brent Delta system was not balanced; the Shetland Platform, Norwegian Landmass, and Mid-North Sea High contributed c. 4 ± 2 Mt/yr, 9 ± 4 Mt/yr, and 8 ± 4 Mt/yr, respectively. These results indicate that along-shore transport by wave-generated currents and/or down-dip transport by gravity flows to the basin-floor likely played a key role in redistributing sediment mass and calibre, and we evaluate the potential effect of these mechanism on the stratigraphic architecture of the Brent Delta system.

Differences in diagenesis of delta plain sandstone from the Yan'an Formation in the Yinjiacheng area, and its effect on reservoir classification

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Diagenesis directly affects the pore evolution of reservoirs and controls the physical properties and oil content of reservoirs. It is of great significance to clarify the differential diagenesis of reservoirs and the sequence of hydrocarbon charging. Several techniques were used to study the sandstone reservoir rocks of the delta plain subfacies in the Yan'an Fm (J_1y) in the Yinjiacheng-Hedao area: observation of cores and thin-section optical microscopy, XRD, fluorescence, physical properties, mercury injection, and other testing methods. The study has shown that the differences in the original sedimentary features and diagenetic fluids are the main reasons for the differences in reservoir diagenesis. There is good correspondence between diagenetic facies, reservoir types and oil production. Medium-to-coarse-grained sandstones in distributary channel sedimentary microfacies have large initial porosity, strong acid dissolution, well-developed grain mold pores and throats, and good pore-throat connectivity. The porosity range is 11~18% and the permeability range is $20\sim1000\times10^{-3}$ μm^2. Displacement pressure fluctuates between 0.02 and 0.1 MPa, and the median pressure ranges from 0.04 to 1.3 MPa. The median radius range is 16~27.1 μm. This develops large pores and throats and results in medium-porosity and medium-to-high permeability reservoirs. This type of reservoir rock has undergone phases 1, 2 and 3 hydrocarbon charging, which produces industrial-grade oil flow and is classified as a Type I reservoir. The diagenetic evolution of medium-to-fine sandstone in distributary channel sedimentary microfacies is relatively slow and homogeneous. Acid dissolution produces a large number of dispersed dissolution pores but the connectivity is poor and therefore its permeability is low. This is its main difference from a Type I reservoir with similar porosity.. The porosity range is 11~17% and the permeability range is $3\sim60\times10^{-3}$ μm^2. The displacement pressure fluctuates between 0.03 and 0.41 MPa, and the median pressure ranges from 0.1 to 2.0 MPa. The median radius is 0.8~7.2 μm. Small-to-mesopores and throats are developed, forming medium-porosity and medium-to-low permeability reservoirs. This type of reservoir rock has undergone phases 1, 2 and 3 hydrocarbon charging, and has low oil flow. It is classified as a Type II reservoir. Pelitic fine siltstone in natural levee sedimentary microfacies is strongly compacted, which is the main cause of the small pore size. It is characterized by the bending deformation of mica. This type of reservoir has a porosity from 5 to 13% and a permeability from 0.05 to 3×10^{-3} μm^2. The displacement pressure fluctuates between 0.4 and 0.9 MPa; median pressure ranges from 2 to 5 MPa. The median radius ranges from 0.4 to 1.3 μm. Such reservoirs are low-porosity and extra-low-permeability reservoirs, or 'tight' reservoirs. Depending to the calcite content, this kind of reservoir may be further divided into two types. One kind has no obvious calcite cementation, and because it develops extra-small pore throats, it is regarded as a low-porosity and extra-low-permeability reservoir. This kind of reservoir has undergone stages 1 and 2 hydrocarbon charging, which has high water production. The other kind has developed both strong compaction and a large amount of calcite cementation. This kind has no hydrocarbon display, and is regarded as a 'dense' or 'invalid' reservoir. This kind of reservoir is a 'dry layer'. Both of these are classified as Type III reservoirs. Strong relationships were found between the spatial distribution of the different reservoir rock types and the oil yields of individual wells, so it is suggested that this study provides theoretical support for the prediction of further productive reservoirs.

Recognition criteria of ancient deep lake line of depressed-type lacustrine basin:An Insight from Triassic Yanchang Formation, Ordos Basin, China

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The sandstones of shallow lake origin are primarily,subaqueous distributary channel, mouth sand bar and sheet sandstone of delta front,and in which subaqueous distributary channel sandstone is at most developed.Whereas, the sandstones of deep lake origin are primarily composed of various sediment gravity flow deposits(including turbidite, debrite,slid and slump deposit),the deep lake sandstone differ from those of shallow lake in such aspects as sandstone thickness ,distribution rule,lithofacies and lithofacied association,ultimately porosity and permeability of the sandstone reservoir. Ordos Basin formed a depressed-type lacustrine basin during the late Triassic,resulted from the rapid uplift of Qinling Mountain associated with a rapid subsidence of the southern Ordos basin.Yanchang Formation(Fm),composed mainly of sandstone,siltstone,mudstone and tuff intervals.which can be further subdivided into 10 Members(Ch-10 to Ch-1,from bottom to top) .The evolution process of deep lake line of Yanchang Fm is relatively fixed at steep slope in southwest, and is holdback orderly at gentle slope in northeast.The deep lake sediments primarily developed during the deposition of Ch-7 and Ch-6. In previous work, Ch-2 and Ch-6, as main hydrocarbon reservoirs, in which delta facies are primarily developed; and Ch-7, as hydrocarbon rocks,were studied in more detail, but there are rarely detailed documents on deep-water sediment gravity current and recognition criteria of ancient deep lake line until today. With the breakthrough of exploration in deep lake gravity flow deposits in recent years, it is a urgent need for sedimentologist to further describe characters of various sandstones and predict their distributions in directions vertically and laterally.Obviously,pre-existing research results would not meet the lacustrine sedimentological development and demands of petroleum industry. The work in this paper is indispensable,in the aim of paleogeographic restoration and searching for petroleum target.The division of deep lacustrine lines is one of the main contents in the restoration of lacustrine sedimentary facies and paleogeography,to identify the sandstone origin.Forthermore,the criteria to differentiate the deposite of shallow lake from that of deep lake, ultimately recognize the deep lake line in plan-view in the late Triassic, which can also be used to other lacustrine basin with similar geologicl background worldwide. Based on plenty of cores, outcrop observation, the deep lake line during Late Triassic Yanchang Fm are studied in details, The result shows that deposit of shallow lake different from that of deep lake by lithology,sedimentary structure,paleo-biology fossil, sedimentary sequence etc. The main aims of the abstract are: (1)to provide a classification scheme of lithofacies and lithofacies associations of Yanchang Fm, (2)to analyse and identify shallow lake and deep lake ,vertically and lateraly,based on their lithofaces types and lithofacies associations, (3) to discuss the recognition criteria for the deposit of shallow lake from that of deep lake, i.e.,lithology, sedimentary structure, Fauna/flora, bore log, depositional sequence, and(4) to construct a depositional model including distribution and evolution of ancient deep lake line during late Triassic , Ordos basin.

Magical geology! When submarine fans vanish...

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Hocus Pocus, Mumbo Jumbo, Abracadabra, Expelliarmus! Alas, one of the problems of science is that it disproves magic. However, here we use science to reveal magic! Approximately 1100 miles to the south of the Hawaiian Islands lie the Northern Line Islands, a chain of atolls, coral islands, guyots and seamounts. We show using new multibeam data, and seismic data, that this island chain produces spectacular submarine channels in excess of 500 kilometres long in some cases. These are by far and away the longest and most surprising submarine channels of their kind ever discovered. The flows that traverse these channels are fed from the seamounts and guyots of this chain, yet at the end of these giant channels there is not so much as a hint of a submarine fan, or any other deposition. Come and join us to examine these spectacular channels, their morphology, and sedimentary processes, and to help solve 'the case of the vanishing submarine fans'. It's one thing to make a rabbit disappear, but a series of submarine fans?!? Now that is magic! Surely…

Mud diapirism and catastrophic fluidization triggered by MTC collapse down a salt scarp: What happens when a hundred billion tonnes of mud falls down a 1km-high slope?

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The US Gulf of Mexico (GoM) continental slope is underlain by salt, at the downdip limit of which is a major escarpment, the Sigsbee Escarpment, which stretches ca. 500km along strike. The modern escarpment, at the downdip limit of shallow salt, typically has a height of 0.5-1km and a seabed slope of 20 degrees. Detailed mapping on 3D data shows that the continental slope has experienced massive catastrophic slope failure events, with some individual Mass Transport Events (MTEs) affecting areas greater than 10000km^2. Many of these originate in the mid-slope, pass over the Sigsbee Escarpment, and terminate on the continental rise below it. Previous studies have focused on processes of mass transport, or on the deposits (MTDs), or oceanographic effects of MTEs such as tsunamis. This study instead considers the effect of the MTE on the neighbouring sediments. Our case-study is of a medium-size MTE that began on the slope and passed over the Sigsbee Escarpment. The MTD deposit at the base of the scarp is a typical chaotic mass. However, the adjacent 20-30km wide regions on either side of the MTD show unusual features. On one side, the slope sediments have been removed; the texture of the omission surface suggests that the missing sediments were fluidized and removed by flow >50km downslope. On the other flank, the top layer of sediment is preserved, but it was destabilized, developing 500m-scale mud diapirs and mud withdrawal basins. Further away from the MTD, the slope sediments are apparently unaffected. We suggest that fluidization was the result of massive energy release as the MTE accelerated down the Sigsbee Scarp, converted to seismic shock and shaking of the adjacent region when the sediment hit the base of the scarp. Niedoroda et al. (2003) suggest that 100m-scale blocks falling down the scarp reach terminal velocities exceeding 100km/hr; a larger unit such as this MTD could reach higher speeds. The MTD that passed over the Sisgbee Scarp exceeds 100km^3 in volume, weighing ~ 10^{14} kg - one hundred billion tonnes. Falling 1km released ~ 10^{18} Joules (equivalent to a 400-Megaton nuclear explosion). Converting 10% of energy into seismic energy would be equivalent to a large earthquake, magnitude Mo = 8.5. Shaking-induced sediment liquefaction has been documented in many earthquakes of similar magnitude (Isihara, 1993). Evidence of widespread shock-induced liquefaction due to MTD emplacement has been found in this first case study; we believe that it may be a common and important process on the lower slope and continental rise of the GoM, and possibly in many other margins.

A statistical approach to quantify the structural controls on the distribution of deep-water slope channels

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Submarine channel systems play a crucial role in governing the routing and delivery of sediments from the shelf edge to deep-water. Understanding their distribution in space and time is important to constrain the locus and magnitude of deep-water sedimentation, and to predict stratigraphic architectures and the location of reservoir facies. Slope channels are often found on passive margins that deform under the effect of gravity tectonics that causes the growth of contractional folds and thrusts and the creation of seabed topography, and the modification of slope gradients creates tortuous corridors which can be exploited by these systems. It is often argued that submarine channels are sensitive to gradient changes and several studies have suggested that the locations where channels cross growing structures are dependent upon along-strike structural variations of thrust-folds and the relative rates of uplift and sediment accumulation. However, this issue has often been addressed on a "case study" basis where examples of individual channels are shown to be diverted around structures, whose deformation rates generally have not been quantified. To date, no work has attempted a statistical analysis of a large number of submarine channel-structure crossings in time and space, where the deformation rates are measured independently.

Here, using 3D industry seismic data covering the outer fold and thrust belt of the southern lobe of the Niger Delta, we determined the frequency distribution of several Miocene to Pliocene channel complexes that crossed eleven fold-thrust structures, at 173 locations, for which the temporal and spatial evolution of strain rates have been recently constrained over 11 Myr. We used a comprehensive statistical approach to quantify what strain and shortening rates are documented where channels have crossed structures, compared to the fault array as a whole, throughout the growth history of the fold and thrust belt. Results show that slope channels respond to increasing deformation rates by 1) being actively driven to the locations of lower strain rates, 2) reducing the overall density of the channel network, and 3) increasing their depth of incision. These results demonstrate the importance of reconstructing and quantifying the evolution of deformation rates as a tool to predict the temporal and spatial distribution of submarine channels and their evolving architecture in response to structurally-driven topography.

The influence of voluminous magmatism on Paleogene sedimentary systems in the West of Shetland and outer Møre and Vøring basins

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Massive breakup-related basaltic sequences and intrusions were emplaced along the UK and mid-Norway continental margins in the Paleogene. The magmatism was initiated at about 62 Ma, with a main peak around 56 Ma. This so-called North Atlantic Large Igneous Province (LIP) had a major impact on the Paleogene paleogeography and associated sediment provenance, transport, and depositional systems. Extensive new 2D and 3D seismic data has been interpreted in combination with borehole data and field analogues, to study the effect of the LIP magmatism on sedimentary systems along the West of Shetland and outer Møre and Vøring basins. Eleven horizons, including top and base basalt, were mapped in the West of Shetland area and correlated into the Norwegian Margin using conventional seismic horizon picking, combined with the interpretational concepts of seismic volcanostratigraphy and igneous seismic geomorphology. Particular focus has been given to 1) the nature of the base basalt transition and the nature of underlying or correlative sedimentary sequences, 2) the Inner Flows and Lava Delta seismic facies units, and 3) top basalt geomorphology. The seismic mapping documents large lateral variations in the basalt thickness, from more than 2 km to a few hundred meters. Locally, the basalt is very thin or absent, e.g. on the Kolga, Mimir, Ygg, Skoll, and Grimm highs. Thin basalts are also mapped in the Erlend and Brendan's igneous complexes, where the basalt thickness is locally constrained by industry boreholes. Well-defined interfingering of basalt flows, and inter-lava sandstones are present in the Rosebank hydrocarbon discovery, documenting the complexity of the base basalt transition. Igneous seismic geomorphological interpretation reveals extensive subaerial lava flow fields, shallow marine flows, and volcanogenic debris flows and lava deltas along the paleo-coastline along the entire margin. The 3D data also reveal spectacular Paleocene sedimentary channel systems, transporting sediments towards the west. A large (c.15x20 km) channel system is imaged within the Flett Formation comprising numerous dendritic amalgamating erosive channels. The channels are diachronous, with the oldest to the south and shallower channels occurring at Top Balder Formation level to the north. The Flett Formation channels in the West of Shetland area are potentially sand-rich because they are sourced from the Shetland Platform comprising e.g. Lewisian gneisses. The top basalt surface is also incised by fluvial channels with a west-to-east direction. Our new interpretations form the basis of a recently submitted scientific IODP drilling proposal with objectives to constrain the magma production and emplacement processes, and the impact of the massive breakup magmatism on the Paleogene climate.

Turbidity current transport, deposition and burial of microplastics

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The increasing plastic pollution of the world's oceans represents a potentially serious threat to marine eco-systems and human health and has become a publicly well-known topic of growing attention. Today the global input of plastic waste into the oceans is estimated to be in the order of 10 million tons per year, with this figure predicted to rise by one order of magnitude by 2025. Much of the plastic that enters the oceans is considered to end up on the seafloor and sediment samples from the seafloor show that plastics are concentrated in submarine canyons. These submarine canyons are occasionally flushed by turbidity currents which are a mixture of sediment and water flowing down the canyon due to their excess density. A single turbidity current can last for weeks and transport more sediment than the annual flux of all terrestrial rivers combined. However, despite the high significance of these flows in the distribution of sand on the seafloor, the mechanisms for the transport and burial of plastics by turbidity currents is unknown. Here we quantify in flume experiments the efficiency of turbidity currents in transportation and burial of plastic fragments and fibres. Plastic fragments are focused at the flow base, whereas fibres are more homogeneously distributed throughout the flow. Surprisingly though, the resultant deposits show the opposite trend with fibres higher concentrated that fragments. We explain this observation with a deposition mechanism where fibres are dragged out of suspension by settling sand grains and thus, get buried in the deposits. Our results demonstrate that turbidity currents can represent efficient transportation mechanisms for plastics over long distances across the ocean floor, and that turbidity currents potentially distribute and bury massive amounts of plastics in seafloor sediments.

Multi-scale influence of topography on depositional architecture of long-term transgressive successions (Jurassic, Neuquén Basin, Argentina)

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Shallow-marine successions deposited during long-term transgressions are considered to develop relatively thin and well-sorted deposits. Thick transgressive successions are rarely preserved in the stratigraphic record, although a few examples are described in subsurface and outcrop studies of rift basins. An outcrop example from the Jurassic of Neuquén Basin (Argentina) is presented here, with the aim to a) refine the model of long-term transgressive deposition in early post-rift settings and b) constrain controls on stratigraphic architecture and lateral facies variability. To do this, a <300 m-thick succession has been studied along a >10 km continuous exposure, with detailed mapping, sedimentary logging and physical correlation of stratigraphic units, integrated with subsurface, biostratigraphic and ichnological data. The lower part of the succession lies unconformably above syn-rift deposits, and comprises laterally-discontinuous (10's m-long), coarse-grained deposits, dominated by 10's m-thick coarsening-up packages and discrete m-scale erosive conglomeratic lenses, and interpreted as mouth-bars and distributary channel-fills. The rest of the succession shows a retrogradational fining-upward development, with several minor order regressive units. They cover the entire outcrop length (>4.5 km) and thicken southwards, although subsurface data reveals a fault-controlled regional extension. They comprise laterally-continuous (>100's m-long), <1m-thick fine-grained structureless and highly bioturbated tabular muddy sandstones and sandy mudstones, with locally-preserved HCS and bioclastic-rich levels. They are interpreted as storm-dominated lower-shoreface to upper-offshore deposits. Internal characteristics and bed boundaries are diffuse, suggesting recurrent periods of seabed oxygenation and colonization of organisms. The coarse-grained nature and lithology of the lower succession are consistent with a proximal sediment source, associated with erosion of intra-basinal highs. Its variable thickness, lateral distribution, and marked onlap termination against underlying syn-rift deposits, demonstrates the partial infill of localized higher-accommodation areas. The rest of the succession shows more extensive, well-defined parasequences internally composed of laterally-continuous bedsets, preserving original stacking patterns. However, the vertical thickness variability of parasequences is interpreted to reflect their transgression over a larger-scale ramp-step and underfilled rift topography. The overall good sorting and fine-grained nature of sandstones indicates a mature, distal source of sediment, which was redistributed alongshore by storm/wave-dominated processes, and accumulated in inherited post-rift depocentres, where intensive biogenic reworking was favored. This study offers new insights in how to interpret transgressive systems based on both primary depositional mechanisms and postdepositional processes, and provides useful tools to understand and predict the nature and potential preservation of these deposits in limited subsurface datasets, especially in syn-rift to early post-rift transitions.

Ephemeral Fluvial-Aeolian Interactions: From Outcrop Studies to Core Analysis

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Arid continental basins commonly comprise sedimentary fill from both fluvial and aeolian environments. While the preserved facies associations within each of these environments have been studied in great depth, the sedimentary interactions between coeval environments have received comparatively little attention, despite their likely influence upon localised reservoir quality and basin-scale fluid migration.

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.

Our work is applied to a case study of cores 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.

Deep-water lacustrine channel analysis as an aid to understanding fold growth history within the South Caspian Sea Basin

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The South Caspian Sea Basin is a unique basin within which 10 km of sediment have accumulated in the last 6 million years, overlying a thick, organic-rich, overpressurised shale known as the Maykop Formation. Shale-cored detachment anticlines and associated mud volcanoes are the most common structures in the basin, and while likely triggered by the complicated plate convergence directions in the area, we are testing the hypothesis that their growth is also influenced by rapid sediment loading, forcing the deep Maykop Formation shale to withdraw from inter-fold areas and inflate the folds. The top 2-3 km of the sedimentary infill of the basin is a Plio-Pleistocene lacustrine turbidite succession containing hundreds of small channels (~100m width) which can be observed in exquisite detail, including well-defined scroll bars, on 3D seismic reflection data (Figure 1). We use the distribution, frequency and channel geometries to better understand the growth of the Shafag-Asiman fold.

A1600km^2 3D seismicr eflection dataset is used for this study and includes two anticlines (Shafag-Asiman) and three mud volcanoes. There are no well data and therefore horizons were interpreted based on seismic character and stratigraphic relationships. Quantitative analysis of the growth strata show the folds to be asymmetrical, with the southern limbs of the folds showing more growth than the northern limbs. Within individual growth packages, that are several 100 metres thick, 10s of channels distributed throughout the vertical succession can be identified by amplitude extraction, allowing further information about fold growth patterns to be extracted on a finer scale (100,000's of years). Channels can be seen to deflect around fold crests or bypass the fold crests, indicating more detail about fold emergence at the seabed beneath the resolution of the growth strata. Integrating information from scroll-bar geometries that allow us to deduce channel flow directions, shows that within one of the seismic growth packages (c.400m thick) the channels originate from the south east of the study area. These results are consistent with the idea that sediment loading from the SE, drove mobile shale withdrawal, similar to that seen in areas of salt tectonics, and allowed more accommodation space to be generated on the south side of the structure and resultant higher growth rates.

Hot and late: clumped isotopes in Middle Jurassic calcite-cemented concretions from Skye

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Spectacular, decimetre-scale, calcite-cemented concretions hosted in the Middle Jurassic Valtos Sandstone Formation of Skye should record, through their geochemistry, the origin of pore waters from which they grew. On the basis of stable isotope data and assumptions about either water compositions or temperatures, these cements have long been thought to form from meteoric water, and various lines of evidence suggested the pore waters were of Middle to Upper Jurassic age (Wilkinson 1993). This said, the concretions from Valtos in Trotternish had some unusually negative $\delta^{18}O_{calcite}$ compositions that were difficult to interpret. Recent availability of clumped isotope measurements mean that previous assumptions about palaeotemperatures can now be tested. Furthermore, knowing both temperature (from clumped isotopes) and $\delta^{18}O_{calcite}$ it also possible to calculate pore fluid compositions. Measurements of a concretion previously studied by Wilkinson (1993) show centre to edge temperatures trending from 50°C to 80°C. Using these temperatures and the measured $\delta^{18}O_{calcite}$ values, pore water $\delta^{18}O$ were calculated. The pore waters show a centre to edge evolution from -12‰ to +3‰VSMOW. The starting composition of -12‰VSMOW is highly significant; it is incompatible with Jurassic meteoric water composition, which is unlikely to have been <-6‰VSMOW (Hudson & Andrews, 1987). Instead, -12‰VSMOW is exactly the composition of Hebridean Palaeocene meteoric water as demonstrated by a number of classic studies. Concretion growth thus began in the Palaeocene. The calculated temperatures of cement formation are higher than previously assumed, suggesting either deeper burial (or higher geotherm) or warmer pore waters. It is possible that Palaeocene pore waters were heated as the Jurassic sandstones underlie basaltic lavas and sills of the Hebridean Igneous Province. Following Palaeocene initiation of concretion growth, the evolution in pore water composition from -12‰ to +3‰VSMOW suggests a water–rock interaction signal. It is not yet clear whether this implies interaction with older basinal mudrocks or with overlying Tertiary (Palaeocene) lavas. We are hoping that cement Sr isotope compositions might be diagnostic. The new clumped isotope data fundamentally alters the interpretation of sandstone concretion growth in this region, showing that the cements formed much later and at higher temperatures than previously assumed. The study exemplifies the power of the carbonate clumped isotope paleothermometer in investigating burial cementation and diagenesis in both sandstones and limestones.

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Cambrian-Cretaceous pre-rift, multi-stage rift, passive margin and emplacement development of the Southern Neotethys: new evidence from the Antalya Complex in the Alanya Window (S Turkey)

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The Eastern Mediterranean is a key region for the understanding of plate tectonic processes including sedimentation related to rifting of ocean basins, sea-floor spreading and active margin processes (associated with subduction and collision). One of these oceanic basin, the Southern Neotethys, is extensively preserved in the Antalya Complex of SW Turkey. Although this area has been extensively studied, the history and processes of continental rifting/break-up have remained unclear mainly because the proximal rifted margin lithologies were mostly overridden and concealed during emplacement/collision. However, fieldwork (2015-2018) in a large, little studied outcrop - the Alanya Window near the Mediterranean coast, has revealed new evidence of rift-related sedimentation, with implications for other regions and basins. The sedimentary rocks in the Alanya Window document pulsed Permo-Triassic rifting in a proximal basin setting adjacent to a Mesozoic carbonate platform. Late Cambrian-Early Ordovician clastic sediments accumulated along the north margin of Gondwana on a shallow-marine shelf. Above an unconformity related to rift-shoulder uplift, Late Permian facies document shallow-marine to evaporitic environments during regional tectonic subsidence (first main rift pulse). Above a second, localised unconformity (both extension and sea-level influenced), Early Triassic carbonates and mudrocks accumulated on an unstable, gently subsiding shelf. Mudrocks, sandstones and lithoclastic debris-flows, derived from the underlying stratigraphy, accumulated during the Middle Triassic (Anisian-early Ladinian), implying strong tectonic subsidence (second main rift pulse). Radiolarian mudstones accumulated during late Middle Triassic-early Late Triassic in a well-oxidised, organically productive, but relatively quiescent, deep-water setting above the CCD. Alkaline basaltic sills locally intruded. Thick (100s m) lithoclastic sandstone turbidites (commonly plant-rich) and minor debris-flows accumulated during the Late Triassic (Carnian), together with detached blocks of underlying lithologies (third main rift pulse). Final continental break-up to create Southern Neotethyan oceanic lithosphere took place regionally during the Late Triassic (Carnian). Latest Triassic-Late Cretaceous deposition records passive margin subsidence. Variable low-grade metamorphism and multi-stage tectonic emplacement took place during latest Cretaceous-Palaeogene. The overall pattern of rifting appears to differ strongly from the hyper-extension that affected, especially the western Mediterranean-central North Atlantic region. Final continental break-up, documented from the Antalya Complex, was accompanied by 100s of metres of alkaline/transitional basaltic volcanism, suggesting comparison with volcanic-influenced (plume-related) margins, rather than low-magma-supply rifted margins. The northern Red Sea rift appears to be a good modern analogue.

