



**National
Oceanography Centre**

NATURAL ENVIRONMENT RESEARCH COUNCIL

BSRG 2010

Conference programme

National Oceanography Centre, Southampton

19-21 December 2010

Convenor: Dr Russell Wynn

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BSRG 2010: Outline programme

Sunday 19 December 2010	
09.00 - 17.00	Fieldtrip to the Isle of Wight
10.00 - 13.00	Core workshop (Sponsored by ExxonMobil) Session 1
14.00 - 17.00	Core workshop (Sponsored by ExxonMobil) Session 2
18.30 – 20.00	Icebreaker reception (drinks and canapés)
20.00 - 21.30	Icebreaker talks

Monday 20 December 2010	
09.00 - 10.30	Plenary sessions: <ul style="list-style-type: none"> • Deep-water processes (Lecture theatre) • Carbonates and diagenesis (Seminar Room)
10.30 - 11.00	Coffee and posters
11.00 - 12.30	Plenary sessions: <ul style="list-style-type: none"> • Glacial processes (Lecture theatre) • Fluvial processes (Seminar Room)
12.30 - 13.30	Lunch
13.30 - 15.00	Plenary sessions: <ul style="list-style-type: none"> • Tectonic & climatic influences (Lecture theatre) • Oil & gas (Seminar Room)
15.00 - 16.00	Coffee and dedicated poster session
16.00 - 17.00	Plenary sessions: <ul style="list-style-type: none"> • Tectonic & climatic influences (Lecture theatre) • Deep-water processes (Seminar Room)
17.00 - 18.00	BSRG AGM
19.00 (sharp)	Coaches depart for conference dinner
12.00 midnight	Coaches return to NOC

Tuesday 21 December 2010	
09.00 - 10.30	Plenary sessions: <ul style="list-style-type: none"> • Deep-water processes (Lecture theatre) • Shallow water & coastal processes (Seminar Room)
10.30 - 11.00	Coffee and posters
11.00 - 12.30	Plenary sessions: <ul style="list-style-type: none"> • Tectonic & climatic influences (Lecture theatre) • Sedimentary processes (Seminar Room)
12.30 - 13.30	Lunch
13.30 - 15.00	Plenary sessions: <ul style="list-style-type: none"> • Sedimentary processes (Lecture theatre) • Deep-water processes (Seminar Room)
15.00 - 15.30	Coffee and posters session
15.30 - 17.00	Plenary sessions <ul style="list-style-type: none"> • Shallow water & coastal processes (Lecture theatre) • Deep-water processes (Seminar Room)
17.00	Conference close

Monday 20 December 2010			Venue: Seminar Room
	Venue: Lecture Theatre		
	Session 1A: Deep-water processes Chair: Russell Wynn		Session 1B: Carbonates & Diagenesis Chair: Peter Burgess
0900-0920	Stevenson et al. Fluid mud generated grain size breaks in turbidites: what can they show us about flow processes?		Humphrey, C.F.. Criteria for interpreting carbonate platform drowning histories and resultant diagenetic fabrics: insights from the actively subsiding platform margins of Hawaii
0920-0940	Patacci et al. Basal Flow Reversals within Ponded Turbidity Currents		Hendry, J. Petrography and diagenesis of silicified aragonitic mollusc shells, Lower Cretaceous limestones, Dorset, UK
0940-1000	Talling et al. New Insights into Submarine Sediment Density Flows and Their Deposits		Alrabib & Taylor Porosity characterization and its destruction by authigenic minerals: reservoir sandstones, Mamuniyat Formation, Murzuq Basin, SW Libya
1000-1030	Keynote talk: David Piper 70% of all turbidites are hyperpycnal!		Keynote talk: Cathy Hollis (Carbonates and diagenesis) Carbonate diagenesis - process, product and predictability
1030-1100	Coffee + posters		Coffee + posters
	Session 2A: Glacial processes Chair: Doug Masson		Session 2A: Fluvial processes Chair: Arjan Reesink
1100-1130	Keynote talk: Julian Dowdeswell A view from the sea: the marine sedimentary signature of past ice sheets		Keynote talk: Jan Alexander Extreme fluvial events
1130-1150	Stewart et al. Seven glacial cycles in the Middle-Late Pleistocene of NW Europe: geomorphic evidence from buried tunnel valleys		Reesink et al. Diversity in bar sedimentology in a single large river: the Rio Parana, Argentina
1150-1210	Langford, H.E. Glacial-lake Deltas or Tunnel-valley deltas? Middle Pleistocene glacial deposits of the Peterborough area, eastern England		Banham et al. Sedimentary character of pre- and post-vegetation fluvial fan successions: comparison of the Precambrian Applegate Formation of Torridon with Permian-Triassic examples
1210-1230	Tyrell et al. New constraints on the provenance of Late Quaternary ice-rafted debris, offshore western Ireland.		Wood et al. Sedimentary Characterisation and Depositional Mode of the Messak Fm, SW Libya
1230-1330	Lunch		Lunch

	Session 3A: Tectonic & climatic influences Chair: Sarah Davies	Session 3B: Oil & gas Chair: Jon Noad
1330-1400	Keynote talk: Niels Hovius Seismic, meteorologic, and geomorphic events, and the patterns of sediment sourcing in an active mountain belt	Keynote talk: Stuart Haszeldine and Mark Wilkinson Carbon Capture and Storage - what's it got to do with you?
1400-1420	Robertson & Tasli Sedimentary evidence of the northerly, active margin of the S Neothetys ocean during Late Cretaceous-Early Cenozoic time: evidence from the Kyrenia Range, Cyprus	Gladstone & Woods Oil plumes rising through deep water
1420-1440	Nairn et al. Tectonic-sedimentary development of the Upper Cretaceous-Middle Eocene Kırıkkale Basin, Central Anatolia, Turkey	Jackson et al. Depositional elements within the Brent Delta (Middle Jurassic) of the North Sea Basin visualised using 3D seismic data
1440-1500	Venus et al. The Interaction of Salt Tectonics and Fluvial Sedimentation: A Case Study from the Permian Cutler Group, SE Utah, USA	Noad, J. The Sedimentology of Resource Plays
1500-1600	Coffee and dedicated poster session	Coffee and dedicated poster session
	Session 4A: Tectonic & climatic influences Chair: Gary Nichols	Session 4B: Deep-water processes Chair: Chris Jackson
1600-1620	Booth, M. The Tectono-Sedimentary Evolution of the Darende and Hekimhan Basins, Central Eastern Turkey	Kilhams et al. Characterising the Paleocene Submarine Fans of the UK Central North Sea (Mey Sandstone Member): Observations from Seismic, Petrophysical and Core Analysis
1620-1640	Andrews et al. Magadi-type chert recorded in East Greenland: evidence for a mid Triassic marine incursion	Pierce et al. Deep-water fan to base-of-slope transition in the Clare Basin, western Ireland, new constraints from behind-outcrop coring
1640-1700	Le Heron, D.P. Sea ice-free conditions during the Sturtian glaciation (early Cryogenian), South Australia	Prelat et al. Integrating outcrop sections and research boreholes to understand the internal organisation submarine lobe deposits
1700-1800	BSRG Annual General Meeting	
19.00 sharp	Coaches depart NOCS for conference dinner	

Tuesday 21 December 2010			Venue: Seminar Room
	Venue: Lecture Theatre		
	Session 5A: Deep-water processes Chair: Peter Haughton		Session 5B: Shallow water & coastal processes Chair: Gary Hampson
0900-0920	Elliott et al. Footwall erosion and sediment pathways in a gravity-driven fault system: An example from the Jurassic Bremstein Fault Complex, Offshore Mid-Norway		Jones et al. Linking The Slope To Shelf: An Example From The Laingsburg Depocentre, Karoo Basin, South Africa.
0920-0940	Georgiopolou et al. New insights into emplacement of the Rockall Bank Mass Flow, offshore western Ireland		Legler et al. Facies-belt pinch-out relationships in a distal, mixed-influence shallow-marine reservoir analogue: Lower Sego Sandstone Member, western Colorado, U.S.A.
0940-1000	Benetti et al. Geomorphological and sedimentological record of glaciation on the western Irish continental margin		Howell et al. Quantitative Bedform Architecture from Virtual Outcrop Data
1000-1030	Keynote talk: Jeff Peakall Faith, reason, and enigmas: the troubling case of submarine channels		Keynote talk: Peter Burgess Measuring and modeling carbonate strata: Patterns and prediction from platforms to beds
1030-1100	Coffee and posters		Coffee and posters
	Session 6A: Fluvial processes Chair: Adrian Hartley		Session 6B: Sedimentary processes Chair: Jaco Baas
1100-1130	Keynote talk: Paul Carling Megaflood sedimentation in the Altai Mountains of Siberia: what can we learn about generic processes?		Keynote talk: Andy Manning Depositional characteristics of natural cohesive sediments
1130-1150	Robinson et al. Palynomorphs deposited in prodelta rhythmites of the palaeo-Colorado delta in the Fish Creek-Vallecito basin, southern California as indicators of high altitude catchment environments.		Sumner et al. As clear as mud
1150-1210	McArthur et al. Late Jurassic slumping in the J Block region of the UKCS Central Graben: temporal and spatial relationship to deep marine turbidite reservoirs		Verhagen et al. Turbidity currents over muddy substrates: Evidence for flow acceleration over a horizontal bed
1210-1230	Vincent et al. Tectonic controls on sediment input into the NE Black Sea -		Eggenhuisen et al. Fluid pressure in turbidity currents: A hidden variable in deepwater

	implications for hydrocarbon reservoir quality	sedimentology.
1230-1330	Lunch	Lunch
	Session 7A: Sedimentary processes Chair: Lotty Gladstone	Session 7B: Deep-water processes Chair: Jeff Peakall
1330-1400	Keynote talk: Jaco Baas Bedforms in mixed sand and mud as narrators of flow history	Keynote talk: Peter Haughton Hybrid event beds in outer fan successions - the greywacke problem revisited
1400-1420	Cartigny et al. A comparative study of sediment waves and cyclic steps based on geometries, internal structures and numerical modeling	Fildes et al. Comparing vertical profiles of volcanoclastic sediments from coarse-grained outcrops and fine-grained core data within the Waitemata Basin, New Zealand
1420-1440	Pidduck et al. Marine nutrient dynamics in turbid estuaries - A case study of the Seine estuary, France	Morris et al. Sandy external levees: origin, geometry and implications
1440-1500	Graham et al. Marsdenian Mudstone Lithofacies Variability in the Pennine Basin, UK	Kane et al. Growth of long sinuous channels on the sea floor through autogenic flow regulation
1500-1530	Coffee and posters	Coffee and posters
	Session 8A: Shallow water & coastal processes Chair: John Howell	Session 8B: Deep-water processes Chair: Dave Hodgson
1530-1600	Keynote talk: Gary Hampson Sediment dispersal, stratigraphic architecture and palaeo-oceanographic interactions across an ancient shelf	Keynote talk: Doug Masson Sediment transport and deposition in a modern submarine canyon
1600-1620	Patruno et al. Core-based sedimentology of a mixed-influence delta system: Sognefjord Formation (Early-Late Oxfordian), Troll area, Norwegian North Sea	Thomas, M. A constrained African craton source for the Cenozoic Numidian Flysch; defining an atypical foreland basin deep marine series
1620-1640	Dowey et al. Sedimentation in an early transgressive estuary: Leiravogur, SW Iceland	Loneragan et al. U-Shaped Slope Gully Systems and Sediment Waves on the Gabon passive margin (West Africa)
1640-1700	Harper et al. Tidally-controlled, restricted-marine depositional environment in a foreland basin setting	Malgesini et al. Field evidence that submarine debris flows can deposit clean sandstone over large areas: Marnoso-Arenacea Formation, Italian Apennines

Poster presentations

Banham et al. The Role of Salt Tectonics in Controlling Fluvial System Evolution: The Triassic Moenkopi Formation (SE Utah) as an analogue for the Triassic Hydrocarbon Province of the Central North Sea

Brackenridge et al. Contourite sands

Colombera et al. A relational database for the digitization of fluvial architecture: conceptual scheme and overview of possible applications

Cooper et al. Is Milankovitch cyclicity recognisable in carbonate sequences? Numerical experiments using the forward model CARB3D+

Dale et al. Glacio-eustatic control upon sedimentation during the Namurian (Serpukhovian to Bashkirian) across northern England

Davidson et al. Downstream geomorphological channel changes on distributive fluvial systems and implications for interpreting the rock record

Duller et al. Validating a mass-balance framework for fluvial successions: Organ Rock Formation, Blackhawk Formation & Castlegate Sandstone, Utah, USA

Eide et al. Along Strike Variations in an Ancient Asymmetric Wave-dominated delta: Insights from a Detailed Virtual Outcrop Study

Elliott et al. Is the sea surface the key to deeper goings-on on the ocean floor? Interaction of a mesoscale eddy with bathymetry in the Porcupine Seabight, West of Ireland

Elliott et al. The evolution of the Gollum Channels, Porcupine Seabight, NE Atlantic: A case of macro 'fill to spill'?

Gales et al. The geomorphology of Antarctic submarine slopes

Gulliford et al. Architecture Of A Sand-Prone Fluvial Succession: Initial Findings From The Moordenaars Member, Beaufort Group, Karoo Basin, South Africa

Hirani et al. Integrated structural, sedimentological and diagenetic evaluation of hydrothermal dolomite, Cretaceous-Eocene, Hammam Faraun Fault Block, Gulf of Suez

Holgate et al. Sedimentological analysis of the Krossfjord and Fensfjord formations, Troll Field, northern North Sea

Holzweber et al. Scale invariance and sediment body geometry in fluvial systems

Holzweber et al. Generation Of Training Images For Use In Multi-Point Statistics-Based Reservoir Modelling Of Fluvial Systems

Hu et al. Geochemistry and sequence of calcite cements in the Chalk of eastern England, UK

Hu et al. Onset of underfilled Himalayan peripheral foreland basin in southern Tibet: implication for timing of India-Asia initial collision

Hunt et al. Chaos in the abyssal: processes affecting distal abyssal plain sedimentation on the northwest African margin

Hunt et al. Comparative development of deepwater turbidite systems along the NE Atlantic margin: variability in depositional facies and potential controls

Ilott et al. Dating the onset of Neogene basin incision in SE Spain using in situ cosmogenic exposure dating

Juerges et al. Sedimentological and Structural Controls on Dolomite Distribution and Timing: an Example from the Great Orme, Llandudno, UK

Kulikova et al. Distributive fluvial system behaviour and resulting sandbody architecture, Huesca System, Ebro Basin, Spain

Leleu et al. Fluvial systems: a limit to depositional models

Noad et al. The Sedimentology 'bucket list'

Olafiranye et al. Seismic architecture and topographic controls on Pliocene deepwater deposits, offshore Angola

Owen et al. Progradation and development of a distributive fluvial system in the Jurassic Morrison Formation, Colorado Plateau, USA

Pe-Piper et al. Early Cretaceous tectonics on the eastern Canadian passive continental margin interpreted from geochronology of detrital muscovite, monazite and zircon

Rawcliffe et al. Late-Permian Volcanism of Southern Gondwana as recorded by tuff deposits of the Tierberg Formation, South Africa

Ross et al. SEM analysis of injected sands from the Namurian of County Clare

Sakellariadou et al. Fluorescence characterization of organic matter released from surface sediments collected from a traverse at the Messiniakos gulf, SW Peloponnese, Greece

Schindler et al. Towards the remote measurement of cohesive sediments dynamics: developing acoustic and optical measurements via *in situ* particle visualization

Schmidt et al. Provenance analysis of Devonian-Carboniferous sandstones from the Clair Basin, West of Shetland using heavy mineral and detrital zircon age data

Southern et al. Early infill of the confined Edale sub-basin of the South Pennine Basin

Stevenson et al. Effects of topography on lofting gravity flows: implications for the deposition of deep-water massive sands

Stuart et al. Sedimentary Architecture And Connectivity Of Reservoir-Quality Facies In Fluvial Overbank Successions

Tarplee et al. The 3D microscopic signature of strain within glacial sediments revealed using x-ray computed microtomography (μ CT)

Taylor et al. Diagenetic Processes in a Foreland Basin Mudstone Succession: The Mancos Shale, Book Cliffs, Utah

Taylor et al. Fine-grained sediment records of climatic variation and ice margin recession within Paleolake Rawtenstall, a Quaternary ice-dammed lake in NW England

Verhagen et al. Turbidity currents over muddy substrates: Evidence for flow acceleration over a horizontal bed

Watt et al. Volcanic island flank collapse and associated seafloor sediment failure: emplacement dynamics and implications for tsunami hazards

Wilson et al. Fluvial Sand Body Architecture in The Lower Beaufort Group, Karoo Basin, South Africa

Wilson et al. Debrite and turbidite sand relationships as observed in the Britannia Sandstone Formation, Early Cretaceous, UK North Sea and the Vocontian palaeomargin, south-east France.

