



**Sedimentary  
Research**

# **British Sedimentological Research Group 51st Annual General Meeting**

**UCD School of Geological Sciences  
University College Dublin**

**18<sup>th</sup> - 20<sup>th</sup> December 2012**



## **Programme and Abstracts**

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## **Welcome**

It is our great pleasure to welcome you to Dublin and to the 51<sup>st</sup> annual general meeting of the British Sedimentological Research Group. It is only the second time BSRG has been held outside the UK, and this is the first time University College Dublin - the largest university in Ireland - has hosted it. Normally this time of year an intrepid group of BSRG stalwarts leave Irish shores for the rigours of winter travel - it is wonderful that this year you come to us (the only downside of course is that we have to organise the meeting!). We hope that you enjoy your visit to Dublin and to UCD, find the technical programme stimulating and the social events equally so!

This year, the meeting will share a venue back-to-back with the annual meeting of the Palaeontological Association (PalAss). To acknowledge this we will jointly host a guest lecture by Prof. Andy Knoll followed by the BSRG icebreaker reception on the evening of the 18th December. Other programme highlights include a technical session hosted by the Clay Minerals Group of the Mineralogical Society of GB & Ireland ("The Glory of Mud"), the conference dinner at the Old Jameson Distillery in the city centre, a field trip to north Dublin and a core workshop (as well of course as the delights of Temple Bar and other attractions!).

The meeting has received generous financial support from a number of organisations (see below) and this has helped keep the registration costs down and meant that we are able to run what we hope will be an exciting technical and social programme. Support from sponsors has also enabled us to organise a series of keynote speakers who will present overviews on a range of topical sedimentological issues.

Céad míle fáilte go Baile Átha Cliath.

The Organising Committee  
UCD School of Geological Sciences  
University College Dublin  
Belfield, Dublin 4.

## **Acknowledgements**

We are extremely grateful for financial support from BG Group, BP, ExxonMobil, the Geological Survey of Ireland (GSI), the Geological Survey of Northern Ireland (GSNI), the National Centre for Isotope Geochemistry (NCIG), NefTex, Lukoil, Statoil, Total and Tullow Oil.

The organisation of this conference was greatly facilitated by the help and logistical support offered by the local PalAss organising committee (Patrick Orr and Aoife Braiden) and the UCD Events Office. The assistance of staff and postgraduate students from the UCD School of Geological Sciences is also gratefully acknowledged. We also thank Prof. John Graham (TCD) for leading the field trip to north Dublin. Dr Jaco Baas, in his role as BSRG treasurer, is thanked for assisting with the transfer of sponsorship funds. Dr Marco Patacci is acknowledged for his help with the website. We would also like to thank recent convenors for general advice and support.



## Venue

The meeting is being held at the Belfield campus of University College Dublin. UCD Belfield is located in the southern Dublin suburbs, some 5 kilometres south-east of the city centre (see maps below).

Registration (available from 4pm on Tuesday 18<sup>th</sup> December), talks and poster sessions will be held on the ground floor of the Health Sciences building (see Map C). A detailed schedule is provided below. Talks will take place in lecture theatres B004, C004 and C005.

For those arriving on campus first thing in the morning, hot drinks and food are available from the Students Union building or from Pulse café (in the Health Sciences Building).

## Transport in Dublin

Buses and taxis offer the best means of travelling to and from UCD campus. Taxis are plentiful in the city and can be found at designated taxi ranks or simply hailed from the street – they offer a more expensive means of getting around. Public transport options are detailed below. For your convenience we include three maps – one of the UCD campus (Map C), one of the City Centre (Map B), highlighting useful bus stops, and one of the wider south Dublin area showing the location of the conference venue (Map A).

Please note that the Rambler bus ticket, given to all delegates as part of their registration pack, will be valid *only* on Dublin Bus services. This includes the Airlink service to the airport (route 747), *but not Aircoach services*. To use your rambler ticket, simply board the bus and wave the card in front of the “validator” box, immediately to your right and opposite the driver. **Please also note that during rush hour, it can take in excess of 45 minutes to get from the city centre to the campus and vice-versa.**

### ***From the airport direct to UCD:***

The best way to get from the airport directly to UCD is to take the Aircoach ([www.aircoach.ie](http://www.aircoach.ie)). This service operates from both Terminal 1 and 2. At Terminal 1, turn left immediately as you exit the terminal building. At Terminal 2, continue along the same level following the signs for buses and coaches, cross the footbridge, and then exit down the escalator on the left hand side. The service runs approximately every 15 minutes at peak times. There are several routes - the Dublin Airport to Leopardstown route passes by UCD adjacent to the main entrance (see Maps A, C). From here, cross the flyover to the front gates of campus.

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Detailed schedules can be found on <http://www.dublinbus.ie/en/Your-Journey1/Timetables/All-Timetables>

***From UCD to the City Centre:***

The best place to catch buses to the City Centre is from the bus stop near the UCD main entrance (Map C). This stop is regularly served until ~11pm.

***From UCD to the airport:***

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## **Clare Core Workshop**

For those who have pre-registered, the Clare Core Workshop will start with tea and coffee from 9.30 to 10.00am on Tuesday 18<sup>th</sup> November. This will be in the foyer of the UCD School of Geological Sciences on the ground floor of the Science West building (see Map C). The workshop will run all day with a break for lunch which will be provided in the foyer again. The core display will take place in Room G01. Follow the signs along the corridor. Introductory talks will provide context for the recent behind-outcrop coring program in Co. Clare and then participants will be split into smaller groups to examine different parts of the

deep-water Ross Sandstone Fm in rotation. The workshop will end with beers and soft drinks over the core and a chance to discuss some of the wider implications and comparisons with analogous sections elsewhere (bring along a Powerpoint slide or two if you would like to contribute briefly to this wider discussion). The workshop will wrap up in time for the joint PalAss-BSRG Guest lecture by Prof. Andy Knoll at 6.00pm (see below).

### **Field trip to north Dublin coastal sections**

John Graham (Trinity College Dublin) will lead a field trip departing from central Dublin on Tuesday 18<sup>th</sup> December. For those who have registered, a coach will leave from the coach stop at Nassau Street on the south side of Trinity College in the City Centre. The coach is due to depart at 8.30am sharp to make best use of the limited daylight this time of year and to avail of low tide. Please assemble in plenty of time (8.15am). Bring water proofs, stout boots and warm clothes. A packed lunch and soft drinks will be provided. The trip will visit Skerries and Rush on the north Dublin coast before returning to central Dublin at about 4.00pm. This will allow time to change out of field gear and make your way out to UCD for BSRG registration, Prof. Andy Knoll's joint PalAss-BSRG lecture and of course the icebreaker reception.

### **Joint PalAss-BSRG Guest Lecture**

This joint lecture supported by the UCD Earth Institute will be delivered by Prof. Andy Knoll at 6.00 pm on Tuesday 18<sup>th</sup> December in B004 of the Health Science Building (see Map C). The title of his talk is "Systems Paleobiology: Physiology as the link between biological and environmental history".

Prof. Knoll is the Fisher Professor of Natural History and a Professor of Earth and Planetary Sciences at Harvard University. He is a member of the Organismic and Evolutionary Biology and Earth and Planetary Sciences faculty at Harvard University and the National Academy of Sciences.

Andy has expertise in diverse research areas including paleobotany, the planetary evolution of Mars, and geobiology. The early evolution of life, Precambrian environmental history, and, especially, the interconnections between the two remain one of his primary areas of interest. Past and current projects also include investigations of problems throughout Phanerozoic Earth history. His talk draws on the interconnectedness of geosphere and biosphere, both now and in the past, and thus how the history of life is best interpreted within the context of an understanding of Earth's environmental history as revealed by the sedimentary record.



*A BSRG Ice Breaker reception will be held in the Student Union Concourse (see Map C) on Tuesday 18<sup>th</sup> December following the guest lecture.*

### **Conference Dinner**

The conference dinner will be held on the evening of the 19th December at the Old Jameson Distillery, Smithfield, Dublin 7. Located on the site of the original Jameson Distillery, our visit will include a drink on arrival, a tour, followed by a 3 course meal, drinks and entertainment. The venue is fully licensed and there will be ample opportunity to sample the renowned produce!

We recommend you use public transport to get to the conference dinner venue. You should aim to arrive at 7pm, which will mean leaving the conference no later than 6pm. The 39a and 145 buses will take you very close to the Old Jameson Distillery (see map B, below).

### **Fancy a drink?**

For those of you lodging in the city centre and finding yourselves thirsty, the following hostelries might be worth a visit:

**The Stags Head**, 1 Dame Court, Dublin 2  
(<http://www.louisfitzgerald.com/stagshead>)

**The Long Hall**, 51 South Great Georges Street, Dublin 2  
(<http://dublintown.ie/bar/the-long-hall/>)

**The Porterhouse**, 16-18 Parliament Street, Dublin 2  
(<http://www.porterhousebrewco.com/bars-dublin-temple.php>)

**Keoghs**, 9 South Anne's Street, Dublin 2  
(<http://www.louisfitzgerald.com/kehoes>)

**The Hairy Lemon**, Stephen Street, Dublin 2  
(<http://www.thehairylemon.ie/>)

**The Market Bar**, 14a Fade St, Dublin 2  
(<http://www.marketbar.ie/>)

**The Palace Bar**, Fleet St, Dublin 2  
(<http://www.thepalacebardublin.com/>)

**Tuesday 18th December**

8.30	<p><b>Field Trip: A Mississippian basin margin on the North Dublin Coast (Leader: Prof. John Graham, Trinity College Dublin)</b></p> <p>Participants will meet in the City Centre, adjacent to Trinity College Dublin. Lunch will be provided. The field excursion is expected to finish at 16.00</p>
9.30	<p><b>Core Workshop: Behind-Outcrop Cores from the Ross Formation, western Ireland</b></p> <p>The workshop takes place in the School of Geological Sciences. Tea/coffee and lunch will be provided during the day. The workshop will finish at 16.00</p>
16.00 - onwards	<p><b>Registration desk opens in the concourse area, Health Sciences Building</b></p> <p>Posters can be affixed and talks uploaded during this time</p>
18.15	<p><b>Joint BSRG - PalAss Guest lecture: "Systems Paleobiology: Physiology as the link between biological and environmental history"</b></p> <p>Prof. Andy Knoll (Fisher Professor of Natural History, Harvard University)</p> <p><i>Supported by the UCD Earth Institute, the Geological Survey of Ireland and the Geological Survey of Northern Ireland.</i></p> <p>Room B004 in the Health Sciences Building.</p>
19.15 - 22.00	<p><b>Icebreaker reception</b></p> <p>Students Union Concourse</p>

## Wednesday 19th December AM

Registration desk open from 8.00, Concourse Area, Health Sciences Building

	Room B004; Health Sciences Building					
08:50-09:00	Welcome address					
09:00-09:15	KEYNOTE: Extreme sedimentology: Emplacement of the Stac Fada impact ejecta deposit in the Mesoproterozoic of NW Scotland (Simms)					
09:15-09:30						
09:30-09:45						
09:45-10:00	Global distribution of modern sedimentary basins (Nyberg et al.)					
10:00-10:15	Avalanche! The sedimentology of snow and ice (Noad)					
10:15-10:30	Rise of the machines: novel insights into marine sedimentary processes using Autonomous Underwater Vehicles (Wynn)					
	The Chalk Sea: a dynamic environment! (Gale et al.)					
10:30-10:45	Plenary (Chair: P. Shannon)			Room C005; Health Sciences Building		coffee & posters
10:45-11:00						
	Room C004; Health Sciences Building					
11:00-11:15	KEYNOTE: Experimental turbidity currents as guides for process interpretation from turbidites in the geological record (Eggenhuisen)			(Chair: C. Jackson)		The Permian 'glass ramp': sedimentology and sequence stratigraphy of the Kapp Staroslin Formation in Bellsund, Spitsberg (Collins et al.)
11:15-11:30						Comparative facies analysis of the sigmoidal and oblique foreset deposits of Gilbert-type deltas: implications for the recognition of short-term relative sea-level changes (Gobo et al.)
11:30-11:45						Dewatering of argillaceous sands (Kane et al.)
11:45-12:00						Driven around the bend: spatial evolution and controls on the orientation of helical bend flow in a natural submarine gravity current (Sumner et al.)
12:00-12:15	Turbidity current flow equilibration to a sinuous channel form (Hunter et al)					
12:15-12:30	Morphodynamics and sedimentary structures of bedforms under supercritical flow conditions: new insights from flume experiments (Cartigny et al.)					
12:30-12:45						lunch
12:45-13:00						
13:00-13:15						
13:15-13:30						

## Wednesday 19th December PM

Room C004; Health Sciences Building		Room C005; Health Sciences Building	
13:30-13:45	<div>Deep-Water Sedimentation: Processes and Products I</div> <div>(Chair: I. Kane)</div>	<div>Aeolian, Fluvial and Lacustrine Sedimentation I</div> <div>(Chair: S. Davies)</div>	<div>KEYNOTE: Exceptional preservation of aeolian successions (Mountney)</div>
13:45-14:00			
14:00-14:15			
14:15-14:30			
14:30-14:45			
14:45-15:00			
15:00-15:15			
15:15-15:30	coffee & posters		
15:30-15:45			
Room C004; Health Sciences Building			
15:45-16:00	KEYNOTE: Source to Sink observations for the deep water Miocene of the North-Central Gulf of Mexico (Pulham & Elliott); (Chair: P. Haughton)		
16:00-16:15			
16:15-16:30	AGM & Awards Presentation		
16:30-16:45	Poster Session (in concourse)		
16:45-17:00			
17:00-17:15			
17:15-17:30			
19:00	Conference dinner at the Old Jameson Distillery		
This will include a brief tour of the distillery. Delegates can use public transport to get to the venue (see detailed instructions on location map B). Finishes 22.30			



## Thursday 20th December AM

Registration desk open from 8.00, Concourse Area, Health Sciences Building

Room C004; Health Sciences Building		Room C005; Health Sciences Building	
09:00-09:15	Basal erosion and mudclast character and distribution in hybrid beds deposited in a ponded minibasin (Castagnola Fm, NW Italy) (Patacci et al.)	Aeolian, Fluvial and Lacustrine Sediments II (Chair: D. Leheron)	Sedimentation in large igneous provinces - the Columbia River Basalt Province (Washington State, USA) as a case study (Ebinghaus et al.)
09:15-09:30	Links between bed type, flow processes and submarine slope channel filling – evidence from a sub-surface example (Stokes et al.)		Gold placer dynamics and paleoclimate change in the Yukon (Lowther et al.)
09:30-09:45	From core to cliff - new insight into the evolution of the Ross Formation from behind-outcrop boreholes in the Clare Basin, western Ireland (Pierce et al.)		Characterisation of the zone of interaction between proximal alluvial fan sedimentation and contemporaneous distal deposition in continental basins (Gough et al.)
09:45-10:00	Influence of subtle bathymetry on flow process and anatomy of submarine lobes: an example from unit A, Laingsburg Formation, Karoo Basin, South Africa (Spychala et al.)		Anatomy of a fluvial avulsion complex: an example from the Lower Beaufort Group, South Africa (Gulliford et al.)
10:00-10:15	Influence of large-scale remobilisations on deep-water reservoir architecture: lessons from Briannia Field, North Sea (Teloni et al.)		Sedimentological characteristics of Upper Shendi Formation outcrops, Musawarat area, Central Sudan (Bashri)
10:15-10:30	Channel-like features created by erosive submarine debris flows: Field evidence from the Middle Eocene Ainsa Basin, Spanish Pyrenees (Dakin et al.)		A comparative study for assessing the influence of controls on large-scale fluvial architecture (Colombero et al.)
10:30-10:45			Analysis of fine-grained floodplain deposits as a tool to interpret autogenic controls on floodplain sedimentation: Cretaceous Blackhawk Formation, Wasatch Plateau, Utah, U.S.A. (Flood, Y. & Hampson)
10:45-11:00		coffee & posters	
Glory of Mud (CMG/BSRG)		Shoreline to Shelf II (Chair: G. Hampson)	
11:00-11:15	KEYNOTE: "Intrabed" turbidity currents: A new type of sediment gravity flow associated with soft muddy substrates (Baas et al.)	Carbonates, ammonites and the fate of aragonite: a new perspective from the Lower Jurassic of Lyme Regis (Jordan et al.)	
11:15-11:30		Development of decimetre-scale clastic intrusions in a shallow marine sedimentary succession; a field-based case study from the Matulla Fm (Upper Cretaceous), Suez Rift, Egypt (Jillings et al.)	
11:30-11:45		Dimensions, distribution and controls on depositional elements in tide-dominated deposits: The Early Jurassic Neill Klinter-Group of East Greenland (Eide et al.)	
11:45-12:00		Far-field effects of tidal marine energy converters on sediment distribution in the Pentland Firth (Marin-Short et al.)	
12:00-12:15		Hydrodynamic modeling of sediment transport and bedform formation on the North Irish Shelf (Evans et al.)	
12:15-12:30	Sedimentology of Upper Eocene red beds in Northwest China (van Cappelle et al.)	Interaction between clinoform trajectory, sedimentary process regime and timing of sediment delivery of an intrashelf clinothem succession, offshore New Jersey (Poyatos-Moré et al.)	
12:30-12:45		lunch	
12:45-13:00			
13:00-13:15			
13:15-13:30			

## Thursday 20th December PM

Room C004; Health Sciences Building		Room C005; Health Sciences Building	
13:30-13:45	External Controls on Sedimentation (Chair: G. Nichol)	Role of Eocene large-scale debris-flows (olistostromes) in the closure of S Neothetys in the E Mediterranean region (Robertson et al.)	Glacial Environments - Ancient and Modern (Chair: S. McCarron)
13:45-14:00		Basement-controlled slope instability, Rockall Bank Slide Complex, NE Atlantic (Georgiopoulou et al.)	
14:00-14:15		External controls on the evolution of a prograding shelf margin: the Craven Basin, UK (Bijlkerk et al.)	
14:15-14:30		Response of fluvial style and preservation of stratigraphic architecture to salt-wall mini-basin development and climatic regime (Barnham & Mountney)	
14:30-14:45		Sedimentary evidence of the Pliocene-Quaternary uplift of the Kyrenia Range, Northern Cyprus (Palamakumbura et al.)	
14:45-15:00		Do N12°E deep-crustal lineaments in the north of Ireland play a part in basin siting, preservation and magmatism? (Cooper)	
15:00-15:15			
15:15-15:30			coffee & posters
Room C004; Health Sciences Building		Room C004; Health Sciences Building	
15:30-15:45	Reservoir Characterisation (Chair: D. Hodgson)	Investigating Environmental Impacts of Offshore CO <sub>2</sub> Storage (Carruthers et al)	
15:45-16:00		CO <sub>2</sub> Enhanced Oil Recovery – A climate mitigation technology? (Stewart et al.)	
16:00-16:15		Use of legacy data from hydrocarbon exploration to appraise a potential CO <sub>2</sub> store (Wilkinson et al.)	
16:15-16:30		Influence of silica diagenesis on physical rock properties and seal development: insights from 3D seismic reflection and well data from the Norwegian Margin (Wrona et al.)	
16:30-16:45		Modelling sandstone connectivity in deep-water lobes (Zhang et al.)	

POSTERS

Fluvial, Aeolian and Lacustrine Sedimentation	
P1	Cretaceous sedimentation in the Barmer Basin, India: An ephemeral fluvial system? (Beaumont et al.)
P2	Stratigraphic evolution of a low-gradient, mixed-load fluvial system: Huesca Fluvial Fan, Ebro Basin, Spain (Burnham et al.)
P3	A database approach to fluvial facies models: example results from the Lower Jurassic Kayenta Fm. (SE Utah) (Colombera et al.)
P4	Determining the palaeodrainage of the Nile river from a provenance study of the Nile delta cone sediments: an on-going geochemical study (Edwards et al.)
P5	Source to sink analysis of the Pleistocene Wasatch catchment and eastern Great Basin (Hovda et al.)
P6	Facies architecture of the Triassic Wolfville-Blomidon Transition, Bay of Fundy, Nova Scotia, Canada: Implications for reservoir characterization and modelling (Jonathan et al.)
P7	Deciphering sedimentary recycling via multiproxy in situ analyses (Lancaster et al.)
P8	High-resolution coal correlation of the Walloon Coal Measures, Surat Basin, eastern Australia (Morris & Martin)
P9	Fluvial point bar architecture produced by ephemeral flows in a semi-arid climate, lower Beaufort Group (Permian), Karoo Basin, South Africa (Wilson et al.)
Shoreline to Shelf	
P10	The Permian 'glass ramp': New insights from Bellsund, Spitsbergen (Collins et al.)
P11	Process response to Holocene transgression: an integrated dataset from the Dogger Bank, North Sea (Eichenauer et al.)
P12	Controls on intra-parasequence facies development in shallow-marine shoreface systems: Results from a quantitative heli-lidar study in the Book Cliffs and Wasatch Plateau, Utah, USA (Eide et al.)
P13	Rhythmic vs episodic: the stratigraphic record of tidal and fluvial interactions in marginal marine, non channelized setting (Lajas Formation, Neuquén Basin, Argentina) (Gugliotta et al.)
P14	Linkage between the geometry and evolution of clinoforms, and slope gullies, Dampier Basin, North West Shelf, Australia (Pankhania)
P15	Sedimentology of fluvial and tidally-influenced channel-to-overbank transitions in low- and high-accommodation settings: Neslen Formation, Utah, USA (Shiers et al.)
P16	Some (preliminary) observations and thoughts on the Favignana Calcarene (Sicily, Italy) (Slootman et al.)
P17	Stratigraphic architecture of a back-filled incised-valley system; Pennsylvanian–Permian lower Cutler beds, Utah, USA (Wakefield & Mountney)
Deep-water sedimentation: processes and products	
P18	The sedimentology, stratigraphy and provenance of the Gwna mélange deposits of the Monian Supergroup of north-west Wales and Anglesey, UK (Dartnall et al.)
P19	The CUMECS project, Central Mediterranean Sea: An investigation of canyon formation and processes in sediment-undersupplied margins (Georgiopoulou et al.)
P20	Palaeo-oxicity changes across the Rhuddanian-Aeronian boundary (Silurian) in the Cwmere Formation, Rheidol Gorge, Wales (Russell et al.)
External Controls on Sedimentation	
P21	Triassic Evolution of East Greenland (Andrews)
P22	Upper Devonian elemental chemostratigraphy of the Lennard Shelf, Canning Basin, Western Australia – Indications of global-to-local environmental changes & utilization as a correlation tool (Caulfield-Kerney et al.)
P23	Palaeohydrology of a rapid climate change event at the Palaeocene-Eocene boundary (Dawson et al.)
P24	The enigmatic evaporites of the Aptian Ariri Formation, Santos Basin, Offshore Brazil: new insights from 3D seismic and well logs analysis (Rodríguez et al.)
P25	The impact of early land plants on continental sedimentation: the Old Red Sandstone in the Midland Valley (Scotland, UK) (Santos et al.)
Glacial Environments - Ancient and Modern	
P26	Seismic images of glaciogenic sedimentation and erosion offshore Norway (Huuse & Huuse)
P27	Pleistocene glaciations of the North Sea using basin wide 3D Seismic data (Lamb et al.)
Reservoir Characterisation	
P28	Clastic injection surface features as an indication of emplacement processes and conditions: an outcrop study from the Laingsburg area, South Africa (Cobain et al.)
P29	The use of noble gases as effective early warning tracers of CO <sub>2</sub> migration in engineered CO <sub>2</sub> storage sites (Kilgallon et al.)
P30	Modelling facies distributions and heterogeneity in aeolian reservoir successions (Romain et al.)
Experimental and Process Sedimentology	
P31	Using climatic insights to guide stochastic process-based modelling of a valley filling fluvial sequence in the Murray-Darling Basin, Australia (Comunian et al.)
P32	Adaptive finite element simulations of sediment laden density currents (Parkinson et al.)

**1km**

**Area of Map B**

**Main entrance**

**MAP A**

### Area of Map B

## Main entrance

UCD  
Belfield  
Campus

# MAP A

The best way to get from the airport directly to UCD is to take the Aircoach ([www.aircoach.ie](http://www.aircoach.ie)). This service operates from both Terminal 1 and 2. At Terminal 1, turn left immediately as you exit the terminal building. At Terminal 2, continue along the same level following the signs for buses and coaches, cross the footbridge, and then exit down the escalator on the left hand side. The service runs approximately every 15 minutes at peak times. There are several routes - the Dublin Airport to Leopardstown route passes by UCD adjacent to the main entrance (see Map A, C). From here, cross the flyover to the front gates of campus.