Ichnological analysis: a tool to characterize deep-marine systems

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Deep-marine systems include a variety of complex sedimentary environments in which numerous processes interacts for developing depositional, erosional and mixed deposits. Three main sedimentary processes including pelagic/hemipelagic, gravitational, and bottom current (contourite) are dominant. End-member deposits in these settings may arise from a single predominant process, while more varied deposits can be formed due to the interaction of processes, and its differentiation and characterization of is not an easy task. In fact, at present, is being a challenge the recognition of valid diagnostic criteria for some of these deposits as pelagic/hemipelagic, debrites, turbidites, hyperpycnites and contourites. The presence of ichnological features and it specific signature on these variety of deposits, could represent a potential useful proxy for its discrimination and a valuable tool in sedimentary basin research. However, ichnofacies analysis have been not considered, under-evaluated or even criticised on the study of the deep-water sedimentary systems for interpreting deep-water deposits (i.e., contourites, turbidites, and hyperpycnites). One of the reasons of these false assumptions if because the idea that ichnological features have nothing to do with the fluid mechanics of the corresponding depositional processes.

In this contribution, it is presenting an updated review for evaluating the relationship between deep-marine sediments and ichnological signatures including, a) a critical view of the state of the art; b) the achieved results; and c) the unsolved aspects and the further necessary research in this field. It is going to be stated that the behaviour of trace makers is recorded on trace fossils providing meaningful information about both the ecological and depositional parameters affecting the trace maker community, which are conditioned by the sedimentary processes. Palaeoenvironmental conditions such as sedimentation rate, hydrodynamic energy, substrate consistency, bottom water oxygenation, salinity or food availability can be interpreted based on trace fossil assemblage. In fact, during the last years, ichnological information has been included as a criterion to differentiate between and into pelagites/hemipelagites, contourites, turbidites and hyperpycnites (e.g., Wetzel et al., 2008; Rodríguez-Tovar and Hernández-Molina, 2018; Buatois et al., 2019), revealing a variability of cases. Consequently, results from ichnological analysis should be considered and integrated with sedimentological data as well as other proxies for characterising deep-marine processes and products.

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The range and variability in sediment gravity flow deposits and petroleum reservoirs

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Modern outcrops and subsurface data sets provide a mapping opportunity to characterize deep- water depositional systems from shelf edge to basin plain. This includes observations of the grain- to basin-scale framework and key stratigraphic surfaces that subdivide the basin-fill. Analysis from recent mapping campaigns (2009-2019) from over 18 stratigraphic intervals in the Americas, Europe and New Zealand yields the following insights. (1) The range and variability in deep-water siliciclastic conventional petroleum reservoirs includes deposits resulting from transport and deposition via fluid turbulence, matrix strength and a combination of those two mechanisms. (2) Sediment distribution patterns in the deep sea are controlled by several key factors including various aspects of grain size and sediment volume, gradient, accommodation and overall basin type. (3) Sub-bed-scale, semi-quantitative analysis of sedimentary fabric ratios commonly gleaned from core and image logs reveals critical information on bulk rock volume, net:gross and porosity to help determine stock tank original oil in place (STOOIP). (4) Sedimentary provenance and source-to-sink routing systems are intimately linked to overall reservoir presence and reservoir quality in fine-grained turbidite reservoirs. (5) Downslope sediment gravity flow behavior can be used to calibrate and understand the predictive attributes in deep-water reservoir type from canyon head to basin plain. The results of these mapping campaigns reveal new observations on sediment gravity flows, their processes of transport and sedimentation, and their bearing on oil and gas exploration and development in deep-water depositional systems.

Late Miocene sediment routing patterns and reservoir-scale architecture of deep-water slope, base-of-slope, and basin-floor fan depositional environments in the Taranaki Basin

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Modern outcrops of the Taranaki Basin, New Zealand provide a field mapping opportunity to characterize deep-water slope, base-of-slope, and basin-floor deposits that represent petroleum reservoirs at depth. This includes observations of the sub-bed-scale sedimentology, lithofacies, stratigraphic architecture, and key stratigraphic surfaces. Analysis from recent field mapping campaigns yields the following insights. (1) In the roughly 400 km^2 area, maximum grain size decreases from shelf to basin floor. However, sand grain size increases within channel-fill from slope to basin floor, yet remains consistently fine to very fine grained in the splays, levees, and overbank areas. (2) Paleocurrent direction is dominantly NW for the Urenui Formation, NE for the upper Mount Messenger Formation, and ranges from NE to WNW for the lower Mount Messenger Formation. (3) Lateral spacing of slope channels and gullies is about 4-9 km, with minimum width estimates of 250–650 m and depths exceeding 30-40 m. Channel-fill is conglomerate- and mudstone-prone along the slope, sandstone- and mudstone-prone at the base of slope, and sandstone-rich at the basin floor. (4) The conglomerate typically exhibits variations on Lowe R(12)3S3 to R3S(3) intervals. From upper slope to basin floor, the sandstone deposits are typically variations on Bouma T(a)bcde with rare S1 intervals. The lack of thick structureless sandstone (i.e. Bouma T_a/ Lowe S_3) intervals is somewhat unexpected and may be a result of the uniformly fine to very fine grain size, lack of sharp changes in gradient, or overabundance of low-density turbidity currents causing deposition via traction.

Constraints on caprock lithofacies and stratigraphy by application of a multi-method approach

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Caprocks form wherever evaporite successions containing highly soluble salt and somewhat less soluble anhydrite come into contact with undersaturated water, for example at the top of salt diapirs where they occur close to, or at surface. Dissolution of evaporites in the subsurface leads to the formation of a range of surface features, such as collapse structures. Within the subsurface, a variety of different lithofacies result from salt dissolution, settling and / or fragmentation of insoluble residues, the recrystallization of minerals and the formation of new minerals (e.g. Warren 2016). Recognition of these lithofacies is the first step towards a successful interpretation of the processes involved in the formation of a caprock, adding to the understanding of salt structure evolution. This study uses a combination of conventional core logging as well as mineralogical and geochemical analyses of caprock units from a North German salt structure comprising Upper Permian to Triassic rocks. Within the caprock, most lithofacies consist of rocks comprising either almost exclusively gypsum or anhydrite, with additional small amounts of carbonate and clay minerals. However, several siliciclastic units have also been identified. Complementary microstructural analyses on representative thin sections reveal the existence of various microstructures within the sulfate rocks. These include ooide like grains, algal mats, veins, shear bands, boudinage and folds and are interpreted to be the results of both sedimentary and tectonic processes. Despite some differences in lithofacies characteristics between the upper and lower parts of the caprock, they give very little indication about the stratigraphic position of the units prior to their incorporation into the caprock. Therefore, stable sulphur and oxygen isotope analyses have been carried out to gain information about the primary age of the sulfate rocks. While oxygen values are relatively uniform (between 11.5 and 14.6 ‰), sulfur isotope values are more variable, building two distinctive groups with values around 12 and 24 ‰, respectively. Values around 12 ‰ are expected for Upper Permian marine sulfates, whereas the occurrence of values around 24 ‰ indicates the integration of Lower Triassic marine sulfates into the caprock. While sulfate rocks of Lower Triassic age have been recrystallised during caprock formation, they still display signs of their primary depositional environment. In contrast, sulfate rocks of Upper Permian age show little to no indication of their primary origin. They are accordingly interpreted to represent the intense dissolution of rock salt units, resulting in the formation of evaporite dissolution breccias. Siltstone units within the caprock are interpreted to have formed as ‘alluvial’ deposits in caverns leached into the salt prior to the formation of the now adjacent sulfate caprock. In this study, the application of a multiple method approach led to a new understanding of the complexity of caprock formation processes and resulting lithofacies as well as a reliable stratigraphic division of the Upper Permian and Lower Triassic units, thereby stressing the importance to apply a combination of suitable analyses wherever applicable.

Hydrogen storage in porous rocks: the storage capacity of the UK continental shelf

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Increasing the amount of renewable energy in the UK reduces greenhouse gas emissions but will also lead to intermittency of supply, especially on a seasonal timescale. Over producing energy when demand is low and under producing when demand is high requires large-scale storage to redress the balance. Hydrogen stored over seasonal timescales in subsurface porous rocks can act as a giant battery for the UK and is a flexible energy vector that can be used for heat, transport and electricity generation.

No large scale assessment of the hydrogen storage capacity of an industrialised region has yet been undertaken. Here, we present a novel method for calculating the hydrogen storage capacity of gas fields and saline aquifers on the UK continental shelf using data previously used to assess carbon-dioxide storage potential.

We find that the storage potential of the UK continental shelf is substantial (several hundred times that required) and that sites can be ranked according to their proximity to offshore wind production and oil & gas infrastructure that could be re-used.

Diagenetic Features and Porosity Dense Evolution of Chang 8 Tight Sandstone Reservoir in Hujianshan Area, Ordos Basin

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An in-depth study is carried out on diagenetic features and evolutionary mechanism of porosity of the Chang 8 tight sandstone reservoir of the Hujianshan area in the Ordos Basin by means of Scanning Electron Microscope (SEM) and high-pressure mercury injection (HPMI) on the basis of extensive rock-core and thin section analyses. Different diagenetic facies, pore structures and their influences on the reservoir quality are further discussed. The results of these analyses suggest that the Chang 8 reservoir is in the mesogenetic stage A in general, as a result of a series of diagenetic processes, e.g. compaction-pressure solution, cementation, and dissolution, etc. Compaction, which caused massive loss of primary pores in the sandstone, is considered the most significant factor behind the tightening of the Chang 8 reservoir; while cementation of carbonates and clay minerals in the second place also contribute greatly. Yet the primary intergranular pores kept intact in the chlorite clay membrane, which was formed early in the diagenetic history of the reservoir, helped maintain the physical properties of the reservoir, and the pore connectivity and permeability were greatly improved by pores due to dissolution of unstable minerals like feldspar under acidic diagenetic environment. Analyses suggest that compaction leads to 19.37% of the average porosity reduction with the loss rate of 51.86%, and cementation 11.97% with the loss rate of 32.66%; while dissolution contributes a porosity increment of 3.26% on average. After considering different diagenetic minerals and pore-evolution features, as well as the logging response characteristics, the entire reservoir area is broken down to four diagenetic facies. Among them the residual chlorite-membrane intergranular-pore facies and the feldspar dissolution facies are deemed the most favorable diagenetic facies.

Microbial Role in Deep-Marine Dolomite Formation within the Gulf of Cadiz Contourite Depositional System

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Dolomite is a common accessory mineral, widely dispersed in deep-marine sediment, but rarely occurs as distinct layers in this setting. Hence, the nature and formation of dolomite layers in deep marine sediments are very poorly understood. Here, we present new data from three separate dolomite layers that occur within the Pliocene-Quaternary contourite succession of the Gulf of Cadiz continental slope, drilled during IODP Expedition 339. These deposits provide a unique access to understand dolomite formation that is uncomplicated by meteoric, shallow marine or deep burial influences. We use a novel approach by investigating the organogenic components extracted from these dolomites. The Cadiz contourite depositional system (CCDS) was developed under the influence of the Mediterranean Outflow Water, which has been active since the early Pliocene. Major hiatuses in the CCDS represent periods of time when highly energetic bottom current activity prevented sediment accumulation. These episodes were most likely linked to tectonic adjustments in the seafloor morphology and/or to dimensions of the Gibraltar oceanic gateway. The most prominent hiatuses are the late Pliocene Discontinuity (around 3 Ma) and the early Quaternary Discontinuity (around 2 Ma). At one of the sites drilled, U1387, these hiatuses have combined to yield a gap in sedimentation in excess of 1 My. The succession is characterised by highly bioturbated, mud, silt and sand contourites, and less dominant turbidites, of mixed siliciclastic (dominant) and biogenic (minor) composition. The three dolomite layers (10-50 cm thick) occur at present-day burial depths of 450 to 630 m at Sites U1387 and U1391 respectively. However, our study suggests that their formation most likely occurred close to the seafloor, associated with development of the hiatuses, and also linked to the influx of formation waters escaping from depth with the sediment column, possibly connected to tectonic activities. Dolomite crystals show a distinct pattern of oscillatory zoning. Both simple rhombic and polygonal crystal shape and zonal accretion are evident, which can be related to pulses of highly alkaline fluids. Dolomites at Site U1387 show more enhanced crystal forms and zoning complexity compared to those at Site U1391. Nucleic acids were extracted from ground-up dolomite and mud samples and DNA was used for 16S rRNA gene amplicon sequencing. Microbial community analysis revealed that the DNA extracted from the dolomites is dominated by Arthrobacter (Micrococcaceae family). Members of this genus are known to induce dolomite crystallisation in a suitable medium of high Mg/Ca concentration. Although the dolomites at the two sites investigated are associated with different hiatuses and show varying crystal morphology, they share a similar bacterial community spectrum. It is inferred that microbes played an essential role in the precipitation of dolomite through increasing pH and alkalinity, and possibly providing nucleation sites for the carbonate crystallization over episodes that can be triggered by fluid influxes and tectonic activities.

What controls sediment delivery to deep-marine basins? An isotopic investigation of the Eocene-Oligocene Alpine foreland basin

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Sediment delivery to deep-marine sedimentary basins is governed by the interplay between sediment supply and the physical space for sediment storage (accommodation). Sediment supply is controlled by climatic and tectonic factors, while accommodation is primarily controlled by relative sea-level, which is modulated by subsidence and eustasy. Deep-marine sedimentary basins represent the ultimate sink of these depositional signals, making their stratigraphic record critical when investigating the controls on sediment delivery to deep-marine environments. Despite this, most field-based studies typically interpret deep-water deposition qualitatively, with quantitative or multi-disciplinary attempts to understand deposition rare. This study aims to address this by constructing high-resolution $\delta^{13}C$ and $\delta^{18}O$ isotopic curves from 138 samples collected through a ~150 m thick exposure of the deep-marine Eocene – Oligocene Grès d'Annot, SE France. The stratigraphy of the Grès d'Annot is marked by coarse-grained sandstone-rich packages bound by fine-grained mudstone and marl-rich packages. Climate, eustasy and tectonism have all been postulated as the controls on this cyclicity, however there remains as yet a robust and quantifiable explanation for this apparent cyclicity. By measuring $\delta^{13}C$ and $\delta^{18}O$ through a sequence comprising periods of enhanced sediment delivery (dominated by coarse-grained deposition) and reduced sediment delivery (dominated by fine-grained deposition) it will be possible to assess the dominant controls on sediment delivery to this deep-marine basin.

Additionally, this study aims to address the effect that the major global cooling event characterising the Eocene-Oligocene transition (EOT) had on deep-marine sedimentation, as the exposed section has been predicted to intersect this key paleoenvironmental boundary. The EOT represents the Earth's largest climatic shift in the last 65 Myr and resulted in long-term deep-sea cooling, growth of Antarctic ice sheets to modern sizes, and a eustatic sea-level fall of ~ 67 m. While the depositional effects of the EOT have been explored in open marine environments, the effects of the EOT on epicontinental seas is not yet understood, with most depositional signals in these environments believed to be controlled by relatively local tectonic events. This study may therefore shed light on the relative impact of global vs. local events on sedimentation in epicontinental seas.

Laminar and transitional sediment gravity deposits as baffles and barriers to fluid flow: a case study from the Magnus Field, northern North Sea

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Characterisation of turbidite reservoirs is a mature area of research. However, assessments of how laminar (i.e. debrites) and transitional (i.e. banded/hybrid) beds effect reservoir quality and distribution has been limited to two-dimensional observations from outcrop, or subsurface studies which focus predominantly on seismic-scale MTDs. Consequently, the influence of debrites and transitional flow deposits on baffles and/or barriers to fluid flow, and the ability of debrites to act as competent sealing units is poorly understood in both hydrocarbon exploration and development, and carbon storage and sequestration appraisal projects. Here, we aim to bridge the gap between seismically resolvable and sub-seismic MTDs and transitional flow deposits, by studying the reservoir distribution and rock properties (i.e. porosity, permeability, texture) within the Magnus Sandstone Member. The Magnus Field reservoir comprises the most northernly of several small (<5km radius) Late Jurassic sand-rich stacked turbidite systems in the northern North Sea. We use core, petrophysical logs, fluid pressure, quantitative evaluation of minerals by scanning electron microscopy (QEMSCAN), and 3D seismic-reflection datasets to quantify facies and rock properties and distribution. Within the system, a range of sediment gravity deposits are observed including: (i) thick/thin bedded structureless and structured turbidite that constitute the primary reservoir units in the field, (ii) banded fine sand to siltstone beds consisting of distinct light and dark couplets interpreted as transitional flow deposits, (iii) beds with graded/ungraded basal sandstone units with sheared contacts into an overlying mud-rich debritic sandstone, interpreted as hybrid event beds, and (iv) heterogeneous mud-rich sandstones interpreted as debrites. Our results highlight the ability of mud-prone debrites to act as fluid flow barriers/seals (Φ <6%, VSH >60%) and in the case of the Magnus Field they have compartmentalised the system into an upper and lower reservoir. In contrast, we suggest the transitional flow deposits (banded and hybrid beds) likely act as baffles and reduce net reservoir but are not laterally extensive enough to compartmentalise the reservoir due to longitudinal flow transformation. Prediction of the rock properties of laminar and transitional deposits and their effect on the later distribution of reservoirs has important implications: (i) for characterisation and modelling of turbidite reservoirs, (ii) reservoir development strategies, and (iii) exploration play concepts, particularly in the application of MTDs as sealing units.

CONTOURITE RESERVOIR CHARACTERISTICS: POROSITY, GRAIN SIZE AND A NEW SORTABLE SILT METHOD

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Contourites are now recognised as having a significant potential as hydrocarbon reservoirs in the subsurface, and several fields have been interpreted as comprising bottom-current reworked turbidite sands. However, very little has been published on the porosity characteristics of contourites. This study documents porosity data from IODP Expedition 339 sites in the Gulf of Cadiz. We use grain-size analyses, porosity-depth plots and exponential models to yield a better understanding of grain-size characteristics and facies, porosity characteristics, and the reservoir potential of contourites in the subsurface.

Porosity-depth relationships from four sites show a high initial porosity for both sand and mud facies (50-60%) and a systematic decrease with depth to around 35-40% near 500 m burial depth. According to the exponential models of porosity with depth, contourite porosity should exceed 10% at 2500 m burial depth. We compare the data from the Gulf of Cadiz Contourite Depositional System, with those of the Eirik Drift, Newfoundland Drift and Canterbury Slope Drifts. Similar depth trends are observed, and all show differences linked to sandy and muddy facies, composition (carbonate vs siliciclastic), and the presence of hiatuses in the sediment record. These results confirm the

We also present new grain size data for over 1000 samples from the IODP 339 sites that builds on the work published by Brackenridge et al (2018) for the Gulf of Cadiz contourites. These data confirm the distinctive trends in textural properties linked to depositional processes under the action of bottom currents. The finest muddy contourites (<20 microns) show normal grain-size distributions, poor to very poor sorting becoming better with decreasing grain size, and zero or low skewness. These are deposited by settling from weak bottom currents with a very fine suspension load and by hemipelagic settling – they are contourite-hemipelagite hybrids. Muddy to fine sandy contourites (20 to 200 microns) trend towards better sorting and initially finer and then coarser skew. These are interpreted as typical depositional trends for contourites from suspended load. As current velocity and carrying capacity increase, more of the finest fraction remains in suspension, increased winnowing and bedload transport becomes more important. Clean sandy contourites (around 200 microns) are the best sorted. Medium and coarser-grained contourites show a trend towards poorer sorting. They result from the action of dominant bedload transport, extensive winnowing, and only intermittent bedload movement of the coarsest fraction at high current speeds. These results strongly indicate the need to modify the calculation 'sortable silt' in contourites to a factor that includes sortable silt and sand'.

Paleoenvironments and Sediment Routing Along the Equatorial Atlantic Cretaceous Margin: New Insights from DSDP/ODP/IODP Borehole Data Offshore Suriname, Cote d'Ivoire, and Ghana

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The Cretaceous margins of South America and Africa host an extensive set of fluvio-deltaic, shelf, slope, and deep-water depositional sequences that formed when some of the last remnants of Gondwana rifted apart to create the Equatorial Atlantic Ocean. Well known for their large hydrocarbon accumulations and high-risk exploration environments, accurate hydrocarbon risk assessment within these margins requires data-rich, multidisciplinary technical studies to properly characterize their complex subsurface structural and stratigraphic frameworks. Drawing upon a wide network of sample locations from coincident stratigraphic intervals, our approach integrates geo-/thermochronology, biostratigraphy, and chemostratigraphy data across the Equatorial Cretaceous margins and inboard African rift basins, including proprietary wells and select International Ocean Discovery Program (IODP) sites offshore Cote d'Ivoire, Ghana, and the Demerara Plateau, to establish a regional chronostratigraphic scheme and build rift margin reconstructions at pre-, syn-, and post-rift stages. We conducted $\delta^{13}C_{org}$ analysis to improve upon existing wellsite nannofossil & foraminifera biostratigraphy, identify stratigraphic boundaries with geologic age-level resolution, and place samples into a global chronostratigraphic context. A dearth of first-order volcanic zircon entering the Barremian-through-Turonian-aged rift sequences precludes the establishment of accurate maximum depositional ages via detrital zircon U-Pb techniques but we identified and correlated multiple diagnostic carbon isotope excursions (e.g., OAEs 1, 2, and 3) across the IODP wells, which allowed us to calibrate the depositional age of "double-dated" detrital zircon U-Pb & (U-Th)/He samples prior to source-to-sink analysis. Sediment provenance interpretations, aided by major and trace element evidence, show drainage networks evolving from short-run, transverse systems that fed a series of *en echelon*, sometimes anoxic, rift grabens into sub-continental-scale catchments that delivered thick clastic sequences into nascent oceanic sub-basins with increased axial communication. Despite the overwhelming, non-diagnostic Pan-African age mode (~550-750 Ma) present in some Gondwana-derived clastic sequences, variations in detrital zircon signals are discernable from east-to-west along the rift zone, providing new insight on the differentiation of Equatorial African and South American Cretaceous drainage networks with continued separation of the two continents.

Localised carbonate deposition above the Gaskiers diamictite – implications for Neoproterozoic cap carbonates?

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The middle Ediacaran-aged (~580 Ma) Gaskiers Formation of the Avalon Peninsula, Newfoundland, comprises up to 260 metres of massive, stratified or slumped diamictite, siltstone and sandstone lithologies. Regional correlation of six logged stratigraphic sections through the Gaskiers Formation reveals considerable variation in its expression across the peninsula. In the south, around the Gaskiers type section, the diamictite is 260 m thick, whereas in the north, on the coast of Conception Bay, the diamictite is stratified and only 11 m thick.

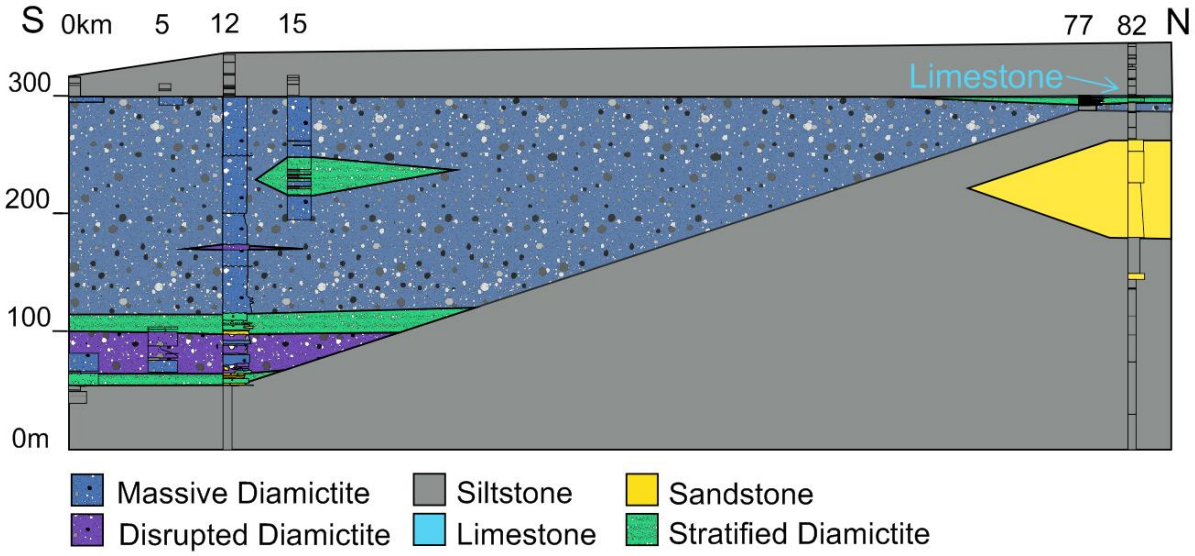

Figure 1 Stratigraphic transect through the Gaskiers Formation across the Avalon Peninsula, Newfoundland.

A 50 cm-thick 'cap' limestone overlies the diamictite at Conception Bay, in common with many other Neoproterozoic glacial successions, but is the only bedded limestone observed in nearly 7 km of conformable siliciclastic and volcaniclastic strata in the region (comprising the Conception, St Johns and Signal Hill Groups). Further, it is restricted to the condensed section in the northern outcrop region, and the same lithostratigraphic interval in the south contains only rare carbonate nodules and carbonate-cemented sandstones.