Wright et al. Ultrasonic Velocity Doppler Profiling of the boundary layer in a fine sand laden river estuarine transition zone (RETZ)

Yang et al. 3D Seismic Imaging of Methane Hydrates offshore of Mauritania



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Extreme fluvial events

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There is considerable debate in the hydrological community about the concept of extreme floods, and probably greater argument amongst geomorphologists and sedimentologists about what constitutes an extreme fluvial event. Many geologists have inferred the occurrence of extreme floods from the rock record. In a geological context extreme fluvial events can be defined by their results rather than their discharge magnitude or return period. An event that produces recognisable geological features (bed(s), erosion feature, sedimentary structures) out of the ordinary for that fluvial setting can be considered an extreme event. This might be an infrequent large runoff event within the normal variability of the system or, and perhaps more importantly, a large runoff event combined with some other event (forest fire, volcanic eruption, etc.) or change to the system that changes the runoff routing efficiency or sediment supply. For example an extensive sheet-sandstone in a mud-dominated floodplain sequence requires an event, that not only transports sand considerable distances from the channel, but also in sufficient volume that subsequent soil processes do not obscure it. Another example is where there is a comprehensive change in sediment grade within an area of channel-body recording a change in sediment supply. Change in channel-body architecture (where not related to bar formation or migration inherent to the channel system) may result from an extreme event or from a transition in style. With current knowledge of variability in channel body architecture this is difficult to interpret.

Hydrologists can use statistical approaches based on *extreme value theory* to plan for infrequent large floods, but this is far from a panacea for planning for catastrophic floods. Neither the total discharge nor the peak discharge may correlate well with the impact of an event and the infrequent occurrence of big events is such that data from one big event can change the statistical prediction model for the system. In the geological context *extreme value theory* could be useful for considering the differences between patterns of extreme events in differing settings and likely variability in channel-body architecture in different settings. In temperate equitable settings the relatively small variability in discharge may be such that channel and floodplains approach equilibrium with the discharge distribution and extreme events are relatively unusual and may leave distinct signatures in the deposits. In arid and semi arid settings with highly variable precipitation and runoff, channel form may rarely reach equilibrium with the discharge pattern and catastrophic runoff events may be relatively frequent, each causing changes in deposition/erosion pattern. These catastrophic events however may not be truly extreme in that setting. A fluvial event might be catastrophic but not extreme, or extreme but with little impact.

Porosity characterization and its destruction by authigenic minerals: reservoir sandstones, Mamuniyat Formation, Murzuq Basin, SW Libya

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The Ordovician Mamuniyat Formation sandstones form an important hydrocarbon reservoir in the Murzuq Basin of SW Libya. Previous studies have highlighted that within the Mamuniyat Formation authigenic quartz, carbonate cements and clay minerals are the main control on reservoir quality and oil recoverability. This present study is based on the analysis of slabbed cores and 152 thin sections of samples collected over 919.74 feet of core. Sandstones samples were selected from cores of seven wells ranging in depth from 5040 to 7181.4 ft and cover various depositional facies. Petrographic examination was performed on thin sections, which were prepared with blue epoxy dye, and the modal composition was obtained by counting 200 points for each selected thin section. Texture and mineralogical composition were studied using polarized light microscopy and scanning electron microscope (SEM). The components in some selected sandstone samples were quantified by images taken using SEM-BSE and SEM-CL. Porosity evolution and quantitative estimation of the amounts of porosity loss by compaction and cementation were obtained from point-count data on cement and pore space abundance.

The texture within the rock is grain or grain-cement supported and the packing is low to medium. In addition the degree of compaction of these sediments generally is moderate to high, evidenced by concavo-convex and tangential grain-grain contacts. Diagenetic phenomena have played an important role on the reservoir's petrophysical characterization. The dominant authigenic cement phase is quartz overgrowth cement (up to 13% by volume) and this is the major mechanism for porosity reduction. Late stage carbonate cements (siderite and dolomite/ferroan dolomite) are present and these minerals infill intergranular porosity and, therefore, further reduce porosity and probably permeability. Authigenic clay minerals are represented by kaolinite, illite and grain coating clay minerals. Kaolinite occurs as booklet and vermicular forms. Minor amounts of illite were noted in the studied samples, which commonly block pore throats, thereby reducing permeability.

Primary porosity of up to 26.5% is present. Secondary porosity (up to 17%) is also present as a result of feldspar dissolution. The high intergranular volume (IGV) of the sandstones indicates that mechanical and chemical compaction played a more important role than cementation of porosity loss in most of the examined samples in the Mamuniyat Formation sandstones.

Magadi-type chert recorded in East Greenland: evidence for a mid Triassic marine ingress

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Magadi-type chert has been discovered in the predominantly continental Mid to Late Triassic succession of the Jameson Land Basin in East Greenland. Chert nodules, 1 to 10 cm in diameter, and more laterally continuous beds, up to 2 cm thick, are recognised which occur in a single interval within the regionally correlatable Gråklint Beds. The nodules commonly display cracked margins and a calcite rind, and are composed of micro-crystalline quartz which displays a patchy rectilinear extinction pattern. Such features are characteristic of Magadi-type chert which forms after Magadiite ($\text{NaSi}_7(\text{OH})_3 \cdot 3\text{H}_2\text{O}$). The chert occurs in the south east of the basin where the Gråklint Beds consist of up to 10 m of organic-rich calcareous mudstones which are divided by a distinctive coarse-grained bed 5-30 cm thick. The chert directly overlies this coarse grained unit which contains rounded quartz grains, bioclastic material, microbialite fragments and limestone clasts and can be correlated over 13 km. In thin section a tripartite, seasonal, lamination can be identified within the mudstones which is characteristic of lacustrine deposition. A low diversity macro-palaeontological assemblage also favours a largely lacustrine setting.

Two possible mechanisms are recognised for the formation of Magadiite; intensive evaporation of alkaline brines with high silica contents, and the mixing of such brines with more dilute acid waters, both of which can lead to supersaturation and therefore precipitation of silica. The identification of a single foram within the chert nodules suggests a marine influence and the underlying coarse grained bed is therefore interpreted as reflecting a high energy marine flooding event which resulted in the introduction of evolved brines and consequently the precipitation of Magadiite. An intra-basinal high is recognised to the NW, across which the Gråklint Beds thicken and contain an intermittently developed restricted marine macro-fauna (abundant modiolid bivalves and locally common spirorbid worms) suggesting that the flooding event occurred from the north.

The Gråklint Beds provide the southernmost record of marine influence from the Boreal Ocean during the Mid to Late Triassic.

Bedforms in mixed sand and mud as narrators of flow history

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The majority of sediment on Earth consists of mixtures of cohesive clay and cohesionless sand and silt, but our knowledge of sedimentary bedforms within such deposits is poor. The results of flume experiments on mixed-sediment bedform development from flat bed conditions will be presented. The experiments compared the effect on bedform development of cohesive forces in the substrate and within the overlying flow. For this purpose, one series of experiments simulated waxing-to-steady flows over substrates with different sand-mud ratios, while another series of experiments simulated waning-to-steady flows, in which bedforms were generated after rapid deposition of mixed sediment from an oversaturated suspension load. The main input variable for both series of experiments was the ratio of cohesive to non-cohesive sediment, thus simulating differences in cohesive strength of flow and sediment bed. The experimental results showed that the growth rate, equilibrium size, morphology and internal stratification of bedforms are highly dependent on the flow history. In the waning-to-steady flows, where cohesive forces in the flow dominated dynamic bed changes, the size of the bedforms increased with increasing clay concentration. In contrast, bedform size decreased with increasing clay concentration in the waxing-to-steady flows, where cohesive bed forces were dominant. Winnowing of clay from the bed during bedform development was important in both series of experiments, but this process was more efficient when cohesive bed forces dominated bedform development. Diagnostic sedimentary structures for the range of boundary conditions investigated in this study will be discussed with the aim to define criteria for the process-based interpretation of natural, mixed-sediment bedforms.

Sedimentary character of pre- and post-vegetation fluvial fan successions: comparison of the Precambrian Applecross Formation of Torridon with Permian-Triassic examples

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A key factor that exerts a significant control on sand-body type and distribution in fluvial fan successions is the degree to which channel bodies are fixed in position by vegetation that can act as a significant agent to stabilize the substrate through its ability to bind and trap loose sediment, thereby influencing both rates of lateral channel migration and the frequency of avulsion. The density and type of vegetation cover additionally controls volumes of sediment entrainment by surface runoff and its presence or absence can lead to significant differences in sediment yield for a given runoff and hence fluvial style and resultant preserved sedimentary architecture. In systems where vegetation is not present to bind and stabilize the substrate, flood hydrographs tend to exhibit a rapid rise to peak discharge and both turbulent overland flow and abrupt rises in the groundwater table in the aftermath of flood events result in the generation of large soft sediment deformation structures due to fluidization and liquefaction.

The Torridonian (Neoproterozoic) Applecross Formation of North West Scotland and the Permian Organ Rock Formation of South East Utah, USA are examples of large fluvial fan successions that formed before and after the evolution of land plants, respectively. The Applecross Formation is characterized by the presence of large scale soft sediment deformation structures, that are here postulated to have arisen in response to the absence of vegetation in this Precambrian fluvial system, thereby rendering the substrate susceptible to deformation due to fluid turbulence associated with flooding and to liquefaction and fluidization in response to rapid upwelling of groundwater in the aftermath of flooding. In similar fluvial fan systems of a younger age, such as the Permian Organ Rock Formation of Utah, a modest vegetation cover likely acted to significantly retard overland flow and prevent rapid, high magnitude changes in groundwater table level through absorption effects, thereby acting to dampen the impact of high-magnitude floods. Additionally, the root structures of such vegetation acted to bind the substrate, thereby reducing sediment yield and decreasing susceptibility to large scale deformation. By comparing the type, scale and intensity of deformation with the style of palaeosol development (or lack thereof) in these Precambrian.

Geomorphological and sedimentological record of glaciation on the western Irish continental margin

**Bennetti, S.*¹, O'Cofaigh, C.¹, Dunlop, P.¹, Sacchetti, F.¹, Cooper, M.², Meighan, I.³,
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OLEX bathymetric data (<http://www.oceandtm.com/>), the high-resolution multibeam bathymetric and sub-bottom data from the Irish National Seabed Survey (<http://www.infomar.ie/>) and from additional surveys collected on the NW Irish continental margin have revealed extensive evidence for past ice sheet advance and retreat across the Irish continental shelf. These marine geophysical data confirmed that the last British-Irish Ice Sheet (BIIS) extended for at least 100 km offshore of NW Ireland and Scotland onto the continental shelf and left a signature of drumlins, moraines and iceberg-scours, both buried and at the seabed. These features provide unequivocal evidence for past extension of the BIIS to the shelf edge, reconfiguration of the ice sheet into a series of lobes during deglaciation, followed by subsequent slow retreat of grounded ice. However, the timing and character of this advance and retreat remain unclear due to the lack of sediment core records.

This problem was addressed by two research cruises in 2008 and 2010 on the Irish RV Celtic Explorer. During these cruises, over 50 sediment cores were collected in the area. The cores are mainly located on three transects that extend from the continental shelf to the deep basin abyssal depths of the Rockall Trough. Core sites were targeted to sample glacial features on the shelf, particularly a series of recessional moraines that record the last deglaciation from the shelf edge, and three major sediment discharge systems (canyons) on the slope.

These cores provide an unprecedented opportunity (1) to obtain the first chronology of the deglaciation of the western margin of the last BIIS, and (2) to investigate the relationship between ice sheet fluctuations on the shelf and the character of slope sedimentation. This talk will report on the initial observations and analyses carried out on both shelf and slope cores, including some insights on the provenance of pebble clasts found within glacial diamicton deposits on the shelf.

The tectono-sedimentary evolution of the Darende and Hekimhan basins, Central Eastern Turkey

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Sedimentological studies provide key constraints on the tectonic setting of sedimentary basins. Here, we focus on the sedimentary and tectonic evolution of the Darende and Hekimhan Basins, in central eastern Anatolia. We use integrated sedimentary, igneous and structural evidence to interpret the controls on basin formation during the Cretaceous to Eocene closure of Neotethys. The Darende Basin and the adjacent Hekimhan Basin developed as part of the northern margin of the Tauride microcontinent during the collision and suturing of Neotethys.

The basins both exhibit a Jurassic to Cretaceous regional carbonate platform 'basement' overlain by a dismembered ophiolite which was emplaced to the south during the Late Cretaceous. Sedimentation in both basins began shortly after, during the Maastrichtian. Ophiolite-derived clastic sediments accumulated in basin depocentres and palaeovalleys, followed by Maastrichtian-aged, rudist-rich patch reefs. In the Darende Basin microbial and evaporitic carbonates record emergence during the latest Maastrichtian. In contrast, similar Maastrichtian sediments in the Hekimhan Basin are overlain by subaqueous within plate-type alkaline basaltic-trachytic lavas and associated volcanoclastic sediments of latest Cretaceous age. The igneous activity was followed by the deposition of pelagic to hemipelagic marls, shallow marine-limestones and dolomites which record emergence in the latest Cretaceous. Both basins remained emergent throughout the Paleocene and an important unconformity developed. Sedimentation resumed in both basins during the Early Eocene with the deposition of variable sedimentary facies including conglomerate, sandstone, marl and shallow-marine nummulitic limestone and widespread but localised basaltic eruptions. These record successive deepening, shallowing and finally emergence of both basins during the Late Eocene. In the Hekimhan Basin several hundred metres of Lower Eocene evaporites accumulated in localised depocentres, followed by fluvial and overbank-type clastics and thin lacustrine limestones, together with Middle Eocene andesitic volcanics. The Oligocene is represented by continental fluvial deposits that are only exposed in the Hekimhan Basin. The deposition of faunally diverse, shallow-marine, Miocene limestones, Pliocene subaerial basalts and Pliocene-Recent continental deposits in both basins completes the sequence. The following tectonically and eustatically controlled stages of basin development are inferred: 1) Late Cretaceous extension initiated basin development (after ophiolite emplacement), possibly related to immediate isostatic compensation and on-going slab-pull during northward subduction of remaining Neotethyan oceanic crust. Latest Cretaceous within-plate volcanics reflect the extensional setting; 2) The latest Cretaceous emergence of the Darende and Hekimhan Basins was possibly controlled by regional flexural uplift as the down-going plate approached the subduction zone to the north (and was possibly also influenced by sea-level change); 3) Early Eocene flexural subsidence was probably caused by regional crustal loading that accompanied progressive collision of the Tauride microcontinent with Eurasia ("soft collision"). This caused the basins to subside and, coupled with a significant eustatic sea level rise, allowed sedimentation to resume; 4) Mid-Late Eocene "hard collision" resulted in progressive restriction of the basins, regional uplift and subaerial exposure; 5) Probable Miocene suture tightening and compression, resulted in reactivation of pre-existing extensional faults and terminated marine sedimentation. Both basins were affected by predominantly sinistral strike-slip faulting during the Plio-Quaternary westward tectonic escape of Anatolia.

Measuring and modelling carbonate strata: Patterns and prediction from platforms to beds

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Traditionally carbonate modelling has been carried out as interpretation of outcrop strata linked to qualitative and often largely speculative conceptual models, for example the sequence stratigraphic model. More recently, quantitative methods and quantitative forward models have become available to more robustly analyse carbonate outcrops, and in the case of forward modelling, to allow experimental testing of the consequences of different stratigraphic processes at a variety of different scales.

Considering carbonate strata at the large scale, current classifications of carbonate platforms use depositional gradient as the main criterion for separating systems into two end member types, ramps and flat-topped platforms. However, many examples do not conform to this simple classification. To investigate why this is and to better understand likely controls on platform development, we have used a series of 2D numerical forward model runs to investigate how sediment production, diffusional sediment transport and other controls such as tectonic subsidence, antecedent topography, and relative sea-level oscillation interact to determine platform geometry. Modelling results reaffirm that rates of down-dip sediment transport are a critical control but also demonstrate that the type of carbonate production versus water depth curve, for example euphotic versus oligophotic, has little impact. Other controls include rotational subsidence and relative sea-level oscillations, the latter tending to produce low-gradient ramp systems by shifting the locus of sediment production laterally. Considering all these possible controls is key to successful platform classification.

Considering carbonate strata at a smaller scale, a key observation is that lithofacies unit thicknesses appear to be exponentially distributed, meaning that there are many more thin units than thick. This is an important observation because it can be tested for its repeatability in various outcrop and subsurface examples, and also because it raises the question of what sedimentary processes and climatic and tectonic settings might lead to formation of a particular lithofacies thickness distribution. Analysis of outcrop examples shows that while many are exponential, many other examples are not. Forward modelling in one and three dimensions shows that exponential distributions can arise from accumulation in systems with periodic oscillations in relative sea-level, and from accumulation in mosaic systems during steadily rising relative sea-level, but the proportion of exponential cases found in these models suggests that other processes are also likely to be important. Ultimately, these modelling analyses will hopefully lead to insight into the link, if any, between vertical and lateral lithofacies unit dimensions.

Mega-flood sedimentation in the Altai Mountains of Siberia: what can we learn about generic processes?

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Sedimentary valley fill within valleys of the Altai Mountains of Siberia consists primarily of valley-marginal giant bar deposits and valley-floor terraced gravels. The sedimentology and stratigraphy may be best explained as owing to Quaternary mega-flood deposition modified by Holocene braidplain evolution and dissection.