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● Buses to UCD

● Buses from UCD

◆ 747 Airlink to Airport

1. Generator Hostel

2. Maldron Smithfield

3. Abigail's Hostel

4. Jurys' Inn,  
Christchurch

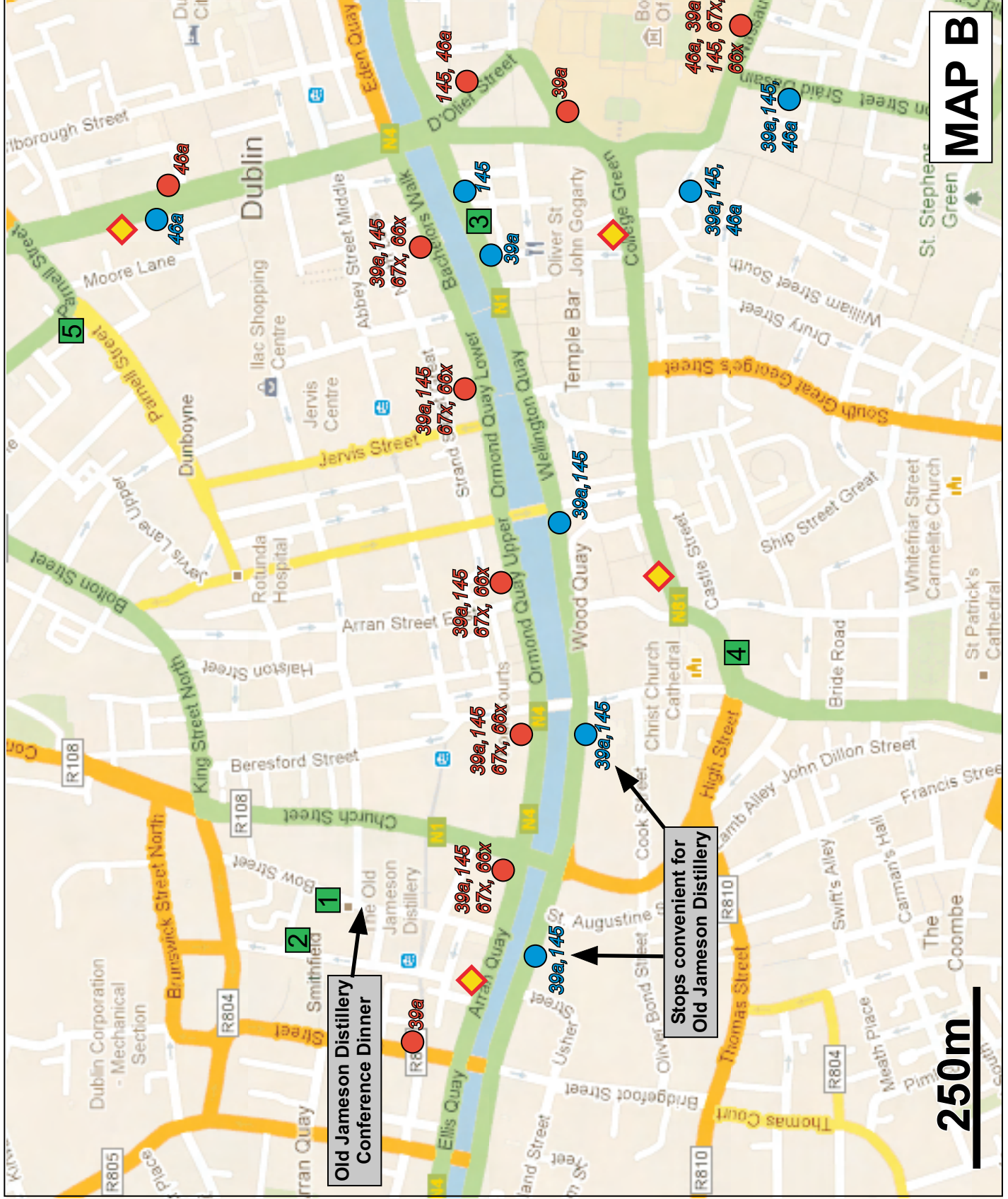
5. Jurys' Inn,  
Parnell St.\*

6. Jurys' Inn,  
Customs House\*

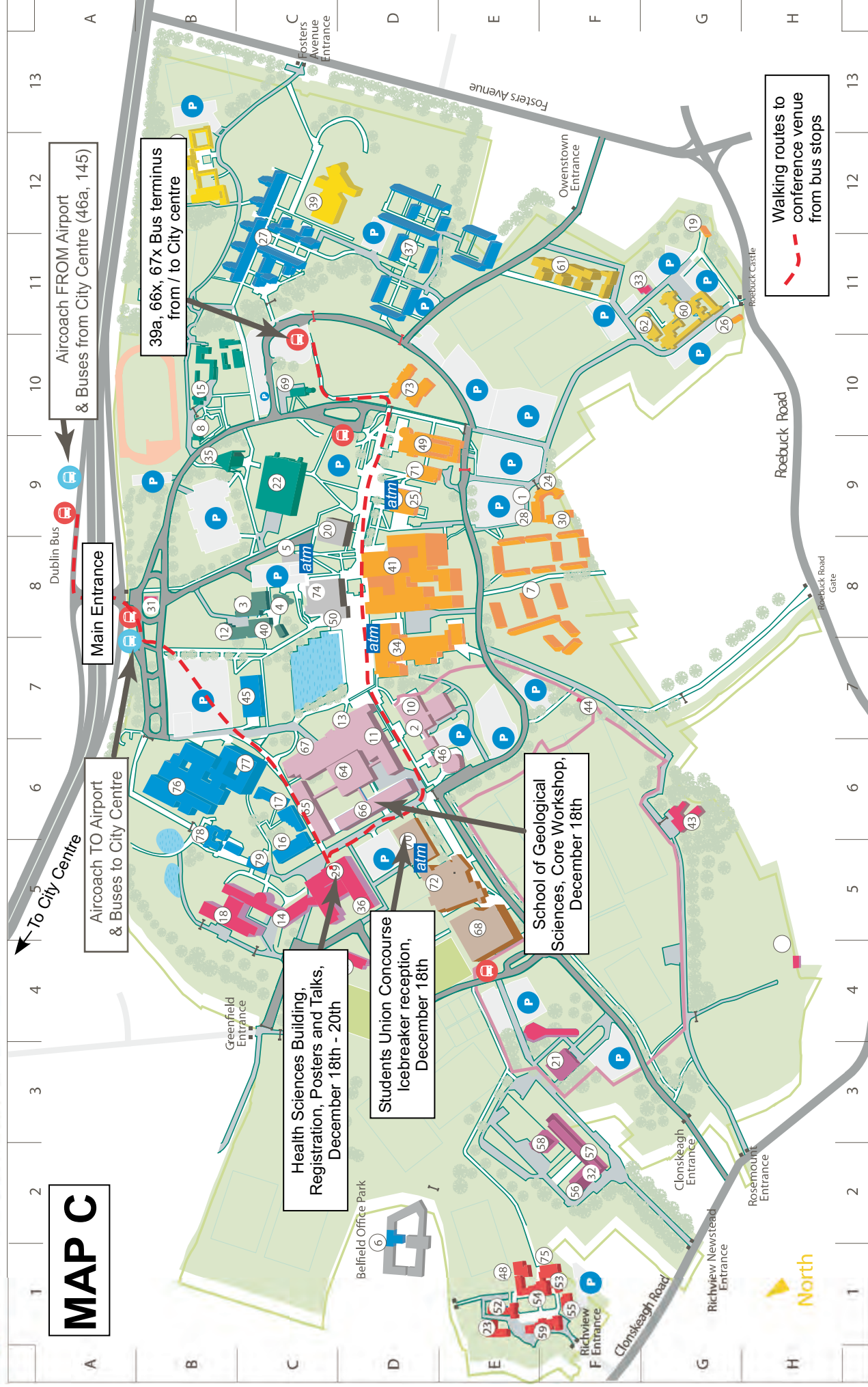
7. D4 hotels\*

8. Hamptons Hotel\*

\* on large scale map overleaf



# British Sedimentological Research Group, 51st Annual General Meeting University College Dublin, 18th - 20th December 2012



# *Talk Abstracts*

**KEYNOTE:**

**'Intrabed' turbidity currents: A new type of sediment gravity flow associated with soft muddy substrates**

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Laboratory experiments on the interaction of cohesionless coal-laden turbidity currents with cohesive soft muddy substrates have revealed a new type of turbidity current characterised by horizontal flow within the substrate. These remarkable 'intrabed' turbidity currents formed when the cohesive substrate contained enough pore water to behave as a fluid mud, and when the density of the turbidity current was higher than that of the upper part of the density-stratified mud deposit. The current kept its characteristic shape and fundamental turbulent properties whilst flowing within the bed, yet the mud above the flow remained largely undisturbed until the top of the current emerged above the bed surface, which was up to 0.1 m behind the current's nose. At the location of emergence, the mud was swept over the top of the head as either mud clasts or as less coherent elongated clouds of mud.

The intrabed turbidity currents formed turbidite deposits with a large variety of potentially diagnostic textures and structures. Mixing of coal and mud resulted in deposits with chaotic textures, containing both randomly distributed mud and clasts of mud. Vertical mixing dominated; hardly any horizontal movement was required to generate the chaotic textures. These deposits could therefore be mistaken for debrites.

Elongated horizons of coal and mud were identified within the turbidites, given the deposits a stratified character. Interestingly, these horizons formed after the current had passed, when the turbidite started to load into the underlying fluid mud and small mud volcanoes formed at the interface between the eroded bed and the base of the turbidite. These strata are therefore interpreted as sediment injections. The load structures were ubiquitous, and their size was related to the weight of the turbidite and the local density of the mud deposit, which in turn was controlled by the depth of erosion.



## **Response of fluvial style and preservation of stratigraphic architecture to salt-wall mini-basin development and climatic regime**

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The accumulation of fluvial stratigraphy in salt-walled mini-basins and the distribution of specific fluvial facies within these basins are ultimately controlled by drainage orientation, and the interplay between rates of salt-wall uplift and rates of sediment supply. Surface topography generated by subsurface salt movement can result in the segregation of drainage pathways, diversion of fluvial flow, and the generation of predictable distributions of fluvial facies and elements in the vicinity of elevated salt walls. Each of these constraints impart their own expression on the accumulating stratigraphic succession: examples include: the accumulation of notably sand-prone or sand-poor intervals within a mini-basin or across several mini-basins; the preferential accumulation of either channelized or non-channelized fluvial elements in predictable locations in mini-basins; and the accumulation of unique facies and architectural elements adjacent to salt-wall-generated topography. In addition to the halokinetic influence exerted on the accumulating stratigraphy, climatic variations can impart an additional type of allogenic control on fluvial style, further compounding the complexities recorded by the basin-fill sequence.

The Triassic Moenkopi Formation of southern Utah is the preserved expression of a low-relief, ephemeral fluvial system, which accumulated both within the Salt Anticline Region – an area influenced by on-going subsurface and subaerial halokinesis – and beyond its confines in the White Canyon region of south Utah. By studying the preserved stratigraphic expression present in both settings, the impact of halokinesis on sedimentation style can be discerned from the impact of regional climatic regime. This provides an opportunity to better understand the degree to which the formation of salt-walled mini-basins influences drainage pathways and ensuing fluvial style.

Preserved fluvial intervals in salt-walled mini-basins form several economically important hydrocarbon reservoirs; it is important to understand the form of stratigraphic complexity that can be attributed to both tectonic (halokinetic) and climatic factors.

## **BRITICE-CHRONO and GLANAM: new exciting developments in the study of circum-North Atlantic ice sheets**

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This talk will present two newly funded projects on the reconstruction of former marine-based ice sheets bordering the North Atlantic Ocean and their effects on the bordering continental margins.

The NERC-funded BRITICE-CHRONO started in October 2012 and its consortium involves scientists from all over the UK with partners in Ireland, Canada and Norway. It aims to carry out a systematic campaign to collect and date material to constrain the timing and rates of change of the collapse of the former British-Irish ice sheet. This will be achieved by focussing on eight transects running from the shelf edge to a short distance onshore and acquiring marine and terrestrial samples for geochronometric dating. The sampling will be accomplished by two research cruises and eight fieldwork campaigns. Three of the transects involve fieldwork in Irish territory.

The FP7-funded Marie Curie Initial Training Networks GLANAM (Glaciated North Atlantic Margins) will start in April 2013 and aims at improving the career prospects and development of young researchers in both the public and private sector within the field of earth science, focusing specifically on North Atlantic glaciated margins. The training network comprises ten partner institutions, both academic and industrial, from Norway, UK and Denmark and will train eleven PhD and four postdoctoral researchers. The young scientists will perform multi-disciplinary research and receive training through three interconnected workpackages that collectively address knowledge gaps related to the glacial sedimentary depocentres on the North Atlantic margins. Filling these gaps will not only result in major new insights regarding glacial processes on continental margins in general, but critically will have particular impact on the exploitation of hydrocarbons in glacial sediments, notably the gas hydrate energy potential on the European continental margin, and will also provide paleoclimate information essential for understanding the role of marine-based ice sheets in the climate system.

## **External Controls on the Evolution of a Prograding Shelf Margin: the Craven Basin, UK**

Jochem Bijkerk<sup>1\*</sup>, Paul Wignall<sup>1</sup>, Colin Waters<sup>2</sup>, Joris Eggenhuisen<sup>4</sup>, Ian Kane<sup>3</sup> & Bill McCaffrey<sup>1</sup>

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Turbidite system style partially depends on controls that are external to the loci of deposition. Here, analogue modelling experiments at the Eurotank Laboratories are used to examine the interplay between basin configuration and sea-level fluctuations. The generic concepts derived from these experiments are that inherited basin configuration is a significant control on fluvial system behaviour, the style of basin infill and the position of incised valley formation. Specifically, in complex post-rift margins, the deepest sections of basins are attractors for incised valley formation. This concept has been applied to outcrop studies in the Carboniferous Craven Basin, where it can account for the variations in style of turbiditic sand-body development.

The Craven Basin is a complex fault-bounded rift-basin. As the basin underwent syn- to post-rift transition, an early Namurian fluvial system caused the progradation of the shelf and slope during early sea-level fall. This predominantly fine-grained delta front succession contains mouth bar and distributary channel deposits that are traceable down-dip into unconfined slope deposits cut by numerous isolated gullies. This system is succeeded by an incised valley that cut across the sub-aerial shelf during late sea-level fall. This conduit carried coarse-grained siliciclastics into the deepest parts of the basin to form a sand-rich turbidite succession up to 500 m thick. The focused routing of sediment into the deep basin led to sediment starvation laterally, which resulted in a shale and siltstone dominated slope.

The difference between confined and unconfined feeder systems has major implications for turbiditic sand-body development in the Craven Basin: only the confined system would be considered a viable hydrocarbon target in such succession. The observations are in close correspondence with the concepts derived from analogue modelling and imply that the recognition of basin configuration as external control allows for a better understanding of basin infill.

## **Quaternary sediment characterisation and distribution in the deep Rockall Trough, NE Atlantic**

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The Rockall Trough is an elongate, NNW-SSE oriented, deep-water bathymetric depression lying west of Ireland and UK. Neogene to recent sedimentation in this area has been controlled by the interplay between ocean bottom currents and gravity mass flows. On the north-western margin of the Rockall Trough lies the Rockall Bank Slide Complex (RBSC), a submarine slide complex covering 24,000 km<sup>2</sup>. On the northeastern margin of the Rockall Trough lies the Donegal/Barra Fan (DBF), a trough-mouth fan covering an area of 7000 km<sup>2</sup>, that formed oceanwards of the shelf break by drainage from the British Irish Ice Sheet.

This research focusses on the morphology and distribution of distal flow deposits, aiming to identify the sources of Quaternary sedimentation in the area, style of basin infill and to distinguish the contribution of downslope transport and alongslope oceanic circulation systems. This work presents the results of characterisation and correlation of seven cores selected from approximately 24 cores, covering a period of 40,000 ka, collected from the deepest part of the trough. Core correlation was made using sediment colour, grain size distribution, relative stratigraphic position, X-Ray images, physical properties and geochemical composition.

Three hemipelagic layers, two turbidite deposits and light-coloured muds were correlated between several of the cores along distances from 40 to 110 km. Geochemical ratios (e.g. Ca/Fe, Zr/T) and physical properties (density, magnetic susceptibility), combined with changes in thickness of turbidites, have allowed us to track the gravity flow deposits towards likely sources on the Rockall Trough margins. One source was located in the northwest margin of the Rockall Trough, possibly associated with the RBSC, whereas the other source was located in the northeastern margin likely linked with the DBF. Strong bottom currents eroded muddy tail of the turbidites, creating sharp upper contacts, demonstrating the interplay of alongslope processes and downslope transport.

## **Facies variability in the Sturtian diamictites of South Australia: implications for Neoproterozoic ice dynamics**

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The pan-global accumulation of Cryogenian diamictites has been repeatedly used to argue in favour of three discrete, globally widespread icehouse intervals; the Sturtian, Marinoan and Gaskiers glaciations. The extent and behaviour of ice masses during these intervals, however, remains poorly understood. We present data from previously little described sections at Oladdie and Holowilena Creeks, in the central Flinders Ranges, South Australia; the type region of the Sturtian (~700 Ma) icehouse period. The succession demonstrates significant lateral and vertical facies variation, wherein the repeated occurrence of striated clast assemblages and abundant ice-rafted debris are used to support a glacial origin for the diamictite facies. The intercalation of gravitationally re-worked diamictites, dropstone-bearing siltstone, dropstone-free siltstone and hummocky cross-stratified sandstone testifies to a dynamic, subaqueous ice-proximal environment subject to local waxing and waning of ice masses. Clear parallels can be drawn with apparently age-equivalent diamictite successions in northern Namibia, where dropstone-bearing and locally subglacially deformed diamictites are intercalated with dropstone-free, interglacial shales. Detailed sedimentological investigation of older Cryogenian diamictite deposits therefore attests to dynamic Neoproterozoic ice masses at both regional and inter-continental scales.



## **Investigating Environmental Impacts of Offshore CO<sub>2</sub> Storage.**

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Carbon Capture & Storage (CCS) is considered an important climate change mitigating technology. In the UK, CO<sub>2</sub> captured from power generation and industrial processes would be transported offshore to be stored in North Sea depleted oil and gas fields or saline formations. Storage capacity in these repositories can be limited by an increase in hydrostatic pressure upon CO<sub>2</sub> injection; as hydrostatic pressure increases towards the lithostatic pressure of the formation, the rock may fracture, breaching the integrity of the storage site.

Hydrostatic pressure may therefore be relieved by producing water to the surface and disposing into the North Sea. This may pose an environmental risk, since CO<sub>2</sub> dissolved in formation fluids will lower pH and potentially promote the mobilisation of trace heavy metals by dissolution or desorption. If high concentrations of these metals in solution are brought to the surface and disposed of - untreated - to the North Sea, would this present a risk to the environment? Simple batch experiments were undertaken which showed that concentrations of metals were elevated under CO<sub>2</sub> conditions. However, comparison with data from the Department of Energy & Climate Change would indicate that the concentrations observed in the experimental work are within the normal range for waters discharged from North Sea oil and gas fields.

Nonetheless, would additional CO<sub>2</sub> storage activities still be within the letter or spirit of current regulations? Are there limits, voluntary or otherwise, to concentrations of heavy metals in produced waters? And where do these metals come from - can a simple risk model be built based on characterisation of the target storage formation?

## **Morphodynamics and sedimentary structures of bedforms under supercritical-flow conditions: new insights from flume experiments**

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Supercritical-flow phenomena are fairly common in modern sedimentary environments, yet their recognition and analysis remain difficult in the stratigraphic record. This is commonly ascribed to the poor preservation potential of deposits from high-energy supercritical flows. However, the number of documented flume datasets on supercritical-flow dynamics and sedimentary structures is very limited in comparison with available data on subcritical flows, and our inability to identify and interpret such deposits might also be due to insufficient knowledge. This article describes the results of systematic experiments spanning the full range of supercritical-flow bedforms (antidunes, chutes-and-pools, cyclic steps) developed over mobile sand beds of variable grain sizes. Flow character and related bedform patterns are constrained through time-series measurements of bed configurations, flow depths, flow velocities and Froude numbers. The results allow the refinement and extension of current bedform stability diagrams in the supercritical-flow domain, clarifying in particular the morphodynamic relationships between antidunes and cyclic steps. The onset of antidunes is controlled by the flow passing a threshold value of the Froude number. Over a range of fine to medium sand, the transition from antidunes to cyclic steps instead is completed at a threshold value of the mobility parameter, spanning a wider range of values for the mobility parameter as grain size increases. Sedimentary structures associated with the development of supercritical bedforms under variable aggradation rates are revealed by means of a synthetic aggradation technique and compared with examples from field and flume studies. Aggradation rate is seen to bear an important influence on the geometry of supercritical-flow structures, and it should be held in consideration for the identification and mutual distinction of supercritical bedforms in the sedimentary record.

**Is there a common distribution for the recurrence intervals of landslide-generated turbidites in distal basin plains, and what are the implications of this distribution for geohazard assessment?**

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In distal settings the thickness of hemipelagite beds between turbidites may be used as a proxy for determining recurrence times between event bed emplacement. Turbidity currents may result in damage to offshore structures and cables as well as providing a record of tsunamigenic events; hence estimation of credible recurrence time can be very important.

During the Pleistocene and Holocene, the Balearic Abyssal Plain has acted as a depocentre for sequences of stacked turbidites, sourced from multiple provenances, which are intercalated by subordinate hemipelagite beds. In the Balearic Abyssal Plain, turbidites comprise more than 75% of the total sedimentary thickness. It is inferred that these turbidites resulted from episodic basin margin slope instability due to their large volume, rather than other processes such as hyperpycnal flood discharge. Statistical analysis of timing between these events over the last 150,000 years shows a near exponential distribution of recurrence times with no significant clustering, suggesting that a governing stochastic or Poisson process may be in effect. This implies that the time to the next landslide on the basin margins is independent of the time since the last landslide. Surprisingly, event timing also appears to be largely independent of variations in sea level.

A comparison is made of hemipelagic mud thicknesses (i.e. recurrence intervals) between turbidites deposited since 15 Ma in the Madeira Abyssal Plain and in the Miocene Marnoso-arenacea Formation of the Italian Apennines. These locations of disparate age provide startlingly similar relationships to those from the Balearic Abyssal Plain, suggesting that the mechanism(s) controlling recurrence intervals of landslide-turbidites may be similar, regardless of locale. The observed frequency distribution of event timings appears to suggest that the systems have no memory. The fact that the same relationships are observed in three varied settings may have significance for future predictions of hazardous landslide-turbidity current events.

## **The Permian ‘glass ramp’: sedimentology and sequence stratigraphy of the Kapp Starostin Formation in Bellsund, Spitsbergen**

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Shallow water biosiliceous sedimentation requires a coincidence of specific palaeoenvironmental conditions. Facies and microfacies analysis are herein employed to determine the depositional setting of the spiculite-dominated, Permian Kapp Starostin Formation on Spitsbergen. An onshore analogue for the Upper Permian Spiculite reservoir in the Barents Sea, deposition took place across a low-angle, storm- and wave-influenced, laterally variable, cool-water ramp. The main environmental parameters supporting biosiliceous activity were: (1) high hydrodynamic energy, (2) normal marine salinity, (3) high silica supply, and (4) high nutrient levels; attesting to inflow of upwelling water from the Panthalassa Ocean. Outer ramp bryozoan mounds or sheet-like thickets straddled SWWB, graded laterally into the dominant spiculite sediments, and controlled finer-siliciclastic sedimentation patterns by acting as hydrodynamic buffers. The lateral variability in facies across this area was accentuated during times of increased terrigenous influx, in part due to the adverse effect siliciclastic input has on carbonate production and hence sediment stabilisation.

An overall upward shoaling trend may reflect both a second-order decrease in mean sea-level during the Late Palaeozoic and an increasingly humid climate, with resulting increases in terrestrial weathering, siliciclastic input, progradation and regression. Variations in facies architecture during higher order sea-level cycles, driven by changes in terrigenous influx and heterozoan carbonate production, may account for the pronounced changes in lithology between systems tracts; eustasy modulation of ocean circulation between highstands and lowstands may have also had an effect. Carbon-isotope data from organic matter at a boundary section between the Kapp Starostin Formation and the Triassic Vardebukta Formation indicates continuous sedimentation (~20cm/kyr) around the Permo-Triassic Boundary.

## **A comparative study for assessing the influence of controls on large-scale fluvial architecture**

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A database approach has been established as a method for the tentative determination of the relative role played by a variety of controls or system variables on the sedimentary architecture of fluvial systems, based on the collation of architectural data from several ancient and modern case histories. At the largest scale, the database describes fluvial architecture in terms of depositional elements classified as channel-complexes or floodplain elements and defined on the basis of geometrical criteria. The stratigraphic volumes to which the depositional elements belong are then classified on a range of attributes describing environmental parameters (e.g. relative distality, channel pattern) and several types of allogenic controls (e.g. basin climate type, tectonic setting).