This presentation discusses explanations for the non-uniform distribution of carbonates in the Gaskiers Formation, and contextualizes the nature of the Gaskiers glacial event with reference to other Neoproterozoic and Phanerozoic glacial events.

Historical eutrophication history and long-term phosphorus fractions retention from sediments in Lake Burgäschi (Switzerland) since the early 1900s

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Excessive human-induced phosphorus (P) inputs have been shown to be the main cause of lake eutrophication worldwide over the past few decades. Lake sediments are valuable archives to record lake eutrophication and P loading history on long time scales prior to lake limnological surveys. Phosphorus accumulated in lake sediments is an important P source for eutrophication in lakes (internal P loadings) where anoxic conditions prevail in hypolimnetic waters. However, few studies have reported P fractions retention in sediments and their temporal responses to eutrophication, subsequent lake management and restoration history, and related changes in hypolimnetic redox conditions in deep lakes. In this study, we investigated the sediment profile from Lake Burgäschi, a deep, eutrophic lake on the Swiss Plateau, since the early 1900s. Sequential P-extractions with five P fractions were performed on n samples spanning from 19xx to present. The changes of sedimentary P fractions retention were assessed with respect to lake trophic evolution (sedimentary green-pigments; Schneider et al., 2018) and hypolimnetic oxygenation regime (Fe/Mn ratio; Zarczynski et al., 2019). Semi-quantitative records of green-pigments, indicated by hyperspectral imaging (HSI) data, showed increased lake trophic levels from the 1930s. Recent eutrophication resulted from external agricultural P inputs since the 1960s. Total P and labile P fractions retention in sediments were mainly controlled by hypolimnetic redox conditions, and only indirectly by lake productivity and external P inputs. Persistent anoxic conditions in the hypolimnion since ~1977 coincide with highly eutrophic conditions, which might have resulted in substantially decreased retention of labile P fractions in recent sediments and recycling of P from the sediment back to the lake. By contrast, Ca-P fraction retention was largely affected by authigenic $CaCO_3$-P precipitation and increased with higher eutrophic levels since the ~1960s. This study implies that, in seasonally-stratified deep lakes like Lake Burgäschi, sedimentary P-fraction retention is not a good proxy to reflect recent eutrophication and to assess the P loading history of this lake.

How grainsize controls a turbidity current structure? A compilation of a successful decade of seafloor monitoring.

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Recent advances in technology are enabling high-resolution measurements of active turbidity currents. These data are answering key questions such as what flow characteristics exist for field-scale turbidity currents? What factors control those characteristic flows? By analysing direct measurements of turbidity currents at different locations worldwide, and from different water depths (65 m to 2300 m), our aims are to (1) understand how similar or diverse turbidity currents are in different settings; and (2) identify which are the factors that control gravity flow behavior. Our study shows that two main flow modes are possible. Sand-rich systems are typical of canyons with coarse axial sediments (<10% mud) and oceanographic-triggers. Mud-rich systems are those where sediments comprise c.10-40% mud and canyons are directly linked to the rivers activity. We suggest that the grain size is a dominant factor in controlling flow characteristics.

Is Geology Normal? The peculiar mathematics of sedimentary provenance data.

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The provenance of siliclastic sediment may be traced using a wide variety of chemical, mineralogical and isotopic proxies. These define three distinct data types: (1) compositional data such as chemical concentrations; (2) point-counting data such as heavy mineral compositions; and (3) distributional data such as zircon U-Pb age spectra. Conventional statistical analysis of such data is fraught with problems. Elementary statistical operations such as the arithmetic mean and standard deviation may produce nonsensical results, and more advanced ordination techniques such as Principal Component Analysis (PCA) can easily break down as well. The fundamental problem with these conventional tools is that they assume Gaussian (aka normal) statistics. However geological data in general and sedimentary data in particular rarely meet this assumption. In a nutshell, the normal distribution has tails that range the entire range of numbers from negative to positive infinity. However, geological data are restricted to a narrow subset of that space. U-Pb ages are strictly positive numbers; chemical compositional are strictly positive numbers that are constrained to a constant sum; and point counting data are integer values that add multinomial noise to compositional mixtures. To solve the problems associated with the analysis of sedimentary data, each of the aforementioned three data types requires different statistical treatment. Central to this is the ability to quantify the 'dissimilarity' between two samples. For compositional data, this is best done using a logratio distance. Point-counting data may be compared using the chi-square distance, which deals better with missing components (zero values) than the logratio distance does. Finally, distributional data can be compared using the Kolmogorov-Smirnov and related statistics. In my presentation, I will mostly focus on point counting data. These are a special type of data that represent mixtures of compositional and multinomial distributions. The statistical treatment of such data is well established in other branches of the sciences, notably in ecology and fission track dating. Vermeesch (2018) has adapted these methods to sedimentary studies and implemented them in an R package called 'provenance' (Vermeesch et al., 2016). It includes functions to visualise point-counting ratios as radial plots (Galbraith, 1986), and Correspondence Analysis (CA) as a multivariate ordination method that is better suited than PCA for counting data. With examples, I will show that both CA and PCA are special cases of another technique called Multidimensional Scaling (MDS), which can also be applied to distributional data. Finally, the provenance package allows compositional, point-counting and distributional data to be combined together as Procrustes or 3-way MDS maps.

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Outcrop analogues for petroleum system characterization of the Central and North Atlantic margins

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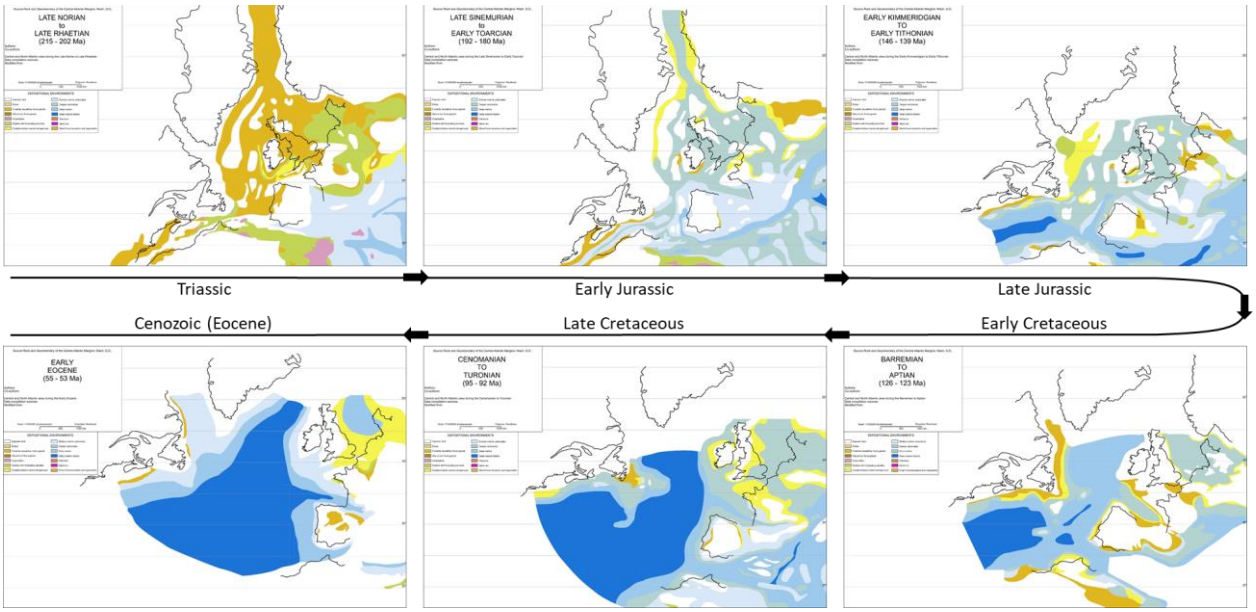
Outcrops and offshore well penetrations of Mesozoic sediments in the conjugate Central and North Atlantic margins provide keys to their inherent petroleum systems. Outcrops provide insights to controls and characteristics of reservoirs, seals, source rocks, and trap styles. Outcrop and well penetrations demonstrate a range of often linked depositional environments from terrigenous and non-marine, shallow siliciclastic and carbonate sediments, through to deep marine sediments, and clarify key stratigraphic surfaces representing conformable and non-conformable surfaces. Validation of these analog sections and surfaces can help predict downdip, updip and lateral potential of the petroleum systems. It is the stratigraphic anomalies we see, often expressed along the Margins, that can lead to new play concepts and discoveries. Geologic interpretation is pattern recognition, but it is the anomalies in those patterns that we search for as geoscientists.



Spatial net-to-gross variability of a saucer shaped sandstone intrusion

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Reservoirs comprised of sandstone intrusions are known to hold significant reserves and are a focus for exploration in the North Sea. Detailed geometry of sandstone intrusions are difficult to define from interpretation of 3D seismic data, due to their complex geometry and size variability within a single injectite complex. Saucer-shaped intrusions are one of the main geometries identified in seismic images. They cross-cut stratigraphy and contain significant volumes of reservoir quality sandstone. Numerous injection features that are below seismic detection limits (subseismic) are typically undetected, but play an important and positive role in the overall connectivity and net-to-gross (NTG) distribution of the system. In subsurface exploration and reservoir modelling outcrop analogues are routinely used to define and refine subseismic sandstone intrusion geometry and architecture. The Panoche Giant Injection Complex (PGIC) in central California provides unparalleled exposure of sandstone intrusions and is an often used subsurface analogue for North Sea injectite fields. The PGIC consists of a variety of different injection styles, including saucer-shaped geometry. This study focuses on the calculation of the NTG of a saucer-shaped sandstone intrusion by mapping all observed intrusions, seismic and subseismic, over a 1.5 km^2 area. Two methods were used: 1) discretisation of the mapped data into a regular grid, at typical reservoir-scale spatial dimensions - 50 x 50 m, and quantifying the NTG in each cell; 2) vertical and horizontal transects ("pseudo-wells") mapped across the study area at the same grid spacing with the NTG quantified along each transect. Results from these analyses demonstrate that NTG calculated along an individual transect leads to underestimation of reservoir volume in an injectite complex. The spatial analytical method demonstrated herein provides increased accuracy of estimation for NTG spatially and should be considered tangential to vertical and/or horizontal transects. These types of data provide improved insight into the net-to-gross variability within a single complex, reservoir connectivity, and ultimately lead to better constrained resource evaluation and extraction.

Extrinsic vs intrinsic controls on the architecture of shallow-water deltas: lessons from mixed systems in a tectonically active basins

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Explaining and predicting the heterogeneity and architecture of delta front sandbodies is a significant challenge in the exploration for, and development of, petroleum fields and aquifers. For modern shallow water deltas, the management of these environmentally sensitive coastal systems is also dependent better prediction of the impacts of changing climate and human intervention at the delta front. This is because spatial and temporal changes in deltas are controlled by, and react rapidly to, a complex interplay of autogenic and allogenic processes. We present the results of the analysis of a spectacularly well-exposed Early Cretaceous fluvio-deltaic succession from the Aliaga area, Maestrazgo Basin in central-eastern Spain. The succession is typical of many basins which were marginal to the Tethyan and Atlantic Oceans at this time and which include petroleum plays in the Middle East. The study uses a combination of remote sensing and geological fieldwork techniques, sequence stratigraphy and architectural element analysis in order to understand the possible autogenic and allogenic processes that controlled the stratigraphy and architecture of the fluvio-deltaic succession. This succession was deposited in a semi-isolated, tectonic rift sub-basin during a rifting cycle from the Late Jurassic to Middle Cretaceous. It is also likely that reactive salt tectonics was also modifying accommodation space and sea-floor bathymetry at this time. The succession displays two regressive phases of shallow-water river-dominated deltas that prograded into a carbonate-dominated shelf during an overall longer term transgression. During the initial regressive phase, separate sediment input points and delta sub-complexes were present and limited fault movement and regionally lower accommodation creation rates led to development of two coeval and extensive delta systems, and so a relatively sheet-like composite delta sandbody complex. During the second regressive phase, growth structure subsidence accelerated, aerially restricting the deltas to the north, and creating stacked multi-story sandbodies. Because these deltas were discharging into coeval shallow marine carbonate platforms, enabling us to evaluate how these contrasting sedimentary systems respond to the same external controls. Detailed architectural element analysis provides a detailed understanding of the evolution of shallow-water mouth bars. The channel mouth bar succession was fluvially-dominated, building out into shallow-water depths of 4-5 m, that were similar to channel depths (3.5-4 m), resulting in the deposition of friction-dominated mouth bars. The mouth bars evolved initially through vertical aggradation, followed-by lateral and/or basinward expansion. Further growth was facilitated by re-channelisation of the mouth bar top, and the addition of sub-bars at the margins of each mouth bar. Where prograding into deeper-water, mouth bars show a process regime change from friction to inertia-domination. Mouth bar growth through the addition of multiple generations of sub-bars ceased when the size of the composite mouth bar became too great an obstacle for the outgoing jet to sustain growth, resulting in abandonment of the mouth-bar through the feeding distributary channel avulsing or bifurcating.

Sub-seismic heterogeneity in early post-rift deep-water lobes; insights from the Angel Formation, NW Shelf, Australia.

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Deep-water lobes can form important hydrocarbon reservoirs in many basins and are potential sites for carbon sequestration. Spatial confinement is a first-order control on the stratigraphic architecture of lobe complexes, and thus the quality and compartmentalisation of related reservoirs. Inherited early post-rift bathymetry, for example compactional drape over syn-rift structural highs, can confine flows, leading to aggradational stacking of deep-water lobes. Seismic mapping of deep-water lobes can prove challenging at economic burial depths (i.e. several kms) due to limitations in data resolution. The early post-rift Upper Jurassic Angel Formation, Dampier sub-basin, NW Shelf, Australia is an example where a thick succession (~300 m) of sand-rich, deep-water lobes are poorly imaged in seismic reflection data. This poor seismic imaging means we must rely on core and well log data to analyse facies and facies distributions changes related to palaeo-bathymetry. A structural framework has been constructed using interpretation from seismic reflection data, enabling the identification of potential sediment dispersal pathways and depocentres. We have logged 20 cores (894 m) that penetrate the Angel Formation and have identified seven core facies. Structureless sandstones, dewatered sandstones, clast-rich sandstone and bioturbated heterolithics dominate the formation. Uncommon facies include laminated sandstone, granular sandstone and injectites. Amalgamated sandstones are 10-15 m thick, and typically pass upwards into clast-rich sandstone or, more rarely, laminated sandstones. Bioturbated heterolithics contain a diverse suite of trace fossils, with the identified ichnofacies suggesting an offshore to basin floor environment. The Angel Formation is anomalous in that no thin-beds are observed; we suggest that such deposits were originally present but were subsequently texturally homogenised by bioturbation. We interpret a system with highly-amalgamated high-density turbidite beds, often dewatered and overlain by a co-genetic mud-clast-rich bed and heavily bioturbated heterolithic mudstone and sandstone. This bi-modal lithology explains the seismic expression of the Angel Formation; i.e. the lack of acoustic contrast between sand-rich beds and heavily bioturbated heterolithic intervals. The stacking of amalgamated sandstones at the base of hybrid beds, and the observed and/or preserved thin-beds differs to that predicted by deep-water lobe models defined largely from unconfined settings (e.g. Karoo). The type and distribution of sub-seismic facies and stacking patterns observed here highlights the requirement for an alternative deep-water lobes facies models designed specifically for confined settings.

10 things we don't know about clay minerals

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Clay minerals are an important component of shales. Despite decades of study there are still fundamental questions that we cannot answer. This reduces our ability to make predictive models of shale diagenesis and properties. Questions include:

1) Why are clay minerals so fine grained? Muscovite is structurally similar to illite, but forms crystals dm across. Illite has such small crystals it was discovered by X-ray diffraction.

2) The most abundant mineral close to the Earth's surface may be interlayered illite-smectite, but we have 2 competing models for the atomic structure of this mineral. Which is correct?

3) Does interlayered illite-smectite even exist? Is the expandability of the clay really due to absorption by illite-illite surfaces, and not actual smectite interlayers?

4) Do 'fundamental particles' (FP's) exist? This model has any 'crystal' visible at SEM scale as a mosaic of smaller particles.

5) Is authigenic 'illite' actually illite, or really illite-smectite as suggested by chemical analysis (the K content of authigenic 'illite' is too low, according to the established structural formula)?

6) Can the hydronium ion (H_3O^+) fit into the illite lattice in place of K, and how does this relate Q.5? How about ammonium?

7) Detrital smectite (or illite-smectite) in shales (and sandstones, discuss) becomes progressively more illite-rich during burial - this was controversial in the 70's and 80's but is well-established now. What is the reaction mechanism (solid state; solution-reprecipitation; Ostwald ripening)?

8) Why is there no 'zero-age' illite recorded (from K-Ar geochronometry)? Many basins are presently at maximum burial depth with porewaters supersaturated with respect to illite (or at least w.r.t. muscovite, as thermodynamic data on illite has proved to be tricky to obtain). Hence, illite should be forming today, and assuming the rate is controlled by temperature, should be forming presently. So why can we not find this?

9) What controls the nucleation of clays? And is nucleation the key to understanding clay growth in natural systems?

And finally one about shales:

10) Is the very low permeability of shales a depositional feature, or due to the growth of authigenic clays that are much finer-grained than the detrital components, with much smaller-scale porosity?

Clay mineral are not just found in shales (where they help to retain hydrocarbons etc) but are commercially very important in products such as dyes and shampoo – you may be wearing clays, as well as have some in your hair!

The role of physical properties in storage and disposal in the subsurface.

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As we move towards a low carbon economy the role of the subsurface will become increasingly more important, whether this be for disposal or storage. It is likely that fine-grained, low permeability formations will be key as they have many properties which lend themselves to both storage and disposal. In order to decarbonise the economy many new energy industries will need to come online, such as Carbon Capture and Storage (CCS), hydrogen storage and Compressed Air Energy Storage (CAES). In industries such as these having a detailed knowledge of the storage unit properties is vital. Understanding the physical properties, such as hydro-mechanics, and the way they may evolve over time is vital to the safe implication of these new industries. The storage aspect of these industries, for example the role of a caprock in CCS, will be controlled by properties such as permeability and mechanical strength. The coupling of these effects is an important research area at the British Geological Survey. A combination of laboratory, field and modelling techniques are used to understand the processes which govern the physical properties. One wide reaching research area is the link between fracturing and fluid flow. For example, in CCS the withdrawal of hydrocarbons and subsequent injection of CO_2 results in a change in local stress conditions within the reservoir. This change in stress conditions may have the ability to cause deformation in both the reservoir and cap rock, potentially leading to the formation of a leakage pathway. Laboratory testing has been used to test the hydro-mechanical response of cap-rocks and reservoir rocks to similar stress changes. The data from these laboratory tests can then be used to test various scenarios which could occur during the time line of a CCS reservoir. The results of this can be used fed into safety assessments. Another example of the link between fracturing and fluid flow in low permeability formations is the flow of pore fluid and gas around a Geological Disposal Facility (GDF). In the construction of a GDF for the disposal of radioactive waste a damage zone will form around the tunnels. Within this damage zone fracture flow is likely to be enhanced for a period of time. The transmissivity of these fractures and the way this transmissivity will change over time is an important aspect of the safety assessment for a GDF. Hydrogen storage or CAES is another growing industry and research in this area has recently focussed on the creation of caverns in salt. In order to be able to control the size and shape of the cavern a detailed knowledge of the salt structure and heterogeneity is required. Small scale laboratory tests have been carried out on this topic and these results now need to be up scaled to a field size in order to test the validity of these results. Again, having a detailed knowledge of the material properties at a range of scales is important to this industry. Several topics are common throughout these industries. For example, the response to hydro-mechanical changes, response to changes in temperate and the way these properties evolve over time. At the BGS several techniques are being applied to answer these important questions. A summary of these techniques and the current theories which govern the physical controls will be presented. Understanding these properties in detail is vital to the growth of these industries and the progression towards a lower carbon economy.

The Digital Rock revolution of reservoir quality; understanding clay mineral morphology and distribution in three dimensions

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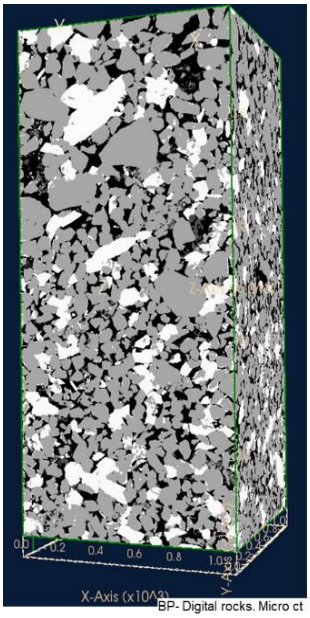
Clay mineral abundance and distribution is seldom homogenous in sandstones. Clay minerals are one of the most important groups of minerals, capable of both enhancing (e.g., grain coating chlorite) or degrading (e.g., pore-filling Kaolinite) reservoir quality, depending on the mineralogy, volume and distribution. In sandstones, clay minerals primarily occur as (i) clay-coats (rims), (ii) in ductile rich rock fragments, or (iii) as dispersed (pore-filling) material. However, the relationship between the morphology of clay and its distribution remains poorly understood. Current understanding, nomenclature, and quantification techniques of clay minerals in sandstones are based exclusively of two-dimensional observations via methods developed as early as 1900.This study introduces a novel Digital Rocks (microCT) method capable of imaging, (i) the three-dimensional morphology of clay minerals, (ii) quantifying distribution patterns, and (iii) quantifying clay-coat coverage in sandstones. The work utilised four North Sea reservoir sandstones, deposited in marginal-marine and aeolian-fluvial environments, to illustrate the variable and often interchangeable three-dimensional nature of clay mineral deposits.



Initial results suggest that current clay mineral distribution and morphology classification schemes, based exclusively on two-dimensional analyses, require re-evaluation. Crucially this study presents the first, three-dimensional, fully quantitative dataset of clay mineral heterogeneity (volume, distribution, and clay-coat coverage) across a range of reservoir sandstones.

The developed Digital Rocks (microCT) method, provides the most complete view of clay heterogeneity in sandstones, pushing scientific understanding. Crucially, the quantification of clay-coat coverage within a three-dimensional volume of rock, represents an industry and academic first.

Quantifying Sediment Distribution in Fluvial-Deltaic Foreland Basins

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Basin scale dimensions of fluvial-deltaic systems are principally driven by the balance between the rate of sediment supply, and the rate and distribution of accommodation generation (often through tectonic subsidence). Whilst conceptually useful, this approach offers limited predictability to sedimentary architecture at outcrop scale. Physical experiments (e.g. Strong et al., 2005) show that fluvial-deltaic systems demonstrate systematic, down basin organisation of sedimentary architecture, resultant from a predictable rate of sediment deposition (mass extraction) corresponding to basin length. The purpose of this study is to test the results of these physical experiments by examining, grain size fining, facies distributions, and variability in channel story dimensions (i.e. basin scale sedimentary architecture) of an exceptional, high-resolution field-core meta data set from the Pikeville formation, Central Appalachian Basin, USA. This represents the first rigorous attempt to apply a mass balance to a rock record. Basin wide coal correlation (~6300km^2) have allowed two fluvial-deltaic systems of different lengths to be mapped in 3D. Sediment volumes of different depositional components, pattern of dip and strike mass extraction, local and basin-scale sedimentary architecture have all been identified with age constraints. Each delta system has been placed in a mass balance framework and sedimentary architecture assessed to ascertain potential adherence to the mass balance hypothesis. Initial analysis observes consistent, down system trends across all investigated metrics; supporting the mass balance hypothesis. Therefore, demonstrating a potentially transformative approach to interpretation of sedimentary successions with a new mesoscale-macroscale framework. However, further work is required to fully integrate mesoscale dynamics.

Controls on microplastic vertical distribution in an urban environment in the River Thames, London, UK

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Plastics are an increasingly relevant environmental, political and public issue, due to their long residence times and potentially negative effects on ecosystems and public health. Despite this, there is little work examining their transport and deposition in sediments, which are key factors in determining their eventual distribution. This study uses core material collected by the British Geological Survey from the River Thames, London, to investigate the link between sedimentary facies and microplastic abundance and type.

The area examined in this study is Cuckold's Point, in the Rotherhithe area of South West London. Traditionally a site for ship-building, the site is currently used for offices and is less than 500 metres from the Canary Wharf. The core itself is variable in sedimentology but is largely dominated by silt and fine sand, with lenses of medium-coarse sand and occasional input of clays and gravels.

The core was logged on a millimetre-scale and sampled every 2cm for microplastics, which were extracted using density separation and subsequently photographed, measured and categorised into type according to their morphology. Over 900 microplastics were extracted in total, and their patterns of occurrence, morphology and composition vary according to their position in the core. A "pre-plastic" time period devoid of any microplastics is evident in the lowest 10 cm interval of the core and the number of microplastics generally increases through time, but with significant variability. Statistical techniques normally applied to community ecological analyses are used here to determine whether there is a facies control on microplastic abundance and distribution. Knowledge of the extent of sedimentological control on the transport and deposition of microplastics may have significant implications for future studies examining their distribution in fluvial environments.