The fill originally may have been complete across the valley floor with the bars now representing marginal remnants of this fill trenched by later river action. Alternatively, bars may have developed across entrances to valleys tributary to the rivers with sedimentation occurring in the main valley floors but at a lower elevation in comparison with the height of the bars. Presently, there is insufficient evidence to choose between these two styles of sedimentation. The origin of the floodwaters was the ice-impounded Glacial-Lake Kuray-Chuja, which emptied repeatedly. At least three major floods occurred of which the first was large and deposited a series of primary bars. Subsequent floods deposited sediments on top of the original bars and also breached the bars producing complexes of flood gravels intercalated with lake deposits. Sedimentological evidence indicates that the stratigraphy of the bars may be attributed to a series of individual floods that over-topped pre-existing flood-bar deposits. Ramped increases in flood level may have been associated with distinct flood surges within individual flooding episodes which provide some of the local differences in styles of sedimentation. Each flood entering the tributary valleys caused the deposition of an individual sequence of sedimentation termed a rhythmite. Sedimentological evidence indicates that there is no obvious hiatus in deposition between rhythms, although the dating control would suggest several thousand years separate some flood units. A simple conceptual model is proposed to link environmental conditions and flood hydraulics with the observed sediment characteristics. Although there are important differences, the timing, scale and the basic style of bar-deposition in the Altai Mountains of Asia are strikingly similar to that described for the Missoula-flood bars in North America, and the sedimentology is similar to that of Icelandic jökulhlaup deposits. These observations raises the possibility of developing a general model for styles of mega-flood deposition both modern and ancient.

A comparative study of sediment waves and cyclic steps based on geometries, internal structures and numerical modelling

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Although sediment waves cover many levees and canyon floors of submarine fan systems, their relation to the turbidity currents that formed them is still poorly understood. Over the recent years some large erosional sediment waves have been interpreted as cyclic steps. Cyclic steps are a series of slowly upslope migrating bedforms (steps), where each downward step (the lee side of the bedform) is manifested by a steeply dropping flow passing through a hydraulic jump before re-accelerating on the flat stoss side. Here, a general comparison is made between sediment waves and cyclic steps. First, the analogies between their geometries and internal structures are explored. Secondly, a basic numerical model is used to construct stability fields for the formation of cyclic steps. These stability fields are compared with large, existing datasets of both fine- and coarse-grained sediment waves. The numerical results enable an explanation of geometrical trends found over series of sediment waves in the upper part of the Monterey Canyon, on the middle Amazon Fan and on a leveed channel in the Makassar Strait in terms of changes in flow properties of the overriding turbidity current. Based on sedimentological arguments and numerical analysis it is concluded that cyclic steps form a potential alternative for the existing interpretations on the origin of upslope-migrating sediment waves.

A view from the sea: the marine sedimentary signature of past ice sheets

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[Abstract pending]

Sedimentation in an early transgressive estuary: Leirarvogur, SW Iceland

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The Leirarvogur Estuary, SW Iceland is seven kilometres long by three kilometres wide has a two to three metre tidal range, and is linked to a 250 km² drainage basin of Tertiary and Pliocene-Pleistocene basalt volcanics, Holocene glacial sediments and peats. Geomorphological features indicate that the estuary is in the early stages of marine transgression. Since the end of the last glacial and the beginning of the present inter-glacial period around 12,500 BP, the area around the estuary has undergone two periods of glacial advance (12,000 & 11,000 BP) and retreat (11,700 & 10,100 BP), resulting in the deposition of glacial and glaciomarine sediments^[1]. After 10,000 BP the area became ice free, and with sea levels up to 80-90 m higher than at present the area around Leirarvogur would have been a shallow nearshore marine environment. Subsequent isostatic uplift of western Iceland^[2] resulted in a significant drop in base level to a position farther seaward than the present day. A lower base level initiated fluvial incision of upland bedrock and low-lying glacial deposits, forming a wide, shallow valley. In low-lying areas around the valley peatland developed; present-day subsurface peat samples have been dated to 6,000 BP^[1]. It is postulated that a (presently offshore) mixed wave-river delta may have developed at this time. Base level rise within the last 6,000 years has inundated the Leirarvogur valley forming an estuary.

The present-day configuration of the estuary is largely wave-dominated, with a shallowly-dipping bayhead delta (muddy-sandy-gravel) draining two main river systems at its eastern fluvial end. The estuary margins are defined by cliffed glacial deposits, peat terraces, and bedrock outcrops. The central part of the estuary basin is composed principally of horizontal to shallowly-dipping sandy (fine to medium grade) intertidal flats, dissected by an approximately 200 metre wide sinuous channel which flows from east to west. The surrounding land is drained by streams, which are channelled across the intertidal flat by small tidally influenced creeks. The marine end of the estuary is marked by a 1.5 km long spit on the north side and a shorter bedrock defined spit on its southern side. Both spits are covered by aeolian dunes and fronted by well sorted and rounded shoreface sands (medium to coarse). Wave action has resulted in erosion of the glacial sediments and peatlands creating the estuary terraces, supplying sediment to the estuary. Ongoing sediment analysis using logged cores and surface sediments is being used to define the mineralogy, grain size distribution and facies within the sediments.

^[1] Ingólfsson, Ó. (1988) *Glacial history of the Bogarfjörður area, western Iceland. Geologiska Föreningens i Stockholm Förhandlingar* 110(4): 293-309.

^[2] Le Breton, E., O. Dauteuil, and G. Biessy (2010) *Post-glacial rebound of Iceland during the Holocene Journal of the Geological Society of London* 167: 417-432.

Fluid pressure in turbidity currents: A hidden variable in deepwater sedimentology

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Even though it is well-known that the pressure distribution in a flow following a curved solid substrate deviates from the hydrostatic pressure, a fully hydrostatic model is assumed in many classic hydraulic analyses. Transposition of this hydrostatic assumption to the study of dilute subaqueous particulate gravity currents (or turbidity currents) has led to significant mis-predictions of properties of experimental flows (e.g. super-elevation in channelized flow), causing some to suggest that the hydrostatic pressure assumption may be flawed for this type of current. Here, an experimental investigation of turbidity currents demonstrates that basal fluid pressures are much lower than those predicted from bulk flow density, in proportion to the kinematic energy density of the flow, a parameter usually referred to as the “dynamic pressure”. Measured basal fluid pressures are of the order of 50% of the calculated hydrostatic pressure under conditions common for turbidity currents ($Fr' \sim 1$). The observed relations simplify to yield hydrostatic pressure distributions for fluids at rest. The insight that the “dynamic pressure” effect is expressed as a significant decrease in basal pressure under dynamic conditions runs counter to common understanding. We suggest that the commonplace assumption of a hydrostatic pressure regime in the process-sedimentological analysis of turbidity currents and their deposits is unfounded. We explore hitherto puzzling or unexplained phenomena in this area of sedimentology that may benefit from the incorporation of fluid pressure as a variable in consideration.

Footwall erosion and sediment pathways in a gravity-driven fault system: An example from the Jurassic Bremstein Fault Complex, offshore Mid-Norway

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Studies of fault systems in active extensional regimes (e.g. Basin and Range) and in exhumed, ancient rift basins (e.g. Miocene Gulf of Suez) have shown a link between the evolution of fault-related footwall topography and erosional drainage systems. In these examples footwall erosion is controlled by footwall uplift and the location of segment linkage points with footwall catchments generally largest in the relay ramp zones between faults whilst on individual faults the largest catchments are found towards the centre of the fault. However, few examples of footwall erosion have been presented from gravity-driven fault systems where footwall uplift is minimal and hangingwall subsidence accommodates throw accumulation on the fault system.

In this study, a footwall erosion system, developed in the Jurassic of the Halten Terrace, offshore Mid-Norway is exceptionally well-imaged on 3D seismic reflection data. The system is 22 km long (along-strike of the fault system) and comprises 96 drainage catchments characterised by erosional channels. These erosional catchments consist of small, linear systems that are up to 750 m long and located along the frontal portion of the fault footwall. Larger, more dendritic channel systems extend further back (up to 3 km normal to fault strike) into the footwall. These channels are up to 7 km long, up to 50 m deep and up to 1 km wide. The axial orientation of the larger catchments varies from fault-parallel in their upper reaches to fault-normal in their lower reaches. The distribution of footwall erosion broadly follows the first-order observations highlighted above, namely the largest catchment is found in the relay ramp zone and along the length of the fault the largest catchments are found towards the centre of the fault. One advantage of 3D seismic data is that the amount of throw on a fault can be measured using horizon cutoffs, and these measurements can be used to determine the growth history of the fault. In the studied fault system, three areas of low throw were identified and interpreted to represent the locations of segment linkage points where smaller faults linked to form a single through-going fault. In published examples these segment linkage points are regions where sediment delivery can be focused. However, when the location of the footwall catchments is compared to segment linkage locations, the distribution is highly variable. From the present study, the segment linkage points do not appear to have been significant sediment pathways as the fault evolved, rather the catchment size and location mirror the overall throw pattern of the fault i.e. largest catchment is related to the highest throw. This relationship implies that segment linkage points in a gravity driven fault system may have formed rapidly and footwall erosion patterns did not have time to adjust to the changes.

Comparing vertical profiles of volcanoclastic sediments from coarse-grained outcrops and fine-grained core data within the Waitemata Basin, New Zealand

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The Miocene Waitemata Basin of New Zealand comprises a suite of deep marine sandstone and siltstones which were deposited by a spectrum of gravity flow types including turbidity currents, debris flows and slumps. Within the basin, distinct thick volcanoclastic event beds are interbedded with sandstones and siltstones. The volcanoclastic units can be represented by a variety of grain sizes (medium sand to conglomerate). At outcrop, focus has been on conglomerates containing boulder/block sized clasts. Recent core studies provided a great insight into the finer-grained examples for comparison. Coarse-grained examples of event beds display a distinct vertical profile with a chaotic base containing large pebble to boulder size clasts. Inverse grading occurs towards a horizon containing large sedimentary clasts (up to 20 metres in size). These clasts are rip-up clasts from the underlying substrate which are entrained into the flow and are often deformed and imbricated. Above, normal grading continues into a medium sandstone. A variety of vertical successions are observed in rock cores of medium to very coarse size massive, volcanoclastic sandstones. The first type (Type 1) is comparable with the conglomerate outcrop examples. The basal section displays reverse grading from small to large pebble sized sedimentary clasts. The rest of the unit is graded normally.

Within the cores it is difficult to observe large size sedimentary clasts as they can resemble in situ strata. The finer-grained event beds contain water escape structures, parallel laminations and are typically capped by carbonaceous material. The second type of vertical succession (Type 2) is more complex. No grading pattern is observed, although large scale banding of distinct grain size horizons occur sporadically in the bed. The bands vary in thickness from ~1 - 50 cm and do not appear to have sharp contacts. The volcanoclastic conglomerates seen in outcrop and the Type 1 sandstone from core data are similar, and they are interpreted as the deposits of hybrid flows, with a forerunner debris flow (depositing the conglomerate), transforming backwards through the flow into a high density turbidity current (depositing the normally graded interval).

Inverse grading within the basal interval is explained as deposition by traction carpet and suspension sedimentation. High-density turbidity currents are also interpreted to deposit Type 1 volcanoclastic sandstone beds; however the coarse basal deposits (lag) are missing. This may suggest the finer-grained deposits are more distal or at a lower velocity flow, with the coarser material depositing more proximal. Type 2 deposits displaying the rapid change in grain size (stratified sand layers) could link to temporal fluctuations in the downward grain flux and in concentration which may arise from flow unsteadiness (e.g. pulsing flow, internal waves or large turbulent eddies) or from heterogeneities of grain-size distribution or concentration within the current as it passes. A lack of sharp contacts throughout all these deposits suggests they are a result of a single event, providing useful chronostratigraphic markers in both coarse and fine-grained environments.

New insights into emplacement of the Rockall Bank Mass Flow, offshore western Ireland

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The floor of the Rockall Trough offshore western Ireland is dominated by the Feni Drift, a giant contourite mound formed by Neogene ocean bottom currents and the scarps and depositional lobes of the Rockall Bank Mass Flow (RBMF). The morphology of the RBMF is unusually subdued, with negative relief bounded by lateral scarps over most of its extent and only subtle positive topography towards the toe of the lobe region. In June 2010 the RV Celtic Explorer cruise CE10008 collected the first comprehensive set of piston cores from the Irish sector of the deep Rockall Trough.

Here we present initial results from a transect of cores extending across the deposits of the RBMF and onto the seafloor down-dip of the failure. The cores (up to 4 m in length) were taken in water depths of nearly 3000 m and reveal that significant coarse sediment (up to coarse sand) was emplaced on the deep basin floor by both turbidity currents and bottom currents. We identify at least 15 discrete turbidite sand and silt deposits with two distinct sources, and one bed of contouritic sand. The youngest two turbidites appear to have been generated from the area occupied by the RBMF. The remaining 13 events suggest an easterly or northeasterly source, probably from the Donegal-Barra Fan. The core record thus shows at least two periods of turbidity current activity; first from the Donegal-Barra Fan, possibly associated with glacial processes, and then more recently from the Rockall Bank linked to slope failures. The switch in source area appears to have occurred after a thick (>1.5 m) structureless water-saturated sand was deposited on the seafloor, possibly formed by bottom current reworking of the Feni Drift. We believe that after initial collapse on the Rockall Bank - instigated by bottom current undercutting of the slope - remobilised sediments loaded the water-saturated contouritic sand that was buried near the seafloor at the time, leading to liquefaction and dewatering. Dewatering and volume reduction in turn caused vertical collapse of the seafloor and potentially further collapses at the head of the slide resulting in the unusual morphology for the RBMF. Backscatter and shallow seismic data collected as part of the INSS and INFOMAR surveys provide evidence suggesting dewatering just beyond the toe of the RBMF.

Oil plumes rising through deep water

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The dynamics of turbulent oil plumes, formed from a suspension of buoyant oil droplets in water, and flowing upwards through water, involve a series of fascinating fluid mechanical processes. Laboratory experiments have been conducted where small scale plumes of oil are released through the floor of an acrylic tank containing water whose salinity varies from the base to the surface of the tank. The experiments identify how the entrainment of ambient water into the oil-water plume as it ascends through the tank impacts the transport and dispersal of the flow (Fig. 1). In particular, as the flow entrains the deeper relatively salty water in the experimental tank, the bulk density of the flow increases, and at some point matches that of the surrounding water. At this stage the upward motion of the plume is arrested and the bulk flow intrudes laterally into the tank. Subsequently, in the experiment, the larger oil droplets are observed to continue to rise upwards to the free surface. The smaller droplets remain within the plume at depth in the tank for longer. The dynamics of these experimental oil plumes, which involve a series of two-phase flow effects, are compared with the dynamics of fresh water plumes, exploring some of the similarities and differences in the behaviour. This work provides insights into large scale oil flows in the ocean.

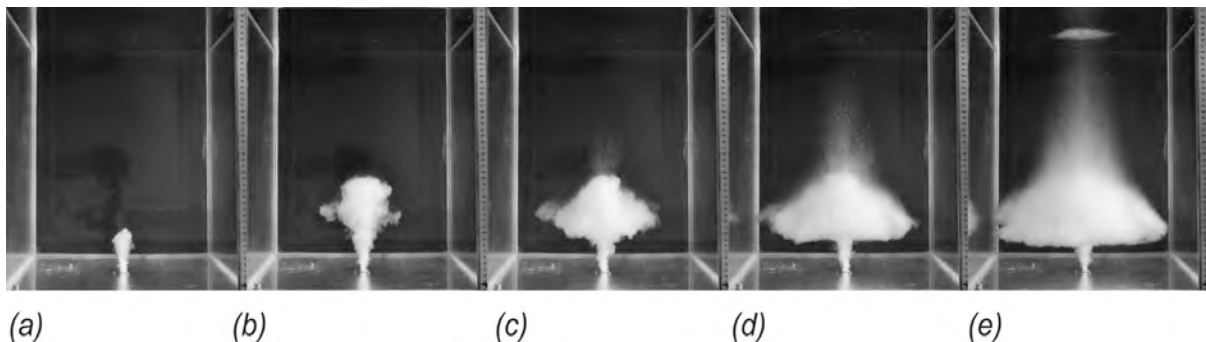


Fig 1: In an analogue experiment, vegetable oil is injected with a high exit velocity to form an oil droplet - water suspension (a). Owing to entrainment of dense salty water, the plume does not rise to the top of the tank but is arrested (b). The plume intrudes at a neutral depth (c) while larger oil droplets rise upwards out of the suspension (d), some of which reach the free surface (e).

Marsdenian Mudstone Lithofacies Variability in the Pennine Basin, UK

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The late Namurian (Carboniferous) successions of northern England were dominated by fine-grained sedimentation across broad, relatively shallow-water shelves. As interest increases in the unconventional resource, Shale Gas, understanding transport and depositional mechanisms of fine-grained material and characterising the lithofacies variability (reflecting the different processes and depositional environments) becomes increasingly important for predicting the location and abundance of prospective successions.