The approach is subject to several limitations: most notably, the lack of constraints in regard to the boundary conditions of the case histories included in the knowledge base impedes the objective assessment of the sensitivity of each system to individual controls. Nonetheless, quantitative comparative studies can be carried out for a large number of partially-classified datasets, thereby enabling the evaluation of architectural changes as a function of a range of system controls or context-descriptive parameters.

The system can therefore be employed to address key research questions in the field of fluvial sedimentology. Example applications include: (i) the assessment of the control of basin-wide aggradation rates on channel stacking-patterns; (ii) the determination of the influence of basin climatic regime on channel-body geometries; and (iii) the relationship between channel patterns or drainage patterns and large-scale fluvial architecture. These specific themes are considered via analysis of the architectural styles of different fluvial systems in terms of channel-complex density, geometry and stacking pattern. Results highlight similarities and differences between fluvial systems characterized by different boundary conditions.



## **Do N12°E deep-crustal lineaments in the north of Ireland play a part in basin siting, preservation and magmatism?**

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N12°E lineaments in the north of Ireland are enigmatic and often rather weak features on geophysical images. Such lineaments are more often inferred through the occurrence of regional strike swing, mapped faults, mineral veins and igneous complexes. Hutton & Alsop (1996) demonstrated a strike swing and facies changes within the Neo-proterozoic Dalradian Supergroup associated with the Donegal Lineament and that six out of the eight Late Caledonian (Upper Silurian - Lower Devonian) Donegal granites were aligned along its path. Taking this forward into the Upper Devonian and Carboniferous, the Donegal Lineament defines an eastern limit to sedimentation around Galway Bay. The Palaeogene Garrison Sill is also located just east of this lineament. To the east, the Cavan Lineament, which includes in its path the Late Caledonian (?Devonian) Crossdoney Granite and in County Tyrone the Curraghinalt gold deposit, defines a eastward thickening of Lower Carboniferous to Jurassic sequences north of the Tow Valley Fault. This lineament also appears to control location of the Palaeocene Magilligan Sill. Further east again, the Draperstown Lineament coincides with a bend in the Tow Valley Fault and the Palaeocene Portrush Sill. The Kingscourt Lineament defines the western side of the Carboniferous to Triassic Kingscourt Outlier, the western side of the Oligocene Lough Neagh Basin and a small Oligocene basin on the Tow Valley Fault near Ballymoney. Furthest east, the Newry Lineament defines the eastern side of the Lough Neagh Basin and passes through the Palaeocene Tardree and Slieve Gallion igneous complexes. The geological influence of these lineaments spans from Neo-proterozoic to Palaeogene and as such they are thought to represent long-lived, pre-Caledonian, deep crustal structures. A striking aspect of the lineaments is their straightness and parallel spacing (from c. 10 – 35 km). In conclusion, it would appear that lineaments do play an important role in siting of basins and their preservation and that they control the position of intrusions into such basins over long time frames which has consequences for location of mineral deposits and preservation of hydrocarbons.

HUTTON, D.W.H., ALSOP, G.I. 1996. The Caledonian strike-swing and associated lineaments in NW Ireland and adjacent areas: sedimentation, deformation and igneous intrusion patterns. *Journal of the Geological Society*, London, 153, 345-360.

**Quaternary coastal lithofacies and depositional sequence architecture in an ice marginal setting, NW Donegal, Ireland.**

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Extensive coastal erosion has exposed a 8.2 km long glacial sequence in NW Donegal. Geographically located on the fringes of the North Atlantic and sited in the most marginal sector of the last composite ice sheet which covered the British Isles, this is a key site for the investigation of the depositional conditions during the last glaciation. In this paper, the lithofacies encountered are described, the depositional environments interpreted and a model for coastal depositional sequence development in an ice marginal setting is presented. Along the coastline, a wave-cut rock platform is exposed and rises inland to a buried bedrock cliff. This is overlain by a raised beach which itself is buried by wave-influenced shallow marine sands. Overlying this is a relatively thin subglacial till which later ice marginal activity resulted in its cannibalization and incorporation into overlying till sequences. A subaqueous outwash deposit of stacked sequences of subaqueous debris flows with winnowed lag gravels and coarse-grained suspension deposits has also been recorded. The depositional sequence is capped by glaciofluvial incision and channel filling associated with remobilised fluvial outwash. Periglacial conditions persisted during the accumulation of glaciofluvial material with several sites containing clear evidence of frost heave.

## **Channel-like features created by erosive submarine debris flows: Field evidence from the Middle Eocene Ainsa Basin, Spanish Pyrenees**

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The Mid Eocene Ainsa basin, Spanish Pyrenees, preserves unprecedented exposures of ancient deep-marine sedimentary deposits including a wide range of mass transport deposits (MTDs), interpreted as the result of debris flows and sediment slides. We present field evidence to show channel-like features likely created by erosive subaqueous debris flows. Evidence from this basin suggests that the most erosive subaqueous debris-flows may create megascours removing up to 35 m thickness of sandy submarine-fan deposits from base-of-slope and lower-slope settings. This study suggests that individual debris flows may have been more erosive than turbidity currents, an observation that is opposed to many previous studies from the Ainsa Basin and other ancient deep-water clastic systems. In the Ainsa Basin, many of the debris flows deposited pebbly mudstones immediately above the basal erosion surfaces into which gouging flow-parallel grooves and pebble scours left isolated pebbles embedded in the immediately underlying sandstones. In one particularly well-exposed case, the sandstones immediately below the eroding debris flow were incorporated into it and preserved as sheared, disaggregated, brecciated, and partially liquefied sandstone beds within the pebbly mudstone. Our study suggests that erosion by large-volume debris flows in base-of-slope settings can be at least as important, if not more so, than turbidity currents in producing submarine megascours (probably chutes that, in cross section, superficially resemble submarine channels). This has important implications for understanding the erosivity of debris flows versus turbidity currents in modern and ancient environments, and it has significant implications for hydrocarbon reservoir continuity and heterogeneity, including the origin and recognition of mudstone-filled chutes or channels.

## **Sedimentation in large igneous provinces – the Columbia River Basalt Province (Washington State, USA) as a case study.**

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The Columbia River Basalt Province (CRBP) is a Miocene-aged lava field within the Columbia Basin in South Washington, West Idaho and North Oregon, USA. The CRBP is constructed by a series of basalt flows, which erupted from vent systems in the eastern and southern part of the basin from c. 17 to 6 Ma. The basalt flows are intercalated with sedimentary interbeds, which were deposited in fluvial and lacustrine environments and are associated with local palaeosol formation.

This study aims 1) to characterize the intra-basaltic drainage systems in terms of lithofacies, depositional settings and distribution in the lava field; and 2) to identify the controlling factors for the (re-)establishment of drainage systems within a continental large igneous province (LIP).

Based on composition, grain size and sedimentary structures, 15 distinct lithofacies are distinguished including the mudstone, sandstone, conglomerate, breccia, tuff, diatomite and palaeosol facies, as well as several subfacies. The lithofacies can be grouped to 7 facies associations, which each of them characterize a certain geomorphic setting. These are the sand-dominated channel, gravel-dominated channel, overbank facies, wetland, mixed lake, siliceous lake and ferralsol facies.

There are several factors, which control and affect the establishment and re-establishment of a drainage system. The most important factors are the length of time between two eruption events, associated with eruption rate and eruption tempo. Furthermore, the distribution and topography of lava flows and the deposition of scoria spatter cones change the flow direction of rivers, and also cause the formation of lakes. Heavy ash fall outs and lava flows entering a river valley may cause river ponding. The input of nutrients has a significant effect on the formation of siliceous (diatomaceous) lakes. Lava-generated high relief proximal to vent systems stops and re-directs major rivers and only allows wetlands and soils to form.

**KEYNOTE:**

**Experimental turbidity currents as guides for process interpretation from turbidites in the geological record.**

Joris Eggenhuisen

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After 70 years of intensifying attention, the link between turbidite sandstones and turbidity currents remains a fascinating puzzle from an academic perspective, and of immense importance for petroleum geology. Especially in the past 15 years, the descriptive framework of deposits in outcrop, on the modern seafloor, and in the subsurface has reached very high standards. In parallel developments, numerical modelling of the 3D dynamics of fluid flow has matured to the point where laboratory currents can be modelled in to the smallest turbulent scales, and natural turbidity currents can be modelled with more pragmatic but appropriate treatments of turbulence. However, the processes of deposition and erosion of sediment from and by the flow are eluding capture by fluid flow models, and the precise link between processes in the flow and the static end-products we encounter in the geological record is accordingly elusive. Here lies a prime challenge to the process-sedimentological community.

In experiments we can observe and study the link between a turbidity current and deposits directly and, if properly translated to the real world, this enables us to move towards inversion of process from product.

Many experiments have focused on realistic representations of the flow dynamics, while neglecting morphodynamic interactions with developing sandy deposits (subject matter where it's prime role for the near future may be defined). This exile of sand from the laboratory is not necessary: with an appropriate experimental approach it is possible to erode, by-pass, and deposit sand within a single experiment. Incorporating sand in experimental turbidity currents opens up a wide array of new lines of investigation. In this presentation I will collate experimental observations and data collected over a number of research projects and use this collation to illustrate processes of sedimentation and erosion by turbidity currents.



## **Hydrodynamic modeling of sediment transport and bedform formation on the North Irish shelf.**

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Multibeam echosounder data, gathered as part of the Marine Institute's Irish National Seabed Survey (INSS - <http://www.gsiseabed.ie>) are used in conjunction with sediment samples from numerous scientific research cruises to give an overview of bedform and sediment distribution across the shelf. This information is then combined with two hydrodynamic models, a ROMS model ([www.myroms.org](http://www.myroms.org)) maintained by the Marine Institute and a MIKE 3 model ([www.dhisoftware.com](http://www.dhisoftware.com)) created as part of this project. Focus is on the forces mobilising sediments in the boundary layer. The resulting outputs will then be used to understand the formative processes of bedform generation on the Irish Shelf as well as allowing conclusions to be made about general sediment mobility and possible pathways. This knowledge is highly relevant given the increase in proposed marine engineering for renewable energy projects on the Irish West coast. Other applications include maritime archaeology management, habitat mapping and management of dredging and fishing operations. This talk presents progress made in the first year of my PhD and outlines general sediment and bedform distribution on the shelf as well as methods and outcomes for early sediment mobility assessment. The future progression of the project is also presented, including the integration of a MIKE3 model (in development) and backscatter classification sediment maps to give a high-resolution understanding of shelf wide sediment processes.

## **Sedimentary process dynamics in the West Bengal Sundarbans: Holocene facies in a peri-marine environment.**

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The Bengal Sundarbans is one of the largest tidal halophytic mangrove forests in the world stretching across the India-Bangladesh border. Situated between the river Hoogli in the west and the Ganges-Brahmaputra delta to the east, the Sundarbans was declared a UNESCO World Heritage Site in 1987 and serves as the primary habitat for endangered flora/faunal species. The relevance of this research is to identify the sources and fate of sediments in the Indian (West Bengal) Sundarbans tidal islands on the contemporary inactive deltaic system to the west of the present day Ganges-Brahmaputra, dominated by river estuary and cyclone activity. Through the application of geochemical and sedimentological facies analysis, an enhanced understanding of the Sundarbans sedimentary dynamics can be discerned. Geochemical, petrographic and textural analyses have been completed on three cores from uninhabited intertidal islands (c 9m max depth). Sedimentation rates have been constrained using  $^{14}\text{C}$  radiocarbon dating approach (Accelerator Mass Spectrometry) with calibration and conventional age-depth modelling. Speculation regarding the sedimentary provenance in the Sundarbans has been viewed as being primarily marine-derived from the currently active delta front of the Ganges-Brahmaputra to the east of the Bengal Basin (Battacharrya et al., in press). The results obtained in this project, question such claims of provenance and processes with sedimentary pathways being more complex. Sediments appear to be the outcome of reworking within the deltaic-estuarine system with siliclastic and possible terrigenous loads dominating the sedimentary facies. Tidal geomorphological processes represent the dominant controls over sediment re-distribution within the Sundarbans, with possible high-energy depositional events characterising stochastic variation.

**Analysis of fine-grained floodplain deposits as a tool to interpret autogenic controls on floodplain sedimentation: Cretaceous Blackhawk Formation, Wasatch Plateau, Utah, U.S.A.**

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Integrated stratigraphic analysis of fine-grained floodplain deposits and channel-fill sandbodies enables interpretation of avulsion style and its links to autogenic and allogenic controls on stratigraphic architecture. Here we use a combination of oblique aerial photographs and fieldwork to carry out such analysis in a large (200m thick by 100km wide) coastal-to-alluvial plain succession; the early-to-middle Campanian Blackhawk Formation of the Wasatch Plateau, Utah, U.S.A. 370 m of measured section was recorded from fine-grained floodplain deposits at three outcrop localities situated within northern (Highway 6, just north of Helper), southern, (I70, west of Salina) and central sections of the NNW-SSE oriented outcrop belt, which is sub-parallel to regional depositional strike, allowing facies analysis and architectural analysis.

Preliminary results suggest that the Blackhawk Formation contains 11 facies which are grouped into three main categories: 1) fine-grained floodplain deposits in which mature cumulative paleosols are gradually developed, 2) fine-grained floodplain deposits that occupy immature compound paleosols which are bounded by heterogeneous packages of sheet and ribbon sandstone bodies associated with levee, crevasse channel and crevasse splay development, and 3) major channel-belt channelised sandstone bodies of multistorey and multilateral character. An upward increase in the proportion of sheet or ribbon sandbodies (category 2), and associated decrease in fine-grained lithologies such as coal and shale (category 1), occurs in non-channelised floodplain deposits from base to top of the Blackhawk Formation. Both stratigraphically abrupt and stratigraphically transitional avulsion deposits are identified, but the proportion of these two avulsion styles and their relationship to adjacent channelised sandbodies do not appear to vary spatially or temporally between the studied localities. These initial observations indicate that avulsion took place in a uniform manner throughout deposition, but further analysis is required to determine whether avulsion was the primary control on deposition.

**Sourcing ice rafted debris deposited around Antarctica using the Pb isotopic composition of detrital feldspar: insights on the sites of Late Holocene subglacial erosion.**

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Feldspars from crystalline bedrock exposures around Antarctica have Pb isotopic compositions that vary geographically. Variations reflect the age and crustal evolution of the host rocks and means the Pb isotopic composition of detrital feldspar is appropriate for sedimentary provenance studies in Antarctica. In this study we explore the sources of feldspars contained within ice rafted debris collected from Prydz Bay and the Weddell Sea. By combining the Pb compositions of Late Holocene ice rafted feldspar with geophysical observations over the East Antarctic ice sheet we constrain the location of subglacial erosion. Our data suggest that ice rafted feldspars originated from geographically restricted areas, where ice velocity and bed roughness are high, and that these regions are concentrated at the continent margin rather than in the deep interior. These observations are consistent with selective and generally low rates of erosion since the growth of the East Antarctic ice sheet.

## **Bed character and high-resolution correlation of sediment gravity flow deposits from the Lago Section (Cilento flysh, Italy).**

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The 280 m thick Lago section represents part of the c. 2 km – thick fill of the syn-orogenic Miocene Cilento piggy-back basin. The section is unusual in the context of the wider succession in that it is characterised by the common presence of hybrid event beds that occur interbedded with turbidites deposited by both high- and low-density currents. Relatively sheet-like geometries and an absence of multi-bed slumps imply that these event beds were all emplaced on an unconfined and relatively flat deep-water basin floor. Three main bed-type categories are recognised: i) “normal turbidites” ranging from HDTC (*facies* F4-F5-F7-F8 of Mutti, 1992) to LDTC deposits (*facies* F9); ii) chaotic and debrite facies ranging from slump-like deposits to medium and thin hybrid event beds; and iii) a class of “mudclast-rich bed” that has characteristics intermediate between the above two end-members.

Although clast-rich and chaotic bed tops can locally be attributed to substrate deformation, and many of the thicker sandstones have extensively injection-modified tops with rip-down of muddy sand, thinner beds have either slump modified or linked debrite divisions suggesting that flow transformations were implicated in their emplacement. Lateral correlations establish significant short-scale (150-400 m) facies variability that has no systematic relationship to paleocurrent direction. This is inferred to relate to complex interfingering of down-dip linked debrites and up-dip sandstone-dominated beds. The logged sections show systematic vertical organization comprising repeated fining- and thinning-upward sequences interpreted as cycles commencing with high-energy events (depositing the thicker beds). These were able to flatten the sea floor followed by smaller volume turbidite and hybrid flows that created stacked lobe elements showing evidence of compensation geometry. The hybrid event beds are interpreted as the downcurrent equivalent of thicker and coarser beds that became progressively overcharged with ripped-up mudclasts that then disaggregated to change the rheological flow behavior and promote debris flow emplacement.

## **The Chalk Sea: a dynamic environment!**

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Most models of Cretaceous Chalk sedimentation have been based around plankton rain, vertical accretion of extensive, sheet-like bedforms, and little or no evidence of redeposition except along major faulted inversion zones as in the Central Graben of the North Sea. Recent high resolution seismic studies across the southern North Sea (Danish and German Sectors) and the Anglo-Paris Basin demonstrate the presence of extensive, up to 150 m deep channel systems, associated with moats, drifts and mass transport complexes formed on the sides of the channels. So where are these features at outcrop? In the onshore UK chalks such features exist, but have been widely interpreted to have formed as a result of tectonic inversion. We identify a deep, broad (5 km+) channel complex developed in early Campanian Chalk on the Isle of Wight, which is directly comparable with similar features in the German North Sea. An extensive mass transport complex in the mid Campanian of southern Hampshire demonstrates the complexity and longevity of such redepositional features. Both have implications for redepositional mechanisms in the Cretaceous Chalk of the North Sea.



## **Basement-controlled slope instability, Rockall Bank Slide Complex, NE Atlantic**

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The Rockall Bank is a structural high forming the steep western margin of the Rockall Trough in the NE Atlantic west of Ireland. Strong ocean currents sweeping this margin are considered partially responsible for an extensive slope failure, the Rockall Bank Slide Complex (RBSC), with an unusual low aspect ratio (150 km long and 120 km wide). The scar area covers nearly 6000 km<sup>2</sup> and the depositional area is 18,000 km<sup>2</sup>. Numerous cross-cutting scarps at different water depths, together with overlapping depositional lobes, suggest a long history of slope instability. The aim of this study is to unravel the sequence of events that took place after the first slope collapse on the Rockall Bank.

With the use of an extensive 2D seismic dataset, re-processed high-resolution multibeam bathymetry, a TOBI mosaic and one piston core we demonstrate that the headwall of the RBSC may have occurred as a multiphase slope collapse in at least three episodes of failure since 16 ka BP. Each of the events is suggested to have generated a slide with a typical elongate morphology and a higher aspect ratio than the composite slide complex. Reconstructions of the pre-slide seafloor suggest a volume of collapsed sediments in the range of 265 and 765 km<sup>3</sup>. Seismic facies investigation indicates that the slope and failed sediments comprise almost exclusively contourites.

A systematic examination of the slope morphology, seismic facies and sub-seafloor structures demonstrates a direct relationship between the RBSC seafloor scarps and the basement morphology. Focused fluid flow along basement-bounding faults, and/or differential compaction across the scarps, are considered to have had an important role in slope failure. This study highlights the importance of deeply-buried structures in the stability of slopes. It also shows how detailed examination of high-resolution data across large areas of slope instability can reveal smaller-scale multiple events.

## **Comparative facies analysis of the sigmoidal and oblique foreset deposits of Gilbert-type deltas: implications for the recognition of short-term relative sea-level changes**

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The geometrical relationship of fluvial topset to subaqueous foreset of a Gilbert-type delta may be 'sigmoidal' (transitional) or 'oblique' (erosional) and is attributed to a rise or fall of the delta's shoreline time-distance trajectory, thus reflecting relative sea-level change. However, every episode of a relative sea-level fall will force the fluvial system to cut down, which may remove the delta-brink sigmoidal signature of a preceding episode of relative sea-level rise. The geometrical record of short-term relative sea-level changes in a Gilbert-type delta thus tends to be obliterated by fluvial erosion.

The component facies of a Gilbert-type delta foreset are deposits of turbidity currents (whether slope collapse-generated brief surges or longer-duration hyperpycnal flows), dense debris flows and loose coarse-debris falls. The present study of the Plio-Pleistocene Gilbert-type deltas in the Gulf of Corinth, Greece, focuses on the relative proportion of these facies in sigmoidal and oblique foreset deposits – revealing significant differences. The foreset beds corresponding to a sigmoidal delta-brink geometry are mainly debris-flow deposits (~50 %), with subordinate turbidites (~27 %) and debris-fall deposits (~23 %). A relative sea-level rise apparently promotes excessive sediment deposition in the delta's brink zone during low fluvial discharges, resulting in gravitational collapses (debris flows); forces sediment bypass during higher discharges (turbidity currents); and causes an excessive accumulation of failure-prone fluvial lag gravel during the highest discharges (debris falls). The foreset beds corresponding to oblique delta-brink geometry comprise debris-flow deposits (~45%), more turbidites compared to sigmoidal intervals (~40%) and minor debris-fall deposits (~15%). A relative fall or stability of sea-level apparently promotes an increased sediment bypass (turbidity currents) accompanied by denser sediment failures (debris flows) and only sporadic gravel-lag collapses (debris falls).

The study suggests that a detailed quantitative analysis of the delta foreset facies may help to reveal the record of short-term relative sea-level changes whose brink-zone geometrical signatures may have been erased by delta-top fluvial erosion.

## **Characterisation of the zone of interaction between proximal alluvial fan sedimentation and contemporaneous distal deposition in continental basins.**

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Deposition in proximal arid continental basins is commonly dominated by alluvial fan sedimentation. These deposits are sensitive to autocyclic processes and short timescale allocyclic controls of climate, base level and sediment supply. Consequently, they provide both complex and varied pathways and barriers to sub-surface fluid migration. The deposits that occur in the distal extent of arid continental basins are sensitive to both localised autocyclic controls, and longer-term climatic cyclicity that affects the basin as a whole. Longer term climatic variation has a more distinct signature on deposition within the distal basin, resulting in a less complex fluid-flow system.

As alluvial fans are commonly long-lived throughout the evolution of the basin they interact with changing distal environments through a transition-zone. This zone may generate flow pathways that link isolated distal permeable deposits via the proximal sediments. Deposition within the transition-zone is difficult to qualify and an appreciation of sedimentary architectures present is crucial to understanding potential fluid migration through the basin as a whole.

The Permian Cutler Group of the Paradox Basin, U.S.A, grades from proximal alluvial fan sedimentation through to distal deposits representing distinct periods of archetypal arid continental deposition. The 'Arkosic Facies' of the Group marks the transition and interaction between alluvial fan deposits and the contemporaneous distal environments. In this work we present spatial and temporal facies models that characterise the varied sedimentation across the Paradox Basin, and how it responds to cyclic controls. These controls affect sedimentation differently in the proximal basin, zone of transition, and within the distal deposits. The models provide an improved understanding of how auto- and allocyclic controls affect the zone of interaction between the proximal and distal sediments, and facilitate the description of interconnectivity of flow pathways from the proximal to distal setting to quantify basin-scale migration.

## **Anatomy of a Fluvial Avulsion Complex: An example from the lower Beaufort Group, South Africa**

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Channel avulsion is a fundamental process in the behaviour and growth of large distributive fluvial systems. Avulsion nodes are sites where fluvial conduits change direction multiple times. The stacking patterns of channel-belts in multi-kilometre scale outcrops of the lower Beaufort Group, permits assessment of the presence or absence of an ancient avulsion complex and criteria to recognise them.

In the lower Beaufort Group, fine- to medium-grained sandstones and intra-formational conglomerates form adjacent to and intercalated with mudstones and moderate maturity palaeosols, with accompanying splays. These facies associations are consistent with a flashy to ephemeral fluvial system. Individual sand bodies measure 4m to 12m in thickness, with typical lateral extents ranging from 200m to 1200m. A hierarchical approach to the stratigraphy has recognised storeys, channel-belts and complexes. Complexes tend to occur in isolation.