Lithological Classification and Oil-Bearing Capability of Tight Reservoir in Permian Lucaogou Formation, Santanghu Basin, Xinjiang, China

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Here we report a set of well-laminated sedimentary rocks in Permian Lucaogou Formation in Santanghu Basin which have been regarded as typical "organic-rich shale" deposited in a profundal rift lake. The NW-SE trending Santanghu Basin is located north of the Bogda Mountains in NW China, and covers about 23,000 km^2. The basin became an intracontinental rift since late Carboniferous, where fluvial-lacustrine sedimentation started since early Permian. The basin has five depressions, and Malang Depression is the center of Santanghu Basin as the focus of this study. Samples from Well L1 in the Malang Depression were subject to petrographic, elemental chemical, and organic geochemistry. Petrographic features of 97 samples show lithology of Lucaogou Formation is complicated, which is characterized by fine laminated black mudstones and interlaminated with or intercalated dolostones, locally silicified. Grains in the mudstones are clay-fine silt sized, angular, poorly sorted, and contain abundant crystal fragments and lack of clay minerals. The lithology of 97 samples is statistically analyzed and roughly divided into five lithofacies, including dolomicrite, tuff, tuffaceous mudstone, tuffaceous dolomite and mixed lithology rock (dolomitic tuffaceous mudstone),which means there are three provenance in Lucaogou forming period(Tuff represents deep source,mudstone represents terrestrial sources,and dolomite represents lacustrine chemical precipitation). The TOC (Total Organic Carbon) data of these five lithofacies are 3.76%, 0.59%, 5.10%, 3.86%, 6.55% respectively, which implied that mixed lithology rock is the best rock type as reservoir among these five lithofacies, followed by tuffaceous mudstone, tuffaceous dolomite and dolomicrite, whereas the pure tuff is the worst. The δ^{26}Mg (‰) of 37 samples ranges from -0.08 to 0.27‰, -0.19‰ on average. ^{87}Sr/^{86}Sr ranges from 0.7049 to 0.7065, 0.7054 on average. These indicate the provenance is strongly affected by materials from deep resource during the forming period of Lucaogou Formation. Mixed deep and terrigenous materials are the best provenance for tight oil accumulation in an intracontinental rift basin, which suggest that the deep source influences the oil formation.

Permeability Change Caused by Stress Damage of Tight Sandstone Reservoir in the Ordos Basin, China

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Permeability Change caused by effective stress damage has an important impact on the development of tight sandstone reservoirs. Therefore, it is necessary to conduct an in-depth study of its stress sensitivity characteristics. For the tight sandstone reservoirs of the Triassic in the Ordos Basin of China, the permeability stress sensitivity evaluation experiment was carried out. On this basis, the influencing factors of reservoir permeability stress sensitivity were analyzed by means of scanning electron microscopy (SEM), cast thin sections and high pressure mercury intrusion (HPMI). The results show that the permeability of the tight sandstone of the Triassic in the Ordos Basin decreases with the increase of effective stress and the decreasing trend gradually becomes slower. After the effective stress is restored, the permeability cannot be fully recovered. The microscopic pore structure of the reservoir has an important influence on the stress sensitivity. The residual inter-granular pore reservoir with the large pore has weak permeability stress sensitivity, the dissolution pore type is second, and that of the micro-pore type is strong. In addition, the compressive capacity of the skeleton particles and cement also has an effect on stress sensitivity. Quartz skeleton particles have strong compressive capacity. The higher the quartz content, the smaller the permeability changes with the stress damage. Clay cement is easily compacted, and the higher the content, the stronger the reservoir permeability sensitivity. The research results can provide reference for the development of tight sandstone reservoirs with permeability stress sensitivity.

Early Miocene to Quaternary unidirectionally migrating canyons in the northern slope of the South China Sea continental margin

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Paleoceanographic pattern in the northern South China Sea (SCS) margin is still poorly known, despite oil-gas exploration activities and ODP Leg 184 have released valuable information. In this paper, we report previously unrecognized unidirectionally migrating deep-water canyons (UMDCs) in the Early Miocene-early Middle Miocene record, based on the analysis of the high-quality 3D seismic and borehole data collected from the northern margin of SCS. The UMDCs are almost U-shaped, low sinuosity and persistently migrated northeastward from 18.5 Ma to 13.8 Ma with a maximum run-out length about 20.5 km and a total laterally migrating distance up to 6.0 km, which are mainly developed on the upper-middle continental slope. During every cut-and-fill cycle, the canyon contains a basal erosional surface (BES) at the bottom and the canyon-fills including thalweg deposits (TDs) and overlying lateral inclined packages (LIPs). Considering the slope environment and the paleo-water depth, we conclude that the UMDCs probably result from the interaction between the along-slope northeastward flowing intermediate water and down-slope turbidity flow. Combined with our previous study about the Middle Miocene-Quaternary UMDCs, the onset and evolution of the UMDCs possibly signal commencement of persistent and gradually enhanced contour current since the Early Miocene along the northern SCS margin. The strengthening of the contour current may also reflect the gradual narrowing and closures of the important ocean gateways from the Early Miocene to Quaternary which intensively enhanced the intermediate water circulation in the western Pacific Ocean.

CO_2 containment and monitoring techniques along Little Grand Wash Fault, east-central Utah, USA

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Our current understanding of sub-surface CO_2 sequestration feasibility derives mainly from valuable small-scale projects, which have mostly been working at injection or human time scales. These projects, however, have not been operational long enough to fully assess flow and/or seepage at longer time scales relevant for subsurface CO_2 storage (e.g. > 10 kY). Many examples of fluid escape have been documented in the offshore subsurface environment (e.g. seismic chimneys), and natural seeps found on land, both active and relict, offer informative analogues to subsurface fluid migration. Of note are the natural seeps located in east-central Utah, USA that are easily accessible and represent suitable onshore counterparts to the offshore fluid escape features. These seeps can improve our understanding of geological and geomechanical factors controlling subsurface CO_2 containment and the expression of fluid escape in geophysical images. A critical concern is how to account for features that are detrimental to subsurface storage containment and are at scales below seismic resolution. This multidisciplinary project aims to address the challenge by collecting surface and subsurface datasets at mesoscopic scales that, through viable upscaling, will be implemented in seismic investigations and reservoir-seal models. Moreover, the project builds upon previous studies detailing the complex development of the Jurassic sedimentary basin in question (Zuchuat *et al.* 2018; 2019; in press) but is also relevant for the Horda Platform region (Aurora and Smeaheia) or other prospective North Sea CO_2 storage sites. Overall, this next research phase specifically focuses on the detailed, post-depositional history of the targeted interval in Utah, addressing one fundamental question: what are the thresholds for detecting CO_2 seeps in the subsurface? This encompasses more targeted questions:

- What is the detailed geological footprint of CO_2 flow along strata, faults, and fractures?
- How did the CO_2 flow migrate through a heterogeneous and transitional, faulted reservoir-seal complex?
- Can seepage from the storage compartment be identified by seismic imaging?
- Can detailed geological datasets and related geophysical models verify the existence of – and facilitate quantification of CO_2 volumes (saturation) required to create offshore geophysical chimneys, and thereby improve integrity assessment of prospective North Sea CO_2 reservoirs?

Poster Presentation Abstracts

Geometry, kinematics and mechanics of inversion- fault reactivation and mechanical stratigraphy: a case study on the Neuqu´en Basin, Argentina

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Inversion systems have been globally extensively studied, with most controls well investigated and constrained. However, the effect of mechanical stratigraphy on inversion systems, especially the varying strength of the megasequeunce packages, has not been fully explored. Previous research [Buiter and Pfiffner, 2003, Jagger and McClay, 2018] has indicated that mechanical stratigraphy has a major influence on the development of inversion systems e.g. a weak post extension would inhibit fault propagation and promote the formation of broad fault propagating folds or a competent syn- extension package would promote more faulting as less shortening can be accommodated by internal deformation. The Neuqu´en basin, Argentina is a classic example of an inverted system, with two distinct phases of inversion from the Late Jurassic to Quaternary. Not only does this basin provide with some well developed inverted structures (Figure 1a), with some characteristic reactivated faults and fault propagation folds, but also has a cyclic and well developed mechanical stratigraphy. The composite stratigraphic column (Figure 1b) highlights the alternation between hard compentent units and softer incompetent units e.g. from Tithonian to Valanginian, making this basin a good natural example to study the role of mechanical stratigraphy on inversion evolution. This research will integrate 1400 km^2 of 3D seismic surveys and 33 wells to constrain the stratigraphic boundaries of the basin, as well as the resultant 3D geomtery of the basin in depth. Allowing an in depth assessment, both qualitatively and quantitavely, of the role of mechancial stratigraphy in the development of inversion systems. This study will not only allow better understanding of basin evolution but also will allow better fracture evolution characterisation in inversion systems, which intimately ties into trap development of petroleum systems.

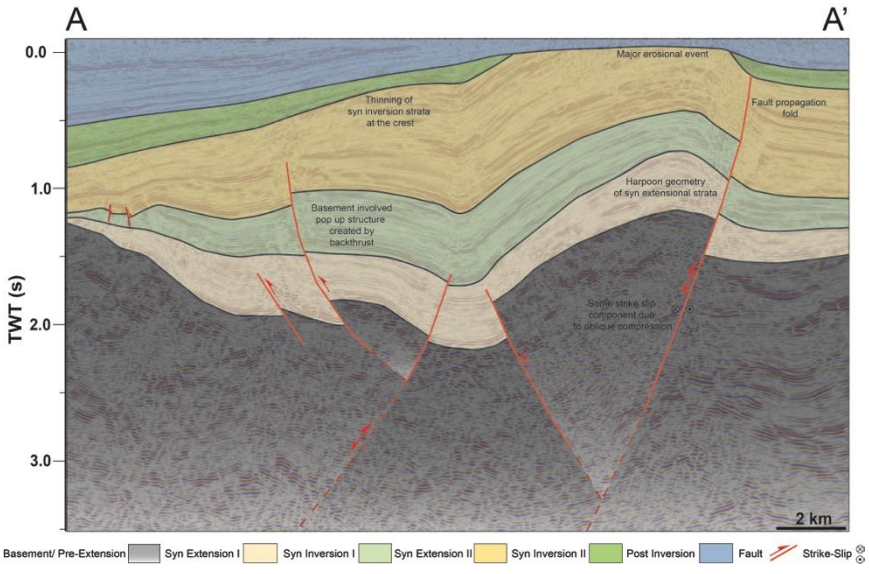

Figure: a) A regional time section of the Neuquen Basin study area

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THIN-BEDDED TURBIDITES, WEST CROCKER FORMATION, MALAYSIA: FACIES, MICROSTRUCTURE AND POROSITY-PERMEABILITY CHARACTERISTICS.

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The West Crocker Formation in Sabah, Malaysia, is a Miocene deepwater turbidite succession that now outcrops on land in northern Borneo. Thin-bedded turbidites are abundant, but are mostly poorly exposed, weathered and vegetation-covered, except where interbedded with thick sandstone turbidites and debrites. More than 500 m of well-exposed section were logged in detail. Samples of the thin-bedded mud-rich facies were prepared for laboratory investigation of mudrock fabric, pores and pore connectivity using light microscopy, scanning electron microscopy and energy-dispersive X-ray spectroscopy. The thin-bedded turbidites are all heterolithic muds, silts and fine sands. The principal facies identified are based on their dominant sedimentary structures, and these are referred to the *Stow* fine-grained turbidite divisions: F1 wavy and lenticular sand/silt-laminated muds (*Stow* T0-1); F2 parallel to irregular silt-laminated muds (*Stow* T2-4); F3 structureless muds (*Stow* T5-7); and F4 bioturbated muds (*Stow* T8), typically with *Chondrites* and *Trichichnus* trace fossils. The sediments have been well compacted and cemented, as well as faulted and veined, during burial and subsequent tectonic emplacement, so that their microstructure now reflects all elements of their history.

The original depositional microfabric was *planar parallel* (anisotropic) for most of the facies, whereas it was more *sub-parallel to random* (isotropic) for the basal silt/sand layers. The planar parallel fabric and associated nano-porosity is retained in the structureless muds (facies 3) with a high clay content, and the sub-parallel to random fabric is retained in the lenticular to wavy sand/silt layers (facies 1). For the other facies, the original parallel to sub-parallel microfabric is disrupted to become more semi-random to random (isotropic). This *disrupted fabric* is attributed to several distinct factors: (1) it develops or is enhanced around isolated silt/sand grains, silt partings, wispy lamination, sand lenses and cross-lamination, in facies 1 and 2; (2) it is caused by post-depositional bioturbation and burrowing, in facies 4; and (3) it is controlled by diagenetic processes and quartz veining (all facies). The main diagenetic processes include: quartz cementation, clay mineral authigenesis, pyrite and marcasite development associated with *Trichichnus* and *Chondrites*, and alkali-feldspar dissolution. More recent weathering as a result of uplift has led to extensive iron-oxide development in places. For thin-bedded turbidites of the West Crocker Formation, and for these facies more generally, reduction in micro-porosity is primarily due to compaction, diagenetic cementation and fracture sealing with quartz veinlets. Porosity enhancement is due to feldspar dissolution and to the presence of a disrupted micro-fabric. We suggest that this disrupted micro-fabric in mud/shale facies plays a significant role in controlling their porosity and permeability characteristics. Disrupted microfabrics create a more isotropic porosity and permeability aspect, whereas well-developed, planar parallel microfabrics are associated with highly anisotropic microporosity and permeability.

Digital outcrop characterisation and Forward modelling of the Calcarenite di Gravina Formation exposed at Matera, Italy: better understanding of seismic sequence stratigraphy

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Outcrop analogues offer significant principal source of information for accurate models. The Late Pliocene to Early Pleistocene Calcarenite di Gravina Formation cropping out in the western margin of the Matera Horst is composed of limestone fragments that onlap structural domains of the Apulian foreland in southern Italy. Outcrop exposure of the accretional units of the Calcarenite di Gravina Formation in Lamaquachiolla, Matera provides a means to understand the stratigraphic history and the record of comparative changes within geological strata. Matera paleoisland was part of the multifarious horst and graben structures of the Apulian Foreland that became an archipelago. The Calcarenite di Gravina Formation is composed of an upper and lower member. The upper member is mostly bioclastic comprising the buildup of skeletal debris while the lower member which is the area of focus is mainly made up of carbonate lithoclasts resulting from erosion of Cretaceous limestone substrate. Field work was carried out in the Lamaquachiolla cliff section and the lidar-based software tool, Virtual Reality Geological Studio (VRGS) was adopted for the characterisation of the digital outcrop model of the study area in a form of textured polygon mesh. The field and digital outcrop studies allowed the identification of seven facies association and four depositional zones. It provides an understanding of the framework, heterogeneity and stratigraphic architecture giving us a better idea of what controlling processes dominate the study area (sediment supply, Milankovitch, tectonics, waves, currents e.t.c). Subsequently, the dataset obtained will be used to build stratigraphic forward model to match field information and observation for seismic forward modelling to give a better understanding of seismic sequence stratigraphy.

Sedimentation of the remnant Tethys in the easternmost Mediterranean region: new evidence from western Cyprus

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Late Cretaceous-Neogene marine sedimentary rocks have been extensively studied around the southern, eastern and northern periphery of the Troodos ophiolite in Cyprus. However, equivalent facies in western Cyprus have received little attention. Here, a Late Cretaceous-Neogene sedimentary succession covers an amalgamated Mesozoic basement. In the southeast, the sedimentary succession begins with matrix-supported breccia-conglomerate, interpreted as debris-flow deposits, with clasts derived from the underlying Mesozoic Mamonia Complex. Paleocene pelagic chalks interfinger with the debris-flow deposits before passing upwards into well-bedded pelagic chalk, several hundred metres thick. An interval of bedded chalk-chert can be correlated with the Lefkara Formation elsewhere in Cyprus**.** The succession continues upwards into chalk-marl, with calcarenite interbeds, representing hemipelagic carbonates and gravity-flow deposits. Miocene nannofossils allow correlation with the Pakhna Formation in other areas. Contrasting sediments are exposed in the north of western Cyprus**,** where two phases of Miocene reef development are exposed on both flanks of the Neogene-Recent Polis graben. On the western flank, pelagic chalk (currently being dated) is locally preserved beneath redeposited shallow-water carbonates including packstones-grainstones and megabreccia rich in corals, thought to have been derived from up-slope reefs. Early Miocene ages have previously been determined (BouDagher-Fadel & Lord, 2006) suggesting that the diverse mass-flow deposits can be correlated with the Terra Member of the Pakhna Formation (first reef phase). The second phase of reef development followed during the Late Miocene, termed the Koronia Member. Partially in-situ patch reefs, with fringing grainstones-packstones, overlie a Late Cretaceous ophiolitic basement in the northwest (Akamas Peninsula). In contrast, the eastern flank of the graben is dominated by mass-flow deposits and calciturbidites (currently being dated) from reefs that were probably located upslope on the Troodos ophiolite margin (but now mostly eroded), dominated by a mixture of poritid coral, calcareous algae and other bioclastic material. Mid-Miocene chalky marls with interbedded gravity-flow deposits characterise the central area of west Cyprus, overlying bedded grainstones-packstones. The regional facies distribution suggests contrasting sedimentation across western Cyprus. The southeast is characterised by outcrops of Paleogene pelagic carbonates, with incoming of redeposited shallow-water carbonate detritus during the Miocene. In contrast, outcrops in the northern area are dominated by two phases of Miocene reef development, with evidence of deeper-water conditions in the central area during the mid-Miocene. Two alternative hypotheses to be tested by future fieldwork, combined with microfossil (and also strontium) dating are: 1. similar sedimentation prevailed across western Cyprus throughout the Paleogene, followed by differential uplift-subsidence related to the Neogene-Recent Polis graben, or 2. the southerly and northerly areas experienced a different sedimentary-tectonic development from the Late Cretaceous onwards.

Is it possible to work out the lateral migration of preserved fluvial system through outcrop?

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While channel migration has been the subject of many studies e.g. Bristow 1987, Best et al., 1993; Nardin et al., 2013; where migration has either been considered at a macro-scale with timeslices on seismic data or at a micro- scale on one or two meander bars, with little completed at the meso-scale, i.e. the outcrop scale. The Old Red Sandstone is a well-documented fluvial system that borders between low and high sinuosity where the outcrops throughout South Wales exhibit exceptional exposure, enabling reconstructions of past environments to be constrained. Classic sedimentological techniques along with modern observation and analysis techniques have been undertaken extensively at these outcrops in order to determine the channel migration.

Here we have developed a new series of palaeoenvironmental reconstructions, from facies analysis and the use of Landsat images in order to highlight the temporal and spatial changes within the system to constrain the dynamics and migration of the fluvial system. Databases will be used to compare morphologies with modern systems, in order to inform the most likely facies and architectures within the system. This data will be used in order to help determine the meso-scale information that is currently missing from the scientific community. This data will generate generic migration models of high and low sinuosity fluvial systems and how they migrate using evidence from outcrop only which will be able to be used against core data.

Exploring prehistoric vegetational and agricultural dynamics using an annually laminated sediment record from Lago di Mezzano in Latium, Italy

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Ongoing climate change and alterations in land use are expected to have a strong impact on natural ecosystems. Understanding past environmental changes in response to climate and human influences may be a key factor to improve our ability to predict future ecosystem dynamics. Paleoecological studies have been carried out on many sites in Central and Southern Europe. However, their chronologies generally have wide uncertainties usually >100 to 200 years. This lack of chronological precision impedes a match with the dendro-chronologically dated archaeological records, specifically because prehistorical settlements often lasted only few years to decades. Similarly, it also limits comparison with historic events. Moreover, highest precision is essential for comparing spatially separated palaeoecological studies among each other and with independent high-precision climatic data. Taken together high-precision varve chronologies are essential to disentangle causes and effects of past environmental, ecological and societal change, and to understand spatial aspects of rural societies (Rey *et al*. 2019a, Rey *et al*. 2019b).

Annually laminated sediments (varves) have been extracted from Lago di Mezzano (a maar lake located at 452 m a.s.l. in central Italy), and offer the unique opportunity to reconstruct the Holocene vegetation, biodiversity, land use and fire history of the region with highest possible chronological precision and resolution (10-20 years vs 5-10 years). Such attempts aspire to reach precisions comparable to those of tree ring chronologies (Rey *et al.* 2019a) and are thus extremely demanding. At Lago di Mezzano we rely on previous efforts such as archaeological excavations e.g. documenting Bronze Age lake shore settlements (Petitti & Rossi 2012) and sediment analyses (Sadori *et al*. 2004), which provide essential information about the material culture, specifically the settlement, production and trading activity.

The main goals of our study are a) to investigate the effects of fire, land use and abrupt climate changes on vegetation communities during the past 8000 years at annual to decadal scales, to understand the following successional patterns in central Italy, b) to verify if anthropogenic land use phases were synchronous between Italian and Swiss sites (Tinner *et al.* 2003, 2009, Rey *et al*. 2019b) and c) to test competing land use and climate impact hypotheses. Given that assessments of vegetation potentials require a thorough understanding of long-term vegetation succession after natural and human disturbance, our data are not only of palaeoecological and archaeological interest, they may also contribute to better projections of ecosystem dynamics under global change conditions.

INTRA-POINT BAR GRAIN-SIZE VARIABILITY: AN EXAMPLE FROM THE HOLOCENE ALLUVIAL SUCCESSION OF THE VENETIAN PLAIN (ITALY)

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Highly populated lowland and coastal areas are drained by sinuous fluvial channels which, over the past millennia, shaped modern landscapes and accumulated sedimentary successions, that host most of the main surficial aquifers, which are commonly exploited for agricultural and industrial purposes. The Venetian Plain is sited in northeast Italy and is the eastern sector of the Po Plain, the largest Italian alluvial plain (ca. 47.000 km^2). The Venetian Plain was generated during Holocene transgression by aggradation of fluvial meandering channels, such as Po and Adige rivers. Being morphologies of these channels, along with other alluvial elements (e.g. crevasse splays), still visible from satellite images, the Venetian Plain is a key site to deepen our knowledge about internal architecture and sediment properties of sand-bodies generated by fluvial meandering channels.

The present study focuses on two paleo-meanders of the Venetian Plain, and aims to define a 3D model depicting geometry of related point-bar bodies, with a specific focus on along-bar sediment grain-size distribution. The study paleo-channel was ca. 25 m wide and defines two main bends (bend 1 and bend 2), which show different geometries. Bend 1 is a wide, strongly asymmetric bend, whereas bend 2 is an open, poorly asymmetric bend. Planform evolution of these bends has been reconstructed by analysing scroll-bar patterns, which are still clearly visible from high-resolution freely-distributed satellite images. Bend 1 and bend 2 progressively expanded during their evolution, and bend 1 was affected by a marked rotation of the bend apex during its final stage of growth. Geophysical investigations (Frequency Domain Electro-Magnetometer) allowed to depict 3D geometries of sedimentary bodies basing on a marked electric conductivity contrast between sandy bar bodies and encasing muddy overbank deposits. Geophysical data were calibrated by recovering several sedimentary cores. This integrated approach between geophysical and sedimentological data provided a link between meander bend planform evolution and grain-size distribution within the related point-bar bodies.

Determining past ice flow direction and ice thickness in Eglwyseg and Glyn Ceiriog, North Wales

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Nine erratic boulders from Eglwyseg and Glyn Ceiriog, North Wales were mapped and then analysed with X-ray fluorescence (XRF) to determine palaeo-ice flow direction. The erratic boulders were identified as volcanic rocks at Eglwyseg and traced back to their source in Snowdonia, North Wales using published XRF data. This suggests that ice flowed from Snowdonia in North West Wales to Eglwyseg in North East Wales. Ice thickness was reconstructed from the altitude of the erratic boulders and is estimated to be approximately 633m in Eglwyseg at the time of maximum ice extent in North Wales during the Last Glacial Maximum (LGM). Ice thickness for Snowdonia and Wrexham was reconstructed to be 1240m and 200m respectively during the LGM. The ice thickness estimate for Snowdonia agrees with some reconstructions and disregards other estimates. The timing of erratic deposition could not be confirmed, further work chronology is needed, but most likely they were deposited during the LGM. Further work should be taken to confirm the provenance of the erratic boulders, by taking samples of bedrock from Snowdonia for XRF analysis. The study has filled a knowledge gap for Eglwyseg, it is the first glacial study in the area in over 70 years.

Figure 1: volcanic erratic boulder at Eglwyseg, North Wales

I would like to thank Chris Darvill and Phil Hughes for their support and enthusiasm for the project and providing excellent guidance.

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Assessing the suitability of infrared hyperspectral imaging to characterise organic-rich mudstones: an example from the Carboniferous Bowland-Hodder shales of the UK

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The formation-evaluation of organic-rich shales still remains a challenging prospect. Conventional methods of compositional core analysis, such as rock-eval pyrolysis and x-ray diffraction (XRD) are inherently destructive and costly to perform, typically limiting their use on difficult and expensive to obtain core. Hyperspectral imaging in the near to short-wave infrared spectrum (1.3-2.5µm) has the capability to non-destructively capture detailed, continuous mineralogical and geochemical data quickly at sub-millimetre resolution. In this study we assess the suitability of hyperspectral-IR as a technique to characterise organic rich shales using examples from the Bowland-Hodder Shales sampled by the Caudrilla exploration well, Becconsall-1Z.

Several cored intervals of shale were selected from this well and scanned using the Spectra-Map SpecCam sensor with 0.5mm pixel resolution and 3mm along line resolution. Semi-quantitative mineral abundance curves and two-dimensional mineral abundance maps were estimated independently of any core data using a reference library of known IR-mineral spectra. This allowed a blind assessment of the technique and we find good correlations of IR-derived TOC and mineral-abundance estimates to those from XRD and rock-eval. We also demonstrate that when hyperspectral-IR is used alongside standard core analyses in a combined approach it has the potential to identify subtle bedding-scale variations in clay type, variable carbonate content and subtle structural fabrics. Such features would be otherwise difficult or impossible to identify from the core non-destructively and are significantly below the resolution of downhole geophysical logs. We find that in this manner hyperspectral imaging can be used as both a reconnaissance tool before further sampling, or alongside conventional core analyses in an enhanced analysis and assessment of the economic potential and brittleness of prospective unconventional shale gas deposits.