A mudstone succession containing a biostratigraphic marker horizon is traced along a 'proximal' to 'distal' transect in the Pennine Basin: from a northern location near Brough in the Stainmore Basin, Cumbria, to one in the Bowland Basin (Pule Hill, Yorkshire) through to the North Staffordshire Sub-basin, adjacent to the Wales-London Brabant High, in the Midlands (Oakamoor, Staffordshire). Mudstone lithofacies are identified based on textures/mineralogy, using optical and electron optical thin section analysis, geochemical variations (whole rock XRF) and total organic carbon content (TOC).

Mudstones deposited closer to the sediment supply have a higher proportion of silt-sized grains which is reflected in higher average SiO₂ (ca. 52%) compared to 45.56% SiO₂ in a more distal location. Total organic carbon abundances range from 1.19-5.31% in proximal locations to up to 8.49% in the more distal location in the Staffordshire Sub-basin.

At Oakamoor, Staffordshire, three sedimentary logs spaced 10's of metres apart illustrate that these mudstones are characterised by twelve lithofacies. The closely spaced sampling of these sections reveals lithofacies including homogeneous clay-rich mudstones, pelleted silt-rich mudstones and carbonate-rich mudstones. Variation is observed vertically, on a range of scales from centimetre to metre scale, and laterally over 10s of metres between the logs at this one location. This method of analysis detailed insights into (1) the transport and depositional processes and (2) the conditions at the site of deposition. Processes include suspension settling to advective transport of sediment by debris flows.

The proximity of a sediment source has an important control on the abundance of siliciclastic material and similar sediment delivery processes are identified from across the basin. However, the regional comparison of lithofacies suggests that some transport and depositional processes are more localised. Geochemical signatures appear vary as a result of a combination of primary production and physical transport and depositional processes

Sediment dispersal, stratigraphic architecture and palaeo-oceanographic interactions across an ancient shelf

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Recent studies of modern shelves demonstrate that a wide range of sediment-transport mechanisms can operate across them, and that shelfal sediment dispersal is much more dynamic than envisaged in the stratigraphic models that are routinely applied to ancient shelf successions. The challenge for sedimentary geologists lies in integrating these insights into processes in modern systems with our interpretations of their products in the ancient record, where we must also disentangle issues of preservation, time-averaging across a range of scales, and the impact of varying external controls (sea-level, tectonic subsidence, sediment supply). The goal is to improve our understanding of the shelf as a site of long-term sediment storage, bypass and erosion in sediment-routing systems (i.e. “source-to-sink” approach), and thereby to develop improved predictive stratigraphic models for the spatial and temporal distribution of various shelfal deposits. The generic issues outlined above are addressed using an outcrop-based dataset that spans a large area (c. 60,000 km²) of the latest-Santonian-to-middle-Campanian (late Cretaceous) shelf along the western margin of the Western Interior Seaway in eastern Utah and western Colorado, USA.

In the lower part of the studied interval, sediment was dispersed via wave-dominated deltaic systems with a “compound clinoform” geomorphology in which an inner, wave-dominated shoreface clinoform was separated by a muddy subaqueous topset from an outer clinoform containing sand-poor, gravity-flow deposits. These strata are characterised by relatively steep, net-regressive shoreline trajectories ($>0.1^\circ$) with concave-landward geometries, narrow nearshore belts of storm-reworked sandstones (2-22 km), wide offshore mudstone belts (>250 km), and relatively high sediment accumulation rates (c. 0.27 mm/yr).

The middle and upper parts of the studied interval also contain wave-dominated shorefaces, but coeval offshore mudstones enclose abundant “isolated” tide-influenced sandstones that were transported sub-parallel to the regional paleoshoreline by basinal hydrodynamic (tidal?) circulation. These strata are characterised by relatively shallow, net-regressive shoreline trajectories ($<0.1^\circ$) with straight to concave-seaward geometries, wide nearshore belts of storm-reworked sandstones (19-70 km), offshore mudstone belts of variable width (130 to >190 km), and relatively low sediment accumulation rates (c. ≤ 0.11 mm/yr).

The change in shelfal sediment dispersal and stratigraphic architecture, from (1) “compound clinoform” deltas characterised by across-shelf sediment transport to (2) wave-dominated shorelines with “isolated” tide-influenced sandbodies characterised by along-shelf sediment transport, is interpreted to reflect increased interaction with the hydrodynamic regime in the seaway as successive shelfal depositional systems advanced out of a sheltered embayment (“Utah Bight”). This advance was driven by decreasing tectonic subsidence rate, which also suppressed autogenic components of stratigraphic architecture.

Tidally-controlled, restricted-marine depositional environment in a foreland basin setting

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The coastal outcrops of the Late Carboniferous (Pennsylvanian), Westphalian A-C, Bude Formation are a well-exposed, highly-accessible and well-studied sedimentary succession located within South-west England. They were deposited within the Culm Foreland Basin ahead of the growing Variscan Mountains to the south. However, there are five depositional models or elements which have been proposed for this clastic succession of inter-bedded fine grained sandstones, siltstones and mudstones. These are: (1) a fining-up delta (King, 1970); (2) a storm-influenced shallow marine environment (Higgs, 1984); (3) a freshwater lake (Higgs, 1986); (4) a prograding turbidite fan (Melvin, 1986); and (5) a shallow marine ramp environment (Hartley, 1991).

From a reappraisal of the sedimentary facies, the Bude Formation strata are seen to exhibit both clay-draped, ripple cosets and rhythmic clay-sand/silt, planar-laminated deposits. The former are strong indicators of tidal influence, the latter being consistent, if not diagnostic, of this interpretation. These deposits are inter-bedded with occasional hummocky cross-stratification structures, massive slump beds, and small-scale slump horizons. Also, there are low density and diversity skolithos ichnofabric assemblages within the sandstone and siltstone beds.

In addition, diagenetic and geochemical analyses of the Bude Formation shale beds reveal numerous bedding-parallel ankerite veins, low carbon-to-sulphur ratios (Lloyd & Chinnery, 2002) and high concentrations of bedding-parallel (< 5 µm) framboidal pyrite minerals. However, the results from these shale bed geochemical analyses contrast with those from more laterally-continuous black shale beds within the Bude Formation.

Further, from petrographic analysis of the Bude Formation sandstone and siltstone samples, the tidally-controlled ripple coset and planar-laminated facies exhibit higher quartz, lower feldspar and lower lithic fragment contents than for other facies. Overall, the mean quartz-feldspar-lithic fragment ratios from this work and that of Freshney et al (1979) in the Bude Formation are similar to the ratios from other foreland basin deposits (Schwab, 1986).

Together, these findings suggest that the Bude Formation deposits were laid down within a tidally-controlled, storm-influenced, seismically-active, fresh-to-brackish-water, anoxic, foreland basin environment. An estuarine aspect or restricted connection to more open marine conditions is implied, the latter possibly controlled by one or more intervening structural sills. These conditions are interspersed with transgressive events that submerged the earlier deposits, cut-off much of the clastic sediment supply, and increased both oxygen and salinity levels to open-marine levels.

Hybrid event beds in outer fan successions – the ‘greywacke problem’ revisited

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During the mid-part of the last century, an important association between clay-rich sandstones (greywackes) and turbidites emplaced in deep-water was identified. The association was curious in that if turbidites represent deposition from currents that were at least in part turbulent, why was the clay not more efficiently segregated from the sand? One explanation was that the clay was not a primary detrital phase but instead the result of diagenetic alternation of unstable lithic grains – an explanation certainly consistent with the lithic-rich character of many active margin sandstones and the apparent lack of clay in many modern deep-sea sands. However, it did not explain cases of quartz sandstones with abundant clay.

Recently, new data from the distal and lateral parts of deep-water lobe systems have shown clay-rich sand/sandstone are indeed common, even where the sand supply is quartz-prone. The clay-rich sandstones occur as components of beds that either show characteristics intermediate between classical turbidites and debris flows (transitional flow deposits), or contain deposits of both turbidity currents and debris flows as part of the same event (hybrid event beds). Relatively thick distal event beds have a distinctive structure involving: a basal clean sandstone (H1), a ‘banded’ division of clean and more clay-rich sandstone (H2), a clay-rich sand (H3), often with mudclasts and carbonaceous matter, and a relatively thin, capping laminated sand (H4) fining into a graded silt- to claystone (H5). The bed structure is thought to reflect the passage of a longitudinally-fractionated ‘hybrid’ flow with a turbulent front followed by a turbulence-suppressed or transitional section (producing the banding) and then a ‘linked’ debris flow. The event is completed (not always present) by a relatively dilute tail (a low-density turbidity current). The widespread occurrence of beds of this type (or variants of it) implies common down-dip transformation to flows with cohesive behaviour, and a role for debris flows (albeit linked to sand emplacement) in the outermost parts of even large fan systems – a feature now confirmed by cores in both modern and ancient fan distal fan fringes. The incorporation of mudclasts, their segregation in near-bed layers and their disintegration to generate dispersed clay that can dampen turbulence are inferred to be key steps in the generation of many distal hybrid flow deposits – although the mechanism(s) and controls remain to be fully understood. Other mechanisms may also operate – such as the propagation of partly transformed debris flows from further up-dip or the rapid deceleration of mixed clay and sand suspensions.

Carbon Capture and Storage - what's it got to do with you?

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Will carbon capture and storage rival the oil industry in size as has been claimed? Since most geological CO₂ storage will be in sedimentary rocks, the fledgling industry has the potential to employ the next generation of sedimentologists, and has the merit of being 'green'. The scale of the challenge is huge – to decarbonise (or at least radically clean up) the generation of power by 2030, while retaining fuel security and enable a transition to renewable sources. The UK's first project may commence in 2014, with 4 others to follow, totalling at least 12 in Europe - all requiring geological storage. RCUK investment in R&D is fundamental to success in the UK,. Specialist training of industry personnel is required.

How are geologists involved? Identifying storage sites; estimating storage capacity and subsurface pressure changes; building facies and reservoir models; and mapping seals are more or less similar to petroleum industry operations, and employ similar data, tools and expertise. Some research is more specialised: subsurface CO₂ properties; effects of drying out close to the wellbore; dissolution and brine flow; chemical reactions of reservoir and seals, and natural storage analogues. Many of the UK offshore reservoir sandstones are potential storage units, but away from hydrocarbon fields where they are poorly understood. Even more neglected are potential seals and enclosing sediments, which must be studied and mapped away from hydrocarbon honeypots. The sedimentological community will doubtless fearlessly traverse the planet looking for analogues, finding them in warm and sunny locations with cheap beer...

Petrography and diagenesis of silicified aragonitic mollusc shells, Lower Cretaceous limestones, Dorset, UK

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Published studies of silicification in calcareous fossils report a conservative range of quartz textures and fabrics, and almost all observations relate to the silicification of calcitic (or previously calcitised) shells. In contrast, Lower Cretaceous molluscs in partly silicified limestones of the Purbeck Formation from southern England were replaced whilst they were still aragonite, and they display some unusual petrographic characteristics.

Specimens were collected from chert nodules at Durlston Bay and Worbarrow Tout on the south Dorset coast. The shelly limestones are dominated by the euryhaline bivalve *Neomiodon* sp. and also contain freshwater gastropods and ostracods, as well as rare charophytes. All thin sections cut from the chert were prepared to standard 30-micron thickness, using conventional epoxy glue for mounting the rock slices and fixing the cover slips. Additional polished and uncovered thin sections from selected samples were examined in cathodoluminescence (CL) and blue light photoluminescence (PL), and several chert samples were etched in 10% HF before examination in a scanning electron microscope (SEM). Silicification only affected aragonite bivalves and gastropods in the limestones; calcitic fossils were not replaced.

The silicified molluscs display a wide range of replacement textures and fabrics. Replacive quartz may exhibit fibrous or equant textures, and frequently both in the same shell. Crystal habits and optical orientations were frequently controlled by original shell structures, as well as by borings and fractures in the shells. The quartz is typically pale to dark brown owing to the presence of organic inclusions from the original skeletal tissue. These inclusions commonly define "ghost" skeletal microfabrics such as growth bands, but may also outline growth zones of the quartz crystals, or alternatively be concentrated in pseudo-fibrous bundles trapped within quartz crystals nucleated around the outer periphery of the shells. Quartz replacement is frequently on a very fine scale, particularly in gastropods where quartz locally pseudomorphs the original cross-lamellar microstructure. The replacement quartz is very dark brown in optical CL and unzoned in SEM-CL, but where rich in organic inclusions it displays a pronounced green colour in PL.

Quartz in replaced bivalves displays anomalously high birefringence, up to low second-order interference colours, as well as pseudo-pleochroism in some cases. This is attributed to the presence of minute oriented inclusions of skeletal aragonite, as well as organic matter, trapped within the crystals. The anomalous behaviour is not seen in silicified matrix or quartz cements. Other unusual features in replacement quartz include apparent shrinkage cracks in some examples, and changes in optic orientation associated with localised growth zones.

Overall, the fine scale of replacement, presence of skeletal inclusions and frequent inward-growth of quartz from the shell margins support a force of crystallisation mechanism for silicification across an ultra-thin solution film. However, the fact that only aragonite was replaced suggests that this took place at a very shallow depth and/or was abetted by incipient aragonite dissolution triggered by organic matter decay.

Carbonate diagenesis - process, product and predictability

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[abstract pending]

**Seismic, meteorologic, and geomorphic events, and the patterns of
sediment sourcing in an active mountain belt**

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[abstract pending]

Quantitative bedform architecture from virtual outcrop data

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Recent advances in digital data collection methodologies have provided a wealth of new, accurate and geospatial constrained data on sedimentary bedforms which have been collected from geological outcrops. These data are commonly used as analogues for building models of subsurface hydrocarbon reservoirs and aquifers. They may also be used to improve our understanding of the evolution of stratigraphic architecture.

Data have been collected with helicopter and ground based lidar from a series of shallow marine and coastal plain deposits which crop out in the Book Cliffs of eastern Utah. These data have been loaded into SAFARI, which is an ARC GIS database of sandbody geometries and interrogated to improve understanding of the controls on stratigraphic variability.

Geometric data extracted from heli-lidar derived virtual outcrops of the fluvial and coastal plain deposits of the progradationally stacked, nonmarine Blackhawk Formation includes data on fluvial channel-belt width, thickness and stratigraphic position. These channels and channel belt deposits show a systematic increase in size, both width and thickness, above a marine datum. This increase in size is interpreted to record the distributary nature of the system. Comparison to modern coastal plain systems has implications for understanding the scale of the palaeodrainage system the distance from the hinterland.

Data from lower shoreface and offshore transition zone deposits were collected using ground based lidar. Data extracted from the virtual outcrops includes information on bed thickness, height relative to a stratigraphic datum, facies tract thickness and lateral variability in bed thickness. A systematic upward increase in storm bed thickness records the upward shallowing of the progradational succession. Differences in the pattern of the upward thickening between different parasequences are interpreted to relate to changes in shoreline trajectory and inherited topography from the underlying, drowned parasequences.

In both case studies, digital data collection and storage in a database allow an improved understanding of very large scale variation in stratigraphic architecture.

Criteria for interpreting carbonate platform drowning histories and resultant diagenetic fabrics: insights from the actively subsiding platform margins of Hawaii.

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Large-scale patterns of carbonate platform development (and thus internal platform architecture) are most strongly influenced by the interplay between eustatic sea-level change and basinal subsidence or uplift. The subsidence regime and drowning history of carbonate platforms are particularly significant for hydrocarbon exploration and reservoir assessment as platform drowning surfaces are known to form diagenetic seals on top of; or permeability barriers within platform reservoirs. Understanding the evolution of the drowned surface often improves the prediction of porosity-permeability patterns and the nature and distribution of diagenetically-determined reservoir seals. So how can we improve understanding and interpretation of drowning histories in the geological record?

Taphonomic and diagenetic signatures (porosity and permeability loss and destruction, boring, encrustation, recrystallisation, cementation) have the potential to record processes associated with sedimentary facies development and platform framework accumulation, both during platform growth and after platform demise - either during subsequent drowning or following subaerial exposure and then re-submergence. Because many of the processes are linked to organisms with relatively tightly constrained bathymetric ranges they can be utilized to interpret depth and environment histories associated with platform drowning. Platforms typically experience a stepped drowning history resulting in an often complex taphonomic and diagenetic history, leading to progressive alteration as the platforms subside into deeper marine settings and/or cycles of meteoric and marine diagenesis are superimposed. However, whilst the taphonomic and diagenetic processes operating within shallow reef/platform environments (< - 30 m depth) are relatively well understood, those influencing carbonate preservation in deep environments (e.g., drowned platform surfaces) from > - 30 m to abyssal depths, are poorly understood.

A unique collection of successively drowned carbonate platform deposits that has been recently recovered from the platform margins of Hawaii are utilized here to examine the effects of progressive platform drowning on the evolution of platform facies and taphonomic and diagenetic fabrics. The samples range from water depths of 0 - 1500 mbsl and encompass a range of platform zones over a substantial time period (500 ka to present). Using the data from Hawaii, a major aim of this study is to develop a diagnostic model, incorporating the different stages of diagenetic and taphonomic alteration that occur during progressive platform drowning, and which can be used to aid the interpretation of drowning surfaces in the rock record. Initial observations of changes with increased depth include: a change from single to multiple phases of boring - sedimentation - cementation and overprinting; increased Fe-Mn crusts and dissolution of corals.