In the Perdekop locality there is evidence of localised channel-belt clustering, forming a 60m thick succession adjacent to extensive overbank mudstone deposits. The apparent lack of a well-defined 'container' surface with mappable margins, suggests that this stacked channel-belt architecture does not represent an incised-valley fill. The similar facies and consistent north-easterly palaeo-transport direction in all channel-belts suggests, however, that they are genetically related and therefore represent a channel-belt complex, rather than a random stack of channel-belts from unrelated rivers that cross in one location. This style of architecture is interpreted to be a function of deposition downstream from an avulsion node. Perdekop was close enough to the avulsion node that there was not sufficient space for channel-belts to spread out and avoid earlier ones, thus producing the complex. The preservation of some floodplain deposits between channel-belts, with only local vertical amalgamation of belts, suggests that accommodation was not particularly low. The oldest channel-belt appears to scour into thinly bedded very fine-grained sandstone, indicative of a gradual avulsion event.

## **Stretch, slide, bend, and confine: formation of a lobe complex behind mass transport complex relief, Neuquén Basin, Argentina**

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Mass flows can entrain large pieces of substrate, and form significant depositional relief that influences subsequent dispersal patterns of sediment gravity flows. Highly-deformed Bathonian-to-Lower Callovian strata at Chacay Melehue, NW Neuquén Basin, Argentina, offer a valuable insight into the processes and influence of a seismic-scale (>7 km-long and up to 70 m-thick), mass transport complex (MTC).

The correlation of marker horizons between measured sections (200-500 m spacing) permits the structural and depositional architecture of the MTC to be constrained. The MTC has a sheared and angular basal contact that displays ~30 m of relief, before stepping up-stratigraphy to be concordant with the underlying stratigraphy. The MTC comprises two main facies. The lower unit comprises tightly-folded, thin-bedded turbidites that are dissected by thrust faults, which is interpreted as a slide. This is overlain by a more extensive, poorly-sorted facies that contains well-rounded, extra-basinal clasts and sub-angular, laminated, intrabasinal clasts, which are supported by an argillaceous, poorly-sorted, sandy siltstone matrix that continues beyond the toe-wall. The upper units also contains clasts of reworked shallow-marine facies that are 100's of metres in length and 10's of metres in thickness. Based on its texture, composition and stratigraphic context, the upper unit is interpreted as a debrite. In up-dip areas only, the MTC is overlain by a >20m-thick tabular sandstone-rich successions, with normally-graded sandstones that are commonly capped by clast-rich muddy sandstone. This succession is interpreted as a confined lobe complex

The MTC exposed at Chacay Melehue is interpreted as a frontally-emergent slide and debrite couplet that was capable of transporting large clasts from an unstable shallow-marine (shelf?) setting, and entraining clasts. The MTC generated sufficient depositional relief to cause capture sand-rich sediment gravity-flows and the deposition of confined submarine lobes.

**Process record at submarine channel mouths: High-resolution stratigraphic analysis of a base-of-slope system at outcrop, Karoo basin, South Africa**

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Sedimentary processes at the mouths of submarine channels are still poorly understood due to the complicated balance between erosional and depositional processes, changing flow behaviour and the lack of sufficient outcrop control in ancient examples.

Fan 3 of the Permian Skoorsteenberg Formation, Tanqua depocentre provides a well exposed lateral spatial transition, within the context of a complete basin floor fan, from a highly confined distributive axis into weakly confined off-axis deposits.

The overall stratigraphic thickness of Fan 3 stays relatively constant (40-50m) across strike towards the west, but thins abruptly towards the east. Over the full strike control of more than 10 km, 6-20 m thick packages of decimetre scale climbing-ripple dominated sandstone beds (0.2-2.5 m) indicate rapid flow expansion. The changing character of the internal ripple structures within individual deposits illustrates the unstable and collapsing conditions of these turbidity currents. Individual beds show substantial variability in thicknesses and evidence of compensational stacking. Mudstone clast and plant-fragment rich hybrid beds are present within these climbing-ripple dominated packages towards the eastern fringe of Fan 3. These deposits are younger, laterally adjacent to and cut by slightly younger channel complexes that comprise channel-fills with a complicated history of cut, bypass and fill processes.

The climbing ripple-dominated packages are interpreted to have been deposited from fully turbulent flows that experienced an abrupt reduction in flow confinement close to the mouths of submarine channels and are interpreted as channel-mouth lobes. These channel-mouth deposits are recorded over a more than 10 km strike width in the proximal region of Fan 3 and are commonly cut by younger channels during system progradation. Some 15km down-dip, terminal lobes do not share the same facies associations, indicating an important flow process difference. Understanding the depositional architecture and establishing identification criteria for these proximal lobes has important predictive implications for subsurface studies.



**Insights into the composition and architecture of seismically-imaged clinoforms constrained by forward seismic modelling of outcrop analogues in the Cretaceous Western Interior Seaway, USA.**

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Seismic stratigraphy allows packages of genetically-related strata to be identified and mapped within a chronological framework. In this context, seismic reflection data can be used to undertake shoreline trajectory analysis, which defines gross stratigraphic architecture by tracking the position of shoreline clinoforms through time. However, the method is restricted by the resolution of the seismic data. For example, well data may indicate many more lithological breaks in a clinoform set than are imaged in seismic data; this raises the following important questions: (1) what combination of lithological attributes generates a seismic reflection?, and (2) how sensitive is the seismic response to subtle changes in the geometry and distribution of clinoform surfaces?

Forward seismic modelling is a novel method by which petrophysical properties from the subsurface are integrated with an interpreted lithology distribution to predict seismic amplitudes. Seismic modelling of outcrop analogues can therefore bridge the critical gap in resolution and scale between well and seismic data. In this study, we use geometrical and lithological data from three outcrop analogues of various shallow-marine depositional environments in the Cretaceous Western Interior Basin, USA to construct forward seismic models: the Ferron Sandstone (river-dominated, normal regressive delta); the Panther Tongue (river-dominated, forced regressive delta); and the Chimney Rock Tongue (wave- and river-influenced, normal regressive delta). The geometry, distribution and lithological character of the clinoform-bearing units are quantified in order to create an array of detailed 'Earth models' that allow the sensitivity of modelled seismic response to these geological parameters to be evaluated. Analysis of the resultant seismic models enables us to quantify the attributes which generate a seismic reflection in shallow marine reservoir sandbodies of the Viking Group, Troll Field, offshore Norway. The results are widely applicable to other shallow marine reservoir sandstones, for which the outcrops studied are considered to be sedimentological analogues.

## **Turbidity current flow equilibration to a sinuous channel form**

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Submarine channels are important morphological features that act as transport pathways for sediment from the continental shelf into deep marine basins. Channel profiles appear to evolve towards a form of equilibrium slope through processes of erosion and deposition, as sequences of flows undergo equilibration to the channel form. Due to their nature and scale, modern submarine channel systems are largely inaccessible for direct study and therefore experimental modelling provides key insight into the mechanisms and feedbacks which govern their development.

The rate of growth of confining levees and the degree of confinement of overbanking flows are very important for channel development, but remains poorly understood as such feedbacks are challenging to model directly. Here, a series of nominally identical sediment-laden turbidity currents were released into a long sinuous channel model consisting of 15 bends. Characterisation of flow and overspill was achieved by measuring the velocity profile of individual flows at specific locations, with data being combined to build a picture of flow evolution along the length of the channel.

Flow morphology evolves and adjusts to the channel form largely through the process of flow stripping. The volume and velocity of the overspill is greatest in the proximal bends and decreases down channel. Three distinct flow regimes can be identified within the channel form, here associated with differing styles and degrees of equilibration. In the initial stage, flows over-fit to the channel equilibrate to it over c. 5 bends via rapid mass loss. The final stage, where flows are under-fit to the channel over the last c. 5 bends, may be representative of a retrogressional system. In the intervening stage (bends 6-10), flows may approximate to some form of equilibrium. The associated overspill flux rate may therefore indirectly characterise the longitudinal form of a system that is close to equilibrium.

## **Seismic stratigraphic investigation of the glacial and inter-glacial evolution of the Northern North Sea during the Cenozoic**

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This investigation used a regionally merged (c. 30,000 km<sup>2</sup>, 50 m bin spacing) MegaSurvey 3D seismic dataset and an extensive set of 2D lines, tied to core and wireline logs, to investigate the evolution of the Northern North Sea over the past 2.7 Myr.

The Naust Formation is Plio-Pleistocene, progradational, glacially-influenced deltaic system, which marks a change in the depositional regime of the margin. An extensive regional unconformity (URU) exists throughout the study area. This truncates the early Naust units and older Cenozoic-Mesozoic strata which are overlain by flat-lying Quaternary glacial/glacio-marine and interglacial strata above. This major erosion surface forms the base of the Norwegian Channel (NC), a large (>700 km long, >400 m deep) and enigmatic cross-shelf trough located along the Norwegian coast. This project is the first to undertake a 3D seismic geomorphological study of the URU, Naust and all major glacial erosion surfaces within the NC fill and in doing so offers a chronology of the infill and the glaciation history of the Northern North Sea Basin.

Mapped erosional surfaces revealed a diverse assemblage of glacial morphologies interpreted as; tunnel valleys, glaciotectionic thrust complexes, terminal moraines and meltwater conduits. Incision surfaces mapped in the Naust suggest iceberg ploughing was common along the margin between 2.7 Ma and 1.1 Ma and that ice streaming commenced prior to 1.1 Ma. During the Late Pleistocene the NC hosted a number of fast flowing ice streams, transporting vast volumes of sediment to the Atlantic margin and shifting the NC margin westward. Over the past 0.8 Myr ice streams have transported > 15,000 km<sup>3</sup> of sediment to the North Sea Fan.

This study offers new insight into the spatial and temporal dynamics of shelf-edge glaciations in the Northern North Sea, pushing back the timing of shelf glaciation to the early Pleistocene.

**Development of decimetre-scale clastic intrusions in a shallow marine sedimentary; a field-based case study from the Matulla Fm (Upper Cretaceous), Suez Rift, Egypt**

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Clastic intrusions in deep-marine successions are typically up to several tens of metres thick and extend several tens to hundreds of metres away from the source sandbody. In contrast, in shallow-marine sedimentary successions, individual intrusions are usually <1 m thick and are typically of relatively limited (<5 m) vertical extent. In this study we use field data from the Matulla Fm (Upper Cretaceous), Sinai, Egypt to describe what we believe is the most vertically and laterally extensive clastic intrusion network ever described from a shallow marine sedimentary succession. Petrographic analysis of thin sections allow us to map-out grain size variations within the intrusion network as a function of height above the source sandbody, and to test models for hydraulic sorting of grain during remobilisation and injection. Our results indicate that the intrusion network was sourced from a single, 2 m thick, shallow marine sandbody. Individual intrusions are up to 50 cm thick, can be traced laterally for several hundreds of metres, and are commonly ptgymatically folded and fractured. The intrusion network extends up to 55 m above the source bed and cross-cuts overlying shallow marine parasequences, before terminating abruptly at the base of a low-permeability chalk unit. Petrographic analysis indicates there is an overall upward-fining from medium-grained in the source sandbody to fine-grained in the intrusion network. We interpret that grain size segregation occurs as a result of elutriation during fluidisation and/or grain crushing due to post-intrusion compaction. Our study suggests that the key control on the development and geometry of large-scale clastic injection networks is the permeability and strength characteristics of the topseal units rather than the original depositional environment of the source sandbody. Furthermore, our petrographic analysis provides support for previous studies of grain size variations in clastic intrusion networks, which have previously been inferred from petrophysical data.

## **Lateral and stratigraphic variability in depositional architecture of stacked exhumed shelf-edge clinothems**

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Sediment supply rate and accommodation represent the primary factors controlling basin margin architecture. However, studies are often spatially restricted, and thus treat accommodation and sediment supply as a two-dimensional (2D) problem, by either selecting or assuming a margin profile parallel to the main sediment supply route. Strike variability in basin margin physiography strongly affects sediment partitioning between the shelf, slope and basin floor and therefore needs including in attempts at stratigraphic prediction.

The lower Waterford Formation, Karoo Basin, South Africa, provides a rare three-dimensional (3D), outcrop-based case study for understanding the sub-seismic scale process-regime operating on a low-gradient basin margin. A single >40 km 2D dip profile enables characterization of the shelf-slope transition for two successive clinothems (WfC 3 & 4) as well as establishing robust criteria for identifying the shelf-edge. WfC 3 is a fluvial-dominated, mouth-bar clinothem; it exhibits a 5 km dip-parallel zone of extensional deformation at the shelf-edge with limited delivery of sediment beyond the shelf-edge. In contrast, WfC 4 is a wave/storm dominated, shoreface clinothem that supplied sediment to the slope via closely spaced gullies at the shelf-edge and a large upper slope channel, producing a 45 m thick, upper slope turbidite succession. Two additional basin margin profiles to the north and south have enabled across strike correlation, revealing significant 3D margin variability.

Lack of evidence for sediment bypass across strike to the south indicates that delivery of sediment to the slope did not occur uniformly across the margin. A greater supply of sediment to the upper slope to the north, in the absence of a clear fluvial driver and during a period of steeply rising margin trajectory, contradicts established hypotheses for delivery beyond the shelf-edge. Therefore, other factors must exert a significant influence in order to deliver sediment to the slope without these well-established criteria operating.

## **Carbonates, ammonites and the fate of aragonite: a new perspective from the Lower Jurassic of Lyme Regis**

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The Lower Jurassic Blue Lias Formation at Lyme Regis, Dorset, preserves a diverse assemblage of invertebrate and vertebrate fossils within rhythmic packages of shales, marls and carbonates. One limestone bed in particular, Bed 29, preserves a unique pavement of very large (up to 72 cm) ammonites, initially buried in carbonate mud before diagenetic cementation.

The ammonite accumulation is most likely due to sedimentological condensation but the mechanisms for preserving an aragonitic shell long enough for it to be neomorphosed to calcite on the seabed are a challenge for conventional taphonomic models.

It has been suggested that early dissolution of aragonite is a major process in offshore deeper ramp settings, resulting in the removal of sediment prior to lithification. We present field-based evidence for a new model of aragonite preservation within a cyclic oxic-anoxic carbonate environment, using ammonite preservation to track the fate of aragonite in different depositional environments.

The carbonate sediment provides a short-term geochemical buffer that militates against the dissolution of aragonite sediment and molluscs, allowing neomorphism to calcite under some conditions. The broader implications of this model for the preservation of molluscan shells and reduced sediment dissolution in carbonate environments under variably oxygenated conditions are evaluated.



## **Dewatering of argillaceous sands**

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Rapid sedimentation from high-concentration mixed-load turbidity currents can result in weakly-sorted, argillaceous sand deposits. These deposits are often devoid of primary sedimentary structure but can be dominated by secondary dewatered structure; in many cases it can be difficult to distinguish between primary and secondary fabrics. Dewatering fabrics include column and dish structure, and variable development of wispy lamination; additionally, dewatering can enhance weak depositional fabrics, e.g., banding, through the elutriation of fines. The wide range of geometrical styles and dimensions of these features is here classified, drawing on examples predominantly from core data, with some outcrop analogues. To better understand these results a series of settling experiments were performed which highlight the importance of sedimentation rate, concentration and sand/mud (silt and clay) ratio on dewatering style. These results illustrate that dewatering fabrics can be good indicators of sedimentation rate and hence provide information about the flow character, potential depositional environments and down-dip flow evolution. The experiments also confirm that hindered sediment settling within mud-rich high-density suspensions, in combination with pervasive dewatering, is a process capable of developing clear grading within weakly-sorted argillaceous sand beds.

## **A Depositional Model for the Accumulation of Organic-rich Namurian Mudstones in Central England, a Potential Shale Gas Reservoir**

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Fine-grained successions from various sedimentary basins and of different geological ages are currently re-evaluated for their potential to source, and to host, significant volumes of hydrocarbon gases. Among the most prospective intervals in Great Britain are Namurian (Upper Carboniferous) mudstones of the Edale Shale Group, which constitute a known oil and gas source rock in Central England. For this study, a 40 m thick core section of Arnsbergian deposits from the Widmerpool Gulf in Derbyshire was logged and sampled in high resolution. We aim to investigate the abundance, distribution and type of organic matter and finally to develop a depositional model to explain how these parameters are controlled by sedimentary processes and depositional environment.

This presentation shows the results of a multidisciplinary study including optical microscopy, stable carbon isotope geochemistry, palynofacies characterisation and Rock-Eval analysis. The bottom 20 m of the core material are made up of interbedded clay-rich mudstones and millimetre- to centimetre-scale silt-rich mudstones with frequent plant debris. In contrast, the top 20 m consist mainly of carbonate-bearing clay-rich mudstones. This overall fining upward trend probably reflects increasing water depth and therefore increasing distance to clastic sediment supply.

A total of seven different microlithofacies have been identified, which show systematic variation in organic carbon content and composition. While the bottom unit displays variable TOC (mean:  $2.3 \pm 1.1\%$ ),  $\delta^{13}\text{C}$  (mean:  $-27.8 \pm 1.2\text{‰}$ ) and kerogen types II-III, the top unit characterised by high TOC (mean TOC:  $4.2\% \pm 1.0\%$ ) and high  $\delta^{13}\text{C}$  (mean:  $-28.7 \pm 0.9\text{‰}$ ), consistent with prevalent kerogen type II. Amorphous organic matter, supposedly produced by marine microbial activity is the main component of sedimentary organic matter throughout the samples, however, in places terrestrial plant fragments are dominant linked with the coarser silt-bearing lithofacies. These results suggest that organic matter type and concentration is dependent on sediment delivery processes, bioproductivity and sediment dilution rates.

## **A Neoproterozoic trough mouth fan deposit in South Australia?**

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The Bolla Bollana Formation is an exceptionally thick (~1500 m) sedimentary succession cropping out in the northern Flinders Ranges, South Australia, which was deposited during the Sturtian (mid Cryogenian) glaciation. Lithofacies analysis reveals three distinct facies associations which chart changing depositional styles on an ice-sourced subaqueous fan system. The sandy diamictite facies association is dominant, and comprises both massive and stratified varieties with a range of clast compositions and textures, arranged into thick beds (1- 20 m). These strata are considered most proximal, representing glaciogenic debris flow (GDF) deposits. A channel belt facies association, most commonly consisting of normally-graded conglomerates and sandstones, displays scour and fill structure of ~10 m width and 1-3 m depth: these strata are interpreted as channel turbidites. Rare mud-filled channels in this facies association bear striated clasts. Finally, a sheet heterolithic facies association contains a range of conglomerates through sandstones to silty shales arranged into clear, normally graded cycles from the lamina to bed scale. These record a variety of non-channelised turbid flows, probably occupying distal and/or interchannel locations on the subaqueous fan. Coarsening and thickening-up cycles, capped by dolomicrites or mudstones, are indicative of lobe build out and abandonment, potentially as a result of ice lobe advance and stagnation. Dropstones, recognised by downwarped and punctured laminae beneath pebbles to boulders in shale, or in delicate climbing ripple cross-laminated siltstones, are clearly indicative of ice rafting. In turn, they also strongly imply a glaciogenic sediment source for the diamictites. The prodigious volume of diamictites in the Bolla Bollana succession of glacial derivation merits a tentative interpretation as a trough mouth fan deposit seaward of a palaeo-ice stream.

## **Gold placer dynamics and palaeoclimate change in the Yukon**

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Since their discovery in the 1980's, the gold placers of the Yukon Territory, Canada, have produced an estimated minimum of 16.7 million crude ounces of gold, a large proportion of which originated from the Dawson Mining District. The auriferous high bench "White Channel Gravels" (WCG) of the Dawson Mining District are situated in the drainage of the Klondike River and continue to be a significant economic resource to the area. Despite their importance the WCG has been the subject of very few detailed studies of their formation and sedimentary depositional environment, particularly in the context of gold placer formation.

The formation of the WCG is classically ascribed to a Pliocene braided river system, which deposited the auriferous gravels continuously. This study has taken a new approach to examining the gravels implementing a sedimentary architectural element scheme to better understand the formation of the WCG's and their placers. This in turn will allow for our knowledge on placer formation on an intermediate and large scale to be expanded. New field data collected suggests a significant break in deposition of the gravels, which contradicts current thinking. This new insight raises questions about placer formation in the deposit and the sources of the gold found within the WCG's. New pollen data collected from within the WCG's also suggests a warmer and wetter depositional environment than currently proposed and one that is radically different from that seen today, with a warmer paleoclimate possibly influencing placer formation within the area. This increase in knowledge about the WCG allows for a new depositional model of the deposit to be developed, as well as expanding our understanding of placer formation at intermediate and larger scales. This enhanced understanding will ultimately lead to the production of better exploration criteria for placer deposits.

## What the floc? Enhanced settling with dynamic shear patterns

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Most seafloor sediments are muddy, formed by settling of individual particles and flocs. The size, shape and density of flocs prescribe the nature of settling in a given fluid. Size, shape and density dynamically change with fluid shear both during settling and in periods where no net settling occurs (when the particles and flocs act as colloids). In a lab experiment flocs were generated in salty water (1 M NaCl<sub>(aq)</sub>) from 100 nm latex spheres with density 1.05 compared to fresh water, and stirred at 30 rpm with a Phipps and Bird jar tester. Particle size distributions were constantly monitored using a Malvern Mastersizer 2000 laser diffraction particle sizer. The median particle size,  $D_{50}$  increased to 400  $\mu\text{m}$  over 100 minutes whilst more particles and small flocs joined existing flocs than broke off them. Over the next 380 minutes the  $D_{50}$  decreased to 225  $\mu\text{m}$  as flocs consolidated through breakage and reattachment to other flocs. Flocs gradually became denser. The same patterns occurred repeatedly in three runs. In subsequent runs flocs were formed in the same shear conditions (same stirring rate) then subjected to increased fluid shear (cf. increased tidal velocity perhaps) causing them to break to a new equilibrium size in c. 75 minutes. Once a new equilibrium size had formed, fluid shear was returned to the initial shear condition and  $D_{50}$  increased. In separate experiments stirring was increased from 30 rpm to 50, 100 and 200 rpm. The  $D_{50}$  with increased shear was 210, 90 and 36  $\mu\text{m}$ , whilst the reformed flocs had  $D_{50}$  of 222, 118 and 136  $\mu\text{m}$ . Compared to the initial runs, flocs were smaller and denser after breakage and reformation in increased and then decreased fluid shear. Muddy colloids can sink without fluid shear decreasing when made denser in this way.

## **Far-field effects of tidal marine energy converters on sediment distribution in the Pentland Firth.**

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The long term effects of placing arrays of marine energy converters on the environment, both local and far-field, are poorly understood. Numerical modelling of marine energy converter arrays is the best method for assessing these effects without putting converters in place. Here, we describe a numerical computational fluids dynamic model, Fluidity, and our method of simulating tidal marine energy converters and their impact on sediment dynamics. Fluidity is an open-source, finite element, code that is capable of simulating a wide-range of scales and processes due to the use of unstructured meshing techniques. The simulations carried out here make good use of the multiscale capabilities as the modelled domain contains elements that vary in size over five orders of magnitude, from 20km to 2m. We calculate the bed shear stress in the Pentland Firth (North of Scotland) with zero, 20, 85, 240 and 400 tidal marine energy converters in place. We describe the computational aspects of this work and show how the bed shear stress maps can be used to infer where sediment in the system will be redistributed. We find effects at distances approximately 2-3 times the size of the array in question, but the most significant effects occurring within the array itself. From this limited study it would appear that significant effects on the sediment regime should not be seen in this area, except for immediately around the array.



## **Geometries of sedimentary structures in the Triassic fluvial Prados Sandstones, Spain.**

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The Prados Sandstones of Northeast Rillo de Gallo, Guadalajara, Spain are at least 30 m thick. These early-mid Triassic sandstones are dominantly medium to fine grained, arranged in fining upwards sequences. Field observations suggest a variation in cross-bedding style with sandstone composition and position. Trough cross-bedding is the dominant style and trough sets are observed in plan-view as spoon-shaped structures. This project aims to improve on previous studies of these rocks and also to obtain a better understanding of the mechanisms that produce spoon-shaped structures. This will enable improved inferences about the fluvial systems in which spoon-shaped structures form. The spoon-shape structures in the Prados Sandstones vary in: grain size, dimension, shape, laminae thickness, long-axis trend and angle between laminae dip direction and long axis trend. The plan form varies from circular to elongate oval, with length and width ranging from 0.53 m to 5.40 m and 0.43 m to 4.30 m respectively. Laminae thickness ranges from < 0.010 m to 0.035 m. Long-axis trend varies from N-S, NE-SW to NNW-SSE. In addition to the form of the spoon-shape structures, the internal architecture varies, and the laminae dip tends to increase in the down stream direction. All this variability reveals relationships between the flow pattern and sediment transport as well as information on the bedform development. For example, 63% of the spoon-shaped structures measured have a ratio of width to length of less than 1. The length of the spoon relates to both the shape of the original scour and the longevity of the scour as the dune lee face progrades into it. However the variations in spoon shape and architecture could be misleading for interpreting the river behavior if the preservation state is not taken into account.