QUANTIFYING MARINE REDOX; USING NON-TRADITIONAL GEOCHEMICAL TECHNIQUES ON LATE TRIASSIC SEDIMENTS

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The vast majority of all marine mass extinction events that have occurred over the past 541Ma are thought to have been caused by marine anoxia [*Bond & Grasby, 2017*]. This marine anoxia is driven by variations in the global carbon cycle, which are strongly linked to the extensive output of isotopically light carbon produced by large igneous provinces (LIPs). The current annual output of anthropogenic (human-induced) light carbon is akin to that released in the past by LIPs, which raises important questions regarding the effect of anthropogenic carbon output on future climate and subsequently marine de-oxygenation [*Zeebe et al., 2016*].

The aim of this research has been to quantify marine de-oxygenation, as a result of environmental perturbation, using the Triassic-Jurassic boundary and extinction event of the Larne Basin, Northern Ireland as an analogue. Elemental and isotopic data (δMo, δZn, Cd/Mo, Co*Mn, C/P) indicate that the Larne Basin was a weakly restricted to seasonal upwelling marine environment during the Upper Triassic. Contrary to the euxinic conditions recorded from other Upper Triassic sites [*Blumenberg et al., 2016; Kasprak et al., 2015*], such conditions were very rare from the Larne Basin with oxic conditions generally prevailing. Implications for Upper Triassic extinction(s) will be discussed.

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Detrital pyroxenes to characterise source to sink processes in volcano-sedimentary environments: 3 examples with global relevance

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Most volcanic systems on land and in the sea produce a large abundance of volcanic debris that are easily preserved as primary or reworked volcaniclastic deposits, and that can form a large fraction of the detrital record in sedimentary basins. Understanding the origin of ancient volcaniclastic sediments/deposits can be challenging as this requires careful assessment of a large range of volcanological and sedimentological processes that can take place in volcano-sedimentary environments but can be easily obscured by weathering and diagenesis. Although the source of volcaniclastic deposits is commonly characterised using the age of detrital zircons, these minerals are not representative of mafic to intermediate volcaniclastic deposits that are abundant in most volcano-sedimentary environments. Because of these limitations, the analysis of detrital pyroxenes is a valuable approach to characterise the origin and provenance of volcaniclastic deposits in a large range of volcanic and sedimentary environments. In particular, clinopyroxenes are excellent source tracers, with a preservation potential during weathering and diagenesis that generally exceeds that of volcanic glass, fine-grained lithics and other rock-forming minerals produced in mafic to intermediate magmas.

This poster illustrates the value of detrital clinopyroxenes through 3 selected examples:

(1) A reconstruction of the sediment flow routing of Pliocene to recent volcaniclastic turbidites collected by IODP drilling (cores and cuttings) in the forearc basin and slopes of the Nankai margin in Japan (Buchs et al., 2015).
(2) A determination of the origin of altered primary volcaniclastic deposits from Upper Cretaceous subaerial sequences of the Caribbean oceanic plateau, with implications for Anoxic Oceanic Event 3 (Buchs et al., 2018).
(3) A determination of the origin of accreted Upper Eocene volcaniclastic deposits and debris flow in a subduction mélange exposed in south Costa Rica, with implications for the long-term crustal mass balance at this convergent margin (Buchs et al., in press).

Other on-going applications of the clinopyroxene approach along the Panama Canal and in the Alps could be discussed at the poster (emails also welcomed).

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Investigating transport processes of macroplastic in fluvial environments

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Pollution of the environment by plastic is a well-known phenomenon, with records across nearly all of Earth's environments from soil and ice through to deep ocean trenches. To date, research focus has been on microplastic in the marine environment and its interaction with the biosphere. Much less is known about macroplastic in freshwater settings. Here we report novel flume tank experiments that explore the transport and deposition behaviour of macroplastic – typified by frequently occurring litter items in rivers. We used a recirculating experimental flume channel facility at the University of Hull and ran a series of experiments using polyester and polystyrene squares, facewipes, crisp packets, plastic forks, sweet wrappers, milk bottle tops, Lego bricks, and disposable razors. Five flow speeds were used (5 cm/s, 13.6 cm/s, 22.2 cm/s, 44.4 cm/s and 66.5 cm/s), and data was collected on mode of transport through direct observations, video capture, and travel time across set distances. Low-density items, e.g. the milk bottle tops, travelled fastest at all speeds and predominantly rotated about a central axis in suspension. High-density items, such as disposable razors, travelled by traction and saltation at flow speeds of 66.5cm/s – 44.4cm/s. However, at flow speeds of 22.2cm/s – 5cm/s, no movement, incipient motion, or 'punctuated traction' (defined as movement along the bed for distances greater than 5cm with rest periods) was observed. Our experiments shed light on how macroplastic behaves in fluvial systems through examining how plastic litter is transported and where it is deposited. Such information has the potential for practical application in the environment through identifying suitable sites for environmental clean-up.

Fantastic flutes and where to find them: a 444 Ma subglacial pavement in South Africa

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Using new Unmanned Aerial Vehicle (UAV) imagery, we present the first palaeogeomorphological map of an Ordovician (444 million year old) subglacial bed. This approach has been widely adopted on modern and Pleistocene glacier forefields, but here we demonstrate how it can be applied far deeper in geological time. Three sets of cross-cutting landforms crop out over an area of ~1 km^2 in the Western Cape Province of South Africa. Firstly, highly elongate (>100 m long) and narrow (<1 m wide) subglacial flutes reflect streamlining of dilatant sediments. Their long length implies rapid ice flow velocities, either related to active temperate glaciation, non-steady state surging, or ice streaming. These flutes are cross-cut and onlapped by low amplitude transverse fold ridges, which are interpreted to record 'rucking' of the subglacial bed as ice decelerates. Finally, both structures are draped by sinuous sand bodies which may represent small channel fill features (e.g. an esker), or alternatively a rafted sand body. The morphology and particularly the cross-cutting relationship of these landforms can only be clearly distinguished and quantified on the bird's eye view aerial imagery, thus highlighting the value of applying this as yet under-utilised technique in the study of ancient (pre-Pleistocene) glacial land-systems.

Figure caption: View westward over the 444 million year old streamlined subglacial bed at Pakhuis Pass, Western Cape Province, South Africa.

Architectural variability in a stepped-slope fan system - implications for reservoir connectivity

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In submarine slopes with mobile substrates, the depositional architecture of turbidite systems can be highly affected by topographic variations. The interactions of flows and seabed topography increase the spatial and temporal architectural variability of submarine channel and lobe systems, and therefore the uncertainties associated with reservoir connectivity in hydrocarbon fields. This study aims to investigate the topographic influence on architectural variability of a Cenozoic turbidite system deposited above a 40 km-long stepped-slope on Campos Basin, offshore Brazil, through analysis of a high-resolution 3D seismic reflection dataset calibrated to dozens of wells. The stepped-slope fan system was deposited from the Middle Oligocene to Lower Miocene above a salt-controlled slope and comprises intercalated deep-water sandstone and mudstone packages. The younger sandstone packages display well-preserved seismic geomorphology that reveals three different contexts. In the proximal part, a high amplitude seismic reflector (HAR), with 20 m average thickness and elongate to slightly lobate geometries, is truncated by low amplitude channel-fills. Well calibration shows that the HAR has high lithological variability, and confirms the mud content of the low amplitude channel-fills. The absence of sand in these channel-fills is evidence that flows largely bypassed down dip. Basinward, planform high-amplitude anomalies reveal lobate features that are thicker (~40 m) and sandier than the up-dip deposits. These lobes were fed by the conduits that cut the up-dip HAR, suggesting system growth. Channel incision is observed, but seismic amplitude anomalies and well penetration indicate a sandy character to the channel-fill. In the distal zone, high amplitude straight features depict a sandy channelised system that was controlled by salt-induced faults with an oblique orientation to the depositional slope. The greatest stratal thicknesses in the whole area are observed in these channel axes. The stratigraphic relationship between this domain and the up-dip part of the system is elusive, although they can be considered synchronous in a broad time range. The architectural variability observed in the Campos Basin stepped-slope is noteworthy. An uneven slope topography is invoked as the primary control for the development of three contrasting reservoir architectural styles. In the proximal part, the record of a sediment bypass-dominated zone might reflect a slope sector with relatively higher gradient, which recorded deposition above an area with limited accommodation and prone to degradation. In contrast, the interaction of flows with a slope break can explain the formation of sand-rich and laterally/compensational stacked lobes in the central area. The stacking pattern suggests deposition in a weakly confined slope configuration. A different context is observed in the distal zone, where sandy channel-fills with increased thickness are vertically stacked, indicating a higher degree of confinement and suggesting the persistence of the sedimentary routes in the same position. The three scenarios present striking differences concerning reservoir connectivity, and completely different development plans might be applied to each case.

The Characteristics of Submarine Landslides in Active Volcanic Settings: Cohesion from Slope Stability Analysis, the Central Azores Islands

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During submarine mass movements, a great amount of sediment can be mobilized in a short period. They can generate hazardous tsunamis threatening populations and constructions close to adjacent coasts. Using high-resolution multibeam bathymetry data, we have located >700 embayments (the evacuated parts of the landslides) in the upper submarine slopes of the Azores islands São Jorge, Terceira, Faial and Pico. The high-resolution bathymetry data has allowed us to form a more complete inventory of the landslides to compare with those from other tectonic settings. In contrast to the gentle gradients typically found in continental margins, the gradients of many parts of the upper submarine slopes in the Azores are steeper than 30°, the repose angle of cohesionless particles. Moreover, some landslide headscarps have gradients exceeding 55°. These steep gradients suggest that the material is significantly cohesive. To get rough estimates of cohesion, we have carried out a slope stability analysis using the infinite slope approximation. Neglecting effects of earthquake shaking, we estimate the sediment cohesion to be 2-30 kPa, typical of more deeply buried and compacted sediments. If these steep sedimentary slopes have survived shaking from past earthquakes, their cohesion is larger and 2-30 kPa is only a lower bound.

Sediment cores collected around the base of slopes have allowed us also to assess the slope material. The cores contain many turbidites, likely originated from failure in the island slopes, as well as volcaniclastic and pyroclastic flow deposits and tephra. X-ray diffraction analyses on turbidite samples revealed the presence of amorphous materials. Much of this material represents volcanic glass or glass alteration products, but some could also represent cements precipitated when the sediment was on the island slopes. The origin of the sediment cohesion is therefore uncertain. The cohesion of sediment is important for hazard assessment. Large landslides are more likely to occur as long as the materials were perfectly cohesive compared to the incohesive materials.

Scales and heterogeneities in mixed siliciclastic-carbonate deposits

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Mixed siliciclastic-carbonate deposits result from the interaction between a siliciclastic sediment source and a carbonate factory. Mixing between the two heterolithic siliciclastic and carbonate fractions can occur at different scales, from bed (core-plug) to stratigraphic (seismic) scales, producing a high vertical and lateral lithological variability. In this study, we show a variety of mixed deposits which originated under the influence of some principal geological factors (such as tectonic subsidence vs. uplift, sea-level changes, climate variations, rate of sediment accumulation, etc.). In particular, allocyclic and autocyclic factors operate at different scale of observations producing (i) *particles mixing* where the two heterolithic fractions accumulate contemporaneously, and (ii) *strata mixing* resulting from the alternation of the two heterolithic fractions in time.

Characterisation of the type of mixing is important to better understand: (i) the physical interaction between siliciclastic and carbonate particles at the time of deposition and the sedimentary processes, (ii) birth and demise of the carbonate factory respect to the siliciclastic dispersal mechanisms, and (iii) the distribution in space and time of the two heterolithic fractions.

Proper understanding of the scales and heterogeneities in mixed deposits is challenging because they provide more sensitive records and unexpected sedimentation patterns than pure siliciclastic or carbonate systems. Furthermore, the petroleum geologists are interested in unravelling new insights about the internal properties (*e.g.*, porosity and permeability) of siliciclastic-carbonate systems and to reconstruct predictive 3D models. This is because the scales of mixing can have an important impact on hydrocarbon exploration and exploitation phases.

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Controls on the geometry, extent and reservoir quality of sand injectites: combining worked industry datasets (Norwegian Continental Shelf) with outcrop analogue studies (Vocontian Basin, Southern France)

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Sand injectites are structures formed in response to fluid overpressure in the subsurface and involve the forceful intrusion of sediment into the overburden. They occur in many sedimentary environments, but most commonly in the deep-marine. Sand injectites are often interconnected to form injectite complexes, which can form economically viable petroleum reservoirs. However, these structures have commonly been ignored due to their complexity and the risks that they may pose during production. In addition, injectites may be sub-seismic or difficult to image in conventional seismic data. In the past, these structures have often been interpreted as poor quality sands within impermeable units, displaying little to no communication, where as in reality they may form highly connected fluid-flow conduits with extremely high porosity and permeability. Outcrop analogues can provide a valuable insight into the scale of these complexes, with a particularly good example exposed in the Vocontian Basin, Southern France. The Vocontian injectites are intruded into the Marnes Bleues Formation, a thick succession of Aptian-Albian age calcareous mudstones alternating with limestone beds that formed in the upper slope domain of a palaeo-passive margin. This formation displays disruption by gravity driven flows, with large exposures of massive sandy turbidites. It has previously been stated that these turbidites are the parent bodies for the injectite complex. It is thought that an understanding of how the geometry and extent of these structures can vary in outcrop could be transferred to help better constrain injectite facies when observed in seismic, core and image logs, as well as tying these to petrophysical data. In this case core, seismic, and well log data from the Norwegian Continental Shelf are used. It is hoped that a combined understanding of all of these different modes of identification and study can be used to help make more accurate predictions of reservoir quality, charging and trapping potential in deep-water fields with significant clastic injectites.

Piracy-controlled geometry of tidal point bars: examples from modern and ancient channel networks

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Laterally extensive point-bar bodies are the product of freely migrating meandering rivers, and exhibit width:thickness ratios of up to 300. Point-bar bodies are also a common architectural element in tidal-creek networks, which exhibit planform-change dynamics overall comparable to their fluvial analogues. However, owing to the high channel density that characterises intertidal areas, tidal meandering channels can hardly migrate laterally for long distances without interacting with other channels. In order to better understand how the interaction between adjacent meandering channels controls the development of tidal-point bars, two ancient point-bar bodies from the Castigaleu Formation (Eocene of Spain) are investigated and compared with deposits of a modern tidal-meander bend imaged in the Northern Venice Lagoon (Italy). The two tidal-point bars studied here are characterised by a low width:thickness ratio (<30), which we interpret as a result of abrupt deactivation of their migrating parent channels. Such abrupt deactivations are likely related to avulsive piracy operated by an adjoining channel in the tidal network, and prevented the bar from generating a laterally extensive tabular sand body. Our inference is corroborated with direct time-lapse observations of similar dynamics in the modern tidal meanders of the Venice Lagoon. We posit that, in densely-drained tidal networks, channel bends cannot meander freely without interacting with adjacent channels, and thus triggering channel piracy. In summary, we present a morphodynamic model to justify a recurring architectural dissimilarity between the deposits of fluvial- and tidal-meandering channels.

A new model of deposition for the Tuaheni Landslide Complex, Hikurangi Margin, New Zealand

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The Tuaheni Landslide Complex (TLC), off the east coast of New Zealand, is characterised by areas of compression upslope and extension downslope. It has been thought to consist of a stack of two genetically linked landslide units identified on seismic data. We use 3D seismic reflection, bathymetry data, and IODP core U1517C (Expedition 372), to understand the internal structures, deformation mechanisms and depositional processes of the TLC deposits. Unit II and Unit III, sedimentary units of core U1517C, correspond to the two chaotic units in 3D seismic data. In the core, Unit II shows deformation whereas Unit III appears more like an *in situ* sequence. Variance attribute analysis shows that Unit II is split in lobes around a coherent stratified central ridge, and is bound by scarps. By contrast, we find that Unit III is continuous beneath the central ridge and has an upslope geometry that can be interpreted as a channel-levee system. Both units show evidence of downslope lateral spreading due to the presence of the Tuaheni removing support from the toe. These results suggest Unit II and Unit III are not genetically linked, that they are separated substantially in time and that they had different emplacement mechanisms, but fail under similar circumstances.

Glacier processes and landscape evolution in a rapidly deglaciating Austrian valley glacier: Gepatschferner, Kaunertal, Austria

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The "Glaciated Valley Landsystem" is highly heterogeneous, with debris input from ice marginal, supraglacial and subglacial sources, and with modification by periglacial and paraglacial processes including slope and fluvioglacial processes. As such, they are highly variable depending on topography, climate and regional geology. To date, most Glaciated Valley landsystems models have focused on high Andean, Himalayan or Icelandic examples, with few available from Alpine environments. Gepatschferner, Kaunertal, Austria, is an excellent example of a clean-ice, temperate valley glacier landsystem that also documents post-depositional landscape response dynamics. New UAV technologies and high resolution remote sensing from satellite imagery allow these processes to be investigated at unprecedented scale and detail, through the use of new orthomosaics and digital elevation models. Gepatschferner is fast-flowing, largely free of supraglacial debris, and is characterized by transverse crevasses, with longitudinal and splaying crevasses in the lower snout region. The rapidly receding glacier snout allows close examination of the ice-bed interface as it reveals a striated, ice-scoured bedrock pavement littered with flutes that extend from tunnels from under the ice, formed in response to ice deformation around obstacles; patches of diamicton with lodged stones; micro-terminal moraines less than 20 cm high; and substantial roche moutonnées, crag and tails. The ice-proximal striated surface and an older pavement exposed in the 1970s down-valley are both characterized by ice-scoured up-ice forms, well-orientated striations and rock polish, and plucked lee-side faces. The differences between the younger and older pavements allow assessment of subaerial erosional processes that can rapidly remove subtle evidence of ice processes. The steep valley sides are plastered with an accumulation of thick glacigenic material, interspersed with ice-scoured bedrock, revealing that subglacial processes are involved in forming these characteristic landforms, rather than purely supraglacial processes. The valley sides are marked by inset narrow benches of largely supraglacially derived material that demarcate the thinning of the ice margin. Periods of ice-margin stabilization, such as the Little Ice Age, are denoted by substantial moraines, but cross-valley terminal moraines are scarce inside of this margin. Paraglacial processes include talus cones, landslides, and fluvioglacial reworking of glacial deposits, with terracing and the formation of a braided gravel river in the lower parts of the valley. Periglacial landforms relating to snow patches are visible in the upper parts of the valley. Our research documents the landscape evolution of this temperate valley glacier through time, from its Little Ice Age maximum to the present day, and offers new insights into the processes of sediment-landform generation and modification through time in the Alpine Glaciated Valley landsystem.

New sedimentary model for Bottom Current Reworked Sands; IODP U1389 and U1388 sites, Gulf of Cadiz

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The ability to differentiate sandy reworked turbidites from turbidites or contourites in sedimentary cores is still an issue on the deep-marine research. The models presented since 60s, bring us to the conclusion that they are inadequate to describe and interpret the complexity of real depositional patterns in deep-marine systems developed by the interaction of along- and down-slope sedimentary processes. Between the two end members as turbidites and sandy contourites, a significant spectra of intermediate variants exists, which show attributes of both facies, and they depend on which kind of sedimentological processes are interacting at the same time (or not) in a specific environment. In order to evaluate the depositional conditions for these sandy deposits and to recognize the involved processes, a rigorous assessment of facies analysis is needed, especially because the interaction of processes along- and down-slope has been traditionally underestimated. The definition of a sequence of facies association proxies neither the ichnological features of redistributed gravity-sediments by contour tractional transport in mixed systems has not been deeply discussed in published examples. In order to solve the absence of a facies model to describe bottom current reworked sands (BCRS), we here propose a new sedimentary model to characterize them. This study is based on BCRS developed on a Pleistocene mixed sedimentary system and based on a multidisciplinary study which has included geophysical data, sediment samples and high-resolution images from cores drilled during the IODP Expedition 339 in the Gulf of Cadiz. These BCRS are located along the middle slope 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. Multiproxies analysis, including grain size, microfacies, X-ray Florescence (XRF) scanning data and bioturbation allow us to interpret that the three main processes (settling, suspension and traction) involved on the deposition of BCRS have been discontinuous. The studied deposits constitute recent/modern analogues of contourite dominated mixed system, contributing to a better understanding of deep-water sedimentation and proposing some conceptual implications to be compared with other areas.

Microbe-mineral interactions in Modern and Ancient Saline-Alkaline Lakes of the Iberian Peninsula: Early Findings from Laguna de Chiprana

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Microbes have contributed to carbon cycling through the formation, dissolution and transformation of carbonate for over 3 billion years, producing laminated microbial mats and corresponding sedimentary deposits known as microbialites that have been geologically significant components of the rock record throughout much of Earth's history (Riding, 2000). Metabolic processes such as photosynthesis and sulphate reduction occurring within these deposits contribute to carbonate precipitation and dissolution (Dupraz et al., 2009), and bacteria can produce cohesive organic matrices which can both bind and trap allochthonous sediments (Altermann, 2008) and simultaneously act as mineral nucleation sites (Douglas and Beveridge, 1998). Microbial mats therefore represent a model ecosystem to study microbial interactions with carbonates, to understand early diagenesis of microbialites, and to act as analogues for unconventional hydrocarbon reservoirs. As such, the saline-alkaline lakes of the Iberian Peninsula which contain many of these biosedimentary structures embody a natural laboratory in which these unique ecosystems can be studied (Guerrero and de Wit, 1992). A wide range of physicochemical conditions govern these systems, and as such, an equally broad spectrum of microbialites both from contemporary lake environments and within Late Holocene lacustrine core sediments have been described. Preliminary sedimentological, tomographical and geochemical analyses of microbial mats in short core from Laguna Salada de Chiprana, a permanent hypersaline lagoon in Northeast Spain, reveal complex mineralogical, textural and morphological characteristics. The mats display clear colour variations that correspond to various functional groups of bacteria and morphological characteristics that vary with water depth, producing pinnacle-like structures on their upper surface in the shallow (<1m depth) waters that are absent in the central lake basin (>4m depth). These structures and corresponding short sediment cores were visualised through use of Computerised Tomographical Scanning at the Henry Moseley X-Ray Facility, University of Manchester, to determine spatial and temporal fluctuations in microbialite morphology and petrology. Subsequent SEM, CL and optical microscopic analyses revealed a variable distribution of carbonate and complex interactions between organic matter and mineral phases both in contemporary mats and mats preserved in Holocene core sediments. These findings will ultimately contribute to knowledge of microbe-mineral interactions, early diagenesis of microbialites and geochemical controls acting upon microbialite mineralogy and petrography.

Diapirism in the Betic Foreland: salt-sediment interaction during the late Miocene-Quaternary evolution of the SW Iberian Margin.

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The SW Iberian Margin (SWIM) underwent a complex tectonic evolution, related to its close proximity to the Eurasian-African plate boundary and the Betic-Rif Orogeny. Due to the westward migration of the Betic-Rif domain, a massive chaotic body composed of deformed Mesozoic to Cenozoic strata was emplaced during the late Tortonian within the Gulf of Cadiz (the Gulf of Cadiz Accretionary Wedge, GCAW). The foredeep Algarve Basin and wedge-top Doñana, Sanlucar and Cadiz Basins developed on the Betics' foreland. Their sedimentary infill is composed of a Miocene turbiditic-hemipelagic sequence and Pliocene-Quaternary contourite deposits that developed under the influence of the Mediterranean Outflow Water (MOW). The aim of this work is to understand the effect of the regional compressional setting on pre-existing diapiric structures, and how it influenced the sedimentary evolution of the margin. This has been accomplished with the analysis of high quality regional 2D multichannel seismic reflection profiles and a chronological framework from well data. Extensive diapiric activity is recorded along the basins, with a more intense activity recorded in the wedge-top domain. The diapirs are characterized by a chaotic seismic facies with steep flanks that are rooted in an older salt canopy or in the GCAW. The most important features are the NE-SW oriented Esperança, Doñana, and Guadalquivir Ridges and the N-S Cadiz Diapiric Ridge. These ridges are roughly parallel to the orogenic front, indicating that tectonic forces related to the convergence of the Betic-Rif with the SWIM controlled diapirism in the region. Inherited margin structures (e.g. Guadalquivir Basement High) also played an important role in the margins' evolution, restricting the GCAW migration and consequently leading to intense compression of the wedge-top basins. Diapiric ridges influenced the late Miocene-Quaternary basins by causing bathymetric relief on the paleo-seafloor which exerted control on sediment transport axes and bottom-current pathways. In the late Miocene, the reliefs diverted gravitational processes, leading to the formation of confined turbiditic channels in valleys between highs (e.g. Algarve Basin). The ridges also controlled the course and intensity of the MOW and thus the development of the well-known Gulf of Cadiz Contourite Depositional System. The onset of the MOW since the Pliocene saw the formation of contourite drifts in depocentres bounded by evolving diapiric structures (e.g. wedge-top basins), and affected by syn- or post-depositional deformation. Furthermore, recent contourite erosional features develop adjacent to diapiric ridges outcropping on the Present-day seafloor. This work demonstrates the importance of the regional compressional setting on the late Miocene-Quaternary evolution of the SWIM – it caused the formation and reactivation of diapiric structures through the Betics' foreland. Together with sea-level and climatic variations, diapiric reliefs and depocentres controlled the evolution and distribution of deep-water contourite and turbidite systems along the SWIM since the late Miocene.