This diagnostic model will be used to more fully understand and characterise the drowning surface that forms an important vertical permeability baffle within the BG Group-operated Karachaganak field, Kazakhstan. This 'Top Carboniferous' (C1) surface is characterised by very localised connectivity between the Carboniferous and Permian reservoirs, but the controls on, and distribution of this connectivity are poorly understood. Comparison with the Quaternary data should improve our understanding of the lateral variability in reservoir quality across the C1 surface, leading to improved history matching of production data, and influencing the planned gas injection strategy.

Depositional elements within the Brent Delta (Middle Jurassic) of the North Sea Basin visualized using 3D seismic data

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Three-dimensional seismic reflection data are used to image lower delta plain deposits within the lower Brent Group, northern North Sea. Seismic attribute maps indicate the development of two types of amplitude anomaly. The first type of anomaly are represented by a series of sub-parallel, high-amplitude stripes up to 15 km in length, 50-100 m wide and spaced 150-200 m apart. In map view these features trend NE-SW to ENE-WSW and are arranged into 'sets' that display subtly different orientations. Well data in regions where these anomalies are well developed indicate pronounced anomaly-perpendicular thickness variations in sand-rich beach-ridge facies within the Etive Formation, and coals and mudstones within the overlying Ness Formation. Based on these observations, the high-amplitude anomalies are interpreted as the seismic expression of coal-filled swales, whereas the adjacent zones of low amplitude are interpreted to represent the cores of sand-rich beach ridges. The second type of anomaly comprises a series of slightly-sinuuous, low amplitude features, up to 500 m wide and up to 20 km in length. These anomalies typically trend NNE-SSW to NE-SW, are up to 500 m wide and can traced for up to 20 km. Well data indicates that high-amplitude regions adjacent to the sinuous anomalies correlate to a fine-grained, coal-bearing deposits. These sinuous low-amplitude features are interpreted as the seismic expression of sand-filled channels within the lower part of the Ness Formation, whereas the high-amplitude areas are interpreted as coal swamps. The results of this study have implications for; (i) palaeogeographic reconstructions of the Brent Delta; (ii) the stratigraphic context and preservation of beach ridges; (iii) datum selection when attempting stratigraphic correlations within the Brent Group; and (iv) the exploration and production of hydrocarbons from beach ridge-type reservoirs.

Linking the slope to shelf: an example from the Laingsburg depocentre, Karoo Basin, South Africa.

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The Permian Eccu Group in the Laingsburg area, South Africa, represents a complete transition from basin-floor deposits, through the channelised submarine slope (Laingsburg and Fort Brown Formations), into the shelf environment (Waterford Formation). This study represents the first detailed sedimentological and sequence stratigraphic analysis of the shelf to slope deposits of the Waterford Formation, enabling detailed characterisation of the transition from submarine slope to shelf setting.

The 300-900 m thick Waterford Formation is exposed along a series of east-west trending synclines and anticlines. Logged sections have been correlated by walking parasequence flooding surfaces for ~33 km in an oblique dip direction, along both limbs of a fully exposed west-east trending syncline. This has enabled quantification of proximal to distal (west to east) changes in sedimentary facies, thickness and depositional environment. Wave-dominated shorefaces and river-dominated mouth bars have been correlated to thin-bedded gully-fills, slide scars, upper slope channels, mass transport deposits, and half-graben. In addition, individual cycles thicken where erosion and mass flow deposits increase. Therefore, for the first time in the Karoo Basin, shelf deposits have been physically correlated to upper slope deposits. This suggests that the shelf-edge is a wide zone (~10 km) rather than a defined break in-slope as commonly indicated in seismic datasets.

Growth of long sinuous channels on the sea floor through autogenic flow regulation

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Long, sinuous submarine channels can extend from the continental shelf for hundreds of kilometers, and are the most important routing system for the transport of coarse terrigenous sediment and organic matter into deep marine basins. Although they often bear a strong visual similarity to rivers, our understanding of the processes which initiate and develop sinuous submarine channels, and allow them to both overspill and bypass coarse sediment, is limited. Here, using physical models, we evaluate downstream flow evolution and overspill in a sinuous subaqueous channel by analyzing grain-size distributions and velocity profiles of particulate turbidity currents. Flows attain an “equilibrium” with the channel through a combination of overspill and intra-channel deposition. Channelized flow adjustment is demonstrated by consistent lateral grain size fractionation of the channel deposit. Fractionation of the overbank and in-channel deposit increases down the channel: initially overbank and in-channel deposits are similar, in distal parts of the system, overspill of only the coarse fast moving part of the body flow results in coarser grained overbank deposits and a finer grained fill. These fractionation effects suggest a form of autogenic flow regulation that can potentially explain observations of similar phenomena from modern and ancient submarine channels, and provide an insight into their downslope evolution.

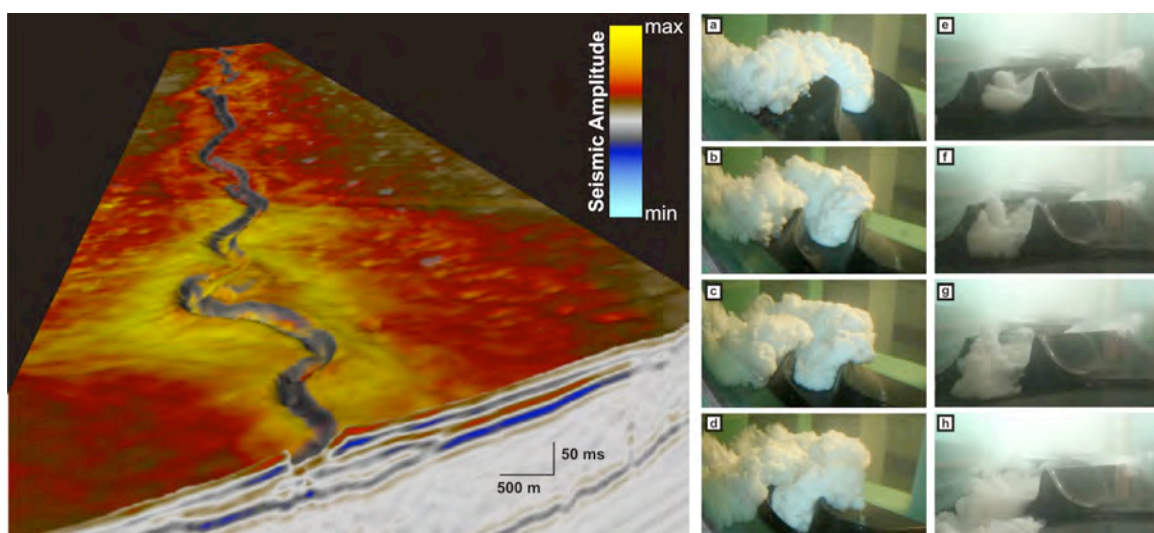


Figure 1 (left). A Quaternary aged submarine channel with levees imaged on the Angolan continental slope using seismic reflection data. The levees are sand rich as indicated by their high seismic amplitude, whilst the channel is a partially empty conduit with a relatively finer grained fill. Figure 2 (right) (a-d) Flow traversing the first bend following entry into the sinuous model. (e-h) Flow approaching the end of the channel model; the flow is fully confined along straight sections but the high velocity dense core overspills at bends.

Characterising the Paleocene submarine fans of the UK central North Sea (Mey Sandstone Member): observations from seismic, petrophysical and core analysis

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The Paleocene basin floor submarine fans of the UK Central North Sea are important petroleum reservoir units recording the cyclic input of sand-rich turbidite flows into the deepwater of the post-rift Central Graben basin. Each of these cycles (Maureen, Mey (Andrew) and Forties) have associated hydrocarbon production with the youngest Forties sands being the most prospective and well understood. Thanks to this regional prospectivity, there is an extensive associated dataset of 3D seismic, well logs and core material. Analysis of these datasets has enabled a regional-scale re-evaluation of these well-known deepwater deposits. Observations from seismic, core and well log analysis are used to map the reservoir quality and seismic stratigraphy of the Paleocene Mey (Andrew/Balmoral) sandstone member and advance our scientific understanding of the syn- and post-depositional dynamics within this sequence and the Paleogene as a whole.

The use of regional seismic data allow observations to be made about the extent, thickness, net to gross, bathymetric interaction and temporal evolution of the submarine fans. Observations from seismic data benefit greatly from correlation with core analysis and an extensive well database. Currently, core from 21 wells has been studied to evaluate the types of facies present and how these relate to bed connectivity, grain size distribution and porosity and permeability trends. Furthermore, integration of a regional well database (containing over 350 wells) allows for large-scale mapping of formation thicknesses and reservoir quality trends. In turn, this has enabled seismically derived maps to be ground-truthed enabling a more quantitative approach to seismic attribute-based reservoir property mapping.

The integration of these observations into a single database enables powerful interpretations to be made with both academic and industrial applications. Examples are presented of potential scientific advances including clarification of our understanding of the spatial and temporal evolution of the submarine fans from source to sink. Observations are made of the impact of basin geometry and salt-induced bathymetric variations on the distribution of reservoir properties as well as potential changes in the source area and the validity of previous models. Maps of sediment distribution and reservoir quality also allow industry workers to consider the remaining prospectivity of these intervals and the impact on the overlying Forties sandstone reservoir. It is hoped that this study will prove valuable to workers in both the Central North Sea and global deep-water sedimentology.

The authors wish to thank PGS for permission to use the Central North Sea MegaSurvey.

Glacial-lake deltas or tunnel-valley deltas? Middle Pleistocene glacial deposits of the Peterborough area, eastern England

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Buried channels beneath the Fen Basin of eastern England were originally attributed to a fluvial origin on the basis of borehole evidence, but a glacial origin has also been proposed based on this same evidence, which envisages bedrock depressions being scoured out by ice moving across the area from the northeast. In one such depression, at March, deltaic sediments are overlain by cohesionless gravity flow deposits, which in turn are overlain by chalk-rich diamicton. The direction of sediment transport is from the northeast. The sedimentary succession is about 28 m thick with its base at more than 23 m below sea level and its top at 5 m OD. The balance of sedimentary evidence from the succession at March does not favour origin of the depression by glacial scour by ice moving from the northeast. In another depression, at Stanground, deltaic sediments are overlain by deep-water deposits, which in turn are overlain by chalk-rich diamicton representing deposition as a subaqueous slide. The direction of sediment transport indicated by the deltaic deposits is from the southwest, but the subaqueous slide was deposited from the northeast. The sedimentary succession is about 20 m thick with its base at about 5 m below sea level and its top at 15 m OD. The sedimentary evidence indicates that this depression definitely does not owe its origin to glacial scour from the northeast. There is no evidence to suggest that the deposits at these two sites were not contemporaneous. Deposition in tunnel valleys in such close proximity to each other and evidence for sedimentary transport in opposite directions seems highly unlikely. The most parsimonious conclusion therefore is that these sediments were deposited in a glacial lake with a surface height at least 15 m OD, but probably 40 m OD based on the distribution of the subaqueous slide facies elsewhere in the area.

Sea ice-free conditions during the Sturtian glaciation (early Cryogenian), South Australia

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In the Neoproterozoic Snowball Earth hypothesis, shutdown of the planet's hydrological system has been attributed to a global ice cover during one or more extreme glaciations. In the central Flinders Ranges, South Australia, the Yudnamutana Subgroup of Sturtian age includes diamictite, sandstone and siltstone units of glaciomarine origin up to 5000 m thick, and is overlain by post-glacial, transgressive siltstone and shale of the Tindeplina Shale Member, Tapley Hill Formation. In the central Flinders Ranges, the Yudnamutana Subgroup consists of (1) the Pualco Tillite (gravity resedimented glacial deposits), (2) the Holowilena Ironstone (glacioturbidites), (3) poorly stratified pebbly diamictite of the Warcowie Dolomite Member, lowermost Wilyerpa Formation (gravity resedimented glacial deposits), succeeded by (4) siltstones and sandstones with abundant hummocky cross-stratification (HCS: storm deposits), and finally (5) a lonestone-bearing succession with cobble-sized clasts in the upper Wilyerpa Formation (ice rafted debris interpreted to record a glacial re-advance) in which HCS is absent. Because the action of oscillating waves is required to produce HCS on the sea floor, its presence indicates an interval of significant meltback, prior to glacial re-advance. Given that the HCS occurs ~2 km beneath the Tindelpina Shale Member, it signifies a major ice free interval during the Sturtian glaciation.

Facies-belt pinch-out relationships in a distal, mixed-influence shallow-marine reservoir analogue: Lower Sego Sandstone Member, western Colorado, U.S.A.

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Lateral and proximal-to-distal facies relationships in mixed, wave- and tide-influenced shallow-marine deposits are poorly documented in the ancient record. This study focuses on outcrops of the Lower Sego Sandstone Member, western Colorado, U.S.A., where tide-dominated sandstones interfinger with wave-dominated delta-front deposits within a series of stacked regressive-transgressive tongues. Several stratigraphic models exist; including sharp-based surfaces at the base of tidal deposits are related to (1) autocyclic erosion; (2) tidal ravinement associated with shoreline transgression; or (3) regressive surfaces associated with base-level fall. The stratigraphic relationships and facies-belt pinch-outs between tide- and wave-dominated deposits have been documented in detail along continuous exposures that cover an area of 7 by 12 km. Wave-dominated deposits are characterized by coarsening-upward successions with hummocky-cross stratified, very fine-grained sandstone in their upper parts. Tide-dominated facies are dominated by trough and herringbone cross-stratified, fine- to medium-grained sandstone, with subordinate intercalations of heterolithic sand-mudstone and inclined heterolithic strata. Tidal deposits overlie wave-dominated lower shoreface deposits across erosive bases and form either (1) thick, amalgamated sand bodies, or (2) thinner sand bodies intercalated with wave-dominated deposits. Clear proximal-distal trends exist, which follow the established regional paleogeography. The proximal (western) area comprises tens of meters wide tidal channels that erode into sub-tidal to upper inter-tidal deposits. Towards the distal (eastern) area, tide-dominated deposits form increasingly sheet-like sand bodies, which were exclusively formed in sub-tidal environments. Along the same proximal-to-distal trend, tidal sandstones decrease in thickness from 32 to 25 m over a distance of 8 km and pinch-out within another 8 km. Towards their pinch-out, tidal sandstones are increasingly reworked by waves due to successive flooding of the tidal bars and channels. Hence, sand body geometry reflects a combination of original tidal deposition and subsequent modification by wave reworking. This study describes and quantifies the intertonguing and pinch-out relationships within this distal, mixed-influenced shallow-marine setting. The stratigraphic significance of intercalated wave-dominated deposits within tide-influenced to tide-dominated deltas will be discussed.

U-shaped slope gully systems and sediment waves on the Gabon passive margin (West Africa)

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There has been much research focus on high sediment-supply parts of passive margins. In these settings canyon systems on the slope typically feed sand-rich submarine fans. In contrast, the low-sediment supply parts of the same passive margins exhibit a different range of less well-understood sediment routing systems. Here we use 3D seismic reflection data to describe suites of sub-parallel slope gullies and associated sediment waves defined at the seabed in a low-sediment supply system on the Gabonese continental margin. There is little or no sediment apron or fan observed down-dip of the gully system in the study area.

The gullies occur on the slope in water depths of 150-1500 m on a slope that has a gradient of 5° decreasing to 2°. The gully sets persist laterally for distances of at least 40 km. The gullies are u-shaped in cross-section, with a relief of 5-30 m, and widths of 50-400 m. Intriguingly, the gullies become narrower and shallower with distance down the slope, as well as increasing in number down slope. The majority of the gullies appear to be erosional but some are found that have resulted from simultaneous aggradation along inter-gully ridges and non-deposition along the adjacent gully floor. Hence, these gullies are interpreted to have formed mainly in response to spatially-variable deposition, rather than erosion. Some of the aggradational gullies have been infilled in and appear to be currently inactive. Upslope migrating sediment waves occur in close proximity to the gullies on the Gabon margin. Gullies cross fields of sediment waves and waves are observed to migrate up-slope locally within both the non-aggradational and aggradational gullies.

Evidence is lacking for any slumping or headward erosion in the headwall region of the gullies, and thus the gullies appear not to have formed by very local sediment gravity flows originating from slumping or shelf-edge collapse as has been observed in other v-shaped gully systems. Hence, it is proposed that the gullies and related sediment waves were formed by diffuse, sheet-like, mud-rich turbidity currents that presumably originated on the shelf. Instabilities in the turbidity currents led to regions of faster and slower flow. For the non-aggradational gullies it is inferred that gully axes experienced flow velocities that mainly exceeded the settling velocity of the sediment in suspension, and thus no deposition occurred. In contrast the aggradational gullies indicate lower flow velocities with sediment deposition both within the gully axes and on the gully flanks.