**KEYNOTE:**

**Exceptional preservation of aeolian successions.**

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The construction and accumulation of aeolian dune fields is commonplace in modern desert and non-desert settings. However, the long-term preservation potential of many present-day dune-field accumulations is very low, chiefly because many such systems are currently developed in stable intracratonic settings for which rates of long-term subsidence are very slow. Large bedforms in many present-day tropical aeolian desert dune fields are legacy forms that were constructed and underwent accumulation during the last glacial maximum when the climate was generally colder, drier and windier than today. Several factors have promoted the stabilization of these legacy bedforms: (i) the present-day climate is not sufficiently windy to enable the aeolian transport of large volumes of sediment for further dune-field construction; (ii) the sediment supply that was used to construct many large present-day dune fields has now been exhausted or flooded during Holocene transgression; (iii) stabilizing agents on dune surfaces (vegetation, precipitate crusts) have become increasingly significant in response to a shift to a more humid climate; (iv) elevated intra-dune-field water tables restrict sand transport across damp or wet interdune surfaces.

In the ancient record, many preserved aeolian successions are interpreted to have accumulated via the synchronous migration and climb of bedforms that led to the generation of stacked sets of thickly cross-bedded strata. However, several other exceptional preservation mechanisms are also documented, including: (i) flooding by transgression; (ii) inundation by flood basalts; (iii) stabilization of bedforms in response to climate change to preserve relic topography; (iv) migration of bedforms into pre-existing topographic depressions ranging in scale from entire basins to salt-solution pockets; (v) the presence of interdune depressions developed between stabilized bedforms that act as local accommodation centres for younger bedforms. These varied preservation mechanisms mean that the aeolian stratigraphic record is far more complex than previously thought.

**Aggradation in internal basins: determining sediment budgets and rates of fluvial depositional processes (Ebro Basin, Spain).**

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Fluvio-lacustrine successions preserved in basins of internal drainage can provide a record of the rates of erosional and depositional processes. The Miocene of the Ebro Basin, Spain, is a largely undeformed succession of the deposits of distributive fluvial systems (DFS) that show little vertical variation in architecture. This aggradational pattern includes the fluvial-lacustrine transition indicating that lake and fluvial facies were accumulating at the same rate. An established palaeomagnetic reversal stratigraphy in the lacustrine successions allows average lake depositional rates of 90 mm/ky to be extrapolated into the fluvial deposits. By mapping the areal extent of one DFS (1,800 km<sup>2</sup>) the volumes of sediment deposited per unit time can be calculated at 162,000 m<sup>3</sup>/yr. This translates into an estimated average sediment load of about 13 kg/s for the palaeo-river that fed the DFS.

Reconstructions of the drainage basin area in the southern Pyrenees suggest it covered an area of 3,140 km<sup>2</sup> from which erosion rates can be determined as being approximately 60 mm/ky. The estimate of deposition rate is consistent with the maturity of stacked paleosols between the channel-fill bodies and the erosion rates are comparable to values derived from thermochronological data from the Pyrenees and sediment budgets for the whole Ebro Basin in the late Neogene.

The average aggradation rate can be related to the vertical intervals between channel-fill sandstone bodies. In the medial areas of one DFS the vertical intervals between channels average 11 m, whereas in distal areas the average is 24 m. With aggradation rates of 1 m in 11.5 ky, these equate to periods of 120 ky in medial areas and 270 ky more distally. This suggests that the recurrence interval of channel belt occupation on individual sectors in the medial part of the DFS is >100 ky, increasing distally across the fan-shaped body.

## **Avalanche! The sedimentology of snow and ice.**

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This is NOT a presentation on glaciology, but on the sedimentology of (modern) snow and ice. Snow behaves like any other material made up of sedimentary particles. It can be deposited, reworked by (wind) currents and gravity, and altered diagenetically through pressure and heating. This diagenesis typically occurs within a few centimetres of the snow surface. There are several types of snow, including snowflakes, which have their own complicated classification, hoarfrost, graupel and polycrystals. The morphology affects their behaviour and depositional character and subsequent diagenesis into ice layers. These layers are studied in ice cores.

Most dramatically snow can form mass flow deposits as avalanches, which occur as two main types, loose snow and slab avalanches, depending on terrain, weather, and snowpack. The latter is composed of ground-parallel layers that accumulate over the winter, and these can be classified depending on age and the transformation from snow to ice. Each layer contains ice grains that are representative of the distinct meteorological conditions during which the snow formed and was deposited. Avalanches may involve dry or wet snow, which in turn affects their triggering and behaviour. As a testament to their significance in human terms, they are thought to have killed more than 50,000 soldiers in the First World War alone.

Snow can also exhibit a variety of sedimentary features more familiar to us from clastic deposits, such as dunes, ripples and even the preservation of footprints. Study of these features in ephemeral winter conditions, particularly as they become subject to effervescence, melting and erosion, provides lessons that can then be applied to similar deposits in other sedimentary environments.

## **Global distribution of modern sedimentary basins**

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For sediments to enter the rock record they must be deposited in an area where accommodation is being created, through subsidence, base-level rise or a combination of the two. Given that modern depositional analogues constitute an important contribution to our spatial, architectural and temporal understanding of the sedimentary record little previous work has been done to document the distribution of modern sedimentary basins.

In recent years however, the availability and accessibility of global Geographical Information System (GIS) and Remote Sensing data have enabled researchers to study the quantitative distributions of modern depositional environments. In this study the global distribution of modern sedimentary basins has been mapped, based on a classification of gradient and the mapped distribution of quaternary sediments with an area threshold greater than 250km<sup>2</sup> for intramontane basins or 10,000km<sup>2</sup> for low lying basins.

Initial results indicate that approximately 16% of the Earth's land surface is in net deposition with the remainder in net erosion. The majority of the sedimentary basins occur in desert climates (~64%), followed by temperate and tropical settings (~30%) with microthermal and polar regions establishing the smallest portion (~6%). The structural regime that define these areas have been described as Back-arc (~1%), Fore-arc (~6%), Intracratonic sag (~48.3%), Extensional (~5.6%), Foreland (~20.4%), Passive margin (~7.5%), Retro-arc Foreland(~12.1%) and Strike-Slip(~5.4%) basins.

The distributions of modern sedimentary basins have significant implications for our fundamental understanding of the stratigraphic and palaeontological record. Modern systems are commonly used as analogues for the ancient record; however the depositional architecture of sedimentary systems within basins is commonly different to that of systems in areas of net erosion. Only animals and plants living within basinal areas have any chance of being included in the rock record, highlighting c. 84% of terrestrial ecosystems have no chance of being preserved in the paleontological record.

## **Facies relationships of a distributive fluvial system on the Colorado Plateau, USA.**

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Analysis conducted on aggradational modern day continental sedimentary basins reveals that distributive fluvial systems (DFS) are commonly the dominant sedimentary pattern present an observation that is expected to be reflected in the continental sedimentary rock record. The fluvial Salt Wash Member of the Late Jurassic Morrison Formation on the Colorado Plateau, USA, has been interpreted as being a DFS from both previous and current studies.

This study has focused on getting a large scale system overview of the fluvial Salt Wash system in order to gain insights into the controls on the system. Through systematic logging across the system some key trends have been identified. Firstly, as expected with a DFS there is a downstream change in both thickness and distribution of facies across the system. Higher energy fluvial facies are found to dominate the high energy proximal areas with lower energy floodplain and lacustrine facies dominating the thinner distal locations. A change in facies distribution and thickness variations are also seen across the system laterally. Sections that are considered to be within the same zone (i.e. medial zone) of the system have a marked difference in thickness with thinner sections (<70m) being found the NW and thicker sections (80m+) being found in the SE. These two zones also display differing paleocurrent trends with the NW zone displaying a north-easterly paleocurrent trend and the SE zone displaying a more easterly trend. Differing facies distributions and trends are also noted with a higher percentage of channel belt facies being found in the SE section.

It is believed that the variations in thicknesses of the fluvial system, the differing facies distributions and differing paleocurrent trends are recording differences in subsidence and accommodation regimes. This implies a much more local control on the architecture of the system, rather than large scale base level controls as reported in the literature.



## **Sedimentary evidence of the Pliocene-Quaternary uplift of the Kyrenia Range, Northern Cyprus**

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We are testing alternative models for uplift in the E Mediterranean (e.g. slab break-off vs. transpression vs. continent-continent collision). The Kyrenia Range has uplifted to ~1000m above sea level (ASL) since the Late Pliocene. Interactions between tectonic uplift, eustatic sea level change and climatic change created marine/continental terrace deposits at different topographic heights. Field relations suggest the terraces become younger downwards. The NE and SW flanks of the range (~80m ASL) are characterised by Pliocene shallow-marine chalk, marl and calcarenite, predating major uplift. The first terrace (~600m ASL) is locally preserved breccia with poorly sorted (<1cm- 2m), angular clasts-mainly limestone, plus chalk, chert, basalt and pelagic carbonate. The next terrace down (~300m ASL; <500m wide), of similar clast composition, is a conglomerate with sub-angular clasts (1 cm-40cm), grading seawards into a marine calcarenite. The third terrace (~250m ASL; <750m wide) is a well-sorted, lenticular conglomerate (of again similar clast composition) grading northwards into cross-bedded calcarenite. The fourth terrace (100m ASL; <500m wide) is a lenticular conglomerate and aeolinite. The widely developed fifth terrace (<75m ASL; >1km wide) is calcarenite, aeolinite, lenticular conglomerate and palaeosol and is rich in bioclasts (e.g. bivalves, calcareous algae, serpulids and rare *Cladocora* coral). The thin and patchily preserved final terrace (<10m ASL; <20m wide) is thin conglomerate, followed by calcarenite, then aeolinite. A comparison with circum-Mediterranean coastal areas, especially S Cyprus, suggests possible formation ages. The first and second terraces may be pre- to late Calabrian (1.80 Ma–0.78 Ma); the second and third, Sicilian (0.78 Ma-0.26 Ma), the fourth Tyrrhenian (0.26 Ma- 0.01 Ma) and the fifth Neotyrrhenian (<0.08 Ma). The highest breccia (>450m ASL) suggests an energetic uplift, driven by tectonics and humid climate. The lower terraces (<200m ASL) were more influenced by eustatic sea-level change /climatic change. This age model is being tested and refined by U-series, OSL and palaeomagnetic dating.

**Basal erosion and mudclast character and distribution in hybrid beds deposited in a ponded minibasin (Castagnola Fm, NW Italy).**

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Hybrid beds are commonplace in many deep-water clastic systems. They are characterised by a vertical association of sedimentary facies thought to be deposited under a turbulent regime (e.g. massive/laminated clean sand) and those deposited under a more transitional or cohesive flow regime (e.g. chaotic mudclast-rich and/or muddy sand), within a single event. Multiple models are proposed for their emplacement, focussing on the rheological changes within a flow, as well as their spatial and temporal occurrence. However our understanding of depositional processes, thus character and distribution of hybrid beds, remains limited.

The Lower Miocene Castagnola Fm. (>1000m) records the deep-water infill of a small (a few km<sup>2</sup>) ponded piggyback sub-basin in the eastern part of the Tertiary Piedmont Basin (NW Italy). Six detailed sedimentary logs taken at similar distances along a 3.1 km proximal-to-distal transect encompass a low net-to-gross (0.2), 250 m thick interval. Generally, bed types comprise either thin (<1m), highly structured deposits, or thicker (1-5m) beds. The latter are commonly hybrid bed-like in character with a poorly structured lower division, overlain by a recessive division frequently enriched in mudclasts whose size range is wide (from cm-sized up to 1-2m) and often bimodal. Erosional scouring and 'frozen' entrainment of mudstone substrate at bed bases allows at least some of the larger mudclasts to be directly related to local substrate rip-up. However, the occurrence of smaller mudclasts, with a vertically variable position within the bed, suggests that these were sourced further upstream and travelled greater distances prior to deposition. Such observations are consistent with other systems where hybrid beds contain far-travelled mudclasts (e.g. Braux system, Marnoso Arenacea system, etc.).

Characterising the degree of local erosion below hybrid beds and the origin of mudclasts within might help to better understanding the depositional processes and the character and distribution of hybrid beds.

**Estimation of progradation rates in ancient shallow-marine clinoform sets: a new method and its application to the Upper Jurassic Sognefjord Formation, Troll Field, offshore Norway**

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We develop a new method to extract progradation rates from ancient shallow-marine clinoforms, and then apply this to refine the depositional model of the Upper Jurassic Sognefjord Formation, which forms the main reservoir in the giant Troll Field, offshore Norway. Our method provides a tool to improve the predictive potential of sequence stratigraphy and clinoform trajectory analyses.

The stratigraphic architecture of the studied succession is constrained by 3D seismic, and densely-spaced core and wireline-log data. The Sognefjord Formation is a 10-200 m thick, coarse-grained clastic wedge, deposited in ca. 6 Myr, by a fully marine, westward-prograding, subaqueous delta system. We identify four, 10-60 m thick, westerly-dipping, regressive subaqueous clinoform sets that can be mapped for several tens of kilometres along strike. Horizontal trajectories are observed in each clinoform set, and the sets are stacked vertically.

Quantification of clinoform age and progradation rates is constrained by 14 regionally correlatable bioevents, and relies on exponential age-depth interpolations. The facies break that mirrors the foreset-to-bottomset transition, which represents storm wave base, is subsequently dated in each well, and progradation rates are measured along transects oriented perpendicular to the clinoform strike and tied to well-based stratigraphic correlations and seismic data.

Our results indicate a fall in progradation rate (from 500 to 30 km/Myr), net sediment flux (from 90 to 10 km<sup>2</sup>/Myr) and simultaneous rise in sedimentation rate (from 15 to 70 m/Myr) towards the basin. We attribute these variations to the progradation of the subaqueous delta into progressively deeper waters influenced by along-shore currents that resulted in net sediment transport out of the study area and sculpting of the linear, elongated clinoforms. Local spatial and temporal deviations from these overall trends are interpreted to reflect phases of subtle structural control on sedimentation; this interpretation is supported by seismic-stratigraphic and sedimentological observations.

## **The sedimentary record of the late-Pleistocene Cordilleran Ice Sheet in the Purcell Trench and the formation of glacial Lake Purcell**

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During the last glacial maximum, the Purcell Lobe of the Cordilleran Ice Sheet (CIS) impounded glacial Lake Missoula and failed catastrophically (likely many times) causing some of the largest floods in the geologic record. The sedimentary record shows that during deglaciation and northward retreat into Canada the Purcell Lobe continued to act as an ice dam to later proglacial lakes in Montana, Idaho and British Columbia. Sedimentary evidence for post-glacial Lake Missoula proglacial lakes exists as extensive silt and clay deposits, which lie north of the glacial Lake Missoula basin in the Purcell Trench. Further sedimentary evidence in the form of kame terraces elucidates a valley wall seal during CIS deglaciation that allowed the development of ice-marginal lakes and streams. This sedimentology, along with the regional topography, suggests that the Purcell Lobe could have dammed large amounts (likely  $>70 \text{ km}^3$ ) of water in glacial Lake Purcell just prior to its drainage into the Columbia River valley.

## **From core to cliff – new insight into the evolution of the Ross Formation from behind-outcrop boreholes in the Clare Basin, western Ireland.**

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The Pennsylvanian Ross Sandstone Formation is well exposed around the Shannon Estuary in western Ireland and represents the sandy deep-water succession of the shallowing-upward fill of the Clare Basin. Twelve research boreholes (>1300 m of core and associated wireline logs) linked to nearby cliff and foreshore sections provide a new composite vertical section through the formation. This underpins a new allostratigraphic subdivision of the Ross Sandstone Formation (R10 to R90 from base to top) constrained by biostratigraphy from zone-bounding condensed sections.

The cores contain a wide range of bed types including conventional turbidites, transitional flow deposits and hybrid event beds. Variability in bed character is expressed at two vertical scales: (1) over 100s of metres vertically through the formation with an upward change from hybrid-prone (R10) through transitional flow deposits with turbidites (R20) to a mix of turbidites and hybrid event beds (HEBs; R30-50) with slumps becoming more important towards the top of the formation (R50 and younger), and (2) over metres to decimetres in the form of switching between turbidite and hybrid bed-prone packages, a motif that is particularly well expressed in the mid-Ross (R30-50). The larger scale variability relates to a combination of position within the system (more proximal upwards) and changing basin morphology as a consequence of deposition. Unusually coarse-grained and thick HEBs that dominate the lowermost Ross (R10) appear to be separate and distinct from the main system (R20-R90). An overall broad progradational signal appears to be punctuated by a more aggradational trend in the middle Ross (R30-50). Smaller-scale mid-Ross variability occurs independent of the condensed sections and may record high-frequency changes in equilibrium gradients, perhaps linked to channel re-location; HEB-prone packages tend to occur beneath amalgamated sheets or channel fills and the latter commonly have lags suggesting bypass of flows bulked with clay clasts.

**Interaction between clinoform trajectory, sedimentary process regime and timing of sediment delivery of an intrashelf clinothem succession, offshore New Jersey.**

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The analysis of shelf-edge clinoform trajectory in reflection seismic datasets or outcrop-based studies has been widely employed as a tool to infer relative sea-level changes, to interpret long-term factors controlling the basin margin evolution, and to predict the timing of coarse-grained sediment delivery from continents to oceans. Accommodation- or sediment supply-driven models have been emphasised, with less focus on the role of the shelf-edge process regime in operation at individual clinothems, and how the process regime change in time and space (across strike). High resolution seismic profiles tied to cored and dated borehole data provide a means to link the depositional architecture (clinoform trajectory) to sediment dispersal processes and patterns. IODP Expedition 313 collected three research boreholes that intersected a set of Miocene clinothems offshore New Jersey to capture a complete record of relative sea-level change through integration of seismic stratigraphy, core and well logs, and chronostratigraphy. Topset deposits are dominated by shoreface-to-offshore facies associations, and rollover deposits are either wave- or fluvial-dominated. Typically, where the rollover is wave-dominated there is little coarse-grained sediment in the toesets. However, the bottomsets to fluvial-dominated rollovers are dominated by coarse-grained turbidites and debrites. This distribution of coarse sediment does not correlate with clinoform trajectory. There is no evidence of deep shelf incision by fluvial channels suggesting a wide distributive supply system that fed sediment downslope to form a gullied apron or coalesced fans. The direct relationship between river-dominated rollovers and sandy bottomsets, suggests that process regime in the shoreline controlled the transfer of sediment from topsets to bottomsets on the New Jersey margin during the Miocene, even at times of rising relative sea-level.

**KEYNOTE:**

**Source to Sink observations for the deep water Miocene of the North-Central Gulf of Mexico.**

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The Miocene deep water stratigraphy of the North-Central Gulf of Mexico has proved a productive petroleum exploration target. Earliest exploration success was 30 years ago, but it has been in the past 15 years that the most sand-rich deep water Miocene reservoirs have been discovered and in lower slope and abyssal plain palaeogeography's. Deposition of these deep water sands is discrete in time and is considered to be controlled by glacio-eustatic, relative sea-level falls. Classic interpretation of the deep water Gulf of Mexico Miocene stratigraphy has established systematic episodes of deposition, at a variety of temporal scales, that describe repeated arrival/onset/initiation, build/growth/aggradation and retreat/abandonment/waning cycles.

Up dip the Miocene deltaic, shelf and shelf margin stratigraphy, primarily onshore Louisiana, was established as a global top 10 exploration province from the 1930's. An early lithostratigraphic nomenclature was rapidly calibrated with foraminiferal biostratigraphy. These analyses established a pattern of regional shifting/stepping deltaic depocenters which include periods of basin margin outbuilding (growth of shelf settings) punctuated by catastrophic episodes of regional basin margin collapse. Interest in the shallow water Miocene waned as the loci of exploration moved south and offshore in the 1950's and 1960's.

The source regions for these shallow water and deep water Miocene sands extend from the palaeo-continental divide of the Rocky Mountains, through the northern states of the USA and to the western and southern uplands of the Appalachians. Across the western Great Plains a huge Miocene alluvial system, the Ogallala Group, forms one of the most important aquifers of North America.

What controls prompted the deposition of regional sand-rich, alluvial, deltaic and deep water Miocene stratigraphy that extend from the northern Great Plains to the abyss of the Gulf of Mexico?

The scales; time and palaeogeography, of the mega-regional story can only be approached by combining global climate and plate tectonic change with the evolving local tectonics of the North America tectonic plate. A key conclusion is that sediment flux, driven by climate change and modulated by sea-level fluctuations resulted in discrete periods of regional basin margin construction. Inevitable catastrophic collapse events profoundly changed the landscapes and seascapes of the Gulf of Mexico basin and these events time the arrival of sands to the most distal parts of the basin floor.



The Miocene depositional history discussed in this presentation should challenge our preconceptions about deep water stratigraphy. Where we see order we should also embrace the potential for chaos. Where we presume near complete depositional records punctuated by condensed sections we should also seek surfaces of regional erosion, bypass and incomplete stratigraphic records. The enigmatic evaporites of the Aptian Ariri Formation, Santos Basin, Offshore Brazil: new insights from 3D seismic and well logs analysis.

## **Role of Eocene large-scale debris-flows (olistostromes) in the closure of S Neotethys in the E Mediterranean region**

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Large-scale debris-flow deposits ('olistostromes') embed important information on regional-scale tectonic-sedimentary processes. Such debris flows occur in a range of settings including divergent and convergent continental margins. Here, we focus on an Eocene active margin setting in N Cyprus (Kyrenia Range), related to northward subduction on the S Neotethys. A Paleogene deep-sea succession (pelagic and redeposited carbonates and alkaline volcanics) passes gradationally upwards into a thick succession (up to 800m) of gravity-flow deposits, exposed in several thrust sheets. The most southerly (structurally lowest) succession, exposed in the eastern Range, is dominated by siliciclastic turbidites and debris-flow deposits with minor hemipelagic marl interbeds. The sand matrix contains abundant ophiolite-related material (e.g. basalt, radiolarite), together with well-rounded clasts of e.g. pelagic limestone, neritic limestone, marble, dolomite and basalt. The interbedded marls contain a planktic foraminiferal assemblage, including *Acarinina bullbrooki*, *A. praetopilensis* and *Morozovella aragonensis*, dated as M. Eocene. The highest levels are dominated by chaotic debris-flow deposits with exotic blocks (up to 100s of m in size), including Permian and Mesozoic neritic limestone, Triassic pelagic limestone, radiolarian chert and dismembered ophiolitic rocks (e.g. serpentinised harzburgite, gabbro, diabase, basalt). A thinner sequence (<200 m) in the central Range is dominated by debris-flow deposits, rich in Paleogene pelagic limestone and basalt. Whole-rock major- and trace-element chemical analysis shows that basaltic clasts in the gravity flows are largely of alkaline, within-plate type. Some of the blocks (olistoliths) are similar to lithologies exposed in the underlying metamorphosed Mesozoic succession, whereas others were derived from unmetamorphosed M. Permian-Mesozoic limestones and from a Mesozoic ophiolite-related assemblage. The likely tectonic trigger of large-scale debris-flow formation was over-steeping of a pre-existing accretionary prism. Mid-Eocene suturing of an ocean basin further N appears to have resulted in a southward jump of the total convergence between Africa and Eurasia to the S Neotethys.

## **Sub-aqueous sand extrusion dynamics: Discrete to sheets**

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Sand mounds and sand sheets are increasingly recognised, yet the underlying mechanisms that control these features, and determine whether deposits are discrete or form areally extensive sheets remain poorly understood. Here we address these issues through study of a well exposed sand sheet in the Shannon Basin, Ireland. Sand volcanoes are shown to have erupted contemporaneously following earthquake-induced liquefaction and fluidisation of delta-front mouth bar sands and silts forming an extruded sheet of sand. The sand sheet formed during a single prolonged eruption event with the interaction of radial gravity currents from the hundreds of vents exerting control on the internal architecture of the extrudite. Based on the understanding of this outcrop, here we develop a process-based model demonstrating that sand extrusions can only form sheets if: (i) multiple vents are extruding coevally, causing gravity currents to interact, or, (ii) topographic forcing, such as channelling, re-directs the otherwise radial gravity currents and results in sheet-like deposition of extruded material away from the vent site. This study provides a new model of sand extrudite formation examines the potential for identifying extrudites from core and bed-scale studies and differentiating them from liquefied beds.

## **Facies variations as an insight to depositional mechanisms in fine-grained sedimentary rocks.**

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Research specifically examining fine-grained sedimentary rocks over the last 20 and more years has documented the diversity of mudstone facies through the geological record and highlighted the importance of erosion and advective (storm-generated currents, turbidity flows and debris flows) transport in the deposition of mudstones. Using field observations and thin section analyses we have examined mudstone lithofacies variability in Carboniferous mudstone successions, from the Edale Basin, Derbyshire, UK, that contain significant marine flooding surfaces.