A revised structural elements map of the North West Shelf

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The widely used scheme of naming basins and their regional subdivisions on the North West Shelf of Australia emerged from relatively sparse data collected during the early stages of exploration. Such data allow the recognition of large-scale structures and depocentres with broadly distinct tectono-stratigraphic signatures. While that scheme has endured, the availability of extensive, high quality seismic data and stratigraphic information from numerous exploration wells means that we can define much more precisely the structural elements that comprise the margin and the stratigraphic signatures of the basin fill. This has highlighted some inconsistencies in the existing nomenclature, the presence of structural elements of different ages and the presence of boundaries between basins that in instances can appear somewhat arbitrary.

We present a revised map of the North West Shelf that shows the structural elements with distinct tectono-stratigraphic signatures that comprise the margin, and applies a consistent nomenclature to them. The aim is to provide a framework that will allow for the better demarcation of distinct hydrocarbon provinces and improved targeting of exploration programmes. This is a work in progress, and can only be improved by broad community input. We invite you to visit our poster, to use the pens available to add details that we have missed, correct errors that we have made, and rectify any omissions. Alternatively, you can add comments to our blog (https://wordpress.com/view/nwshelfstrucelements.home.blog) where you will also be able to see that latest version of the map, share your thoughts and contribute to a stimulating discussion.

What does the evolution of sedimentary basins on the North West Shelf of Australia tell us about Gondwana break-up?

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The widely held view of the evolution of the North West Shelf of Australia is that the fundamental basin architecture was established by NW-SE oriented extension in the Carboniferous and Permian associated with rifting of the Lhasa terrane, by a further phase of NW-SE oriented extension in the Lower and Middle Jurassic associated with the separation of the Argoland terrane and by E-W oriented Upper Jurassic to Lower Cretaceous extension that culminated in the separation of Greater India and Australia.

The presence of fundamental NE-SW oriented Carboniferous to Permian aged rift structures is well established, and with seismic data that now images deeper structures more effectively, the architecture of that rift system is becoming increasingly apparent. What is less clear is the nature of Triassic deformation, which forms a passive, post-rift sequence in most of the Carnarvon Basin, but shows a continuation of the Permian extension, and a significant episode of volcanism, further to the NE. However, evidence of a failed Permian rift raises questions about the location and timing of separation of the Lhasa Terrane.

A renewed phase of extension began in the latest Triassic in the western part of the Northern Carnarvon Basin, but became progressively younger to the NE. A very clear and consistent pattern of ENE oriented extension, that interacts with the older NE-SW oriented Permian aged structures, is apparent across the whole of the Northern Carnarvon and Roebuck Basins, and in to the Browse Basin. This is at odds with the NW-SE oriented extension predicted by Argoland rifting.

Upper Jurassic and Lower Cretaceous extension is surprisingly localised, being most evident in the SW corner of the Northern Carnarvon Basin (in the Exmouth sub-basin), around the Thouin Graben which marks the boundary between the Northern Carnarvon and Roebuck basins, and in the area of the Vulcan sub-basin. Elsewhere this event has surprisingly little expression, but the fact that it is evident in locations so far removed from the site of Australia-Greater India separation is puzzling, and perhaps requires a re-appraisal of existing models of Gondwana break-up.

GEOLOGICAL STUDY OF DETRITAL RED FORMATIONS IN THE CENTRAL HIGH ATLAS (MOROCCO): STRATIGRAPHIC AND PALEOENVIRONNEMENT IMPLICATIONS

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The Moroccan High Atlas mountain belt exposes a thick superposition starts and formations, from the Precambrian to the Quaternary. In the Center High Atlas, the Jurassic-Cretaceous red formations are deposed in the center of large synclines with flat bowls. They overcome the marl-limestones of Bajocian-Bathonian (Bin El Ouidane and Tilougguit). These thick detrital series, about 1450m in Imilchil, are classed in three superposed formations. The Guettioua Formation at the base, formed by sandstone bars, silt levels with conglomerate channels. The Iouaridene Formation, characterized by clays, marls and gypsum in the middle part. In addition, the Jbel Sidal Formation in the top, it is very similar to the Guettioua Formation.

Stratigraphic and Geodynamic studies, analysis of lithostratigraphic logs and geological cross-sections logged in many outcrops, have allowed to emerge and define the different mechanisms responsible for sedimentation of these red sediments and to monitor the evolution of paleoenvironments at the time of deposition. Wherever, the highlighting of the changes affected these composite formations and even at the scale of facies with fossils that conceal. The principal factors such as tectonic, sea level variations and sediments origin allowed to the differences noted between the center and borders sections.

A Source-to-Sink and Reservoir-Quality Prediction Workflow: The Offshore Nile Delta

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This paper outlines a novel workflow for utilising hinterland datasets to predict reservoir quality and distribution in frontier exploration regions and applies this methodology to a case study in the Nile Delta. Geochemical data are intersected with drainage areas to derive first-order bulk chemical compositions. Drainage polygons are modified using thermochronological data and paleocurrent information to create paleo-drainage areas. Volume of denuded sediment is then estimated from uplift data and integrated with stratigraphies to verify the link between hinterland and offshore geology. Finally, inorganic geochemical data are used to predict the modal composition of sediment within key reservoir and seal horizons.

The workflow presented utilises datasets otherwise overlooked (Figure 1) in the exploration process and reduces the reliance on more speculative inputs such as paleogeographic reconstructions and paleoclimate modelling. It provides quantitative predictions with percentage certainties, allowing explorers to understand the degree to which results can be relied upon.

To demonstrate this workflow, we look at the offshore Nile Delta sediments in the Eastern Mediterranean. The Nile's vast hinterland is comprised of sediments derived from the Congo Craton and Saharan Metacraton, Cenozoic Flood Basalts and Phanerozoic sediments from the Ethiopian Highlands, and Phanerozoic sediments and Cenozoic carbonates from the Egyptian Red Sea Hills. Recent detrital studies on the offshore Nile Delta have shown the provenance of the Oligocene-to-Pleistocene sediments remained the same since the Rupelian, 31 Ma (Fielding et al., 2018). Fluctuations in the amount of mafic material recorded in the delta during the Oligocene and Pliocene versus the Miocene and Pleistocene have implications for discontinuous reservoir quality in the basin. Using the workflow outlined above and incorporating additional datasets and methods, we aim to quantify this variation in mafic sediments and its implications for predicting reservoir quality in the offshore Nile Delta.

Sedimentary structures and textures in sand injectites. Insights from dikes and sand blows of the Holocene fluvial sediments (Emilia, Italy)

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As discussed by Hurst et al. (2011), studies of sand injectites, including sand extrusions, are relatively scarce in the geological literature, although these phenomena were recognized in many geological settings (Quigley et al., 2013: Ross et al., 2014). A trench dug across dikes and sand blows formed as a consequence of the 2012 Emilia earthquake allowed a direct observation of liquefaction structures (Fontana et al., 2015, 2019). Sand dikes crosscut the fine-grained host sequence at high angles with a vertical extension of at least 5 m. The width of the fractures varied from a few cm to 30 cm. The injected sand showed complex sedimentary structures: the most common was a distinct banding, longitudinal to the dike length, or perpendicular to the dike margins. The bands oriented parallel to the dike were bounded by sharp contacts marked by thin clay veneers defined by differences in grain size and grain alignment. We observed both direct and inverse vertical grading from medium sand to mud. The fractures were rhythmically injected and filled of slurry sand and mud during the compression pulses end emptied by the rushing of the slurry back down deep into the fractures during the extension peak. The grain-size distribution along dikes and sand blows showed that some sorting occurred within injected dikes, probably due to pulse flows, and further segregation occurred as the material was extruded following the generated excess pore-water pressure. This may have caused the dispersion of the fine silt–clay content, producing highly sorted sand boils. The composition of sand dykes adds an important constraint in identifying the source layer. Regarding the possibility that selective mechanism due to flux variation may have influenced the sand composition, our data seem to indicate that no major variation was induced by injection phenomena.

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Hybrid turbidite-drift channel complexes - an integrated multi-scale model

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The interaction of quasi-steady deep-marine bottom currents with episodic-unsteady sediment gravity flows affects global sediment transport, forms climate archives and controls the evolution of continental slopes. Despite their importance, contradictory hypotheses for reconstructing past flow regimes have arisen from a paucity of studies, and the lack of direct monitoring of such hybrid systems. Here, we address this controversy by analyzing deposits, high-resolution seafloor data, and near-bed current measurements from two sites where eastward-flowing gravity flows interact with northward-flowing bottom currents. Extensive seismic and core data from offshore Tanzania reveal a 1650 m-thick asymmetric hybrid channel levee-drift system, deposited over a period of ~20 Myr (Upper Cretaceous to Paleocene). High-resolution modern seafloor data from offshore Mozambique reveal similar asymmetric channel geometries, which are related to northward near-bed currents with measured velocities of up to 1.4 ms^{-1}. Higher sediment accumulation occurs on the lower angle stoss-sides (down-stream of bottom currents) of channel margins, with inhibited deposition or scouring on the steeper lee-side (where lee wave velocities are highest). Toes of the drift deposits, consisting of thick laminated muddy siltstone, progressively step back into the channel axis over time, resulting in an inter-fingering relationship with the sandstone dominated channel-fill. These findings contrast with previous models that lacked direct current measurements or paleo-flow indicators. We finally show how large-scale depositional architecture is built through the temporally-variable coupling of these two globally-important sediment transport processes. Our findings enable more robust reconstructions of past oceanic circulation and diagnosis of ancient hybrid turbidite-drift systems.

Structural control on the downslope-alongslope sedimentary processes in the Cadiz upper slope

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The Cadiz upper slope is located at the Atlantic exit of the Strait of Gibraltar (latitude 36º10'-36º40'N). It runs from the continental shelf-edge at ~120 mwd to the connection with the middle slope at 400-500 mwd. It is covered by a plastered contouritic drift created by the Mediterranean Outflow Water (MOW) and incised by upper slope gullies. This work investigates the interaction between gravitational and contouritic processes under the influence of a highly dynamic tectonic regime controlled by diapiric activity rooted in the Gulf of Cadiz Allochtonous Unit. Tectonic activity and sedimentary processes are inferred from the stratigraphic analysis of airgun seismic profiles that cover the sedimentary record from the Mid Pleistocene. Two seismic units have been identified and placed in a regional chronostratigraphic framework. The lower unit SU-II (Mid Pleistocene to Late Quaternary) is deformed by the activity of NE-SW-oriented outcropping and buried diapirs. It shows layered and wavy reflections in the southern upper slope, where some gullies occur related to diapir-rooted faults; parallel layered reflections prevail in the northern upper slope where only a few gullies occur in inter-diapir basins. This unit is interpreted as patchy plastered drifts that infilled the space created by the diapiric uplift as the main Mediterranean Outflow Water (MOW) flowed through a channel located about 5 km to the east of a major present-day contourite channel (i.e., the Cadiz contourite channel). The upper seismic unit SU-I (Late Quaternary-Present) records the inactivation of most of the NE-SW-oriented buried diapirs, and the activity of the outcropping diapiric ridges and buried NW-SE-oriented diapirs. This unit is composed of four sub-units (SU-ID to SU-IA). The lower two sub-units led to the progradation of the southern upper slope and the migration of the main channel to its present-day position. Along-slope sedimentation took over as the main morpho-sedimentary process due to the strengthening of the MOW upper core, as suggested by the orientation of depocenters and the occurrence of wavy deposits in the northern upper slope. Gullies incision and slope instability in the southern area resulted from renewed diapiric activity. Sub-unit SU-IB records a quiet tectonic stage. Layered high-acoustic amplitude reflections on the upper slope are interpreted as a plastered drift deposited under a tabular flow of the MOW. The last stage (sub-unit SU-IA) is characterized by a reactivation of the NW-SE-oriented buried diapiric highs and the outcropping diapiric ridges, and the onset of sedimentary instability that eroded the previous sub-unit. Mounded drifts infilled the eroded surfaces and a new plastered drift covered the entire upper slope. The incision of gullies was particularly important in the southern area, although their asymmetric pattern and NW migration suggests important MOW influence. The northern area is characterized by downslope prograding chaotic-transparent deposits with sediment waves, suggesting high sedimentation rates and flow instability related to diapir uplift. This work reveals that the paleoceanographic and paleoclimatic interpretations of deep-water environments require a careful analysis of the tectonic control influencing the complex interplay between downslope and along-slope sedimentation.

READING TIDAL PROCESSES WHERE THEIR SIGNATURE IS CRIPTIC: THE MAASTRICTIAN MEANDERING CHANNEL DEPOSITS OF THE TREMP FORMATION (SOUTHER PYRENEES, SPAIN)

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Tidal currents can propagate tens kilometres landward, forming dense networks of meandering channels, which drain vegetated areas and range in width from tens to hundreds of meters. Sedimentology of these channels differ from that of meandering channels developed in intertidal flats, and sedimentary products of inland tidal channels are poorly documented in the fossil record. The present study contributes to fill this gap investigating Late Maastrichtian meandering-channel deposits of the Tremp-Graus Basin (Southern Pyrenees, Spain). These deposits belong to the Lower Unit of the Tremp Formation and accumulated in a growth syncline, which allowed development of a 20 km wide, and 100 km long, tidal embayment. Channelized deposits consist of 2-9 m thick sandstone bodies, which are commonly floored by mudclast-rich channel lags. Sandstone are mainly ripple cross laminated, although trough- and plane-parallel cross strata occur at the base of sandstone bodies. Sporadic occurrence of rhythmites and bidirectional currents confirm the occurrence of tidal processes, but their dominance is inferred through a number of evidence, including: i) landward shallowing of the deepest channels; ii) disproportion between depth of the larger channels and related catchment area; iii) landward-accretion of point-bar bodies; iv) landward fining of point-bar bodies and v) reconstruction of paleo-flow pattern at the meander bend scale. This work shows that 3D architectural modelling and reconstruction of bar planform transformation styles can provide a string contribution to understand tidal control on sedimentation in inland areas.

Localised rotational effects on granular temperature in granular flows

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The granular temperature of a granular flow is analogous to the Reynolds stress of a fluid flow. In both cases they represent the transfer of energy/momentum through the medium. The main difference between a fluid and granular flow is that the physical behaviour of fluid flows is determined by viscosity, whereas the physical behaviour of a granular flow is governed by inter-particle collisions and micro-scale imperfections on particle surfaces. A recent paper by Higham et al. (2019) highlights the importance of including rotational moment transfer between colliding grains, mediated by grain surface imperfection. Surprisingly, these small, three-dimensional rotations are not accounted for when modelling granular flows, but as these have a large effect on the individual energy/momentum fluxes, this heavily reduces their accuracy. We present an experimental investigation of a two-dimensional driven vortex in a granular flow experiencing continuous shear that is imposed by an enclosed belt system. Grains are represented by mini plastic footballs to enable accurate tracking. Particle tracking will enable the spatial and rotational translations on individual grains to be determined. This will allow us to determine the effect of the localised rotations on granular temperature and create a set of partial differential equations which can fully describe the flow. Our results will have major implications for understanding and modelling the transport and evolution of geophysical mass flows. These include, but are not limited to, longitudinal grain fractionation in turbidity currents, grain interaction and basal friction in debris flows, pyroclastic flows and lahars, avalanches and much more.

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Identifying a source-to-sink framework of modern and palaeo-rivers: A case study from the offshore Central Luconia Shelf and onshore Sarawak, Malaysia

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Palaeo- and modern rivers can be related to a source-to-sink framework, with the modern rivers often corresponding to erosion-dominated zones, while the palaeo-rivers preserve deposition-dominated zones. Integrating palaeo- and modern systems within a source-to-sink framework can aid understanding of the river characteristics, sediment distribution and longer-term evolution patterns. However, there is a lack of source-to-sink studies connecting river catchments in the hinterland with their inferred equivalents in the depositional basins. This study links the source zone of several modern rivers in Central Sarawak (NW Borneo) with their paleo- (Quaternary) equivalents on the now submerged Central Luconia shelf. Palaeo-rivers were mapped using 3D seismic reflection data for the Luconia shelf and modern rivers and their source catchments were evaluated using 30 m ASTER DEM data of NW Borneo. Palaeo-rivers were mapped on, and below, the seabed using time-slices through the 3D seismic volume at 10 ms TWTT intervals, covering an interval of stratigraphy of 100 ms TWTT (~85 m) thick. Then, cross-sectional profiles of the interpreted channels were extracted every 5 km to evaluate the changes of width and depth. Preliminary findings show two major palaeo-river systems in Central Luconia and five significant river catchments of the onshore Central Sarawak (Rajang, Baram, Kemena, Balingian, and Tatau river catchments). In the upper part of the seismic data two major channels are consistently identified, which are continuous and prograde towards the basin. In the lower part of the studied interval, fragmented and discontinuous channels are observed in the time-slices. By integrating the interpretations from the time-slices, we identify several river mouths and tributaries flowing northward. We use cross-sectional profiles of the palaeo-rivers to evaluate the downstream evolution of channel hydraulic geometry and we use this to infer Quaternary river behaviour. By linking the palaeo-channels of the Central Luconia shelf to the modern rivers of onshore Central Sarawak, their source zones were likely to be smaller river catchments - the Kemena, Balingian, and Tatau rivers – based on our observations of proximity and channel orientation.

Sedimentary and mineralogical features of evaporitic red bed sediments from Permian diapir structures, North Germany – a comparison

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Evaporite associated red sediments are found as part of Permian evaporite successions in Northern Germany alongside halite and anhydrite sequences. They represent episodes of continental influence on deposition in the center of the South Permian Basin by siliciciclastic input. The red colouration indicates deposition in shallow water or under aerial exposure in an oxidising environment. Sample material was retrieved from both diapiric and stratiformal evaporites within the North German Basin. The sequences represent red sediments from two different stages of the Upper Permian (Rotliegend and Zechstein): Halitic red sediments of the Upper Rotliegend represent deposits of the Rotliegend central Southern Permian Basin (SPB) before the Zechstein transition. «Roter Salzton» represents a horizon of salty mudstone that marks an episode of high siliciclastic input into the marine evaporitic Zechstein basin at the base of the 4th Zechstein cycle. The sediments represent salt flat-sedimentation at different stages of the late Permian Basin. Changes in basin development can be tracked using the mineral record of detrital and evaporite phases based on ICP-OES and XRD measurements as well as petrographical and microscopical observations. Preserved sedimentological structures include euhedral secondary formed halite crystals and anhydrite nodules enclosed in the red sediments. Some areas preserve frequent halite filled desiccation cracks. Additional common characteristics include local discolouration connected to anhydrite and generation of halite-filled fractures. The detrital fraction of the sediments consists of quartz, feldspar and phyllosilicates. While Rotliegend strata show mineral phases like plagioclase and a lower clay mineral content, Roter Salzton provides a greater variety of clay minerals with lower concentrations of other phases like K-feldspar and quartz. Differences in depositional environment can be traced from the content of evaporitic minerals: Rotliegend halite is characterized by low bromide contents below 60 µg/g, indicating the dominance of continental brine sources on mineral formation in the basin center. Roter Salzton shows bromide concentrations up to 300 µg/g_{halite}, which indicates highly evaporated marine brines as a source for crystallisation despite the continental influence on deposition. The difference is also reflected in the dominance of dolomite or magnesite in the diagenetic carbonate content. Further sediment characteristics are authigenic quartz and carbonate seams and carnallite-filled fractures enclosed in the red sediments. Common cement types include anhydrite, halite and phyllosilicate cement. Detrital mineral contents have been preserved from early diagenesis or depositional environments. The presence of authigenic minerals can be explained by brine mixing in an oxidising environment. The traceability of mineralogical characteristics as well as preserved sedimentological and diagenetic features points out that the palaeogeographical evolution of the North German Basin can be identified even from sequences in tectonically influenced structures. These findings also simplify the evaluation of potential later tectonic overprints. The results can be used for further genetic studies connected to the investigation of salt structures.

Deep-water bottom current deposits from Cyprus

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One of the best examples of ancient bottom current deposits described in the literature come from the Eocene to the early Miocene succession Lefkara and Pakhna formations (Cyprus). During five field campaigns (2014, 2015, 2016, 2017 and 2018) *The Drifters Research Group* (RHUL) has been studying these deposits in order to understand the organisation of sedimentary facies and compare this example with analogue deposits in modern / recent deep-water environments. Field campaigns have been undertaken for the identification of the best outcrops at the Petra-Tou Romiou, Agios Konstantinos, Kalavassos and Korfi localities. Detailed sedimentary logging, and sedimentary and ichnological analyses were carried out. A revised chronostratigraphic framework was established, based on a study of planktonic and benthic foraminifera, and nannofossils constraining the age of the studied sections respect to previous works. Moreover, thin section analysis, direct and indirect measurement of porosity, scanning electron microscopy for elemental analysis and X-ray diffraction for mineral analysis, have been executed. The dominant sedimentary facies consist of calcarenites, chalks, cherts, marls and calcilutites interpreted as the result of contourites, turbidites, reworked turbidites, and hemipelagic and pelagic depositional processes acting along and down the continental slope setting. Sandy contourite beds are identified in three main packages and, although digenetic processes have been intense, parallel lamination, cross-lamination, banding, flaser structures and dune geometries have been recognised. The porosity values of these deposits exceed 10% and bioturbation is high throughout. Ichnofacies distribution indicates a general shallowing upward trend through the succession. These preliminary results reveal that microfacies, ichnological features and sedimentary structures could be diagnostic criteria for the determination of sandy contourites. Their characteristics in the studied outcrops are very common in modern deep-water sedimentary environments (e.g., contourite terraces and plastered drifts) and they are of great scientific and economic significance, but further research work is needed for their better understanding and distinction from other deep-sea deposits.

The influence of local low-density basement anomalies on the distribution of fluvio-deltaic sediment in rift basins: the early Carboniferous Fell Sandstone Formation, northern England

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Local low-density basement anomalies are an important part of a rift basin's inherited structural framework that can influence basin stratigraphy. Large granitic intrusions can cause local alterations in the basement's density and often spatially correlate with fault-bounded highs (blocks) or convex-shaped regional flexural highs due to their isostatic responses. We investigate the influence of local low-density basement anomalies on the deposition of the fluviodeltaic Fell Sandstone Formation in the northern Pennine rift basin, northern England. The integration of a variety of data sources has enabled regional correlation of the Fell Sandstone Formation with basinal, time-equivalent stratigraphy. Spatial variations in the preserved facies, palaeocurrent and sedimentological characteristics of the Fell Sandstone are documented and the most important controls upon these variations are considered. Along the eastern margin of the granite-cored, flexural Cheviot High, the Fell Sandstone fluvial system is locally confined by the High leading to preservation of ~98% well-sorted sandstone. In the Northumberland-Solway Basin, the Fell Sandstone fluvial system is less confined, leading to sediment dispersal and downstream reduction of net sand. Based on this study, proximity to the dominant clastic sediment source, regional subsidence variations and basin palaeotopography are considered important controls upon spatial variations across the Fell Sandstone Formation. Regional subsidence variations and basin palaeotopography in the northern Pennine Basin are influenced by the Cheviot High and the Maryport-Stublick-Ninety Fathom fault system, which bounds the Northumberland-Solway Basin and the Lake District and Alston Blocks. Both the Cheviot High and the Lake District and Alston Blocks are structures caused by the isostatic responses of local granite-induced low-density basement anomalies. This study shows that flexural highs can act as baffles to fluvial systems, locally confining them and leading to the deposition of high quality reservoir. Fault-bounded highs can act as barriers and their deep bordering half-graben troughs can act as confines for clastic sediment, leading to starvation further down system.

INVESTIGATING MICROBIAL DEGRADATION OF DISSOLVED ORGANIC MATTER LEACHATES FROM MARINE BLACK SHALE

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Drilling activities involve the interaction of fluids (injected and returned), cleaning water and produced water with rocks, which stimulate immediate physicochemical and possibly microbiological perturbations in the deep subsurface. The nature of such fluid-rock-microbial interactions and their effects are not well understood. The induced mobilisation of leachable materials (including radioactive elements, heavy metals, Persistent organic pollutants (POPs), etc.) may potentially harm the environment, in the subsurface but possibly also at the surface if mobilised with drilling backwaters or geological fractures. Release of dissolved organic carbon (DOC), dissolved organic nitrogen (DON), sulphide, etc. may stimulate biodegradation which can lead to reservoir/borehole souring or well fouling. There is an urgent need for reliable data of aerobic biodegradability of organic compounds and their environmental impact under realistic subsurface conditions (Miles and Doucette, 2001, *Chemosphere*, **45**(2001): 1085- 1090).

This research uses black shale DOM leaching combined with microcosm experiments under controlled conditions (enclosed microcosm system kept at room temperature in the box away from sunlight with supply of oxygen in the headspace when depleted), to determine the abundance and nature of DOM, its availability for microbiological degradation and quantify the produced gases (CO_2, methane).

We use milliQ-H2O as percolating liquid to leach immature organic carbon rich shale samples 7.5 to 10.5 % TOC. The DOM leachate was then used for microcosm experiments to stimulate microbial degradation. We measured CO2 in the microcosm headspace using a gas analyser. The experiment started 97 days ago and is ongoing, with microcosms showing marked differences in response, depending on the experimental setups (experimental setup consist of each triplicate of only leachates microcosm with identical microcosm containing only filter or milliQ-H_2O or both and or autoclave filter as controls). We observe the strongest CO_2 production range for microcosms with leachates, confirming microbial biodegradation stimulated by shale DOM leachates.