Field evidence that submarine debris flows can deposit clean sandstone over large areas: Marnoso-Arenacea Formation, Italian Apennines

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The Marnoso-arenacea Formation in the Italian Apennines is the only ancient rock sequence where individual submarine sediment flow deposits (beds) can be mapped out in detail for up to 120 km. These bed correlations provide new insight into how submarine flows deposit clean sand in the deep ocean. The shape of clean sandstone intervals provides an independent test of depositional process inferred initially from the sandstone's internal characteristics. Beds have four different geometries (facies tracts) in down flow transects. Facies tracts 1 and 2 contains clean graded sandstone intervals that were deposited layer-by-layer by turbidity current, and these intervals thin gradually down flow. Muddy sandstone deposited by debris flow occurs in the distal part of facies tract 2. Facies tract 3 contains clean sandstone with a distinctive swirly fabric formed by patches of coarser and better sorted grains. This distinctive fabric most likely records pervasive liquefaction. This type of clean sandstone pinches out abruptly, and this abrupt pinch out suggests that this clean sandstone was deposited by debris flow. Facies tract 4 contains massive ungraded sandstone intervals that also pinch out abruptly, and this shape indicates deposition by debris flow rather than steady turbidity current. This field data therefore indicates that submarine debris flows can spread clean sand over large expanses of the sea floor.

Depositional characteristics of natural cohesive sediments

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Tidal estuaries are dominated by muddy sediments; typically a mixture of clay minerals and various types of organic matter. When this cohesive sediment is entrained into suspension, the particles tend to flocculate. These flocs are less dense, but faster settling than their constituent particles. As flocs grow their effective density generally decrease, but their settling rates rise due to a Stokes' Law relationship. This presentation will review some of the recent advances made in the study of the flocculation process through the use of video image technology. These video devices can be adapted to observe floc spectral physical properties, which include: floc size, settling velocity, effective density, porosity and floc shape. Examples of *in-situ* estuarine measurements of flocs in turbulent tidal waters will be presented. In addition, examples of how such video floc data can be used to parameterise floc settling characteristics for use in modelling will be demonstrated.

Sediment transport and deposition in a modern submarine canyon

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Nazaré Canyon extends from a water depth of 50 m near the Portuguese coast to 5000 m at the edge of the Iberian Abyssal Plain. The canyon location is fault-controlled. It is not connected to a modern river and obtains its present day sediment input by capture of along-shelf transport. Nazaré Canyon is morphologically complex, with an entrenched steep-sided upper section, an incised axial channel flanked by perched terraces in the middle section, and a broad flat-floored lower section that merges with the Iberian Abyssal Plain some 200 km offshore. The lower canyon is flanked by an extremely asymmetric levee system, with the larger levee to the north. This levee is built from a stacked series of turbidites and interbedded hemipelagic sediments that accumulated at ~0.5 m per thousand years through the last glacial. Turbidite input to the levee essentially ceased at the start of the Holocene when sedimentation rates decreased to ~0.1 m per thousand years. This scenario is repeated in the lower canyon where a thin drape of Holocene mud overlies sands and gravels of presumed late glacial age.

The middle canyon (between 2700 and 3800 m) is a highly heterogeneous environment and distinctly different from the lower canyon. It is a significant Late Holocene sediment depocentre with an estimated annual sediment budget of ~620,000 t, about one and a half times the annual sediment discharge of the Tagus River. Areas of both high and low Holocene sedimentation rates, exposed rock outcrop, erosion, and stable and unstable slopes lie in close juxtaposition. The main morphological characteristic of the middle canyon is a narrow, steep-sided, thalweg channel flanked by gently sloping 'terraces'. Small-scale landsliding, active at the present day, is the main process that exposes a variety of substrates, ranging from semi-consolidated Holocene sediments to rock of probable Mesozoic age, on the steep thalweg channel walls. Landsliding is probably driven by high rates of sedimentation on the adjacent terraces. The thalweg floor is characterised in part by large-scale sediment bedforms and in part by landslide debris, suggesting some reworking of landslide debris by currents within the channel. The 'terraces' are interpreted as inner levees with high sedimentation rates. Cores show a dominantly muddy sequence interrupted by thin turbidite sands emplaced on decadal timescales. The fine-grained sedimentation is the product of quasi-continuous settling from nepheloid layers. Down-canyon transport appears to be the result of west-directed residual tidal currents, rather than gravity flows, although the nepheloid layers may be created by transformation of weak gravity flows in the upper canyon.

Late Jurassic slumping in the 'Block' region of the UKCS Central Graben: temporal and spatial relationship to deep marine turbidite reservoirs

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Mass-transport complexes (MTCs) have been recognised in the Upper Jurassic succession of the UK Central North Sea "J Block" area, associated with two horst blocks. The timing of the MTC events relative to the deposition of local reservoir units in the Late Jurassic may have consequences regarding reservoir potential.

Using well log, core and seismic data, two olistostrome blocks, in excess of 100 m in thickness, length and width have been identified within Upper Jurassic marine sediments. Examination of well and core data indicates these olistostromes were derived from the footwall of the Judy and Jade horsts, that each block represents an isolated slump event and they are the correct way up. In addition to the olistostromes, nineteen distinct breccia and conglomerate horizons, interbedded with marine mudstones and sandstones, have been recorded from a cored section within the Upper Jurassic. These represent classical submarine debris flows, being chaotic, very poorly sorted, matrix supported (coarse sandstone), with sub-angular to sub-rounded clasts ranging from pebble to boulder size (<2 cm - >20 cm). The provenance of the clasts is observed to vary through time and does not present a conventional unroofing history, with the oldest and youngest debris flows containing Triassic clasts, punctuated by a period when clasts were derived from a Jurassic source. Both the olistostrome and debris flow events are interpreted to have originated from the footwall of a horst, where Triassic strata was exposed, which developed during Late Jurassic rifting of the Central Graben.

Biostratigraphic dating of the sediments encapsulating the MTCs demonstrates that these events were not contemporaneous with the deposition of local reservoir units. Deposition of the reservoir facies represented the initial rift stage, whilst MTCs occurred during the rift climax, once major faults had broken to the surface. In terms of paleogeographic setting, the terrestrial palynomorph data indicates that one of the horst blocks was subaerially exposed, whilst the second horst examined may have remained largely submerged. The evolution of the rift related topography and consequential extent of horst exposure has implications for the deposition of reservoir quality facies and for determining the provenance of the sandstone bodies.

Sandy external levees: origin, geometry and implications

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External levees to submarine channel systems are generally perceived to be mud- and silt-prone. Here, an example of a sand-rich external levee is presented from Unit C3 of the Permian Fort Brown Formation, Karoo Basin, South Africa. The geometry and facies distribution of this unit has been captured by high-resolution detailed logging of behind outcrop core as well as correlation and mapping at outcrop. The unit thins and thickens from 17.5m to 3m over 700m lateral distance. Sandstone beds downlap onto an underlying mudstone unit that maintains a constant thickness, which indicates a demonstrably depositional form to C3. The sedimentary facies is dominated (in both core and at outcrop) by dm-scale sigmoidal bedforms, with low-to-high angle climbing ripple laminated fine-grained sandstones indicating high rates of deposition. A channel-fill adjacent to this levee has not been recorded during outcrop studies. Either this is not exposed at outcrop, or, the construction of the levee occurred in front of the parent channel, and the channel did not lengthen to subsequently incise and further develop the levee. Deposits with similar geometry and facies characteristics have been found towards the base of larger more established external levees in the Fort Brown Formation supporting the interpretation that the C3 deposits may represent a rare example of a 'proto' external levee preserved at the initiation of levee development.

Tectonic-sedimentary development of the Upper Cretaceous-Middle Eocene Kirikkale Basin, Central Anatolia, Turkey

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Central Anatolia, Turkey, lies in the Alpine-Himalayan orogenic belt and is one of the world's best localities to study the tectonic-sedimentary processes involved in an ancient continental collision zone. In this area, a strand of northern Neotethys subducted northwards under the Eurasian (Pontide) margin in Late Cretaceous-Early Cenozoic time. Subduction generated ophiolites, magmatic arcs, accretionary prisms and accretionary forearc-type sedimentary basins, now preserved in a wide E-W-trending suture zone which is exposed throughout Central Turkey. However, there is still debate on the timing and mechanism of subduction and continental collision.

In order to reconstruct the tectonic history of the region, we have gathered and synthesised new sedimentary, structural and geochemical field data. One approach is to study the sedimentology, stratigraphy and provenance of a series of Upper Cretaceous-Middle Eocene syn-tectonic basins which are located at the southern margin of the Eurasian margin. The best example is the Kirikkale Basin, situated ~60 km east of Ankara. This basin developed on a mainly Late Cretaceous subduction-accretion complex and the margin of a Mesozoic microcontinent to the south of a volcanic arc. Basin deposition began with deep-marine Campanian volcanoclastic sediments (750 m) which pass upwards into Maastrichtian calciturbidites (500 m). These sediments represent arc magmatism and the erosion of a shallow-marine carbonate platform to the north. Above come Palaeocene deep-water siliciclastic turbidites (500-800 m) and thin (30 m) units of detached limestone blocks and debris flows which record the erosion of a subduction- accretion complex and an associated corallgal carbonate platform to the north. During Early to Middle Eocene time, shelf-type shallow-water limestones (50 m) and terrigenous siliciclastic sediments (200-300 m) were deposited, typically unconformably on crystalline basement rocks in a shallow-marine deltaic-type setting.

These new data can be used to test and develop current models of Late Cretaceous subduction processes in this region, where existing models point to either: 1) a stationary, north-dipping subduction zone which was active beneath the Eurasian margin and generated continental margin magmatism or; 2) a north-dipping subduction zone which was active beneath the Eurasian margin and subsequently migrated (rolled back) southwards triggering intra-oceanic arc magmatism. Based on the oceanic provenance of basin-fill sediments during subduction, the evidence presented here is consistent with option 2.

The sedimentology of resource plays

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The oil and gas industry in Canada and the US has undergone a transformation over the past few years with a dramatic shift to production from so-called unconventional oil and gas plays, or resource plays. Typically these plays involve relatively unstructured, extremely low permeability deposits which are drilled up with horizontal wells and then fractured at extremely high pressures to open conduits to hydrocarbon flow. Three main classes can be recognised: basin centred (or tight) gas, oil and gas shales, along with oil sand deposits (although the oil sands are considered "unconventional" rather than resource plays, and will not be considered here).

While some fields can be drilled up as "factory fields" i.e. on a "drill to a pattern", well by well basis with almost no technical input, sedimentology has a significant role to play both in targeting so-called sweet spots for production, and also in improving overall yields. Tight gas plays produce from tight, low permeability rocks, and an understanding of reservoir architecture is critical. Oil and gas "shales" often comprise siltstones and/or fine grained carbonates, with carrier beds of coarser deposits. Mapping of such interbeds is critical in drilling into the correct horizons. Interpretation of electronic logs can also facilitate the development of accurate geological models that lead to increased understanding of reservoir behaviour.

After giving a quick overview of the classes of resource plays, new sedimentological strategies will be presented that can be utilised to maximise exploration and production success in the subsurface. Sedimentological aspects such as the impact of reservoir architecture on facies and hence porosity distribution, sequence stratigraphic analysis and correlation, isopach variation due to clinoform geometries, diagenesis and the role of sediment composition, and outcrop analogues and the use of a handheld scintillometer to measure gamma radiation, will be addressed.

The importance of these hydrocarbon resource plays cannot be underestimated, and has led to a renaissance in North American gas (and oil) production. Incorporating sedimentological models is critical in maximising returns from these deposits.

Basal flow reversals within ponded turbidity currents

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Turbidity currents can be confined by sea floor topography (leading to deflection, reflection or constriction of the flow). When a turbidity current is discharged into a topographic low and its duration exceeds the time needed for an upstream-moving bore to propagate from the counter slope to the inlet area ('sustained flow'), it becomes ponded and a thick sediment-bearing suspension cloud is generated. One of the key features which has been widely used in the field to identify deposits of confined and ponded turbidity currents is evidence for palaeocurrent reversals within an individual bed, recording changes in flow direction of the current (or at least of its near-bed layer). While it is intuitive how surge flows can generate basal flow reversals (as the entire current can be fully reflected), the origin of such features in the case of ponding of sustained turbidity currents is still unclear.

Flume experiments were designed to reproduce full and partial ponding of turbidity currents meeting a counter slope. A new non-intrusive 3D velocity measurement technique (based on the Ultrasonic Velocity Profiler by Met-Flow) was designed to image the velocity field above the confining slope. A two-layer circulation system within the sediment-bearing ponded cloud can be recognised, with a basal outbound-moving layer overlain by a layer characterized by return flow. Data show four types of basal flow re-orientation: 1) 'initial rebound', 2) 'oscillating interface', 3) 'basal layer' and 4) 'cloud collapse' flow reversals. 'Initial rebound' reversals are generated shortly after the current has reached its maximum run-up and they represent the initial collapse of a portion of the flow. This type of reversal can be of significant duration (lasting longer than the head of the current) and they are characterised by high values of turbulence. After being generated above the confining slope, the reversal 'travels' upstream and can reach well into the basin. 'Oscillating interface' reversals occur if the interface between the velocity layers shift downward (e.g. because it is vertically displaced by the passage of an internal wave) and the upper return layer reaches the slope floor. These usually are repeated periodically. 'Basal layer' reversals represent flow collapses within the basal outbound layer which may or may not reach the slope floor. They are often long in duration (tens of seconds) but their velocity is rarely significant given the experimental boundary conditions. Finally, after the current wanes and the suspension cloud collapses, long-duration slow-moving reversals ('cloud collapse' reversals) are generated.

The new experiments give insight into the generation mechanisms and the character of basal flow reversals within a sustained ponded turbidity current and can help better characterise and interpret vertical sequences of palaeocurrent indicators with opposite directions within an individual bed.

Core-based sedimentology of a mixed-influence delta system: Sognefjord Formation (Early-Late Oxfordian), Troll area, Norwegian North Sea

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In this study, we examine the sedimentological features of a Late Jurassic, shallow marine delta (Sognefjord Formation, Troll Field), covering an approximate area of 1,500 km² on the Horda Platform, northern North Sea. The analysed epoch was a time of episodic rifting for the northern North Sea Basin, which could have influenced the sedimentary patterns.

Core logging of 13 wells on the Horda Platform indicates a complex, mixed-process deltaic system, which is internally subdivided into outer-shelf, wave-dominated shoreface, tide-influenced shoreface and marginal-marine depositional settings. Outer shelf deposits (facies associations A and B) mainly comprise well-bioturbated mudrocks with rare higher energy beds.

Wave-dominated lower shoreface deposits (facies association C) include fine-grained, bioturbated sandstones interbedded with hummocky cross-stratified and/or sharp-based, coarser-grained event beds. Upper shoreface deposits (facies association D) are mostly composed of cross-bedded, medium- to coarse-grained sandstones. Thick-bedded, coarse-grained, structureless beds occur in both associations, possibly as the result of river-flood and/or rip-current processes.

Tide-influenced lower shoreface deposits (F) are distinguished from facies association (C) based on the near-absence of coarse-grained event beds and much lower intensity of bioturbation by a distinctive *Planolites-Palaeophycus* assemblage. Mud-draped, cross-stratified sandstones are diagnostic of the tide-influenced upper shoreface (G).

Marginal-marine deposits comprise tide-influenced bay-fill and delta front facies associations. Tide-influenced bay-fill (facies association H) is composed of mud-draped, rippled, very fine-grained sandstones, which are commonly interbedded with sharp-based, metre-scale, fining-upwards packages interpreted as tidal channel fills. Delta front deposits (I) are characterised by coarse-grained, debris flow and dune-scale cross-stratified sandstone beds with floating clasts, closely associated with fine-grained sandstones. Sporadic sharp-based packages also occur within association (I) and are interpreted as potential distributary channel fills.

The Sognefjord Formation is a sand-prone clastic wedge sourced from the Norwegian mainland and prograding westwards through the Horda Platform and the bordering fault-bounded terraces. This unit thins from 180 m in the east to its western pinch-out. It comprises a series of 10-40 m thick, shallowing-upwards units bounded by marine flooding surfaces associated with ravinement lags. The parasequence stacking pattern reflects overall progradation. In line with previous studies, we identify four genetic sequences within the Sognefjord Formation. The overall importance of tidal processes increases in the uppermost two series, as in most wells the shoreface facies evolve from wave-dominated to tide-influenced.

In the north-eastern corner of the Troll West area, mouth bars and lagoons accreted incrementally towards the south-west; further west and south-east, sediments were variably transported and reworked by wave (e.g., longshore drift) and tidal processes. As a consequence, a southerly elongated spit and/or strandplain built out in the remaining Troll West area, with wide tide-influenced, partly sheltered, shoreface and marginal marine environments behind it (Troll East area). The palaeogeographic distribution of the facies associations in the study area can thus be explained by the westward progradation of a mixed-influence delta. Its facies and process regime patterns are generally consistent with previously proposed, smaller-scale case-studies.

Future work will focus on constraining the 3D geometry of the shoreline (seismic geomorphology) and its migration through time (shoreline trajectory analysis).