These mudstones are an excellent natural laboratory because they have been the subject of much research that has developed a comprehensive sedimentological and stratigraphic framework. Previous researchers have concluded that mudstones associated with marine flooding surfaces were deposited in low energy, deep water conditions associated in settings where the water column was prone to developing anoxia or associated with hemipelagic sedimentation between turbidity current events. A detailed petrographic study has revealed a particularly distinctive organic-rich (>2% TOC) lenticular clay-rich mudstone facies within a range of different facies.

Interpreting this lenticular fabric in the light of recent experimental research, suggests that at least some of the fine-grained material preserved in these successions was not actually deposited in the clay-size fraction, but rather was deposited as aggregate grains in the coarse silt-, sand- and granule-size fractions. Larger aggregate grains were produced variously by: (1) reworking of the sediment interface forming intraclastic aggregates, (2) cohesion effects associated with chemical changes in the water column (flocculation), (3) mechanical aggregation in high density flows (floc formation), and (4) biological aggregation in the water (marine snow formation).

Our new data provide alternative explanations for the depositional processes responsible for transporting fine-grained materials which have far-reaching implications for the mechanisms responsible for burial of organic matter and controls on lithofacies variability in ancient mud-dominated settings.

**KEYNOTE:**

**Extreme sedimentology: Emplacement of the Stac Fada impact ejecta deposit in the Mesoproterozoic of NW Scotland.**

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Clastic sedimentology involves various processes operating on rock particles erosion, deposition and, ultimately, diagenesis. Erosion and deposition typically operate under normal temperatures and pressures at the Earth's surface. In contrast, ejecta from a hypervelocity meteorite impact experiences the same processes as 'normal' sediments, but operating under extreme pressures and temperatures. Furthermore, whereas normal sedimentary processes can be observed in the field or laboratory, those associated with hypervelocity impacts have never been witnessed and can be deduced only from the resultant deposits and from modelling. The 5-10 metre thick Stac Fada Member, in the Mesoproterozoic Stoer Group of the Assynt region of north-west Scotland, was identified as an impact ejecta deposit in 2008 (Amor et al, 2008). The location and size of the impact site is unknown, and just a narrow elongate outcrop of the ejecta deposit survives, but it exemplifies the extreme processes involved in the emplacement of impact ejecta. The surface immediately beneath the Stac Fada Member is strewn with angular gneiss blocks representing ballistic ejecta launched from the impact site. The Stac Fada Member itself was emplaced as a hot, ground-hugging surge of impact melt clasts that became increasingly diluted by entrained sand and water as it advanced across the fluvial plains of the Stoer Group. At Stoer the force of this advancing slurry surge was sufficient to lift and entrain huge slabs of the unlithified fluvial sands beneath. Large-scale sedimentary structures within the Stac Fada Member, and in the overlying lacustrine sediments, are crucial to locating the impact site. They suggest that it lay to the east of the Stoer Group outcrop, in Lewisian gneisses now deeply buried beneath the Moine Thrust. The presence of a deep gravity low beneath Lairg, due east of the Stoer Group outcrop, suggests that the crater itself may still survive.

*Amor, K., Hesselbo, S.P., Porcelli, D., Thackrey, S., and Parnell, J., 2008. A Precambrian proximal ejecta blanket from Scotland: Geology, v. 36, p. 303-306.*

## **Reconstruction of channel and barform architecture in a Namurian (Silesian) fluvio-deltaic succession: Brimham Grit, northern England.**

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Pebbly fluvio-deltaic sandstones of the Brimham Grit (Kinderscoutian, northern England) form a complex array of Millstone Grit tor outcrops, which permit detailed resolution of 3D lithofacies architecture whereby relationships between adjacent sand-bodies (e.g. channel, barform, dune and sheet-like elements) facilitate palaeoenvironmental reconstruction of a braided channel network.

Although the depositional palaeoenvironment was supplied with sediment delivered from a range of provenances, eroded remnants of Scottish and Norwegian Caledonian Mountains located ~450 and ~950 km towards the north and northeast, respectively, dominated sediment supply. Previous studies suggest the system evolved from a shelf-edge- to slope-ramp delta, which ultimately delivered sediment to a series of submarine fans developing in the deep-water depocentre of the Craven Basin.

A detailed depositional model depicting fluvial processes responsible for generating the preserved stratigraphic architecture has been developed through high-resolution architectural analysis utilising 1D sedimentary logs, 2D architectural panels, pseudo-3D fence diagrams and paleocurrent rose diagrams. Sedimentary lithofacies include trough- and planar cross-bedded sets, compound co-sets of cross-strata, planar-bedded sandstones and gravel beds, arrangements of which define variable architectural elements including single-storey, multilateral- and multi-storey channel elements, downstream- and laterally-accreting macroforms. Architectural elements are typified internally by distinctive lithofacies arrangements with highly variable paleocurrent distributions indicative of systematically fluctuating barforms from lateral to downstream accretion, with accumulation occurring in a poorly-confined network of fluvial channels allied with major sandy barforms, indicative of a frequently avulsing braided fluvial system in an upper-delta plain setting. The presence of fossilised plant remnants (e.g. *calamites*) implies local swamp-like conditions adjacent to active channel belts and a degree of channel-bank stability.

Data from this study are contributing to a broader research program investigating the linkage of fluvio-deltaic successions from shelf-edge deltas to slope and submarine-fan successions and focussing on how basin morphology influenced sediment delivery mechanisms within the Central Pennine Province, UK.

## **Transitional and composite flow deposits: character and distribution in the Maastrichtian Springar Fm., Vøring Basin, Norwegian Sea.**

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Transitional and composite flow deposits (e.g. beds dominated by compositionally-banded sand and clean sand with overlying, potentially co-genetic, highly argillaceous sand, respectively) record deposition from flows with spatially and temporally variable turbulent-laminar rheologies. Accordingly, the deposits exhibit strongly contrasting reservoir quality at the bed and intra-bed scale. Predictive concepts for the distribution of intermediate and mixed rheology flow deposits are, however, in their relative infancy. The Hvithval Member of the Maastrichtian Springar Fm. comprises a south-westward dispersing deep-water system in the Vøring Basin, Norwegian Sea. Five cores have been cut along a c.150 km downstream transect; sedimentological logs totalling ~240 m were collected and analysed alongside thin-sections from key facies, conventional core plugs and continuous mini-permeametry data, in order to characterise deposit distribution.

A range of flow types, including high-density turbidity currents, transitional and composite flows, are inferred from bed types characterised by differing relative proportions of discrete depositional facies, each contrasting in their compositional and textural character. Grain-size and clay content increase downstream, with an increase in the proportion of composite and transitional flow deposits relative to turbidite deposits. Bed stacking patterns and lateral variations between wells are used to infer cycles of progradation and retrogradation. These trends suggest deposits formed from discrete process along a downstream continuum of evolving flow rheology from relatively turbulent and well-mixed flow to progressively less turbulent, higher concentration flow containing segregated distinct rheological divisions. Transformation by relative concentration increase occurred via one or more of the following: 1) entrainment of fine-grained material; 2) deceleration associated with flow expansion; 3) longitudinal segregation of sediment types. Furthermore, their occurrence alongside more distinct facies (e.g. channel bypass lags), coupled with seismic data, improves constraint on respective depositional environments. These observations aid interpretations of the spatial and stratigraphic distributions of “non-classical” deep-water deposits and wider system development.



## **Influence of subtle bathymetry on flow process and anatomy of submarine lobes: an example from Unit A, Laingsburg Formation, Karoo Basin, South Africa**

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The submarine lobe-dominated succession of Unit A, Laingsburg Formation, Karoo Basin, South Africa, shows the influence of subtle ( $<1^\circ$ ) seabed bathymetry at the time of sedimentation, which influenced sediment gravity flows and dispersal patterns. Logged sections over an S-N transect (20km) along strike permit the documentation of sedimentary facies changes within subunits A.1 to A.6. Extensive mudstone horizons documenting basin-wide shut downs serve as marker units and allow correlation of the subunits. Mapped facies distributions and thickness changes suggest that the confining slope was SE-facing, which is orthogonal to the regional paleocurrent pattern. The nature and origin of the slope is not clear, although it is not coincident with the present-day structural configuration.

There are two changes in the facies associations observed towards the confining slope, which conforms to a typical terminal lobe deposit. Laterally extensive silt-prone intervals, which were deformed syndepositional, pinch out to the SE. These are interpreted as slides and debrites that were sourced from the NW. Overall, the thickness of Unit A decreases to the NW from 300m to 140m as the proportion of deformed strata increases. The most northward outcrops display silt-prone thin-bedded successions that share close affinities to submarine levee deposits identified in other parts of the stratigraphy. The transition to this second facies association is accompanied with an overall thickening of Unit A from 140m to 180m. Increase of thickness could either result of 1) flow spilling over a seabed high or 2) construction of a levee through flow stripping and rapid deposition of dilute parts of sediment gravity flows.

The logged transect in Unit A shows how submarine lobe successions react to lateral confinement. Instead of onlapping onto the confining structure it has been observed that lobes can experience several sedimentary facies transition to compensate the relief.

## **CO<sub>2</sub> Enhanced Oil Recovery – A climate mitigation technology?**

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Carbon Dioxide (CO<sub>2</sub>) enhanced oil recovery (EOR) is a technique that has been applied commercially in the United States since the mid 1980's to enhance recovery from oil fields. Typically after both primary and secondary oil production a large percentage (sometimes exceeding 50%) of oil will remain in the reservoir. With the application of EOR techniques an additional 5-15% of the original oil in place may be recovered. In the US where large volumes of CO<sub>2</sub> are readily available from natural sources, CO<sub>2</sub> has been utilised as the primary recovery agent in EOR operations. In Europe however the lack in availability of low cost CO<sub>2</sub> has restricted development of CO<sub>2</sub> EOR. With the prospect of carbon capture technology developing across the EU, the required volumes of CO<sub>2</sub> may become available from anthropogenic sources. This availability of low cost CO<sub>2</sub> in potentially high volumes may cause CO<sub>2</sub> EOR to be economically attractive in a number of depleted oil fields in the UK and elsewhere.

This work focusses on assessing the role of CO<sub>2</sub> EOR projects in reducing anthropogenic CO<sub>2</sub> emissions, and evaluating the role CO<sub>2</sub> EOR projects may play in aiding the deployment of Carbon Capture and Storage. Work will address how CO<sub>2</sub> injection strategies into onshore low permeability fields in the US compares to modelled strategies for fields in the United Kingdom Continental Shelf (UKCS), and what affect this may have on the net carbon balance of CO<sub>2</sub> EOR operations. A review of hydrocarbon miscible gas injection in the UKCS will also be presented with findings of how effectively these projects can be used as an analogue for CO<sub>2</sub> EOR developments.

## **Links between bed type, flow processes and submarine slope channel filling – evidence from a sub-surface example**

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Submarine slope channels can have very heterogeneous fills, often including a spectrum of deposits ranging from chaotic debrites to stacked sandy turbidites. Input flow characteristics and slope gradients control overall channel grade and changes in either or both can promote cycles of incision and aggradation at a range of scales. Slope erosion can locally modify the way flows behave through bulking, overloading or providing additional confinement and forcing parts of the flow to bypass. Where flows are erosional and become charged with mudclasts and clay, they may show features intermediate between classical turbidites and debris flows (transitional flow deposits), or contain components of both turbidity currents and debris flows as part of the same event (hybrid event beds). Whereas deposits of transitional and hybrid flows are increasingly recognised in distributive lobe systems downslope from channels, the latter in particular are also seen in channels, especially where these back-fill.

This study utilises a sub-surface dataset recovered from an undisclosed slope channel system to provide insight into the distribution of bed types axially along, and transverse to, the channel. Of notable interest is the character, distribution and context of units (up to 10m thick) containing hybrid event beds (HEBs) and their relationship to other channel fill facies. The HEBs typically comprise clean turbidite sandstone with few to no mudstone clasts overlain by argillaceous sandstone or sandy mudstone with more frequent clasts; bed-tops are commonly bioturbated confusing the definition of linked debrites. The data shows the occurrence of HEBs either at the base of the channel or above embedded re-incision surfaces within it. The style of HEB becomes increasingly debritic when stacked vertically and we ascribe this to the effects of knickpoint migration as erosion back-steps upslope and progressively further from the point of deposition.

## **Driven around the bend: spatial evolution and controls on the orientation of helical bend flow in a natural submarine gravity current**

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Submarine channel systems transport vast amounts of terrestrial sediment into the deep sea. Understanding the dynamics of the gravity currents that form these systems is fundamental to predicting system architecture. In particular, understanding how flows interact with and form bends is critical to predicting how channel systems evolve. Bend flow is characterized by a helical structure and in rivers comprises inwardly directed near-bed flow and outwardly directed near-surface flow. Following a decade of fierce debate, it is now accepted that helical flow in submarine channel bends can exhibit a variety of complex structures. Most importantly, near-bed flow can be opposed to that observed in rivers. The new challenge is to understand what controls the orientation of helical flow cells within submarine flows. We present data from the Black Sea showing how three-dimensional velocity and density of a submarine gravity current evolves at multiple cross sections around a bend. By calculating the forces acting on the flow we evaluate what controls the orientation of helical flow cells. We demonstrate that radial pressure gradients caused by lateral stratification of the flow can be more important than centrifugal acceleration in controlling the orientation of helical flow cells. We also demonstrate that non-local acceleration of the flow due to topographic forcing and downstream advection of the cross-stream flow are significant terms in the momentum balance. This has major implications for conceptual and numerical modeling because it shows that three-dimensional models that incorporate lateral flow stratification are required to accurately represent curvature induced helical flow.

## **Influence of large-scale remobilisations on deep-water reservoir architecture: lessons from the Britannia Field, North Sea.**

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The Aptian deep-water Britannia Sandstone Formation, Outer Witch Ground Graben, UK North Sea hosts the extensively cored Britannia gas-condensate field. Unlike the upper reservoir zone, which is characterised by a series of thick, tabular sandstones beds, the lower and middle zones comprise a number of large-scale slope failures that interrupted the deposition of broadly tabular deposits and produced significant excavated topography. The aim of this work is to study in detail the interaction between such large-scale remobilisation and subsequently sand infill, and ultimately to characterise the architectural heterogeneity at the system scale induced by episodic slope failure.

The study is based on documentation of approximately 3000 feet of high-quality core together with wireline data from 11 wells in the densely-cored platform area. It shows that the topography of the sea floor was excavated by large-scale failures that transected and modified pre-failure sand-bodies via incision and substrate deformation. The accommodation left by large-scale remobilization has been partially healed by well-mixed debrites, probably sourced from further upslope. The balance of the accommodation has been filled by younger sandstones characterised by both banded and massive facies whose variation highlights the response of the sand-bearing flows to failure-induced seafloor rugosity.

This work, when combined with earlier studies, shows that the Britannia Sandstone Formation was controlled by a series of failure-recovery cycles, particularly evident in the lower and middle reservoir sections where depths of failure excavation were greatest. The infill deposits can form good reservoir, but have spatially restricted distributions, whereas tabular, post-healing deposits form a framework of through-going beds. The key challenge in the Britannia Field has been to identify the scale and geometry of the slope failures and their associated debrites and to understand how the sandy flows were able to smooth and restored the sea floor, thereby establishing the larger-scale reservoir architecture.

## **Sedimentology of upper Eocene red beds in Northwest China**

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The aeolian origin of the Quaternary Chinese loess has since long been recognized. Large scale dust accumulation is the final result of long-term cooling and aridification of the Asian continental climate during icehouse conditions in the Late Cenozoic. In recent years, it has been shown that deposits on the Chinese Loess Plateau down to latest Oligocene in age (25 Ma) also have at least an important aeolian component. Here, we present detailed sedimentology of upper Eocene deposits (38.5 to 34 million years ago) from the western margin of the Quaternary Loess Plateau to detect evidence of aeolian transport. Macro- and microscopic observations, grain-size distributions, clay mineralogy and quartz grain surface morphology indeed suggest aeolian processes with striking similarities to the sediments of the Chinese Loess Plateau. The clastic material of predominantly aeolian origin was likely deposited on a dry mudflat environment with warm, semi-arid to arid climate conditions where occasional local sediment reworking took place by surface water transport. These dry aeolian climate phases were alternated by pronounced wetter phases in a wet-dry climate cyclicity, where the wet part is characterized by perennial to ephemeral saline lakes.

## **Use of legacy data from hydrocarbon exploration to appraise a potential CO<sub>2</sub> store.**

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Exploration for sites for geological CO<sub>2</sub> storage is similar to exploration for hydrocarbon reservoirs. Many of the techniques, skills and data sources utilised are the same for both activities, and the role of the geologist and sedimentologist is similar. The aim of an initial appraisal of an area is to identify locations, which may be quite large geographical areas, which display suitable geological characteristics (storage 'plays'), using available data and at low cost. Key uncertainties must be identified, along with possible data acquisition that will reduce such uncertainties. Identification of an individual drill site is not expected at this stage.

Key data are well records (logs, pressures, temperatures); scarce borehole core; and in the UK at least, published descriptions of reservoirs, stratigraphy, and sedimentology. An initial screening enables potential reservoirs to be identified, along with potential seals. Analogue data from any nearby (10's - 100's km) hydrocarbon fields give confidence in reservoir and seal effectiveness. Lateral seals are identified using regional structure and stratigraphy from the available literature – these are important in the event of lateral movement of the CO<sub>2</sub>.

In the study described here a potential storage area was discovered in the Permian Rotliegend Sandstone Formation, sealed vertically by overlying evaporites, and sealed laterally by low grade metamorphic basement. Estimated storage capacity was 170 – 690 Mt of CO<sub>2</sub> along a 50 km long strike section of the reservoir. Preliminary modelling suggests that all of the CO<sub>2</sub> will be retained within the reservoir for at least 10,000 years. There are very few boreholes in the area, which limits the data available but minimizes the potential for leakage. One of the biggest risks is drilling into a previously undiscovered gas field – parts of the area may be underlain by Carboniferous coals – a hazard that most commercial ventures could probably live with!



## **Influence of silica diagenesis on physical rock properties and seal development: insights from 3D seismic reflection and well data from the Norwegian Margin**

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Diagenetic reactions in biogenic silica-rich sedimentary rocks can strongly influence their physical rock properties, and may potentially affect fluid flow and seal development within hydrocarbon-bearing sedimentary basins. The dissolution and re-precipitation of biogenic silica can cause large reductions in porosity and permeability. Two key silica diagenetic transformations are recognized: (1) biogenic silica (opal-A) to cristobalite and tridymite (opal-CT); and (2) a subsequent transformation of opal-CT to quartz (Q).

We use 3D seismic and borehole data to map the opal-CT transformation zone in the Oligocene to Miocene succession offshore Norway. The top opal-A-CT boundary is expressed as a high-amplitude reflection at 500-700 mbsf, while the basal opal-CT-Q transition corresponds to a medium-to-low amplitude reflection at 700-1000 mbsf.

Well data indicate that the effective porosity decreases relatively abruptly by 37% (from 49% to 31%) across the opal-A-CT boundary. We attribute this porosity reduction to an opal-CT cementation in the pore space. Both diagenetic boundaries are cross-cut by a polygonal fault system. Quantitative analysis of fault throws shows that 65% of the polygonal faults nucleated at the same depth as the present-day opal-A-CT boundary (+/-50m), proposing that fault nucleation is related to silica diagenesis. We suggest that the dissolution of opal-A decreased the host rock cohesion and, coupled with an increase in pore fluid pressure following the release of water during silica diagenesis, initiated polygonal faulting.

We introduce a model for the initiation of a natural, polygonal fault network due to silica diagenesis and hope to test it by a future, detailed well-cuttings analysis. We also think that the diagenetic transformation from opal-A to opal-CT decreases the porosity and permeability of the host rock, creating an effective seal. The hypothesis predicts a positive correlation between reductions in effective porosity and opal-CT contents which we plan to determine by a XRD analysis of cuttings.

## **Rise of the machines: novel insights into marine sedimentary processes using Autonomous Underwater Vehicles**

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Recent advances in Autonomous Underwater Vehicle (AUV) technology mean that they are now an essential component of the modern marine sedimentologist's tool-kit. AUVs are propeller-driven unmanned submarines that can carry a variety of payloads, including high-resolution multibeam bathymetry systems, acoustic sub-bottom profilers, high-definition colour cameras and Acoustic Doppler Current Profilers (ADCP). They can therefore be used to map the distribution and character of seafloor sediments, bedforms and other sedimentary features (e.g. scours and carbonate mounds), and collect information on active sedimentary processes, e.g. density-driven flows. The NERC AUV fleet can operate in all areas of the ocean, from the continental shelf to water depths up to 6000 m, and their independence from the host vessel means they can even be used to explore underneath ice shelves.

This paper presents a series of spectacular case study datasets collected with the NERC Autosub vehicles during recent collaborative NERC-funded projects. The case studies outline how AUV data have provided new insights into modern marine sedimentary processes, and how this has helped inform geohazard assessment and spatial conservation planning. The case studies include 1) morphology and distribution of giant erosional scours and sediment waves generated by turbidity currents on the northeast Atlantic continental margin, 2) distribution of carbonate mounds and iceberg ploughmarks off northwest UK, and trawling impacts on vulnerable cold-water coral communities, 3) distribution of mobile sediment bedforms and associated habitats in a proposed Marine Protected Area on the southwest UK shelf, and 4) ADCP imaging of a quasi-steady density-driven flow in the Black Sea, that undergoes multiple hydraulic jumps as it moves over seafloor scours within a submarine channel.

## **Bedforms in bedrock channels: Genesis and evolution using a novel modelling approach**

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Bedrock channels are an important but understudied type of river channel. Our understanding of sedimentary processes within these has been restricted by the slow rate of bedform development limiting field studies, and the difficulty of replicating such features in the laboratory. As a consequence fieldwork on bedrock channel erosion features has mainly concentrated on the geometric forms, and associated classifications. Few flume-scale experiments have been conducted to investigate the evolution process of the features on the bedrock channels, because short-period erosion on bedrock produces very limited geomorphic change, and long-period experiments are typically unfeasible. That is why, until now, there have been no studies on simulating the whole process of the genesis and development of erosional bedforms in bedrock channels.

Here we show a new way of modelling these processes on realistic time-scale using physical experiments. Essentially, bedrock features are produced by abrasion, at least for non-carbonate rocks, and this process of abrasion can be modelled by using a substrate sufficiently hard that it does not undergo erosion except by abrasion, but one that has a resistance that enables relatively rapid abrasion. Optimisation of clay beds has enabled us to successfully match clay strength and abrasion rates. The experiments reveal a suite of erosive bedforms that have clear equivalents to those observed in bedrock rivers, and yet using these experiments the genesis and evolution of each of these forms can be identified enabling a much clearer understanding of the formative processes.

## **Modelling sandstone connectivity in deep-water lobes**

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Recent progress in understanding the internal architecture of deep-water lobes has benefited from high-resolution seismic data and detailed outcrop studies, and has identified a 4-fold hierarchical geometrical arrangement involving beds, lobe elements, lobes and lobe complexes. Quantitative modelling of the hierarchy is important since understanding different scales of heterogeneity is one of the most critical factors influencing oil production from lobe reservoirs. A novel object-based numerical modelling approach (vbFIFT) is developed aiming not only to reproduce the detailed architecture within lobe complexes, but also to investigate the connectivity of sandstones within and between different hierarchical components. Input parameters include the dimensions, shapes, orientations and sedimentary properties (NTG, Amalgamation Ratios) at each hierarchical level, and are based on published datasets. The model successfully captures the 4-fold hierarchy and many of the characteristic features of deep-water lobes such-as the distal pinchout geometry, dominance of thick sandstone beds in lobe axes alternating with mudstones and thinner-bedded sandstones in lobe fringes, thickening-upward cycles and compensation stacking. A bed-scale correlation of lobes and shallow channels in the Carboniferous Ross Fm. at the eastern end of Kilbaha Bay, western Ireland, provides a 'real-world' example against which to compare the model output. The influence of unknown properties such as the boundary transmissibility at each hierarchical level can be tested by varying the input parameters, and analysis of models can help refine the underlying sedimentary parameterisation. Future work will include analysing the static and dynamic connectivity and exploring what are the key depositional factors controlling reservoir performance and flow behaviour.

# *Poster Abstracts*

## **Triassic Evolution of East Greenland.**

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The Jameson Land Basin lies within the Greenland-Norway rift, to the south of Triassic basins on the Halten Bank and East Greenland shelf, and can therefore offer insights into the evolution of these less well documented offshore basins. Continental sedimentation, which persisted through the Mid Triassic into the Early Jurassic, was largely controlled by tectonic and climatic factors. These controls have important implications for reservoir and source rock development and also for sediment delivery into the adjacent marine realm.