The microcosm experiments will continue until no further changes in gas production is measured. In parallel we will determine the composition of DOM before and after microcosm incubation using next generation OCD-OND-UVD liquid chromatography.

Transfer of microplastics from terrestrial to marine environments: Tracking transport from the River Mersey to Liverpool Bay

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The effects of microplastic contamination in the global oceans has become a major environmental concern. Microplastics are increasingly recognised in the sedimentological record; however, there is still much uncertainty about the processes that transfer microplastics from terrestrial sources to marine sinks, and how they control microplastic dispersal or concentration. Previous studies have identified microplastics in rivers, and others in the deep sea, few have focused on estuaries - the critical transition zone between the two. Using new sediment samples acquired from the River Mersey estuary and the shallow marine Liverpool Bay we show how sedimentological processes and morphology control microplastic transfer and accumulation. Based on a type- and size-based classification of microplastics, we find that microbeads and microplastic fragments are largely being sequestered in the sediments of the River Mersey and the estuary and are not transported to the shelf (Liverpool Bay) component of the system; a trend that has not yet been documented. Our new data demonstrate the importance of characterising fundamental properties of microplastics, such as shape and density, as they play a strong control on whether they will become locally concentrated or more widely dispersed at the transition zone from fluvial to marine transfer. These results underline the important role of sedimentology in characterising and quantifying the global microplastics cycle.

Distal sediment waves on the Argentine passive continental margin: characterization and implications

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In recent decades contourite research has accelerated due to the acquisition of new high-resolution seismic reflection data in deep marine settings, and an increasing scientific and economic significance of bottom current controlled sedimentation. Understanding contourite features and the oceanographic processes that control their formation aids in hydrocarbon exploration as well as in fields such as (paleo)- oceanography where feature geometries and internal architecture can help decode circulation patterns. Presently the Argentine continental margin is influenced by several water masses (stratified by density) with circulations that have resulted in the evolution of a contourite depositional system (CDS) stretching from the upper continental slope to abyssal plain. A field of large sediment waves (magnitudes ranging from 150 to 270 m) has been characterised at an intersection between two broadband 2D seismic profiles parallel and perpendicular to the trend of the margin. The field is situated ~41°S and ~55°W and formed between 4200 – 4600 m wd under the influence of the Antarctic Bottom Water (AABW) at >3600 m wd. Margin parallel the field is dissected obliquely and shows sigmoidal packages with apparent wavelengths ranging from 7500 m to 11250 m whilst perpendicular to the margin a wave migration and elongation can be identified in a NW (obliquely upslope) direction. The field pinches into an alongslope erosive surface situated on the lower continental slope (between 3600 m and 4200 m wd). Both the wave field and erosive surface broadly align with the seafloor interface of boundary layer between the AABW and the overlying Lower Circumpolar Deep Water (LCDW), currently at ~3500 - 4000 m wd. This could suggest vigorous bottom current activity and, perhaps, evidence for deep tides. The results from this study demonstrate the role of local palaeoceanographic processes on the development of large contourite morphologies. There is scope for further work on the Argentine and Uruguayan margins using broadband 2D and 3D datasets. This project is funded by a joint industry project supported by BP, ENI, ExxonMobil, TGS, Total and Wintershall under the framework of The Drifters Research Group based at Royal Holloway University of London (RHUL).

Understanding human-driven ecosystem change in a tropical Southeast Asian wetland

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Tropical areas are undergoing rapid environmental change as a combined result of climate change and human impact on the landscape, which significantly threatens the quality and biodiversity of freshwater ecosystems. Tasik (Lake) Chini is a flood pulse wetland located on the Malaysian Peninsula, and is a critically endangered site comprising twelve interconnected lake basins. The natural vegetation of the lake's catchment and surrounding area has become increasingly influenced in recent years by rubber and oil palm plantations, mining, fruit farms, logging, and tourism, which have resulted in pollution, soil erosion, and external nutrient loading to the lake. The main outflow river was also dammed in 1995 to help stabilise the water level. Together, these activities have changed the hydrological balance of the lake, influenced biodiversity causing species and habitat loss, and decreased the sustainability of the ecosystem due to eutrophication. To understand the influence of major changes in catchment land use on the lake and to investigate the key drivers of ecosystem degradation, gravity cores were recovered in 2015 from three sub-basins of Tasik Chini. The first core is from a site adjacent to a tourist resort, the second core is from a basin situated close to mining activity and rubber plantations, and the final core was retrieved from a site furthest from major catchment disturbance. An established chronology based on ^{210}Pb dating shows each gravity core dates back to the late 19th century and covers the transition to enhanced human impact within the catchment. Organic geochemistry (%C, C/N, δ^{13}C, Rock-Eval pyrolysis), diatom assemblage, elemental concentrations, and sedimentary pigments have all been analysed on each core to reconstruct past environmental conditions within the basin. Data show how past variability compares to recent anthropogenic-induced environmental change and define how different catchment disturbances have contributed to ecological change at this internationally important wetland site. This information is vital to assess ongoing human impacts at the site as a means to provide future science-based management and conservation strategies and thereby counter the main drivers of ecosystem degradation.

Distribution of the Southern Contourite Channel (SE Gulf of Cadiz) after the opening of the Strait of Gibraltar

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Offshore seismic reflection data from the continental slope of the southern Gulf of Cadiz, reveals a succession of deeply incised valleys/channels (concave-up), several channel fills and mounded (concave-down) features within the Pliocene-Quaternary sedimentary record. These valleys are interpreted as paleochannels (PC) which developed coevally to regional unconformities (from older to young, PC-1 to -9). Regional correlation between the IODP Exp. 339 Sites with reflection seismic lines allowed the characterisation of the sedimentary evolution of these channels, in particular, the larger Southern Channel located in the proximal sector of the Contourite Depositional System (CDS) at the exit of the Strait of Gibraltar, which is being influenced by the Mediterranean Outflow Water (MOW).

The first and most prominent erosional feature observed during the Early Pliocene (PC-1) corresponds with the onset of the Southern Channel, about 9 km wide and 4 km eastward from the present-day channel. From *Early Pliocene to Early Quaternary* (PC-5), a series of channel fills and erosions (PC-1 to 5) are determined in approximately 400 ms of thickness, showing similar seismic features. The lateral distribution displays a SE-NW trend since their origin proximal to the exit of the Gibraltar Strait, and then, 10 km north the actual Gil Eanes, it changes to a more E-W trend. All these channels are developed in the central depression between two structural highs. From the *Early Quaternary to Late Pleistocene*, erosive incisions located similar than the previous channels, but exhibiting a significant change in the sedimentary features implying the development of three channels (PC-5 to 9) as well as the formation of adjacent smooth mounded drifts on their distal side. The most recent occurs after the *Late Pleistocene to present* (PC-9 to seafloor), when the Southern Channel settles at its present-day location. The vertical and lateral stacking pattern of the Southern Channel can be correlated with both the main tectonic pulses and climatic (orbital) variations. This correlation provides new evidence for the complex interplay of Pliocene-Quaternary tectonics, climate, sea-level and bottom-current circulation changes. These modern channels are great analogues for ancient sandy contourite channels which could potentially represent valuable plays for future hydrocarbon exploration.

Palaeohydrology of Late Cretaceous sediment routing systems, Utah, USA, in space and time.

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Quantifying the evolution of palaeohydrology in space and time is a crucial first step for understanding the past movement of water and sediment across Earth's surface. This requires reconstructing the morphologies and dynamics of palaeo-rivers from stratigraphy which will, in turn, deliver sophisticated insights to the sensitivity and response timescales of fluvial systems to tectonic and climatic drivers.

Here we reconstruct the spatio-temporal evolution of palaeohydrology in Late Cretaceous sediment routing systems of central Utah, USA — we focus on transverse fluvial systems that drained the Sevier orogenic belt eastward towards the Western Interior Seaway (WIS). Palaeohydrologic field data were collected during 2 field campaigns and involved characterising the channel-fill stratigraphy of up-dip to down-dip alluvial, fluvial and coastal plain sediments. Depositional-dip transects were determined for the up-dip Indianola Group and correlative down-dip Mesaverde Group (Blackhawk Formation, Castlegate Sandstone, Price River Formation). Our data encompass 5 regional transverse fluvial systems, for 7 Santonian–Maastrichtian time slices, and include more than 20,000 grain-size measurements, 11,000 cross set measurements, 1500 palaeo-flow measurements, as well as the geometries of channel sand–gravel bodies and major architectural elements.

We present field results for the distribution and maxima of cross set heights which we use to estimate original fluvial bedform heights. Additionally, we present downstream grain-size fining constraints for our depositional-dip transects. With these data, we use a well-established quantitative framework, based on a suite of empirical, experimental and theoretical work, to calculate the flow depths, palaeo-slopes, geometries and flow dynamics of rivers draining into the WIS. We reconstruct regional spatio-temporal trends in palaeohydrology and recover up-dip to down-dip, north–south and temporal trends in palaeohydrology. We link observed trends to regional changes in subsidence and sediment supply in Late Cretaceous central Utah and, finally, consider the impact of long-period climatic forcing (Late Cretaceous cooling).

Pore Structures and Occurrence Characteristics of Movable Fluid of Tight Sandstone Oil Reservoir in Huachi area, Ordos Basin, China

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Nuclear Magnetic Resonance (NMR) experiment has been conducted to study the occurrence characteristics of movable fluid of tight sandstone oil reservoir in Chang 6 member of Triassic Yanchang formation in Huachi area, Ordos basin, and experiments such as CTS, SEM, image porosity, high-pressure mercury injection, constant-rate mercury injection and microscopic water-flooding are combined to investigate the impact factors of microscopic pore structures where movable fluid occurs. It is showed that the average porosity of this area is 8.71%, the average permeability is 0.148mD and the average saturation of movable fluid is 33.89%; the main pore types are residual intergranular pore, dissolved pore and pore-fracture, and movable fluid shows different occurrence characteristics in different sandstone reservoirs with different pore types; pore throat size and ratio are essential for movable fluid saturation, and effective throats whose radiuses are higher than water film thickness play decisive role in the flow and saturation of movable fluid.

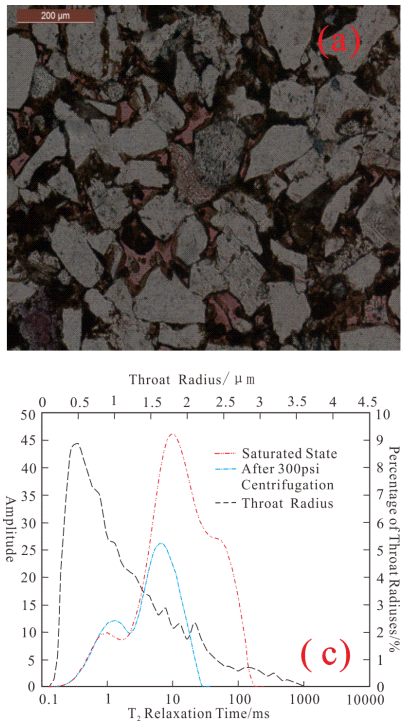

Fig. 4 T_2 Spectrum Distribution of Residual Pores and CTS of the Representative Sample a. Semi-orientated arrangement of grain, residual intergranular pores developed, rock matrix is surrounded by chlorite film, CTS, well B427, 1938.25m; b. residual intergranular pores filled by chlorite, the red frame shows the pores preserved by the inclusion of chlorite around framework grains, the blue frame shows the blocked throats by chlorite fillings, well B427, 1938.25m; c. distribution of T_2 spectrum and throat radius before and after NMR centrifugation, well B427, 1938.25m; d. final stage of water-flooding, uniform displacement, well B427, 1938.25m (the direction of water-flooding is from the left to the right, the blue spot is water and the red is oil).

Contourite depositional systems in the Exmouth Plateau (North West Shelf, Australia) during the Mesozoic the Cenozoic

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The Exmouth Plateau (EP) is a prominent submerged topographic relief between 800 to 4000 m water depths. It is about 400 km wide and 600 km long and is located in the Northern Carnarvon Basin (NCB). At least 10–15 km of sediments are laid down above the extended continental crust of the EP. The extension started in the Paleozoic, followed by Triassic to Jurassic rifting events, which involved successive rotation and dispersion of continental blocks until the final separation of Greater India from Australia. Final continental separation during the Early Cretaceous lead to the opening of an oceanic gateway, that connected the circumantarctic area with the NCB, which resulted in the entry of southern high-latitude waters. This inflow conditioned the oceanographic circulation patterns in the basin, as well as the control of the sedimentary processes on this marginal plateau. Recently, the deep and ultra-deep waters of the EP are becoming an important spotlight for hydrocarbon exploration. However, there is little understanding of the impact of bottom (contouritic) currents and its associated along-slope processes in the EP. The main aim for this research is determine the regional sedimentary evolution during the Mesozoic and Cenozoic of the EP, focusing in the evolution of bottom-current (contouritic) processes. It has been executed using 2D multichannel seismic reflection and biostratigraphic information from well. Seismic interpretation allowed the separation of three tectono-sequences: a) TS-1: *pre-rift tectono-sequence* is the Norian age at the top, characterized by non-marine interbedded sandstones, siltstones, claystones. b) TS-2: *a syn-rift tectono-sequence* from Rhaetian at the base to Valanginian in the western flank of the EP and c) TS-3: *a post-rift tectono-sequence* is defined from Early Cretaceous to the present day, which is characterized by siliciclastic sedimentation above syn-rift sequence, but changing to calcareous sedimentation after Cenomanian. Four sedimentary stages were identified in the post-rift sequence: (1) *The Early Cretaceous,* which is characterized by siliciclastic sedimentation with the predominance of mounded contourite drifts, probably related to the onset of the Greater Indian break-up and creation of an embryonic S-N ocean gateway. 2) *The Late Cretaceous*, characterized by calcareous sedimentation and dominant contouritic deposition, forming a diverse set of depositional and erosional features (plastered, mounded & fault-controlled drift). 3) *The Paleogene*, dominated by downslope gravitational (turbidites and mass-transport) processes at the slope of the basin and intermittent contourites deposits; and 4) *Miocene to Recent deposition,* mainly characterized by large mass-transport deposits towards Kangaroo Trough. However, plastered and mounded features dominated west and central areas of the EP. This spatial and temporal distribution of contourite drifts shows dynamic bottom-currents flowing after Early Cretaceous, linking tectonic events with palaeoceanographic changes that punctuated the deep- water sedimentary evolution of the NW Shelf, Australia.

Sedimentological characteristics and evolution of the deep-water system in the Porcupine Basin: conceptual and economic implications.

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The Porcupine basin is an extensive north-south trending Mesozoic Basin situated on the Irish Atlantic margin, NW Europe). This extensive basin is the result of three extensive phases subsequently by three phases of thermal subsidence. The dominant phases occurred during the Permo-Triassic, Mid-Late Jurassic and Early-Late Jurassic, followed by phases of subsidence in Hettangian-Aalenian, Early Cretaceous (Berriasian-Aptian) and finally in the Late Cretaceous-Pliocene. The basin is comprised of Carboniferous to Permian basement, predominantly Jurassic syn-rift and Cenozoic post-rift sequences. Dominant Jurassic and Cretaceous extensional faulting is followed by further rifting and subsidence within the Cenozoic succession. The Porcupine Basin is divided into North and South, with a Median Volcanic Ridge developed in the Cretaceous dominating the southern sector and is characterised by deep-marine condition and water depths. The Mesozoic sedimentary infill is up to 10 km thicker in the southern sector than in the north. Dominant gravitational deposits have been established in the Cenozoic throughout the Basin, and dominant contourite drifts throughout the Cretaceous, and into the Paleogene and Neogene, developed in response to bottom current activity. The aims of this project are to determine the evolution of the Porcupine Basin with a special focus on the characterisation of the deep-water systems, for evaluating the interplay of time on gravitational vs contourite deposits by using extensive and regional 2D and 3D seismic data and well data. Moreover, the conceptual implications on the sedimentary stacking pattern on continental margins sedimentary stacking patterns will be evaluated and its economic implications on hydrocarbon exploration discussed.

OrangeS and Phenoms: deconstructing a Cretaceous meandering channel in southern Alberta

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Three dimensional outcrops of the Campanian Upper Oldman Formation, exposed in badland topography in Dinosaur Provincial Park, in central Alberta, reveal a striking sandbody that extends over several square kilometres. The sandbody is approximately 4 metres in thickness and is a dull orange colour, which provides a striking contrast to the generally grey terrestrial deposits.

The basal portion of the channel comprises fine grained, well sorted sand with abundant unionid (freshwater) bivalves preserved as original shell material or as siderite steinkerns. Rare extraformational clasts have also been recorded. These are overlain by a metre of sand with fugichnia, where the bivalves burrowed upward through the sediment. The orange hued succession is capped by around 2 m of dipping inclined heterolithic sediments (IHS) comprising thin centimetre to decimetre interbeds of siltstone and mudstone.

The succession of orange sedimentary beds is interpreted as having been deposited by a meandering channel. The unionids and their ichnological signature suggest relative rapid deposition of the basal channel sands. The excellent exposure has enabled the individual meander bends to be mapped out over at least 4 km^2, bounded by incision relating to channels of the overlying Dinosaur Park Formation. The size and character of the mapped meander belt can be compared to a previous, similar study undertaken on a meander belt exposed in the overlying Formation.

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Lateral variation of submarine landslide frontal emplacement: a case study from Makassar Strait, offshore Indonesia

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Frontally-confined submarine landslides (hereafter termed 'slides') are generally characterised by a ramp that separates them from undeformed, pre-existing strata. In contrast, frontally-emergent slides are marked by deposits basinward of their frontal ramp. Although the general seismic expression and structure of both types of slides are well-known, the processes occurring in the contractional domain remains poorly understood. This is important because it governs both the type of slide that develops and its potential geohazard. We here present a case study of the Mandar Slide (Makassar Strait), which is a recent slide located in 2000 m of water, just below the present-day seabed. The study is based on exceptionally high-quality 3D seismic reflection data, which enable characterisation of the lateral variability within, and at the frontal margin of, the slide's contractional domain. Results enable the geological factors governing both types of slides to be inferred. The Mandar Slide covers an area of at least 118 km^2, with an estimated minimum volume of 11 km^3. The slide's proximal domain is dominated by megaclast-bearing debrite, whereas its contractional domain mainly displays imbricate forethrusts and backthrusts that define pop-up blocks. The slide's map-view geometry is radial, with pop-up blocks trending E-W (90^o) in the south and trending N-S to NE-SW (0^o-20^o) in the west. The slide is bound by E-W trending erosional lateral margins, it was sourced from the north-east and transported towards the south-west. The slide is the thickest (c. 200 m) in its axis and thins laterally to c. 70 m. The southern end of the slide is dominated by folded semi-continuous reflections bound by forethrusts and backthrusts. Where thickest, the slide is frontally-confined and thrusts are spaced c. 400 m apart. An unusual zone of high strain is located beyond the frontal margin of the slide, which may record distributed shear in the substrate ahead of the basinward-propagating slide. The south-west part of the contractional domain is dominated by partially-disaggregated materials and a progressively shallowing basal-shear surface (BSS). The shallow depth of the BSS allowed the slide to emerge from the frontal wall; hence, slide-related material ran out a short distance (c. 500 m) above the contemporaneous seabed. The western part of the slide is also frontally-confined but is here dominated by partially disaggregated strata and more closely-spaced thrusts (c. 100 m). The slide is confined here despite being at its thinnest, possibly due to insufficient energy to override the frontal wall. We interpret that lateral variations in the degree of frontal confinement of the slide is dictated by the depth of the basal shear surface, with a shallower BSS making it possible for the slide to emerge from its frontal wall. In addition, thickness of the failed mass appears to influence the formation of compressional structures, with more closely-spaced thrusts are located where the slide is thinnest. Quantitative strain analysis implies a short translation distance (0.6-1.1 km), equating to a shortening magnitude of 8-14%. This study shows that the frontal geometry of large submarine slides can change laterally, and that the overall geometry and kinematics of such bodies is influenced by deposit thickness (or depth to BSS), even if the mass is translated only a very short distance.

Contourite facies and cyclicity: new update of geostatistical approach

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The contourite depositional systems (CDS) of Gulf of Cadiz show clear bi-gradational patterns of a coarsening-finning upward sequences, ideally of 3-7 layers separated by gradational contacts. Variation in cycle length and complexity are widely recorded within the CDS, both vertically and laterally across various sites. Furthermore, these cycles are locally affected by erosion resulting in sharp or erosional contacts and omission of particular layers.

The present research provides a comprehensive synthesis of cycles at Sites U1386 and U1387 covering the assessment of duration, complexity and frequency of sediment cycles in the CDs of Gulf of Cadiz since the mid-Pleistocene to current.

Between 120 and 134 sediment cycles were measured at Sites U1386 and U1387 within the first 414.92 mbsf. Geostatistical approach is applied to both assess and interpret the cyclicity pattern. Analyses included clustering, autocorrelation, frequency analysis as well as transition probability matrix of Burgess (2016). The latter is designed to express two criteria: (1) Facies succession and (2) stratal thickness. Highest transition probability occurs from mud to silty mud layers and transition from silty mud to mud layers. This indicates the dominance of 3-layer-cycle model (mud – silty mud - mud).

Cross-correlation function showed a strong correlation of Sites U1386 and U1387 with average frequency of 8.66 ky and 12.06 ky respectively. Preliminary studies of Site U1389 showed less significant cyclicity and weak correlation with Sites U1386 and U1387.

Based on cycle frequency at Sites U1386 and U1387, the sediment sequence can be divided into three stages: (1) high-frequency period during the past 500 ky, (2) lower frequency during 500 – 700 ky and (3) high frequency during 800 ky to 900 ky ago.

The CDS of Gulf of Cadiz show a well-established cyclicity with dominant 3-layer-model. The thickness of each cycle is disordered in vertical distribution, while it is closely related to drift evolution stages and the MOW strength fluctuation being driven by major climatic events during the past million years.

A Review of Thin Bedded Pay Determination and Produceability

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This field based study has focussed on late Cretaceous aged reservoir targets located at the head of a large type 1 canyon system which is 3.5 Km wide and 1.5 Km deep. The canyon fill is complex and is dominantly characterised by a randomly filled modified embedded stack.

This study has employed an integrated approach to transcend from the scale of the canyon down to the bed scale though utilising a rich suite of subsurface data including 3D PSDM seismic data, bayesian inversion products, conventional wireline, core data, special core analysis and production data.

Integrated route mean squared amplitude and facies mapping has characterised the inter-canyon channel system as a channel levee complex for which the average thickness of the reservoir interval is 290 Metres within which thin bedded sands have been proven as attractive secondary reservoir targets and succeed in providing an effective means of communication between discrete bodies of massive sands.

A prospective target within the channel levee complex has been identified in the Campanian turbidite sands where the production potential from thin bed sands is likely to be greatest. Within this zone, the dominant style of thin bed inheriting from the proximal levee is the thick-thin beds classified as lithofacies 2 for which thicknesses range between 2 cm and 20 cm, porosities range between 10 % and 16 % and permeability is 680 mD.

Although thin beds are unlikely to contribute significant increases to the effective stock tank oil in place (STOOIP, while in production), thin bedded zones of the reservoir should not be overlooked as evidently there is resource in place that can offer opportunities to increase production value by perforating behind pipe prospects at relatively low cost and may offer opportunities for infill or step out drilling.

The key findings of this study are important in the context of declining production from a field currently deemed as a late life asset and so provide insightful value toward potentially extending the commerciality of this field through informing future business decisions involved with maturing research, well-tests and production strategies.

Ultimately, thin beds are considered an important resource for increasing value late into the natural life of the field.

Seismic reflection data reveal Mesozoic-to-Recent bottom current activity in the Browse Basin, offshore NW Australia

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Contourites are marine sediments deposited by thermohaline-induced, deepwater bottom currents. The presence, direction, and strength of such currents are sensitive to changes in basin geometry, thus the distribution, geometry, and size of their related deposits provide a potentially rich archive of basin evolution. To date, however, relatively few studies have assessed the utility of ancient contourites as 'tape recorders' of long-term basin evolution, especially on the NW Shelf of Australia, where several major thermohaline currents interact along a tectonically active margin. Here we use extensive (75,000 km^2) 2D and 3D seismic reflection datasets from the Browse Basin to study the interaction between marine currents and tectonics. These data reveal the basin contains five main Palaeocene-to-Miocene and Recent seismic-sequences. The lowest sequence (S1) contains continuous to semi-continuous, low-to-moderate amplitude reflections, whereas the overlying sequence (S2) is composed of two sub-units; (i) a lower sub-unit composed of continuous reflection and, we infer, well-stratified deposits; and (ii) an upper units characterised by discontinuous, low-amplitude reflections that perhaps suggest higher-energy conditions and more seabed reworking by bottom currents. S3 contains large (400 ms TWT high by 10 km long wide by 5 km long) clinoforms that are intensely gullied. These clinoforms may document progradation of the basin margin or giant bedforms formed by bottom currents. S4 also contains up to 300 ms TWT high, steeply-dipping clinoforms. The shallowest sequence (S5) extends up to the seabed and contains abundant evidence for locally deep (up to 200 - 300 ms TWT by a few hundred metres wide) erosion, and the formation of contourite bedforms and related scours. Our preliminary analysis indicates the Browse Basin is an ideal location to study the deposits related to ocean bottom currents. 2D seismic imaging has allowed us to map the regional distribution of the main mega-sequences, providing insights into the geometry and scale of some of the main depositional elements and related erosional features; future analysis of 3D seismic reflection volumes will us to refine our interpretations and results.