Effects of topography of lofting gravity flows: implications for the deposition of deep-water massive sands

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Hyperpycnal flows are generated in the marine environment by sediment-laden fresh water discharge into the ocean. They frequently form at river mouths and are also generated in proximal ice-melting settings and are thought to be responsible for transporting a large proportion of suspended river sediment onto and off the continental shelf. Hyperpycnal flows are an example of gravity currents that display reversing buoyancy. This phenomenon is generated by the fresh water interstitial fluid being less dense than that of the ambient seawater. Thus after sufficient particles are sedimented the flow can become positively buoyant and loft, forming a rising plume. Here we present results from physical scale-modelling experiments of lofting gravity currents upon interaction with topography. Topography, in the form of a vertical obstacle, triggered a localised lofting zone on its upstream side. This lofting zone was maintained in a fixed position until the bulk density of the flow had reduced enough to allow lofting along its entire length. The obstructed lofting zone is associated with a sharp increase in deposit thickness. By inference these experimentally established lofting dynamics are applied to improve understanding of the potential for hyperpycnal flows to deposit deep-water massive sands. This study provides a depositional mechanism by which large volumes of sand can be deposited in the absence of traction and the fines removed, leaving thick deposits of structureless sand with a low percentage of mud. This conceptual model for the first time provides a framework by which the geometries of certain deep-water massive sands may be predicted within specific depositional and basinal settings. This is crucial to our understanding of massive sand deposits in modern and ancient turbiditic systems and in the commercial evaluation of hydrocarbon potential of such sedimentary successions.

Marine nutrient dynamics in turbid estuaries - A case study of the Seine estuary, France

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Tidally-influenced cycles of sediment deposition and resuspension are a prominent feature of estuarine systems. Sediments are a potential reservoir of nutrients, in both the pore-water and solid phases, but the effects of sediment transport processes on water column nutrient concentrations and water quality are poorly constrained.

To address these issues, an integrated approach was undertaken to assess the sedimentary flux of macro-nutrients (nitrogen and phosphorus), from a physico-chemical perspective, in a pilot study conducted on the Seine Estuary, France. In this work, hydrodynamic data collected using CTD and ADCP instrumentation, were compared with the nutrient concentrations of the upper and lower water column. Profiles of the master variables, temperature, salinity and turbidity, were obtained hourly over a tidal cycle in the turbidity maximum zone. Current velocity was collected continuously by ADCP, while nutrient concentrations (nitrate, nitrite, ammonium and phosphate) from surface and bottom waters were determined in the laboratory post-collection.

Results collected across a ten hour sampling period demonstrated significant variability in hydrodynamic conditions, particularly turbidity. Suspended sediment concentrations ranged between 0.16 and 4.5 g.L⁻¹ while salinities ranged between 1 and 22 PSU. These characteristics contributed to the formation of a turbidity maximum zone, associated with a tidal intrusion. Nutrient concentrations throughout this period responded to distinct changes in the suspended sediment concentration, indicative of physical forcing.

The results presented here highlight the importance of understanding the relationships between sediment properties and nutrient availability and their implications for water quality and estuarine management. The results are also relevant to other turbid, macrotidal estuaries.

Deep-water fan to base-of-slope transition in the Clare Basin, western Ireland: new constraints from behind-outcrop coring

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The Namurian Clare Basin, western Ireland preserves a progradational fill involving deep-water fan, slope and stacked deltaic cycles. The basin floor Ross turbidite system is overlain by slope deposits of the Gull Island Formation. A recent coring programme has acquired almost 700 m of large-diameter (PQ) core and associated data from behind a series of key cliff sections in the basal Gull Island and Ross formations on Loop Head. The cores will ultimately form part of a new training resource in Co. Clare as well as providing new insight into the depositional evolution of the system. Two pilot holes (101 and 93 m long) were drilled in the upper Ross at Fishermen's Point and the basal Gull Island and uppermost Ross near Cross. The two cores have been logged in detail and matched to wireline and orientated Televiwer logs from the boreholes and then correlated to the adjacent outcrops. These data together with a photomosaic of the cliffs on the north side of Loop Head acquired from the sea have been used to construct a 5 km correlation panel for the Upper Ross that is tied using condensed sections and laterally-extensive slumped units.

The cores and correlation panel characterise the transition from the inner axial fan system of the Ross Sandstone to the toe of slope deposits of the Gull Island Formation. The cores show bed scale variations often obscured by weathering in outcrop including the character of bed tops, particularly where clay-prone, and a wide range of soft-sediment deformation features in the slumped units. Many of the structureless sandstones have clay-rich sand upper divisions and resemble hybrid event beds rather than conventional turbidites. The slumps can be either dominantly muddy or with large sand rafts. Internal structures in the slumps include abundant folding, sand injections, dense arrays of extensional and reverse faults, and low-angle slide surfaces. The upper Ross (c.200 m thick) comprises at least six slump bodies (including the Ross Slump) with lateral extents of 3-4 km alternating with stacked turbidite sheets (dominant motif), channels (subordinate) and at least 4 condensed sections. Obvious channels in the cliffs are distinguished in the cores on the basis of high bed amalgamation and basal mudclast breccias, where present. The succession shows an upward increase in complexity and heterogeneity consistent with progradation of a muddy slope system into the basin.

70% of all turbidites are hyperpycnal!

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“Often you have to decide when the data are not as good as you would like.” Many features of sandy turbidites that puzzled Bill Normark and me over the years make sense if hyperpycnal flows are common in marine turbidite successions. Yet documented examples of sandy turbidites originating from hyperpycnal flows are sparse. This is partly because we live at the wrong time (sea-level highstand), as a society have offset the sediment supply effects of land- use change by building dams, and have carried out research in the wrong places.

Unlike sediment gravity flows that evolve from sediment failure, hyperpycnal flows are already well established where the river or subglacial discharge enters the sea. Proximal settings are thus important for distinguishing the two flow types. Observations on Laurentian Fan, where the 1929 slump-generated turbidite overlies a 19 ka ice-margin hyperpycnal turbidite, are helpful in illustrating some important features of hyperpycnal flows. Multibeam bathymetric surveys provide evidence for present-day direct flow from rivers to the ocean. Thick basin-wide sand beds far exceed the dimensions of single river-flood discharges or reasonable sizes of initiating failures: erosion of sand from canyons and channels is an essential part of the sediment budget of many large turbidites. Once a slump-generated turbidity current has made the transition from a mass flow to a turbulent flow, it will evolve in a manner similar to a hyperpycnal flow and the two types are likely indistinguishable distally. The answers to questions about hyperpycnal flows will thus largely depend on modern marine investigations, not the study of ancient rocks.

Large slump-generated turbidity currents supply sediment to oceanic basins. Medium-sized mountainous rivers commonly deliver sediment to tectonically active settings, in many cases on continental crust, and thus have a higher preservation potential. They are likely sources of both hyperpycnal flows and slumps. The 70% estimate in my title is “back of the envelope” speculation designed to encourage debate.

Kuenen’s early experimental work approximated a hyperpycnal flow. Then Heezen and Ewing discovered the 1929 Grand Banks slump and turbidite that had two generations thinking that slumps produce classic turbidites.

Integrating outcrop sections and research boreholes to understand the internal organisation submarine lobe deposits

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The internal organisation and the lateral distribution of submarine lobe deposits is here documented by using research boreholes and outcrop observations from Fan 3 (a lobe complex of the Tanqua depocentre), and Unit A (a composite sequence set of the Laingsburg depocentre) of the Karoo Basin, South Africa. A hierarchy of depositional elements has been described and ranges in thickness from a few centimetres to more than 350 meters. Depositional elements, from small- to large-scale, are named bed, lobe element, lobe, lobe complex, lowstand systems track, sequence, composite sequence, and composite sequence set. A ~ 550 m behind outcrop core allows characterisation of fine-grained units that overlie individual sand-prone elements, which is essential to interpret depositional elements. Through integration of the research borehole and the surrounding outcrops, lobe complexes can be correlated over 15 km in a down-dip direction and individual lobes can be correlated for km's. Contrary to several published models, thickening-upward is only one of several stacking patterns in lobes. Internal stacking patterns can change laterally from thickening-upward, thinning-upward, static thicknesses and thickening then thinning-upwards.

Mapping individual lobes also facilitates analysis of the spatial and temporal distribution of sedimentary facies. Four environments of deposition are defined at a lobe scale: axis, off-axis, fringe, and distal fringe. Each environment is characterised by a sedimentary facies association, thickness range, and position within the mapped element. They show a finger-like distribution within the lobe body and toward the pinchout, illustrating that several turbidity current flow 'pathways' existed during the evolution of a single lobe. Away from the main flow pathways (axes), lobe deposits tend to thin and preserve more bed stratification, and include a greater proportion of siltstone and hybrid beds.

The integration of core and outcrop from the Tanqua Karoo merits close attention as an outcrop analogue to systems of a similar scale and character (like reservoirs in the Paleogene Wilcox Group, Gulf of Mexico).

Diversity in bar sedimentology in a single large river: the Rio Paraná, Argentina

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Alluvial facies models assume that channel deposits can be characterised by assemblages of sedimentary structures that relate to specific hydro-dynamic processes, and hence geomorphology. The validity of this approach depends critically on the variability *within* river systems, which is not well defined. This paper explores the diversity in sedimentology of 15 sandy mid-channel bars in one of the world's largest multi-channel rivers: the Paraná River, Argentina.

The investigated bars differ in size, shape, evolutionary history and location relative to the finer-grained Rio Paraguay tributary. 40 cores and 70+ km of Ground Penetrating Radar (GPR) data show that the composition of mid-channel bars varies considerably. The distribution of radar facies *within bars* is spatially uneven. Such local variability is attributed to local differences in flow and sediment transport over the bars and individual development histories. Facies composition *between bars* varies considerably as a result of different evolutionary histories, different relations with the shifting sinuous thalweg, and different boundary conditions such as reach-scale differences in grain size. The data show that multiple bars and large areas need to be investigated to provide reliable statistics of facies composition in a river system.

The observed variability in bar sedimentology suggests improvement of facies characterizations may not be realized by treating compound bars as individual entities, but rather as a collection of smaller depositional units with comparable formative processes and internal structures (e.g. unit-bars, cross-bar channels, gradual vertical accretion).

Sedimentary evidence of the northerly, active margin of the S Neotethys ocean during Late Cretaceous-Early Cenozoic time: evidence from the Kyrenia Range, Cyprus

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Sedimentology and planktonic foraminiferal biostratigraphy shed light on the tectonic development of the northern, active continental margin of the Mesozoic Neotethys ocean (S Neotethys) in the Kyrenia Range. Following regional Triassic rifting a carbonate platform developed during Jurassic-Cretaceous time, followed by its regional burial, deformation and greenschist facies metamorphism. The platform rocks were exhumed by Maastrichtian time and unconformably overlain by locally derived carbonate breccias, passing upwards into pelagic carbonates of mainly late Maastrichtian age. In places,† pelagic carbonates are interbedded with siliciclastic or calcareous sandstone turbidites derived from mixed continental-type, basic volcanic, neritic carbonate and pelagic source materials. Two contrasting volcanogenic sequences are exposed in the western and central Kyrenia Range, separated by a thrust fault. The structurally lower of these is made up of a thickening-upward sequence of mainly Maastrichtian-aged pelagic carbonates, silicic tuffs, silicic lava debris flows and thick-bedded, to massive rhyolitic lava flows. The structurally overlying volcanogenic sequence comprises mainly late Maastrichtian and Late Palaeocene basaltic pillow lava, pillow breccia and hyalotuff, interbedded with pelagic carbonates. Additional basaltic lavas exposed throughout the central and eastern Kyrenia Range and the Karpas Peninsula mainly erupted during Late Maastrichtian and Late Palaeocene time. In the favoured tectonic model the Mesozoic carbonate platform of the Kyrenia Range capped a rifted† continental fragment within the southern Neotethys. During the Late Cretaceous the Kyrenia platform subducted northwards beneath a† larger Tauride microcontinent unit to the north, underplated and then rapidly exhumed, possibly owing to oceanic slab rollback. Pelagic carbonates and sandstone turbidites of mixed, largely continental provenance then accumulated locally along a deeply submerged continental borderland. Both the silicic and basaltic volcanogenic rocks are likely to have erupted in adjacent basinal areas above exhumed Mesozoic continental basement during Maastrichtian time. The probable tectonic setting involved a combination of northward subduction during the Late Cretaceous, followed by Maastrichtian and Palaeocene extension-, or transtension-, related volcanism that was associated with anticlockwise palaeorotation of the Troodos microplate. The contrasting silicic and basaltic volcanic sequences were later juxtaposed, probably related to southward thrusting during Mid-Eocene time, driven by the a later stage of closure of the southern Neotethys.

Palynomorphs deposited in prodelta rhythmites of the palaeo-Colorado delta in the Fish Creek-Vallecito basin, southern California as indicators of high altitude catchment environments.

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The Pliocene delta of the Colorado is well-exposed in the Fish Creek-Vallecito Basin, southern California. Its deposits can be divided into three units: a lower sand-rich turbidite unit, overlain by a thick unit of pro-delta rhythmites, capped by a very thick unit of delta-top cycles. By analysing palynomorphs from the prodelta rhythmites (Early Pliocene, c.5 Ma), we can demonstrate the environments from which sediment was sourced and through which they may have travelled.

The rhythmites consist of very fine sand-muddy siltstone couplets ranging from 5-30 cm thick, with no sharp contacts, suggesting continuous traction-dominated deposition. Samples of the muddy siltstone bed of the rhythmite couplets were collected every 5 m from a 105 m section of rhythmites and prepared for palynomorph analysis by hydrofluoric acid digestion.

Palynological analysis reveals evidence of several different environments within the catchment area, including a lowland swamp and a relatively dry upland environment. The pollen taxa *Inaperturopollenites hiatus* (Cupressaceae, *Metasequoia*) and *I. distichum* (Cupressaceae, *Taxodium*) are representative of large, moisture-tolerant trees living on the river floodplain. Farther up the river system, ferns (eg. *Deltoideospora* spp.) and fern allies are indicative of the back swamp region, distal to the main water source. The samples also exhibit bisaccate pollen (Piniaceae), suggestive of drier conditions, possibly of higher altitude due to the presence of fir pollen (*Abiespollenites* spp.). Pollen of angiosperms, cycads, ginkgophytes and palms are also present. Many of the samples contain degraded and/or reworked palynomorphs, suggesting that they have travelled a significant distance from their source. Evidence of cubic pyrite development is apparent in some samples, which suggests that an anoxic environment was present in the system. This may be evidence of a lacustrine environment along the course of the river, or stagnant pools of water trapped in the swamps.

These results suggest that by the early Pliocene the Colorado River was connected into an elevated area and, unlike the modern river, had important lacustrine areas in its hinterland. We will explore the implications of these results for the past climates of the SW US and the evolution of the Grand Canyon.

Fluid mud generated grain size breaks in turbidites: what can they show us about flow processes?

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Sharp surfaces across which there is an abrupt upward decrease in grain size (grain size breaks) have been observed in turbidites from numerous disparate locations around the world, including both ancient outcrops and modern cores. Understanding how these grain size breaks form is important because they are a departure from classical models of turbidite evolution, which describe progressively finer sediment being deposited from waning flows to form a smooth fining upward trend.

Here we present extremely detailed analyses of grain size breaks from the Moroccan Turbidite System, offshore Northwest Africa. Over the last 200,000yrs this system has hosted some very large events with volumes exceeding 100 km³. Three interconnected basins comprise the Moroccan Turbidite system stretching 2000 km from the Seine Abyssal Plain in the Northeast to the Madeira Abyssal Plain in the Southwest and the Agadir Basin situated in the central part of the system. Each basin records complex turbidite infill from a variety of source areas including siliciclastic flows from the Moroccan continental margin, volcanoclastic turbidites from Canary Island landslides and carbonate rich turbidites derived from local seamount failures. Excellent core control, from over 300 shallow piston cores, coupled with a strong chronostratigraphic and geochemical framework has enabled extensive correlation of individual turbidites between the basins.

Such detailed field data enables grain size breaks to be documented in across flow and down flow directions, confirming that the missing grain sizes are found long distances down slope. These proximally bypassed grain sizes are found within very thick mud caps (up to 5m). The architecture of the mud caps is strongly controlled by topography with turbidite mud preferentially ponding into very subtle topographic lows. The volume of this bypassed material is impressive, exceeding 150km³ in some turbidites. Two types of grain size break are recognised, both overlain by ungraded mud. Type I grain size breaks are found throughout the system and are underlain by fine sand (typically rippled) indicating deposition from a waning turbidity current. These breaks are interpreted to be the result of intermediate grain sizes being bypassed within a cohesive fluid mud layer, developed at the rear of the decelerating turbidity current. Type II grain size breaks are found distally and are underlain by ungraded structureless mud-rich sand deposited from a cohesive debris flow. This type of grain size break is most likely the result of an internal boundary within the flow at which there is a sharp transition in both sediment concentration and grain size. In both cases, the missing grain sizes are bypassed within a fluid mud layer developed at the tail of the decelerating turbidity current. Such grain size breaks occur throughout the Moroccan Turbidite System, and could provide evidence of large scale fluid mud generation.