The Jameson Land Basin is orientated north-south, delineated by the Stauning Alper Fault to the west and the Liverpool Land high to the east. A total thickness of over 1.5 km of Mid to Late Triassic strata has been measured, predominantly comprising continental deposits laid down during arid to semi-arid climatic conditions. Initial coarse clastics of the Pingo Dal Formation are overlain by a series of finer grained fluvio-lacustrine units which form the Gipsdalen and Fleming Fjord formations.

Lateral thickness variations have been identified within the basal coarse clastic portion of the Mid Triassic succession which provide evidence for syn-sedimentary faulting. Sites where syn-sedimentary faulting has been inferred have been examined more closely through geological mapping. More detailed sedimentological analysis has also been carried out through the upper, lacustrine portion of the succession to evaluate evidence for climatic trends. Macro palaeontological and palynological studies have allowed this work to be placed in the wider regional context of the North Atlantic rift system.

## **Cretaceous Sedimentation in the Barmer Basin, India: An Ephemeral Fluvial System?**

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The depositional setting of the Cretaceous succession within the Barmer Basin, Rajasthan, India, is currently poorly understood and therefore its influence on reservoir potential is equivocal. Previous studies (Bower 2004; Clarke 2011), suggested that the sediments were deposited within a continental, fluvial setting, but elucidating their exact nature and architectures was problematical. Fluvial systems can have good reservoir potential, dependent upon the details of their depositional setting and the allocyclic influence of palaeoclimate, tectonics and sediment supply. Therefore, a detailed understanding of the depositional environment and the influences of external controls are crucial to evaluating its subsurface reservoir potential.

The Sarnoo and Darjaniyon Ki Dhani hills, in the east of the basin, expose the Lower Cretaceous aged Ghaggar-Hakra Formation. Detailed field examination of the exposures reveals textures, sedimentary structures and architectural relationships generally consistent with deposition in a fluvial setting. However, facies, associations and relationships are inconsistent with neither meandering nor braided systems.

Here, we present preliminary three-dimensional depositional facies models for the Ghaggar-Hakra Formation. Facies associations within channelised elements are inconsistent with 'standard' models, but could be a consequence of rapid, high magnitude fluctuations in river discharge and sediment load. We suggest an ephemeral, highly mobile fluvial depositional setting, to explain the facies and architectures of the channel-dominated successions. Preliminary palaeocurrent and provenance studies suggest that local and regional tectonics, coupled with climate, may be controlling the discharge variability and sediment supply.

These models demonstrate the highly varied sedimentology that can result from ephemeral fluvial systems and the resulting impact on reservoir potential. Some successions within the Ghaggar-Hakra Formation have strong reservoir potential, whilst others do not. Our work demonstrates that a detailed understanding of discharge, load, channel variability and a regional understanding of the controls upon the ephemeral fluvial system are required to assess the potential reservoir quality.



**Stratigraphic Evolution of a Low-gradient, Mixed-load Fluvial System:  
Huesca Fluvial Fan, Ebro Basin, Spain.**

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The Oligo-Miocene mixed-load Huesca fluvial fan of the Ebro Basin is well exposed along canal and road-cuts and natural canyon walls in northern Aragon, Spain. The sinuosity of the canal-cuts and canyon walls offer a unique view of the three-dimensional geometry and connectivity of architectural elements in the system. Therefore, these exposures lends well toward using terrestrial based geophysical and photogrammetric methods to better characterise the architecture of the fan sediments. A central aspect of the project will be the integration of Digital Outcrop Models (DOMs) and digital photogrammetry with standard field observations (sedimentary logging, facies analysis, photomosaic). The geostatistics derived from the DOMs will be used to build geocellular outcrop models which will allow for visualization and improved understating of the depositional systems as well as aiding in the application of the outcrop analog data to the subsurface. The end goal of the project will be to provide a conceptual model for the stratigraphic evolution of the Huesca fluvial fan, geocellular outcrop models of key parts of the exposures, geostatistical data suitable for inclusion in a database system, and an improved methodology for geocellular-modeling for these types of depositional systems.

## **Upper Devonian Elemental Chemostratigraphy of the Lennard Shelf, Canning Basin, Western Australia – Indications of Global-to-Local Environmental Changes & Utilization as a Correlation Tool**

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The Canning Basin Chronostratigraphy Project (CBCP) aims at developing alternative methods for high-resolution chronostratigraphic correlation to address problems such as subsurface data limitations and poor biostratigraphic resolution. One type of constraint is 'Elemental Chemostratigraphy', and has been widely applied and successful in siliciclastic settings. Its use in carbonate settings, however, is infantile, reflecting a lack of understanding in how elemental parameters respond in carbonate settings. Whether carbonate chemostratigraphic correlations can be viewed as lithostratigraphic or chronostratigraphic, and the nature in which base level fluctuations are detected, are examples of remaining challenges.

To address these uncertainties, elemental data have been obtained for ca. 50 elements on nearly 7000 plug and hand samples collected from outcrops and shallow cores along the Upper Devonian (Givetian Frasnian and Famennian) Lennard Shelf, Canning Basin, Western Australia. Elemental data are well-constrained within a regional framework developed from the integration of magnetostratigraphy, stable isotope chemostratigraphy, biostratigraphy, and sequence stratigraphy.

Phase 1 of the study focused on platform top settings from the Windjana Gorge area. The results show clear high-frequency trends in  $\text{Cr}/\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$  and  $\text{Zr}/\text{Al}_2\text{O}_3$ , which infer changes in heavy metal compositions, clay mineralogy and siliciclastic input. Phase 2 will introduce samples from other carbonate environments [such as the slope], and when combined with Phase 1 results, highlight local elemental trends that vary with respect to palaeogeography and depositional environment versus regional signals that appear in all settings. These elemental signals, especially those of regional significance, will offer correlation constraints that were not previously utilized and/or recognizable in traditional sequence stratigraphic practices.

## **Using Climatic Insights to Guide Stochastic Process-Based Modelling of a Valley Filling Fluvial Sequence in the Murray-Darling Basin, Australia.**

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Fluvial sequences have complex architectures due to numerous processes that interplay and control the evolution of valley filling sequences. These processes include: gradient, bedrock form, climate, vegetation, source material, tectonic and isostatic movement. The geological record shows that there is no simple set of rules to predict the river meander wavelength, lateral migration, rate of avulsion, or channel dimensions. The processes-based stochastic modelling techniques that have been developed in recent years permit including such complexities in 3D models of fluvial systems.

The aim of this study is to demonstrate that such modern process-based modelling techniques can be used to incorporate insights about past climates, and therefore improve the representation of alluvial sequences. We demonstrate the approach by simulating the evolution of the valley filling sequence in the lower Namoi catchment in Australia. These sediments were deposited from the mid-Miocene to present times, in a palaeovalley carved through Cretaceous sedimentary rocks. Pollen near the base of the sequence indicates that 11.5 million years ago the region was covered with a closed forest and received 1500 mm of rainfall per year. The onset of aridity in the Pleistocene corresponds with a marked increase in intermixed floodplain and aeolian clays. In contrast, since 1890 rainfall has averaged 658 mm per year over the instrumental period, indicating drastic changes in climatic and sedimentological conditions.

The 140 m thick lower Namoi sedimentary sequence is modelled using Flumy, a stochastic process-based algorithm. The model is constrained by 278 lithological logs, which are used to calibrate the simulations so they transition from the high energy mid-Miocene rivers to the low energy modern meandering environments. The goodness-of-fit is assessed by examining the fractal dimension of bed thickness, the transition probability (clay/silt to sand/gravel), and at each elevation the ratio of fine to coarse sediments.

**Clastic injection surface features as an indication of emplacement processes and conditions: an outcrop study from the Laingsburg area, South Africa.**

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Clastic injections can impact hydrocarbon reservoir architecture, and connectivity. For this reason they have become an increasingly important subject of research, particularly in turbiditic successions. Studies thus far have focussed on common patterns, features, and trigger mechanisms of injectite complexes using outcrop and seismic datasets. Here the flow processes involved in clastic dyke and sill emplacement are considered. The architecture of a >2 km long injectite complex situated in the submarine lobe dominated deposits of the Laingsburg Formation, Karoo Basin, South Africa was documented. The detailed textures of clastic sills and dykes include plumose patterns on the top and basal surfaces of small-scale (decimetre to metre thickness) injections as they were emplaced into a host mud. Thus preserving vital clues to mechanical processes involved in clastic injection as well as properties of the host mudstone. Preliminary results show varying types of plumose fractures most prominent at the Buffels River outcrop, suggesting the mud at the time of injectite emplacement was partially compacted providing an indication of injection depth. Changes in the type of surface texture might be related to upward or downward stepping of sills through mud(stone) with changing rheological properties, and abrupt thinning/thickening. Multiple hypotheses can be derived from this initial work to be tested in future investigations from both outcrop studies and physical modelling. Velocity of fracture propagation can be tested through physical modelling; contributing to the understanding of both the processes of injection and providing an indication of source direction.

## **The Permian ‘glass ramp’: New insights from Bellsund, Spitsbergen**

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Shallow water biosiliceous sedimentation requires a coincidence of specific palaeoenvironmental conditions. Facies and microfacies analysis are herein employed to determine the depositional setting of the spiculite-dominated, Permian Kapp Starostin Formation on Spitsbergen. Deposition took place across a low-angle, storm- and wave-influenced, laterally variable, cool-water ramp. The main environmental parameters supporting biosiliceous activity were: (1) high hydrodynamic energy, (2) normal marine salinity, (3) high silica supply, and (4) high nutrient levels; attesting to inflow of upwelling water from the Panthalassa Ocean. Variations in facies architecture during sea-level cycles, driven by changes in terrigenous influx and heterozoan carbonate production, may account for the pronounced changes in lithology between systems tracts. The diagenetic recycling of nutrients and dissolution and reprecipitation of biogenic silica during early burial resulted in a complex reorganisation of spiculitic sediments, later accentuated by multistage dolomitisation. Furthermore, new carbon-isotope data from organic matter at a boundary section between the Kapp Starostin Formation and the Triassic Vardebukta Formation indicates continuous sedimentation (~20cm/kyr) around the Permo-Triassic Boundary.

## **A database approach to fluvial facies models: example results from the Lower Jurassic Kayenta Fm. (SE Utah)**

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Traditional facies models for fluvial depositional systems qualitatively summarize the sedimentary architecture of fluvial environmental types (e.g. meandering system, terminal system) by synthesizing observations from different real-world examples, usually in the form of ideal logs or block diagrams, which could serve as reference for several general and applied problems. However, facies models are affected by some limitations: many traditional models are based on a very limited number of case studies and present information in a qualitative form. To overcome this limitation, a database approach has been established to generate quantitative fluvial facies models based on the objective synthesis of many different fluvial systems, which incorporate information derived from both field and literature datasets.

A combination of field and literature data relating to the sand-rich Lower Jurassic Kayenta Formation (SE Utah, U.S.A.) are shown to exemplify practical issues concerning the generation of facies models and to demonstrate strengths and limitations in the approach. Typical information that can be included in the model is illustrated by example database output consisting of proportions, geometries and spatial relationships of genetic units belonging to hierarchically-nested sedimentary units (architectural elements and facies units, in these examples).

Advantages of a database approach to facies modelling include the ability to: i) quantify architectural properties, ii) model on different scales of observation, iii) classify the model on multiple environmental categories; iv) synthesize many case histories objectively; and v) store and retrieve data associated with individual systems or genetic units independently. The capability to improve facies models by incorporating quantitative database-derived information has important implications for subsurface-prediction problems, since such models contain information that can be readily transferred to deterministic and stochastic models of subsurface sedimentary architecture.

## **The sedimentology, stratigraphy and provenance of the Gwna mélange deposits of the Monian Supergroup of north-west Wales and Anglesey, UK**

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The geological history of the Monian Supergroup of Anglesey and the Llŷn peninsula of north-west Wales is complex and elusive. The island of Anglesey consists of a series of elongate tectonic slices, aligned broadly parallel to the Menai Strait Fault System, south of which the pre-Ordovician geology is quite different. Extensive study in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries described the nature of many of the field relationships in the area. Subsequent research began to synthesise the Monian Supergroup into a broader geological context, at first looking for correlation with Precambrian outcrop on the Irish Sea margins and more recently assessing the potential for a Neoproterozoic peri-Gondwanan accretion association.

The ~3 km thick Gwna group is considered to be the youngest Monian unit and contains substantial, varied mélange deposits which crop out north of the Menai Strait Fault System from Bardsey Island, along the north-west coast of Wales and in various localities on Anglesey.

This research project is focussed on the sedimentology of these seemingly chaotic deposits and is concerned with understanding the depositional environments of each of the main constituent clast and matrix groups using field observation and petrographic study, leading to targeted chemostratigraphic and AMS investigations.

Main questions include;

- How many melange deposits are there?
- How are these individual deposits related to each other?
- When and how were the deposits emplaced?
- Is there a stratigraphy within the mélange?
- Can provenance of the main constituents be established?

Early observations indicate that there may be two separate mélange deposits based on the co-occurrence of clast types, modal composition, matrix foliation and clast morphology. The Neoproterozoic age (Horák and Evans, 2010, *Geol. Mag.* **148**) of some north Anglesey clasts is confirmed by the presence of molar tooth structures, a diagenetic fabric restricted to pre-Cryogenian carbonates.



## **Palaeohydrology of a rapid climate change event at the Palaeocene-Eocene boundary**

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The Paleocene-Eocene Thermal Maximum (PETM) ca. 56 Ma, represents one of the major global environmental aberrations of the Cenozoic (Zachos et al., 2001). It is characterised by a major negative carbon isotope excursion (CIE) associated with the release of between 6000 to 8000 Pg of carbon into the Earth's atmosphere, inducing a mean global warming of between 8-10°C. The carbon release is equivalent to estimates of the entire present-day fossil fuel reserves (McInerney and Wing, 2011). Therefore the PETM may be used as a possible analogue for future human-induced climate change. This project aims to investigate the behaviour of the hydrological cycle associated with the CIE and global warming.

The response of the marine realm has been well characterized (e.g. Zachos et al., 2005). However relatively few studies have documented the response of the terrestrial environment to the behaviour of the hydrological cycle at the PETM. The Tresp Formation in the Spanish Pyrenees records a regional intensification of the hydrological cycle that manifests itself as the Claret Conglomerate (CC), a laterally extensive conglomeratic braid plain, covering at least 500 km<sup>2</sup> (Schmitz and Pujalte, 2007). Rather than the CIE occurring at the Claret Conglomerate, as previously reported (Schmitz and Pujalte, 2007), high resolution  $\delta^{13}\text{C}_{\text{TOC}}$  studies of the Claret and Tendrury terrestrial sections place the onset of the CIE below the base of the Claret Conglomerate (Manners et al., in review; Domingo et al., 2009). Recent findings from the Bass River (New Jersey, USA) core, however place the onset of the CIE a few thousand years after and intensification of the hydrological cycle (John et al., 2012). This investigation will tackle the relationship of the hydrological cycle to the CIE, using both tested (sedimentological and mineralogical) and novel (isotopic) techniques.

Applying a multidisciplinary approach, the broad objective of this project is to develop a continuous and high-resolution record of the paleohydrology predating and postdating the PETM. Unravelling the nature and relative timing of environmental signals prior to, during and post the CIE, will facilitate a better understanding of the possible precursors, feedbacks, and responses of terrestrial environments, to rapid and severe climate change.

## **Process response to Holocene transgression: an integrated dataset from the Dogger Bank, North Sea**

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The Dogger Bank forms a topographic high in the southern North Sea, and was once part of the land bridge connecting NW Europe with the UK mainland that formed through a combination of terrestrial, pro-glacial and sub-glacial processes, with over-printing due to glaci-tectonic processes. Its initial formation dates from the Pleistocene, when sea level was about 120 m below today's Ordnance Datum. However, over the course of the Late-Pleistocene and Holocene, sea-level rise resulted in the Dogger Bank becoming an isolated island prior to final inundation by the North Sea after 7 ka BP. Considering the present rate of sea-level rise and the likely impacts of an elevated sea level on coastal communities and infrastructure, the study of past transgressions is paramount in the context of coastal protection and disaster mitigation.

The aim of this study is to decipher the transgressive sedimentary process response of the Dogger Bank in both paralic and littoral environments since the onset of the LGM ~ 27 ka BP. The study will integrate seabed bathymetry and imagery, closely-spaced 2D-seismic lines, and vibrocores and well-log data acquired across the Dogger Bank Round 3 windfarm zone by the Forewind consortium and BGS. This will enable the 3D-distribution of Late-Pleistocene to Holocene depositional environments and grain sizes to be mapped. Peat horizons, if present in the cores, will allow for a precise dating of the deposits, constraining the chronological evolution of the Dogger Bank. An improved understanding of the Holocene stratigraphic and sedimentary evolution of the Dogger Bank will add value to shoreline process response understanding during periods of sea-level rise, thereby refining sequence stratigraphic models for continental shelf settings, and to the North Sea Basin relative sea level curve.

**Controls on intra-parasequence facies development in shallow-marine shoreface systems: Results from a quantitative heli-lidar study in the Book Cliffs and Wasatch Plateau, Utah, USA.**

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The first order control on the distribution and dimensions of depositional elements in shallow marine reservoirs is the relative influence of waves, tides and river processes. However, even within relatively “simple” wave dominated systems there is significant variety. This is due to less well-studied second order-controls that influence intra-parasequence architectures. The aim of this work is to use quantitative techniques to improve understanding of the detailed architecture of shallow-marine deposits.

Measuring depositional elements using conventional field techniques is time-consuming and lacks precision. In the present study oblique helicopter-mounted lidar scanning was used to collect large enough volumes of spatially constrained data over very large areas of outcrop. The database consist of 40 km of outcrop models calibrated with measured sections, and covers the wave-dominated, river-influenced deposits from the Star Point and Blackhawk Formations of the Mesaverde Group, Central Utah. This dataset facilitated interpretation of facies along strike- and dip-oriented profiles for several parasequences.

The results show that three factors influence intra-parasequence facies development: bathymetry, shoreline trajectory, and proximity to fluvial input points. Shoreface systems prograding into deep water are characterized by thick facies tracts and planar beds in the offshore transition, while thinner facies belts characterize shallow-water deposits. Beds in the offshore transition become less tabular and more erosive as the shoreline approaches the deeper water that lies basinwards of the previous parasequence.. The shoreline trajectory of these systems is typically horizontal. However, there are distinct intervals which record relatively steep rises (up to 5 m). These do not dislocate the shoreline landward but manifest themselves as bedset boundaries which are associated with a significant increase in facies tract thickness and the frequency of intra-shoreface mudstone intervals. Fluvial input points in the shorelines occur as asymmetric deltas, which are characterized by a threefold increase in the amount of mudstone interbeds in the shoreface.

## **The CUMECS project, Central Mediterranean Sea: An investigation of canyon formation and processes in sediment-undersupplied margins.**

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Gravity flows are considered the dominant mechanism in canyon incision and erosion. Understanding canyon formation in sediment-undersupplied margins and explaining activity in canyons disconnected from terrestrial sediment sources systems remains challenging. Hydrodynamic processes and slope failures play a vital role in generating gravity flows and in the overall canyon development, for example through widening. At the same time, such processes are important in regulating habitat diversity and abundance, but the extent of their influence on canyon habitats is unknown because their monitoring is difficult.

CUMECS is an EU/EUROFLEETS-funded interdisciplinary project designed to address some of these unanswered questions using data collected during a recent expedition aboard *RV Urania*. The expedition focused on the Malta-Sicily Escarpment, in the central Mediterranean Sea, which is an excellent natural laboratory for such a study. This 250 km long, seismically-active fault system is incised by numerous canyons that appear to have remained isolated from inputs of fluvial/littoral sediments, even during sea level lowstands. The newly-acquired dataset consists of bathymetry and backscatter data, CHIRP and Sparker seismic reflection profiles, 9 gravity cores and ROV imagery. Preliminary investigation of the dataset using geomorphometry and core logging techniques (lithological descriptions and physical properties measured on a multi-sensor core logger) revealed evidence of shallow landslides, exposed and buried channels, densely-incised canyon heads, contouritic deposits, turbidites, deep-water coral communities, as well as fishing trawl marks and litter. Our current model suggests that canyons incising the Malta-Sicily Escarpment are primarily formed by gravity flows associated with hydrodynamic processes, widened by mass movements and that their location is controlled by tectonic structures. This study is currently in progress and more detailed analyses of the data are planned.

**Rhythmic vs Episodic: The stratigraphic record of the tidal and fluvial interactions in marginal marine, non-channelised setting (Lajas Formation, Neuquen Basin, Argentina).**

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The transition from fluvial to tidal settings includes a relatively wide zone characterized by the interaction of unidirectional fluvial currents, oscillatory tidal currents and other shallow-marine processes. Most studies on the fluvial-tidal transition have been carried out in channelized settings, thus how tidal and fluvial processes interact in non-channelized areas is not still completely understood.

The tide-influenced Middle Jurassic Lajas Formation is well exposed in several kilometres long outcrops, which offer an opportunity to investigate fluvial-tidal interactions in marginal marine, non-channelized settings. Many stratigraphic sections have been studied in detail by sedimentological logging, facies and geometry analysis. Photopanel interpretations were also made to capture architecture.

The 50 m thick study section shows an overall regressive trend, passing from marine mudstones/shell-rich beds, into subtidal-to-intertidal flat-bedded sandy-heterolithic deposits and ending with upper intertidal mudflat deposits and supratidal carbonaceous black siltstones and shales. Non-channelized tidal deposits are organized into regressive fining upward cycles (1-3 m thick) typically showing rhythmical interbedding and/or interlamination, bidirectional current ripples, 3D dunes with bundling and abundant coaly/muddy drapes. These deposits are usually cut by tidal, fluvial and tidal\fluvial channels or by moderately\well sorted tabular sandstones deposited during episodic floods due to stronger fluvial input. These latter deposits usually show erosive bases, rip-up mud clasts and small-scale load structures and may be organized into bedsets (1-2 m thick) with a coarsening and thickening upward trend.

The initial interpretation of depositional environment is that of a bay in which fluvial process can locally be dominant, but in which tidal processes prevail away from fluvial input points and at times between seasonal (?) river floods. The exact nature of the coastline is yet to be determined.

## **Source to sink analysis of the Pleistocene Wasatch catchment and eastern Great Basin**

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Source to sink studies consider the sedimentary systems holistically from the erosional hinterland to the depositional basin. Such studies are often challenged by poor constraint on key parameters controlling sediment production, transport and deposition, such as base-level and climate history, catchment source area and source area geology. The Wasatch Fault is a large active normal fault system in northern Utah. The fault zone separates the Wasatch Mountains from the Great Salt Lake Basin, which contained a very large endorheic lacustrine system during the late Pleistocene (Lake Bonneville). Climatic changes caused the lake level to drop in several discrete phases starting 14500 years bp leaving a series of distinct mapable shorelines, resulting in a total lake-level fall of 110 meter. The sediment delivered to these shorelines is derived from a series of drainage catchments linked to 5 major canyons that cut across the Wasatch Fault Zone. Each of these catchments drains a specific and very contrasting geology in the footwall of the fault. Lithologies including granite, quartzite, limestone and a soft, Triassic mudstone were eroded and then deposited as alluvial fans and fan deltas at the mouths of the different canyons. This area is thus well suited for studying source-to-sink relationships since the recent base-level history, source area geology, climate, catchment area and the subsequent shoreline deposits are all well constrained. Mapping using a lidar derived 2 m DEM, satellite images and field work were undertaken. Data were uploaded into a reservoir modelling software to calculate sediment volumes and map fan and shoreline morphology at the mouths of each of the canyon systems.

## **Seismic images of glaciogenic sedimentation and erosion offshore Norway**

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The Northern Hemisphere has been intermittently glaciated since at least 2.6 Ma. The onshore record of glaciogenic sedimentation and glacial-interglacial cycles is at best patchy and yet 95% of all glaciologists and Quaternary stratigraphers focus their work on this record. This has led to a significant bias of observations and potentially incorrect notions of the glacial history of the onshore areas.

The Pleistocene stratigraphic record offshore Norway is dominated by large-scale progradational sequences, which record the waxing and waning of ice sheets on- and offshore Norway. 3D seismic images from the offshore petroleum basins contain rich evidence for glacial activity including iceberg scours, mega-scale glacial lineations, glaciogenic debris flows, grounding-line wedges, etc.

The sequence of glaciogenic features seen within the Pleistocene deposits clearly documents a protracted glacial-interglacial history spanning the entire Pleistocene and, along with the ice-rafted debris record from deeper offshore regions, questions the notion of a dominantly Late Pleistocene glacial history of Britain and mainland Europe.

The glaciogenic features in the Pleistocene not only serve to inform our reconstructions of past climate and ice cover, but also serve as analogues for oil and gas fields in ancient glaciogenic sequences, including the Permo-Carboniferous of South America, the Middle East and Australia and the Ordovician of North Africa, and the Middle East.