Backwater Hydraulic Geometry of Lowland Deltas

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Deltas, as one of the most populated and most productive regions in the world, are facing multiple threats from direct anthropogenic-caused stressors (e.g. land subsidence, water extraction, severe drought) and climate change-induced phenomena (e.g. sea-level rise, flooding, increased storm intensity and shoreline erosion). Their low relief combined with subsidence (both naturally- and anthropogenically-induced) makes deltas highly vulnerable to sea-level rise, especially in areas along shorelines and riverbanks. Populations living close to delta riverbanks are more at risk because of how the channels interact with sea-level rise and the innate morphodynamic behaviour that makes them move both laterally and vertically through time. The backwater zone in the lower part of the delta, where the ocean water affects the flow in the channel, has been considered to be a fundamental boundary in the fluvio-deltaic system. The present findings of backwater region see changes in channel geometry, grain size and lateral channel mobility compared to the channels upstream of the tidal influence. The locus of channel avulsion, and associated in-channel sedimentation and erosion, have been related to the tidal limit. This study tests the previous findings, which mainly come from scaled physical models, to the natural system using satellite images from 7 deltas. Measurement was taken to test if the backwater zone impact outstrips the avulsion length (L_A) impact from the Mississippi, Mekong, Nile, Volga, Zambezi, Niger and Rhone deltas. We measured the standard sinuosity index (SI) as an indicator of channel hydraulic conditions, channel width and river long profile from the shoreline up to the point where the river exits its valley utilising freely available Landsat images and Earth digital elevation model (30-m resolution SRTM). Measurements used the oldest images available to reduce the influence of human-made infrastructure along the river. As a highly sensitive value towards bankfull water depth, especially in lowland deltas, backwater length impact falls behind the avulsion length and knickpoint impact in most of the deltas measured. In the region beyond the avulsion node up to the shoreline, the average standard sinuosity index (SI) value increased by 12-26%, and the average channel width decreased by 26-60% in comparison with its upstream fluvial region in river-dominated deltas except in the intensively-engineered Mississippi and Rhone deltas. In contrary, the average channel width increased by 28% downstream, and the average standard SI slightly decreased by 2% in tide-dominated delta type. This significant change of river geometry in the avulsion length region challenges the backwater length as a fundamental boundary in the fluvio-deltaic region. Instead of the backwater length, avulsion length is a fundamental boundary in the change of standard sinuosity index and the river geometry in lowland deltas. The other 111 deltas selected from a different climate and tectonic regions are needed to be measured in detail to understand the avulsion length effect in a variety of climates, catchment sizes and vegetation indices. The impact of avulsion length in the natural system suggests that their significance is likely underestimated in the previous deltaic models and palaeogeographic reconstruction.

Temporal high-resolution recording of land use and fire dynamics from the Iron Age to the Early Middle Ages at Lake Murten

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Impacts of climate and land use as well as synergetic effects on the succession trajectories of Central European vegetation communities are poorly understood due to the lack of high temporal precision and resolution time-series. While archaeological finds help to corroborate and explain prehistoric societal change, these studies are almost never continuous but show gaps in time since settlements have shifted in space and/or their remains may have vanished. Moreover, archaeological studies cannot provide information about the natural environment of prehistoric societies and their impact on the landscape. This lack of knowledge is significant given that a thorough understanding of natural succession trajectories in response to climate and/or human forcing is crucial for developing sound nature conservation, mitigation and management strategies under global change conditions. Here, the palynological and geochemical composition of the annually laminated (varved) sediment record of Lake Murten, Switzerland is examined to reconstruct the agricultural and vegetation dynamics of the Roman Age and adjacent periods (800 BC to 800 AD). Non-destructive core scanning techniques (micro X-ray Fluorescence [µ-XRF] and hyperspectral imagining [HSI]) and the ^{14}C wiggle-matching dating technique will provide the base of the chronological framework (i.e. 10 years). The varved sediments will be analyzed to reconstruct vegetation and land use histories using a multi-proxy analysis of pollen, spores, macrofossils, charcoal and geochemical indicators. These indices will be examined using cross-correlation analyses to investigate synchronisms, diachronisms, leads and lags as well as the climatic and social causes of past agricultural dynamics and land use changes. These results will also be compared to the outputs of the processed-based dynamic vegetation model LandClim. We aim to test three competing climate-societal change scenarios with a focus on the Roman Age to improve our understanding of the underlying mechanisms that prompted observed changes in vegetation composition. A high-precision sedimentary chronology of annual laminations such as those found in Lake Murten for the Roman Age will help elucidate the impact of climate on societal change and the long-term effects of these changes on the natural vegetation, land use, fire, and agricultural yields.

Changes in depositional environments across an arid continental lacustrine system: Insights from the Moenave Formation, western USA.

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Arid lacustrine systems provide a major sink for sediment transportation in arid continental basins. However, the extremely heterogeneous nature of lacustrine margin deposits, as influenced by surrounding depositional environments, makes the distribution of reservoir quality extremely difficult to predict. While the preserved facies associations within each separate environment have been studied in great depth, the relationships between coeval depositional environments has received relatively little attention, despite their potential effect upon reservoir quality and basin-scale fluid migration. This study characterises lake-margin systems at the environmental scale and provides a partial correlation of depositional environments and facies associations across the lake system.

Lacustrine deposits of the Moenave Formation of the Colorado Plateau, USA, are studied, along with lake-marginal contemporaneous aeolian and fluvial sediments. Facies analysis is conducted on sixteen bed-scale sedimentary logs that form an east to west transect through the lacustrine system, and a 4200m^2 terrestrial photogrammetric dataset. The data show the dominance of lacustrine sediments in the west and the interactions between fluvial-aeolian sediments in the east of the study area. This interpretation highlights the lateral discontinuity of facies associations and depositional environments along a lacustrine margin and evidences two potential lacustrine cycles. The results of this study show the inherent complexity in the correlation and spatial juxtaposition of depositional environments, where dissimilar assemblages of depositional environments may be recorded within apparent conformable depositional successions across the lacustrine system. This has implications for the understanding of sandbody connectivity and reservoir quality and distribution in hydrocarbon plays hosted within lacustrine sediments.

Late Cretaceous hybrid (turbidite-contourite) system offshore Argentina: morphology, evolution and paleoceanographic implications

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Mixed or hybrid turbidite-contourite systems are formed by the interaction between down- and along-slope processes. These systems are characterized by a wide range of erosional and depositional features. Globally, several hybrid systems have been recognized in the Cenozoic record, however their identification in the Mesozoic remains rather modest. This issue is further aggravated by a lack of knowledge of the Mesozoic oceanic circulation patterns.

Argentina has one of the largest continental margins in the world, formed during the E-W breakup of Gondwana and diachronous opening of the South Atlantic Ocean, from south to north. This margin is characterized by a remarkable hybrid turbidite-contourite system formed during the Late Cretaceous, which offers a key sedimentary record to understand past bottom-current dynamics and their interaction with turbidity currents. Thus, the objectives of this work are: 1) to identify significant modifications and physiographic features in the Cretaceous sedimentary stacking pattern, 2) to distinguish the factors responsible for the formation and evolution of each feature and 3) to study the relationship with the main regional and paleoceanographic events. This study is based on newly acquired broadband 2D seismic reflection data provided by TGS and established regional well data.

The hybrid system comprises 23 downslope elongated drifts on the lower continental slope and rise. The drifts are characterized by asymmetric mounded morphologies, with smooth aggradational NE sides and steep, eroded SW sides. The drifts are separated by large, individual channels that start at the continental shelf/upper slope and cut through the margin's topography. The interpretation of these results aims to propose a conceptual model for hybrid depositional systems and clarify the role and influence of bottom-current versus turbidity currents.

An Analysis of Facies and Architectural Elements in the Lower Cretaceous Wessex Formation, Wealden Group, Isle of Wight

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Fluvial sequences act as reservoir rocks for some of the world's major oil fields, however, internal lithological complexities present baffles to fluid flow that are challenging to predict in the subsurface. Such baffles include the inclined heterolithic strata laterally accreted onto point bars and the overbank fines that make up the floodplain. These small-scale heterogeneities cannot be resolved in seismic data but geological exposures provide valuable information on these characteristics and provide analogues for sub-surface hydrocarbon reservoirs. Here, we investigate the Wessex Formation, part of the lower Cretaceous Wealden Group, exposed along a NW-SE orientated 1.85 km section in the cliffs between Brook Chine carpark and Chilton Chine on the Isle of Wight. We collected data from twelve localities across the outcrop including field sketches, photographs, logs and facies descriptions. Sixteen facies have been defined. These facies are present across a minimum of four distinct architectural elements. Palaeocurrent measurements from lateral accretion surfaces, bedding planes, primary current lineations and ripples provide an indication of palaeoflow variability. Logs measured from eight localities, two from near Brook Chine carpark and six from closer to Chilton Chine form the basis of two correlation panels. Aerial imagery of the cliff section has been captured using a drone. This data has sufficient resolution such that, when paired with the field data, the large-scale architectural elements are apparent. A cross-section through a point-bar deposit, with the abandoned channel exposed on either side is exposed. Calcretes observed within the channel at the south-eastern margin of the exposure suggest a slow abandonment over thousands of years. Using our data in tandem with the drone footage, we aim to reconstruct the river and its abandonment through facies analysis, correlation of log panels and an examination of the lateral variations across the outcrop.

Contourite features from the northern South China Sea

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The presented case study examines interaction of different oceanographic processes that influence the development of contourite features in the northern South China Sea. The multidisciplinary approach for this case study combines physical oceanographic monitoring, numerical simulation, multibeam echosounding, seismic reflection profiling, and sediment core interpretation. The developed contourite features are depositional (drifts and sediment waves), erosional (channels and moats), and mixed (terraces and irregular depressions). This study indicates that glacial-interglacial variations in the intensity of quasi-steady along-slope regional water circulations (geostrophic current) modulate the long-term development and spatial distribution of large-scale (10–100 km) contourite features (drifts, channels, moats, and terraces). Furthermore, intermittent but energetic oceanographic processes (eddies and internal waves) generate medium- and small-scale features that are superposed on the large-scale features, forming a complex seafloor morphology. Westward to south-westward migrating mesoscale eddies not only enhance erosion and deposition in large-scale contourite features, but also produce medium-scale (1–10 km) irregular bedforms through energy dipping to sub-mesoscale eddies. Mesoscale eddies at large-scale contourite features are found to enhance erosion during glacial periods and deposition during interglacial periods. In addition to that, the evidence suggests that westward-propagating internal solitary waves along the main water mass interfaces and their interaction with topography are responsible for forming coarser-grained sediment waves during glacial periods and finer-grained waves during interglacial periods.

Patterns of erosion and subsidence associated with the mid-Aptian unconformity in the Jeanne d'Arc Basin, offshore Newfoundland.

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Important basin-wide and regional unconformities can form during continental extension and the associated patterns of uplift and erosion can have a significant impact on stratigraphic development and basin in-fill. The Jeanne d'Arc Basin lies 350 km NE of St. John's, Newfoundland and is one of an array of Mesozoic extensional basins developed during the breakup of Pangea. The basins have a complex multiphase history of rifting. This study addresses the development of the mid-Aptian unconformity in the central Jeanne d'Arc Basin and assesses its impact on sedimentation during a time when important unconformities were also developed in adjacent basins, including those on the conjugate margin in western Europe. The stratigraphic interval of interest is bracketed by the mid-Valanginian and the Base Tertiary unconformities and corresponds to the last phase of tectonism to affect the Jeanne d'Arc basin. The B-Marker limestone records flooding of basin during the Valanginian and corresponds to a reduction in fault-controlled subsidence (Tankard et al. 1989). The overlying Barremian strata show evidence of basinward migration of the depocentre to the NE. This supports the interpretation of renewed tectonic uplift of the area at the south-western end of the Jeanne d'Arc Basin related to a feature known as the Avalon Uplift (Jansa and Wade. 1975). This rejuvenated uplift culminated in the Aptian with the development of a major unconformity above a regressive package of strata including shoreface sandstones. Erosional truncation is most evident to the south approaching the Avalon Uplift and over tectonically and salt-influenced ridges that were actively growing during this time. 2D and 3D seismic data are being used to identify and characterize patterns of faulting along with changes in uplift, subsidence, and sedimentation. The dominant fault array identified as active during this time trends NW-SE, supporting interpretations that regional extension had re-orientated and was now NE-SW. Detailed mapping of truncations and stratal relationships above and below the mid Aptian unconformity on the 3D data identifies a broad syncline formed between the Egret Ridge and the Terra Nova Arch, in the axis of which is a prominent sinuous erosional valley. This is funnel shaped and opening to the NNE at the level fluvial sandstones are encountered down-dip in certain wells. Valley formation is interpreted to have been controlled both by the developing syncline and the active faults that cross-it at a high angle. Abrupt thickness variations across faults demonstrate growth during erosion on the unconformity surface and during the transgression that followed unconformity development. Deposition of retrogressively stacked fluvial and marine strata above the unconformity occurred during the Aptian and Albian. The bulk of the faulting terminates prior to widespread deposition of the Petrel limestones.

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Flow Power of Turbidity Currents and Fluvial Rivers

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Turbidity current is a gravity-driven submarine flow in which sediment is fully or partially suspended by its turbulence. Turbidity currents can create huge deposits called submarine fan, which is an analogue of the subaerial river delta system as they both create similar delta-shape geomorphology composed of complex channel-levee systems, but the scale of a submarine fan can be tens to hundreds times larger than a fluvial delta. Notwithstanding, turbidity currents become more diluted by entraining ambient water as well as they seem more easy to dissipate because they are driven by the excess in density of suspended sediments compare with fluvial river where the driving force is the flow itself. Although many attempts have been conducted to explain this paradox by taking into account 'self acceleration' effects, stratification of turbidity current and mixing events along the sinuous channels, none of the numerical models of turbidity current so far succeeded to model satisfactory the turbidity currents at field scale. Excess of density of suspended sediment is one of the driving forces for a turbidity current, so whether the flow is erosional or depositional becomes an important factor when it comes to the sustainability of the current itself. Most of the current numerical models are created on the flow power assumption which is based on the hypothesis that the flow power should be proportional to the work done, in equilibrium flow conditions, to keep sediment in suspension . This hypothesis is verified in fluvial conditions however it has not been proven for turbidity currents due to the lack of measurements in steady-state conditions. Nevertheless, many of the current shallow-water models used the entrainment function that is based on the flow power model. Here we gathered the available dataset of flume experiments of quasi-steady turbidity currents and compared them with the fluvial dataset. As a result, we found that turbidity currents do not follow the fluvial flow power model (Fig. 1). While the fluvial rivers show an almost linear correlation between the flow power and the work done to keep suspended sediment, the turbidity currents show a non-linear correlation. This result indicates that there are some important flow mechanisms we are overlooking that play a significant role in terms of sediment transport and the aim of this study is also to evaluate which are the relevant parameters.

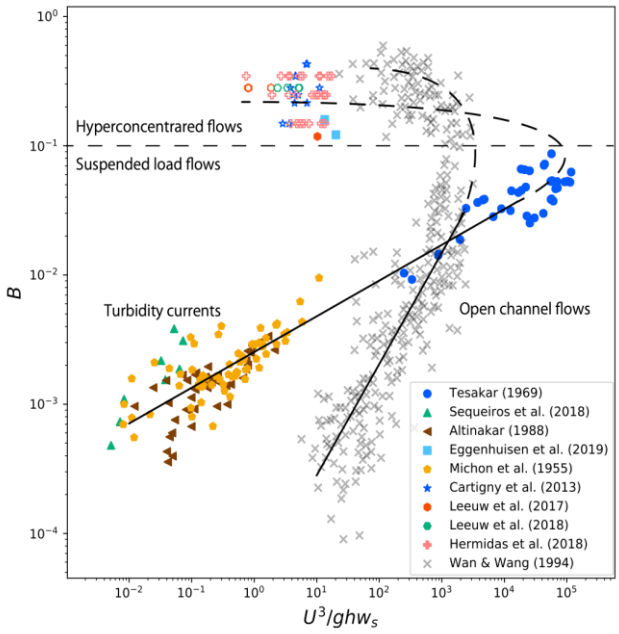

Figure 1. Scatter plot of Flow power against the work done to keep suspended sediment. *U* is the layer averaged flow velocity, *B* is the buoyancy term which is the product between relative density and layer-averaged volumetric sediment concentration, *g* is the gravity acceleration, *h* is the flow depth, and w_s is the settling velocity.
Unfilled marker represents the dataset without the concentration profile and the initial concentration in mixing tank is used instead of the actual concentration. The flow parameters of other points are calculated from the measurement points of velocity and density profile in each paper based on the same method.

Temperate glaciation on a Snowball Earth: Glaciological and palaeogeographic insights from the Cryogenian Yuermeinak Formation of NW China

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Ubiquitous glaciation was the hallmark of the Cryogenian Period (ca. 720–635 Ma), therefore understanding the character, behaviour, extent and configuration of Cryogenian ice bodies is a fundamental requirement in reconstructing climates and environments from the period. Unfortunately, despite abundant evidence for glaciation, there is a strong preservational bias towards basinal glaciogenic sedimentary strata and against subglacial strata. In particular subglacially striated surfaces, owing to their fragile millimetre-thickness, are very rare and represent only a tiny proportion of the global Cryogenian outcrop area. Thermal regime is one of the most important controls of glacial behaviour and subglacially striated surfaces are one of the very few means of determining an ancient temperate thermal regime. In this context we present sedimentological and detrital zircon detail of a fortuitously preserved Cryogenian (Marinoan) outcrop in the Aksu-Wushi area of the Tarim Craton, NW China. The Yuermeinak Formation preserves not only a subglacially striated surface and palaeotopography but also a thin, locally preserved, subglacial tillite. Together these indicate grounded ice. The remaining formation reveals glacial retreat and deposition of predominantly supraglacially-sourced debris within a dynamic, open-water, ice-proximal proglacial environment. A palaeogeographic reconstruction is proposed in which the Aksu-Wushi area developed from a deeper-water basinal environment, without clear evidence for glaciation, during the early Cryogenian, to an area of mountainous uplift with nearby grounded glacial ice, during the latter Cryogenian. Combining detrital zircon data of this study with published data it is further proposed that this development was linked to an active margin setting, either through expansion of an Andean-type mountain range to the north of the study area or flank-uplift of a back-arc basin.

Sedimentary provenance of the Nicobar Fan - Raman spectroscopy heavy mineral analysis reveals more than zircons alone.

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The Nicobar Fan is situated between the Ninety-East Ridge and north west Sumatra within the Indian Ocean. This submarine fan forms part of the larger Bengal–Nicobar Fan that extends southwards from offshore Bangladesh into the Indian Ocean and the sources of sediments shedding into it have key implications for the development of Himalayan uplift, Indian Ocean plate tectonics, and the Asian monsoon.

IODP expedition 362 obtained drill core from the Nicobar Fan offshore north west Sumatra in 2016. Initial stratigraphic logging and U–Pb detrital zircon geochronology indicate that sedimentary deposition increased dramatically in the Mio-Pliocene and was dominantly derived from Greater and Tethyan Himalayan sources with minor input from the Indo-Myanmar Ranges. Our study provides 'big data' heavy mineral analysis using Raman spectroscopy (~40,000 analyses) for a series of Plio-Pleistocene sediments sampled during IODP leg 362. The heavy mineral analyses indicate an abundance of arc, wedge, and ophiolite detrital minerals (epidote, amphibole, Cr spinel) and metastable skarn-associated minerals. Likely source regions for these minerals include the proximal Indo-Myanmar Ranges, Andaman Islands, and Sumatran Arc, instead of the metamorphic assemblages typically indicative of Himalayan sequences. This multi-proxy approach shows that while some of the initial igneous and metamorphic sources of detrital zircons into the Nicobar Fan may be Himalayan in origin, they have likely been recycled through more proximal systems (e.g., Indo-Myanmar Ranges, Andaman Islands, Sumatra Arc). Finally, the study shows the importance of using a multi-proxy big data approach in sedimentary provenance.

New insights into the internal structure of turbidite deposits from physical modelling of relevant erosional and depositional processes.

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Sediment Gravity Flows (SGFs) are the principal agent for the transportation of sediments that are initially stored on the shelf and eventually enter into the deeper parts of sedimentary basins. The most common downslope transportation pathway – and arguably the most important – occurs as a result of gravity acting on a relatively dense sediment-water mixture to produce a near-bed turbulent downslope current, commonly referred to as a 'turbidity current'. These highly complex flows and their seabed deposits have considerable economic importance for oil and gas exploration, with turbidites – the sedimentological deposits from turbidity currents – forming substantial hydrocarbon reservoirs and having significant potential for future carbon sequestration projects. Once deposited, turbidites may undergo considerable reworking as a result of erosion and deposition processes from subsequent SGFs that often lead to complex internal structure and arrangement of sand body connectivity. A better understanding of how turbidity currents interact spatially with erodible sediment substrates, and therefore how this affects preserved sedimentological features of the deposits, should therefore enhance our knowledge and understanding of turbidite formation, crucial for future hydrocarbon recovery and CO2 storage. This research project, therefore, address this current knowledge gap by combining scaled physical modelling, fieldwork, and seafloor studies to elucidate the fundamental behaviour of laterally confined, channelised turbidity currents. The study focuses on the flow dynamics of the current and the resulting sedimentological features produced by the current passing over an erodible bed. It will also investigate the flow and deposit transitions from channelised confinement into unconfined depositional lobes on the basin floor. Of particular interest is the generation and preservation of supercritical bedforms, as well as coalesced long-lived scours, both of which are critical features of Channel-lobe Transition-Zones (CLTZ). This study will, therefore, yield new data on how turbidity currents impact multi-layered sedimentary beds and determine parametric controls on erosion, deposition and bed restructuring processes. Field studies will focus primarily upon the analysis of nested and meandering channelised turbidite outcrops and CLTZ sediments exposed within the Tabernas Basin, southern Spain. These sediments are of particular interest as sand body pinch out, and erosional truncations can produce excellent stratigraphic traps in large petroleum plays, whilst large erosional scours lead to complex arrangements of sand body juxtaposition. In this regard, the project aims to understand the complex internal heterogeneities generated by erosion-deposition processes in evolving slope and CLTZ systems.

Stratigraphic architectures and break-up unconformity system in Zhujiangkou rifted margin during the seafloor spreading of South China Sea

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The lithosphere breakup processes from initial rifting of the crust to the complete rupture of the lithosphere underwent several tectonic evolution stages and resulted in the formation of distinct stratigraphic architectures and associated unconformities accordingly. In this study, a dense grid of seismic profiles tied to industrial borehole data are used to investigate the stratigraphic architecture and unconformity interfaces in the Pearl River Mouth basin of the northern South China Sea margin. Based on sedimentary strata records of the offshore Pearl River as a passive continental margin, there four stages indicated lithospheric breakup process of South China Sea have been identified, i.e. initial crustal rifting, crust detachment, crust disrupt and lithosphere break. A number of unconformity interfaces have been formed accordingly. In order to better reveal the continental break-up processes from basin-filling sequences, we combine these relevant unconformities into an assemblage defined as “break-up unconformity system”. In this termination, some key unconformities include, such as, the “rifting onset unconformity” or “basement unconformity” corresponding to initiation of continental crust rifting, the “continental crust breakup unconformity” corresponding to totally continental crust rifting and subsequent mantle emergency, and the “(lithosphere) breakup unconformity” corresponding to break-up of the whole lithosphere. These interfaces show distinct characteristics in the proximal and distal zones of the passive continental margin.

Our results indicate that distinct stratigraphic architectures with well defined unconformities are formed in the proximal to distal zone of the margin. The syn-rift strata have been constrained by the top of basement unconformity and the lithosphere breakup unconformity. In the proximal domain, multiple episodes of syn-rift strata are characterized by vertical superimposed half-graben or graben type stratigraphic patterns separated by crack-related unconformity. However, in the more distal zones, syn-rift strata composed two distinct intervals separated by detachment-related unconformity, including small-scaled dispersed half-graben or graben at the lower part and large-scaled wide syn-detachment depression at the upper part. Based on these observations we provide an effective method for the correlation of sedimentary strata from the proximal to distal domains of the passive rifted margins during the lithospheric rupture process.

What are the dominant controls on submarine channel evolution? Detailed insights from thirteen years of repeat mapping in Knight Inlet, British Colombia.

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Submarine channels are conduits for sediment-laden flows called turbidity currents, which play a globally important role in the deep sea transport of sediment and organic carbon. Turbidity currents, and the submarine landslides that may trigger them, also pose a hazard to critical coastal and seafloor infrastructure, including hydrocarbon pipelines and seafloor cables that underpin our daily lives. It is therefore important to understand which different processes control sediment transport in submarine channels and how they shape channel evolution over different timescales, in order to better interpret what is ultimately recorded in the depositional record. Until recently, most previous studies of submarine channels were based on scaled-down experiments or analysed deposits from rock outcrops and sediment cores, making uncalibrated inferences about their evolution. Recent advances in seafloor mapping now enable the direct observation of submarine channel evolution at high temporal resolution, and provide the basis to calibrate deposit-based interpretations. Here, we present new high resolution seafloor data from an active submarine channel in Knight Inlet, British Columbia. We present differential bathymetric mapping over a period of 13 years to document a range of different processes that have exerted a variety of influences on the evolution of a dynamic submarine channel system; from river source to a deep-water terminal lobe. The processes documented include river mouth avulsion, delta front collapse, outer bend erosion, localised landslides, bedform migration and knickpoint retrogression. We provide an initial overview of our morphologic analysis and discuss broader implications for the evolution of other submarine channels worldwide.

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