Base of slope fans, leveed channels and grounding-zone wedges are among the reservoir scale deposits that originate from glacier-front sedimentation and are beautifully imaged by 3D seismic data from the Pleistocene offshore Norway. Large-scale glaciotectonic deformation is also clearly seen in the offshore records and provides evidence for the load and stress transfer associated with grounded glaciation and thus is an important part of the subsurface record of glacial-interglacial fluctuations.



## **Facies Architecture of the Triassic Wolfville-Blomidon Transition, Bay of Fundy, Nova Scotia, Canada: Implications for Reservoir Characterization and Modelling**

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Outcrop studies of the Wolfville-Blomidon transition provide useful insights to reservoir architecture of subsurface equivalent deposits offshore Nova Scotia, North Africa and the North Sea. The well exposed outcrops of Late Triassic fluvial and lacustrine sandstones in the Fundy Rift Basin of Canada present exceptional analogues for detailed facies architectural investigations. The primary aim of this research is to understand fluvial depositional processes and characterize fluvial deposits quantitatively in three-dimensions, and using the resulting geostatistical information to produce realistic geocellular reservoir analogue models. Traditional sedimentological field methods are combined with lidar digital data capture techniques to describe and interpret facies geometry and distribution. Changes in facies distribution and architectural style are used to subdivide the stratigraphic succession into two parts. The basal section (upper Wolfville) consists of channel sandstone bodies alternating with limited overbank mudstone deposits. Within the upper Wolfville Formation, a dominant trend of upwards finning is observed with sedimentary structures ranging from ripples, parallel lamination, planar to trough crossbedding. Whereas the upper section (lower Blomidon) is dominated by laterally continuous fine sand to muddy units interpreted as lacustrine deposits. The geostatistics derived from both lidar and traditional field mapping have been used to build a geocellular outcrop model of the Wolfville-Blomidon transition area. The final model shows the differences in heterogeneity between the sandy braided fluvial Wolfville Formation and overlying Blomidon Formation dominated by sheetflood sandstones and interbedded extensive playa mudstones.

**The use of noble gases as effective early warning tracers of CO<sub>2</sub> migration in engineered CO<sub>2</sub> storage sites.**

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The capture and long term storage of CO<sub>2</sub> in the subsurface is one of the most promising ways of mitigating the current level of anthropogenic CO<sub>2</sub> being released to the atmosphere. A major issue surrounding long term storage is the risk of failure of CO<sub>2</sub> containment. Developing an early warning monitoring strategy for CO<sub>2</sub> leakage would allow measures to be implemented to reduce the impact of containment failure. Engineered storage sites can be monitored before, during and after the injection of CO<sub>2</sub>. Engineered storage sites allow the opportunity to artificially fingerprint the injected CO<sub>2</sub> with a unique and distinct signature using tracers. Monitoring how noble gases behave under the same petrophysical conditions relative to CO<sub>2</sub>, indicate that they could behave as an early warning for CO<sub>2</sub> movement. Using experimental equipment, constraints affecting the transport of the noble gases relative to CO<sub>2</sub> are investigated. Initial travel time experiments using Ar and CO<sub>2</sub> independent of rock properties, have determined the parameters required for complete mixing of the gases. Core flow transport experiments using CO<sub>2</sub> and noble gases will be undertaken on different rock core samples - including porous sandstones and less porous fractured mudrocks. Parameters affecting the advective and diffusive flow and transport of noble gases relative to CO<sub>2</sub> will be examined under realistic in situ conditions. Resulting data will establish which noble gases could behave as early warning tracers in CO<sub>2</sub> migration.

## **Pleistocene glaciations of the North Sea using basin wide 3D Seismic data**

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The knowledge and understanding of the imprint of Pleistocene glaciations on the North Sea basin has to date relied mostly on widely scattered boreholes and 2D seismic profiles. Recent work utilising 3D seismic data have made significant progress in improving understanding, albeit on a relatively local scale. The aim of this project is to use extensive high-quality 3D seismic data, acquired for the hydrocarbon industry, to look at the glacial successions and related geomorphological features of the Central and northern North Sea on a basin scale. Particular emphasis will be placed on early evidence for glaciations and the chronology and manifestations of changing glacial – interglacial conditions throughout the Pleistocene.

The project will use Petrel and GIS software with the PGS Central North Sea merged 3D seismic MegaSurvey to build up a basin-wide stratigraphy of Quaternary deposits calibrated to well and borehole data provided by the British Geological Survey. Geomorphological features such as tunnel valleys, ice-berg scours and mega-scale glacial lineations will also be mapped and integrated into the stratigraphic framework.

Part of the project will utilise new high-resolution 2D seismic data acquired in the Dogger Bank region for the wind power consortium Forewind in conjunction with the BGS. The Dogger Bank study area provides an excellent high-quality comparison of a glaciogenic succession which will be incorporated into the 3D survey and used to correlate glacial units and landforms across the North Sea Basin.

Initial work has included the mapping of a mid-Miocene horizon over the entire study area and the identification of a number of geomorphological features including a previously unstudied tunnel valley in the eastern part of the dataset. The current focus of the project is the identification of a base Pleistocene seismic horizon calibrated using published studies and borehole data from the BGS.

## **Deciphering sedimentary recycling via multiproxy *in situ* analyses.**

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Sedimentary rocks and modern sediments sample large volumes of the Earth's crust, and preserve units that vary greatly in age and composition. Determining the provenance of component minerals is complicated by the ability of some minerals to be recycled through multiple sedimentary cycles. To untangle these multi-stage signals, two or more chemical signatures measured in minerals with different stability are required, such as Pb in K-feldspar and U–Pb/Hf in zircon.

One sedimentary succession suitable for testing this hypothesis is the Upper Carboniferous Millstone Grit Group, a fluvio-deltaic, upward-coarsening sequence of mudstones, sandstones and conglomerates deposited in the Pennine Basin of northern England. New K-feldspar data clearly indicate two dominant populations with  $^{207}\text{Pb}/^{204}\text{Pb}$  ratios of c. 13.5 and 18.5, consistent with Archaean–Palaeoproterozoic and Caledonian material, respectively. Zircon U–Pb data from the same rocks record two peaks at c. 400 and 2700 Ma, most likely corresponding to the two K-feldspar peaks, while a broad spread of U–Pb ages between 900–2000 Ma have no direct corollary and are most likely recycled. Zircon Hf model ages form two broad peaks at c. 2000 and 3300 Ma, indicating the Caledonian granites are derived from reworked older crust and their common Pb ratios were reset during crystallisation.

These distributions are consistent with a stable source area stretching from Labrador to Scandinavia, including younger material from Scottish Caledonian granites or their offshore correlatives. Hf model ages are the least useful for fingerprinting unique source rocks, but can discriminate between single and multiple sources for each U–Pb population. Changing proportions of both K-feldspar and zircon distributions within the Group may correspond to changes in environmental or storage conditions within the feeder river system. Further work is needed to quantify the processes controlling these fluctuations, and the possible biasing of effect of grain size on zircon age distributions.

## **High-resolution coal correlation of the Walloon Coal Measures, Surat Basin, eastern Australia**

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Despite an ever-growing wealth of well data associated with ongoing coal seam gas [synon. coal bed methane] exploitation in the Surat Basin (SE Queensland) coal body lateral extents and geometries have not yet been closely examined.

During a 6-month placement, as part of BG Group's Graduate Development Programme, a project conducted to investigate the coal body architecture provided interesting insights into coal development within part of this intracratonic basin. The study focused on the correlation of plies and seams within the Walloons Coal Measures. Key emphasis was placed on better understanding the areal extent of these Mid Jurassic coals and their association with the fluvio-lacustrine, non-coal interburden.

Although very much in its infancy, the study forms part of a larger ongoing project, to construct a robust, regional correlation framework in the Walloons across BG/QGC acreage in the Surat Basin; integrating sedimentological, bio- and chemostratigraphical analysis.

Experimental techniques involving surface mapping of interburden deposits with lithology pie chart overlays have allowed channel system orientations and geometries to be interpreted, using 120 wells from the Berwyndale South block (Central Surat QGC/BG acreage). Derived palaeoflow orientations corroborate published literature for Surat Basin channel sands observed from outcrop locations.

A detailed high-resolution analysis of coals encountered within a single key well reveals the areal extent of a collection of coal plies and seams and their varying geometries. The results are compiled on an area versus maximum thickness graph. Some of the coals clearly extend beyond the limits of the 67.4 km<sup>2</sup> study area and many exceed the local open-cast mine economic coal extent of approximately 9 km<sup>2</sup>. Implications of these results include increased accuracy for reservoir modeling and gas-in-place calculations in addition to potential modifications to future well planning in the Surat Basin.

## **Linkage between the geometry and evolution of clinoforms, and slope gullies, Dampier Basin, North West Shelf, Australia**

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Determining the morphology and distribution of basin margin-scale clinoforms is key to understanding the development and evolution of slope gullies in Eocene-to-Miocene strata of the Dampier sub-basin, North West Shelf, Australia. Seven clinoforms were mapped in a high-resolution 3D seismic dataset which covers 7700 km<sup>2</sup>. The seismic facies within the clinoforms has been analysed, and has been tied to well data to infer lithology variations within different clinoform sets. Furthermore, the shape of each clinoform has been quantified using various morphometric parameters, such as clinoform height, length and dip. Foresets steepen as the clinoforms prograde into the basin, and clinoform trajectory analysis shows that there is a distinct change from a predominantly progradational to an aggradational stacking pattern. Gullies are particularly common near the top of Middle Miocene age clinoforms, although narrow and shallow precursor gullies can be imaged in older strata. The slope gullies are observed to initiate as narrow, single, closely-spaced features that coalesce through time. The progradational-to-aggradational clinoform trajectory implies an abundant supply of siliciclastic sediment to the margin of the North West Shelf at this time, while gully development indicates sediment transport beyond the shelf edge during Middle Miocene times. These results are consistent with high sediment and water discharge on to the shelf during a period of warm, wet climate, and sea level highstand conditions during the mid-Miocene.

## **Adaptive finite element simulations of sediment laden density currents.**

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Density currents, also known as gravity currents, occur wherever two fluids with different densities meet. The density difference creates a pressure gradient that causes the more dense fluid to intrude beneath the less dense fluid. Density currents can occur at very large scales in the ocean when continental shelves collapse. The discharged sediment increases the bulk density of the fluid in which it is suspended. As the flow is diluted by entrained fluid turbidity currents form that can carry sediment hundreds of kilometres, at speeds of up to a hundred kilometres per hour, over the sea bed.

These currents can be tsunamigenic and they have the potential to cause significant damage to submarine infrastructure, such as submarine telecommunications cables or oil and gas infrastructure. They are also a key process for movement of organic material into the depths of the ocean. Due to this, they play an important role in the global carbon cycle on the Earth, they form a significant component of the stratigraphic record, and their deposits can form useful sources of important hydrocarbons.

Modelling large scale sediment laden density currents is a very challenging problem. Particles within the current are suspended by turbulence that occurs at very short length scales in comparison to the size of the current. Models that resolve the vertical structure of the flow require a very large, highly resolved mesh, and substantial computing power to solve. In our work we have been using the Fluidity model to simulate these currents with an adaptive unstructured mesh. The mesh requirements are reassessed at regular intervals. In areas where solution gradients are high the resolution is increased. Conversely, where gradients are low the resolution can be decreased. This results in a minimum number of elements, and decreased processing requirements for these very demanding problems.



## **The enigmatic evaporites of the Aptian Ariri Formation, Santos Basin, Offshore Brazil: new insights from 3D seismic and well logs analysis**

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The Santos Basin has been the focus of attention in recent years due to the major hydrocarbon discoveries made beneath a 2 km thick salt layer. This Aptian-age salt sequence is the main seal and a major control on the structuration of the basin. Although several wells have been drilled into the salt, few studies have attempted to characterize the depositional stratigraphy and its impact on salt-related deformation in the basin.

In order to investigate the depositional stratigraphy of the Ariri Formation, integrated analysis of 3D seismic and well data was undertaken. A combination of well logs was used to interpret the lithology and to define key stratigraphic intervals for regional correlation. In addition, seismic mapping and attribute analysis were used to infer the lithology and stratigraphy between the wells.

Our study shows that the Ariri Formation is composed of anhydrite, halite and K-Mg salts. Overall, four key stratigraphic intervals are recognized: (i) a variably-thick, lower halite-rich unit (A1), which overlies the lacustrine carbonates of the Barra Velha Formation. A1 consists of transparent, chaotic seismic facies that contain strongly-reflective stringers of other evaporites; (ii) a thick, strongly-reflective unit (A2) consisting of interbedded anhydrite, halite and K-Mg layers; A2 can be correlated for several kilometres and it is characterized by minor syn-depositional thickness variations associated with movement of the lower halite (A1); (iii) a relatively thin, transparent upper halite-rich unit (A3); and (iv) a strongly-reflective sequence (A4) that thins and is truncated near the larger salt structures.

Our observations reveal Aptian-age syn-depositional deformation possibly related to pre-evaporite basin configuration, reactivation of rift-related extensional faults and/or by tilting of the margin. This supports a multi-stage tectono-stratigraphic evolution for the Ariri Formation and suggests a relationship between the depositional stratigraphy as well as the timing and nature of salt-related deformation in the basin.

## **Modelling facies distributions and heterogeneity in aeolian reservoir successions.**

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Based on the reconstructed morphology, scale and style of migratory behaviour of bedforms from a variety of aeolian outcrop and subsurface reservoir successions, a series of semi-quantitative sedimentological models have been developed to predict the three-dimensional distribution of facies and architectural elements present in a variety of types of dry and wet (water-table-controlled) aeolian successions. Models account for the likely mode of evolution of dune and interdune systems and the mechanisms that dictate their style of preservation. Models describing the stratigraphic architecture typically present in several types of aeolian succession provide quantitative estimates of likely three-dimensional sand-body geometries. The equivocal nature of the data means that a range of probable dimensions is proposed for each model. These are sufficient to define the scale and shape of architectural elements that can be used, for example, for the development of reservoir models and for the assessment of the sensitivity of such models to the range of estimates provided.

Interpretations made regarding the gross-scale morphology and style of migratory behaviour of a variety of modern and ancient aeolian successions have been used as input to several numerical modelling software programs (both publically available and in-house developed). These software packages model the expected two- and three-dimensional patterns of dune and interdune elements and the erosive bounding surfaces generated by the migration and climb of a series of bedforms. Once the architectural framework of the succession has been modelled, aeolian facies are mapped onto the preserved set architectures based on distributions predicted from quantitative assessments that describe how aeolian facies types are distributed in similar modern dunes and in ancient aeolian successions exposed in outcrop. The geometry, scale and degree of inter-connectedness of the various architectural elements and the facies that they contain can then be assessed and used as input for reservoir models.

**Palaeo-oxicity changes across the Rhuddanian-Aeronian boundary (Silurian) in the Cwmere Formation, Rheidol Gorge, Wales**

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The latest Ordovician to early Silurian Cwmere Formation of central Wales has been characterised as a mudrock unit laid down in consistently anoxic sea floor conditions, following the major transgression after collapse of the end-Ordovician glaciation; the formation is correlative with major oil source rock units in Saudi Arabia and elsewhere. Detailed analysis of the classic Rheidol Gorge section has shown, though, a closely-spaced succession of oxic-anoxic changes around and just preceding the biostratigraphically-constrained Rhuddanian-Aeronian boundary. The lithological expression of these oxicity changes is demonstrated through burrowed sediments and pyrite bands, and the stratigraphic succession is compared with sea level changes recently inferred in the shelf type Llandovery succession to the south-east in Wales.

## **The impact of early land plants on continental sedimentation: the Old Red Sandstone in the Midland Valley (Scotland, UK)**

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This research examines the extent to which current models are effective in accounting for the role played by early vegetation in governing the sedimentation process. Fieldwork undertaken in NE Scotland has investigated the Silurian to Early Carboniferous Old Red Sandstone in the Midland Valley. The succession comprises a near-complete record of sedimentation through the 9 km-thick ORS deposits, which, since it covers the main episode of land plant colonization, is one of the most appropriate successions known globally with which to develop an understanding of the interplay between early land-plant evolution and fluvial sedimentation.

Although simple plants were present in the LORS, the progressive colonization of the fluvial plain by land plants was apparently not matched by a related increase in the occurrence of mudrock in the Midland Valley, as predicted by existing models of weathering processes. Indeed, preservation of mud-prone deposits is more prevalent in the Middle-Silurian LORS than in the Middle Devonian LORS, a situation interpreted here as a consequence of environmental conditions. The interplay between climatic conditions and land-plant colonization is recorded by other sedimentological factors: Middle-Silurian deposits do not preserve calcrete nodules, whereas Middle Devonian deposits preserve localized examples of concretions in overbank deposits, as well as re-worked clasts of calcareous mudstone; the Early Carboniferous succession (Upper ORS) records abundant examples of calcrete horizons and hardpans, and prolific occurrences of rootlets (rhizoliths and rhizocretions), recording the enhanced effects of biogenic surface stabilization by this time. Results record not only increasing biogenic control on continental sedimentation through time, but also document the establishment of a semi-arid climatic setting in the region from the Middle Devonian to the Early Carboniferous. This research is contributing to an improved understanding of the main controls on landscape evolution during the early phases of land colonization by vegetation.

Acknowledgments: this work was supported by awards from the BSRG Steve Farrell Memorial Fund and the IAS Postgraduate Grant Scheme

## **Sedimentology of fluvial and tidally-influenced channel-to-overbank transitions in low- and high-accommodation settings: Neslen Formation, Utah, USA**

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The Upper Cretaceous (Campanian) Neslen Formation, Mesa Verde Group, is well exposed over a 120 km-long strike transect along the Book Cliffs of eastern Utah and is composed of sandstone, siltstone, carbonaceous mudrock, coal and rare mud-chip conglomerate. These deposits accumulated in a meandering fluvial system that traversed a low-relief, low-gradient coastal plain passing seaward into a paralic coastline and shallow marine setting at the margins of the Western Interior Seaway.

The Neslen Formation has been studied via vertical measured profiles and stratigraphic panels between Floy and Thompson Canyons, a 7 km-long, 100m thick section, which is representative of a tidally-influenced part of the lower fluvial plain.

The aim is to document the depositional architecture and to develop a series of quantitative depositional models that account for the dispersal of sediment from major channelized elements to neighbouring floodplain sub-environments via crevasse splays and distributary channel networks. A range of sedimentary structures, including wavy, flaser and lenticular bedding, inclined heterolithic stratification, brackish water ichnofacies, mudstone drapes, wave-ripple strata, mud-chip pebbles, reactivation surfaces and herringbone cross-bedding; demonstrate that the fluvial channel elements in the lower part of the succession were significantly influenced by tidal processes. Overall, the preserved thickness of sand bodies representing channel elements increases up-succession, and each successive sand-body records a progressive increase in the dominance of fluvial processes over tidally-influenced processes. By contrast, intervening floodplain mudrock and coal packages decrease in thickness upwards as elements representing channel complexes become amalgamated. Thus, the succession records the overall progradation of the coastal plain with an inferred change from a higher-accommodation setting in the lower part to a lower-accommodation setting in the upper part. This studied succession is interpreted to record a maximum flooding surface at the base of the succession (transgressive shell debris lag) followed by a major highstand system tract.

## **Some (preliminary) observations and thoughts on the Favignana Calcarenite (Sicily, Italy).**

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The eastern side of Favignana Island (19 km<sup>2</sup>), western Sicily, consists of Pleistocene calcarenites with a maximum observed thickness of 50 metres. These are characterised by a wide range of prograding sediment bodies comprising mainly (very) coarse, (in places) very porous grainstones. The preliminary results of lithofacies and microfacies analyses are presented here.

**Lithofacies** – High-energy structures (e.g. horizontal to undulated plano-parallel beds, with parting lineation, crudely stratified beds and scour fills, antidunes, cyclic steps?) and low-energy structures (e.g. small-scale trough cross-bedding, large sets of stacked tabular cross beds) occur together. Occasionally, sediments are covered by microbial mat deposits with a lateral continuity up to tens of metres, which stabilised the sediment surface and prevented erosion. Additionally, large scale scours (<50 m wide and <30 m deep) with homogenous, poorly sorted infills were observed.

**Microfacies** – Biological assemblages are composed of fragmented red algae, bryozoans, echinoids and (mainly benthic) foraminifera with, in places, rhodoliths and/or well preserved mollusc shells. Microfacies are of heterozoan origin indicating relatively cool-water conditions. This is confirmed by the presence of so-called Boreal Guests (e.g. *Arctica Islandica*) at the base of the wedge which have been dated by strontium isotope stratigraphy at 1.29 ± 0.07 Ma.

The combined observations reflect bi-modal deposition characterised by either low-energy currents or supercritical currents, probably on a cool-water carbonate ramp. Up to 4 m thick turbidite-like facies occurring together with facies normally associated with shoreface deposits do not point to a conclusive depositional environment. For the moment, it is unclear whether low-energy cross lamination (indicating southward paleotransport) was created by ramp-parallel or down-ramp currents. What about the inferred super critical currents? A possible explanation may come from the paleoceanographic configuration resulting in the funnelling of storm or tsunami-induced currents travelling southwards through the Tyrrhenian Sea, favouring the down-ramp interpretation.

## **Stratigraphic architecture of a back-filled incised-valley system; Pennsylvanian–Permian lower Cutler beds, Utah, USA**

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The lower Cutler beds (Pennsylvanian to Permian) represents the lowermost formation of the Cutler Group in the Paradox Basin of southeast Utah. The lower Cutler beds is a tripartite succession that comprises, in near equal proportion, lithofacies assemblages of aeolian, fluvial and shallow-marine origin, deposits of which record a complex set of competing interactions between coeval depositional systems. The succession records a series of transgressive-regressive sequences, the origin of which was driven by repeated episodes of climatic variation and linked changes in relative sea-level, within which highstands can be demonstrably linked to phases of increased climatic humidity, whereas lowstands equate to relatively more arid climatic phases. Changes in base level associated with relative sea-level variations led to fluvial incision and the generation of a series of incised valley systems during falling-stage and lowstand episodes. Subsequent transgressive and highstand episodes resulted in the back-flooding of these incised valley systems and their infill via shallow-marine and estuarine processes. Back-flooding generated broad marine embayments, where additional local accommodation space was infilled by a distinctive suite of lithofacies arranged into architectural elements representing a lowermost basal fill of fluvial channel and overbank elements, passing upwards into barform elements with indicators of tidal influence, including inclined heterolithic strata, brackish water ichnofacies, mud-drapes and reactivation surfaces. The incised-valley fills are capped by laterally extensive and continuous limestone elements that record the drowning of the valleys and, ultimately, flooding and accumulation across surrounding interfluvies. Limestone elements preserve an open-marine fauna and represent the preserved expression of maximum transgression. These back-filled incised valley systems are of particular interest since they represent a type of shallow-marine and shoreline succession that has hitherto received little detailed study regarding the sedimentary response to a complex set of coeval autogenic and allogenic processes.



**Fluvial point bar architecture produced by ephemeral flows in a semi-arid climate, lower Beaufort Group (Permian), Karoo Basin, South Africa.**

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Meandering stream facies models are based largely on studies of Holocene perennial rivers from European temperate climates. Recently authors have highlighted the shortcomings of using these facies models to interpret rock record fluvial deposits laid down in other climate and discharge regimes (e.g. Fielding et al. 2009). We assess the control of climate regime on fluvial architecture by comparing point bar architecture from Permian Beaufort Group strata, deposited in a semi-arid climate, to facies models for perennial temperate streams. The Beaufort Group fluvial deposits in South Africa's Karoo Basin were laid down in an intracratonic basin at a palaeolatitude of 30°S. Mean annual temperatures were 16-20°C and precipitation was in the range 500-800mm per year delivered by infrequent summer rainstorms, which led to flashy ephemeral discharge (Smith 1990). The effect of these conditions on sedimentary processes and the architecture of fluvial strata are diverse - including early surficial lithification of overbank splays, and channel fill deposits containing components of peak and waning flow conditions from a range of magnitude-frequency events. Point bar architecture in the Beaufort Group is the product of a three-phase process: (1) sandy lateral accretion from low magnitude-high frequency flood events, followed by, (2) scour from high-magnitude low-frequency events producing local channel straightening and sediment bypass, followed by, (3) slackwater ponding leading to settling of mud in ephemeral ponds along the river channel. The product of these cycles of deposition is a heterolithic, irregular point bar architecture with abundant internal scour and muddy trunk and chute channel fills. Recognition of the effects of ephemeral discharge regimes on point bar architecture, as they differ from those in perennial streams, will help to explain some non-standard architectural features in other channel belt styles.

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