Seven glacial cycles in the Middle-Late Pleistocene of NW Europe: geomorphic evidence from buried tunnel valleys

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The deep-ocean marine isotope record and the Antarctic and Greenland ice caps record numerous glacial and interglacial cycles since the Middle Pleistocene, yet evidence for similar numbers of ice-sheet advances over the continent and shallow shelves of NW Europe is absent. Here we present seven generations of regionally correlatable subglacial tunnel valleys that record the geomorphic imprint of ice sheets traversing the North Sea basin between ca. 500 and 40 Ka, consistent with the pattern predicted by proxy records of glacial and interglacial climate change. Over 180 subglacial tunnel valleys that incise into Pleistocene sediments in the North Sea basin were mapped over ~60,000 km² of 3-dimensional seismic reflection data. Using a subset of these data we have identified seven separate episodes of subglacial erosion which can be correlated regionally in the UK sector of the central North Sea. The characteristics of the valley morphologies, orientations and infill stratigraphy indicate that each set of tunnel valleys formed during a separate ice sheet advance and retreat cycle. Stratigraphic data suggest that the tunnel valleys formed significantly later than the Brunhes-Matuyama reversal event at 780 Ka and before the Last Glacial Maximum (marine isotope stage [MIS] 2; 21 Ka). These results imply a more complicated glacial history for mainland NW Europe with more glaciations than the three-glaciation model traditionally interpreted from the terrestrial record for the last 500 k.y. Our data provide the most complete documentary evidence for repeated advance and retreat of the NW European ice sheets since the Middle Pleistocene and for the first time indicate that terrestrial ice-sheet advances in the North Sea can be matched in number with the cold events recorded oceanic and/or ice-core proxies of climate change in the last 500 k.y.

As clear as mud

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Experiments were conducted in an annular flume to investigate the deposits of mixed flows of sand, clay and water. The aim of these experiments was to provide insight into how the dynamics of gravity currents are recorded in their deposits. Two different types of clay were used in the experiments: kaolinite and bentonite. It was found that flows with similar yield strength but different clay type produced different types of deposit. Under the experimental conditions tested flows containing kaolin produced the same deposit type regardless of deceleration time, whereas with bentonite suspensions deposit type depended on the deceleration time of the flow. This is probably because yield strength takes time to develop in a decelerating flow and therefore other parameters such as suspension density play an important role in controlling deposit character. Once the flow has stopped the final deposit type can be controlled by the relationship between the time taken for yield strength to develop and the settling velocity of the sand particles. In an extreme case it was found that after the flow had stopped a homogeneous-looking clay- sand suspension evolved into a deposit with patches of cleaner and muddier sand with a swirly texture, overlain by a sand layer that foundered into the muddier parts of the deposit.

New insights into submarine sediment density flows and their deposits

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Submarine density flows are arguably the most volumetrically important process for moving sediment across our planet; a single flow can transport ten times the annual sediment flux from all the World's rivers. Understanding these flows remains a grand challenge as they are notoriously difficult to monitor directly. Much of our understanding is therefore based on their deposits. Here we outline a novel and relatively simple classification of submarine flows based on their deposits. This classification scheme incorporates new insights from long distance correlations of individual flow deposits, and high speed laboratory experiments. Turbidites are deposited progressively in a layer by layer fashion by turbidity currents, from which larger and smaller grains segregate. Debrites are deposited predominantly by en-masse consolidation during which larger and smaller grains do not segregate. Low density turbidity currents deposit rippled and planar sand (T_c and T_d divisions) overlain by turbidite mud (T_e division) that commonly forms thin (< 40 cm) beds. Turbidite mud deposition is complicated significantly by cohesive (colloidal) bonds that develop at times between fine mud particles. This leads to a rich variety of behaviour including mud bypass, large distance flow reflection and ponding of thick mud within basinal lows. High density turbidity currents, in which hindered settling is important, often deposit stepped laminated (S_2), massive (T_a) and finely planar laminated (T_b) sand that typically form the basal parts of thick beds. We differ from Lowe [1982] in attributing finely planar laminated sand (T_b) to deposition from laminar shear layers at the base of high density flows, and we show that these laminated intervals tend to form the core of thick beds rather than being part of a thin upper drape. Highly mobile low strength fluid debris flows form thin (< 2 m) muddy- sand debrites, and can deliver large volumes of sediment to the further fringes of submarine fans. These fluid low strength debris flows often form after transformation from turbulent flow, with flow transformation triggered by small amounts of mud. They achieve long run out distances due to low yield strength rather than by basal layers with high pore fluid pressure that lubricate flow. High strength (traditional) mud-rich debris flows produce thicker cohesive debrites that extend down slope from an initial slope failure. We conclude by presenting new field data showing that en-masse deposition of clean sand by debris flow can also occur, but the origin and mobility of these clean sand debris flows is poorly known.

A constrained African craton source for the Cenozoic Numidian Flysch; defining an atypical foreland basin deep marine series

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Within underfilled foreland basins, deep-marine turbiditic fans are typically synorogenic and sourced from the uplifting orogenic wedge. Here we present the results of a multiproxy review coupled with new data (Thomas et al 2010), assessing the provenance of the Oligo-Miocene Numidian Flysch which constrains an atypical cratonic source for this regionally important formation.

The Numidian Flysch was deposited into the Maghrebien Flysch basin, a remnant of the Neo-Tethys ocean. Its provenance has remained a controversial subject since the 1960's, with suggestions of both the active northern, and cratonic southern margins. Given the regional extent of deposition, sediment provenance has important implications for the controls upon Numidian Flysch sedimentation, and also the western Mediterranean in terms of foreland basin slope architecture, evolution and drainage.

The Numidian Flysch crops out within the Alpine fold-and-thrust belt in Spain, Morocco, Algeria, Tunisia and Italy. Sediments include a variety of density flow deposits recognised in upper-slope incisional channels, lower-slope channel and overbank environments and depositional lobes. Four lines of commonly used evidence regarding provenance are here discussed within a regional context.

Throughout the regional basin, two distinct deep-marine series are observed which may be defined by several characteristics. Petrographic analyses define two distinct flysch petrofacies; an ultramature quartzarenite (Numidian Flysch), and an immature heterolithic series (Mauretanian Flysch). When viewed in a regional context, Numidian Flysch is overthrust by nappes of this immature series, which are in turn structurally overlain by basement blocks of the northern active margin. The Numidian Flysch and immature Mauretanian Flysch are thus constrained to the southern and northern portions of the basin respectively. Published studies of detrital zircon suites similarly show distinct differences. Numidian Flysch suites show age ranges of 2.15 to 1.65 Ga, and 570 to 510 Ma. These age ranges correspond to the African-Eburnian and PanAfrican tectonic events respectively. In contrast, published detrital ages from Mauretanian flysch deposits in Sicily show a Hercynian age range of 310 to 290 Ma which is typical of European basement. A comparison of palaeocurrent studies demonstrates no statistically significant orientation, while comparison to analogue foreland basins demonstrates that flow is commonly axial and therefore of limited value in provenance studies.

These lines of evidence therefore constrain an African craton source with large volumes of sediment shed northwards to the basin via a passive margin, contrary to classical foreland basin models. Numidian Flysch deposition correlates with a general switch from carbonate to clastic successions in North Africa and we suggest that Atlas uplift of the margin coupled with a humid climate controlled the timing of deposition.

New constraints on the provenance of Late Quaternary ice-rafted debris, offshore western Ireland

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Late Quaternary climate was driven by Milankovitch astronomical variations resulting in alternations of colder glacial and warmer interglacial states. Higher-frequency, millennial-scale (stadial-interstadial) fluctuations also occurred and these episodes of rapid warming followed by gradual cooling (termed Dansgaard-Oeschger (D/O) oscillations) reveal that glacials were climatically more unstable than interglacials. D/O oscillations are bundled into 'Bond cycles' which are separated by periods of enhanced ice-sheet instability caused by extensive surging, collapse and calving of Northern Hemisphere ice sheets. These periods of instability led to widespread dispersal of icebergs in the North Atlantic and the deposition of layers particularly rich in ice-rafted debris (IRD). Up to six distinct IRD-rich horizons are recognized from the Last Glacial and have been interpreted as representing episodes of increased ice-rafting mainly from the Laurentide (LIS) and Greenland (GIS) ice-sheets. These 'Heinrich' layers bracket other, less-significant millennial-paced, ice-rafting events. Numerous hypotheses have been suggested for the cause of the prominent Heinrich events and they have been widely linked to disruption of the North Atlantic Meridional Overturning Circulation (AMOC). It is unclear how/if these events impacted on or were coupled to the behavior of other ice sheets, and in particular, the British-Irish Ice Sheet (BIIS).

Understanding the provenance of IRD provides an important constraint on the pattern of ice sheet instability and the coupling between oceanographic currents, ice margins and the climate system. This presentation reports the results of a pilot study using the Pb isotopic signal in K-feldspar to link ice-rafted sand grains and lithic fragments back to their basement source/s. This technique offers advantages as unradiogenic Pb compositions are envisaged to dominate LIS and GIS sources, whereas more radiogenic compositions should be diagnostic of feldspar derived from the BIIS.

K-feldspar Pb isotopic analyses have been obtained from a number of IRD-bearing horizons in two well-characterised gravity cores on the margins of the Rockall Basin offshore western Ireland. Inferred Heinrich layers have been identified using a variety of proxy data, radiometric dating and correlation with expanded deep marine cores. The Pb isotopic data show that K-feldspars form two distinct arrays, one consistent with derivation from the LIS and GIS and another consistent with a BIIS source. LIS and GIS sources dominate inferred Heinrich layers, whereas BIIS sources mainly contributed the IRD between Heinrich layers. Furthermore, the dominant grain population in non-Heinrich IRD accurately matches the Pb isotopic composition of crystalline basement onshore western Ireland. Distinct groupings in the isotopic composition of inferred Heinrich IRD are also present, but a lack of sufficient comparative data means that these cannot yet be matched to discrete sources within Greenland or North America.

The Interaction of Salt Tectonics and Fluvial Sedimentation: A Case Study from the Permian Cutler Group, SE Utah, USA

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The proximal part of the Permian Cutler Group of southwestern Colorado and southeastern Utah is characterised by a thick succession of conglomerates and sandstones of mixed fluvial and aeolian origin that accumulated to a thickness of up to 4000 m in the foredeep of the Paradox foreland basin. In the area to the east of the town of Moab, the sedimentary evolution of much of this succession was influenced by active salt tectonics associated with movement at depth of the halite-, gypsum- and potash-bearing Pennsylvanian Paradox Formation. Throughout deposition of the upper part of the Cutler Group, salt withdrawal caused localised subsidence, resulting in the development of a series of salt-walled mini-basins that collectively form the Salt Anticline Province. Sedimentary architectural relationships, including onlap and localised erosional truncation, together with abrupt lateral facies variations and complex palaeocurrent patterns testify to the influence of the growing salt structures on the fluvial systems within the evolving basin. Assessing the direct relationship between active salt tectonics and ongoing fluvial system evolution has been possible through the collection of a varied suite of field data, including 60 sedimentary logs, 15 architectural panels representing 6 km of outcrop.

Facies associations and architectural relationships in the salt mini-basin area reveal dramatic thickness variations (c3000m-250m) over distances of less than 500m, these are indicative of a range of styles of syn-sedimentary salt movement. Fluvial elements include axial channel-fill complexes that occupy through-going fairways along the axes of salt withdrawal structures, sheet-like elements adjacent to elevated and growing salt walls, and fine-grained overbank elements away from major channel axes. Paleocurrent data demonstrate palaeoflow diversion around salt highs and along salt-generated corridors.

Onlapping and unconformable relationships demonstrate at least 5 phases of Cutler Group sedimentation with each impacted by repeated, localised synsedimentary uplift episodes. Fluvially-reworked gypsum clasts derived from the erosion of the Paradox Formation are locally present at one key stratigraphic level, suggesting that Pennsylvanian strata were temporarily exposed at the surface during one of these episodes. Aeolian dune elements increased in geographic extent in areas of restricted fluvial activity, especially in the lee of salt highs, such as south of the Castle Valley Salt Wall.

This research serves as an outcrop analogue study with which to potentially develop an improved understanding of subsurface fluvial-aeolian hydrocarbon reservoirs developed in active salt provinces, such as the Triassic of the Central North Sea.

Turbidity currents over muddy substrates: Evidence for flow acceleration over a horizontal bed

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The bed surface of many sedimentary environments is soft and muddy, but this has largely been ignored in process-based sedimentological models, despite the fact that this is expected to have a significant impact on flow properties and the ability of flows to erode, transport and deposit sediment. In turn, this is believed to affect the sedimentary facies, spatial distribution and architecture of sediment deposits. Therefore, it is timely to establish the differences between flows over hard, sandy substrates and soft, muddy substrates and to determine how this is expressed in sedimentary successions.

New laboratory flume experiments on the interaction of turbidity currents with soft, muddy substrates revealed several unique feedback processes that are related to the ability of such substrates to be soft and fluid-mud like, hard and consolidated or plastically deformable, depending on degree of consolidation. In the experiments, which were carried out in Hydrodynamics Laboratory at Bangor University, the degree of consolidation of the substrate, the turbidity-current velocity and the current density were varied to investigate the criteria for bed erosion versus coherent deformation without erosion and suspension collapse (c.f. Winterwerp 2001) versus continuity of the flow, with possible flow deceleration or acceleration.

The specific aims of the experiments were to determine: (1) what happens to turbidity currents when they move over a soft, muddy bed, both in terms of their velocity profile and turbulence structure; (2) what happens to the muddy substrates in terms of deformation and erosion, when they are subjected to shear by turbidity currents; (3) whether thresholds can be determined for erosion, plastic deformation and flow deceleration/acceleration. The laboratory experiments showed evidence for erosion, mixing and formation of shear waves at the interface between muddy bed and turbidity current. Moreover, under certain combinations of flow density and bed consolidation state, flow acceleration across the horizontal muddy substrate was observed. This unexpected result might be caused by plastic deformation of the substrate in front of the turbidity current and closely linked streamlining of the head of the current.

To be able to formulate diagnostic criteria for flow over muddy substrates, fieldwork was carried out in the Annot Sandstones of Peira Cava (S. France). Observations of the different boundaries between sandstones and underlying mud/siltstones were used to characterise different forms of interaction between turbidity currents and their soft, muddy substrates. Variations in the thickness of mudstone layers underneath turbidite deposits were inferred to be a possible indication of the preservation of these interactive processes.

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Tectonic controls on sediment input into the northeastern Black Sea - implications for hydrocarbon reservoir quality

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Siliciclastic reservoir presence and quality are key exploration risks within the Eastern Black Sea. Large-scale fluvial systems draining the crystalline East European Craton to the north had the capacity to deliver significant quantities of reservoir quality sand into the basin (and its pre-rift) during the Mesozoic and Cenozoic. This potential is exemplified by the adjacent South Caspian Basin that, during its Messinian isolation, received up to 7 km of Productive Series fluvio-lacustrine sediment, largely from the incised palaeo-Volga River system. Sandstone-prone elements of this series form the main reservoir interval within the South Caspian Basin and are estimated to contain reserves of ~7 BBOe and 1.2 trillion m³ of gas.

The northern margin of the Eastern Black Sea (unlike the South Caspian) has been the locus of long-lived active basin- and mountain-forming events. The Greater Caucasus Basin opened during Early Jurassic extension to transtension and formed an intermediate sediment sink for southerly-draining sediment transport systems during much of the Jurassic to Eocene. This was subsequently inverted from the Late Eocene-Oligocene onward during the evolution of the Greater Caucasus mountain belt. As well as forming a barrier to northerly-derived systems, this range also formed a source of more locally-derived sediment of variable reservoir quality. These factors are likely to limit the amount of East European Craton-derived reservoir quality sandstones within the Eastern Black Sea, although detailed facies mapping and provenance analysis have identified the presence of other, more localised, quartz-rich sediment sources that may have contributed sediment to the basin.

Sedimentary characterisation and depositional mode of the Messak Fm, SW Libya

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The Late Jurassic-Early Cretaceous Messak Fm outcrops along the northern and western flanks of the Murzuq Basin of southwest Libya. The formation outcrops spectacularly along the Jebel Messak Escarpment which extends for over 500km with an average exposure thickness of 250m. Little previous work has been carried out upon the Messak Fm. However, it has been considered to represent the deposits of a long lived braided fluvial system that dominated the North African margin for much of the Mesozoic era.

Here, we present the preliminary results collected over two field seasons in which 13 sections have been logged and correlated along a 100km transect on the western edge of escarpment. Two members are identified and represent a transgressive-regressive episode. The lower, overall transgressive, member displays a marked fining-up sequence from amalgamated sandstones bodies to isolated sandstone and heterolithic bodies to massive mudstone in the maximum flooding zone.

The lower member is overlain by an overall regressive upper member. This member is dominated by amalgamated medium-coarse cross-bedded sandstone units with interbedded heterolithic packages.

This presentation will examine the key facies of the Messak Fm and identify the major facies associations. Through log correlation we illustrate facies variation both in proximal-distal and lateral trends. We present arguments for multiple phases of marine incursion into the Murzuq Basin during the Early Cretaceous, pushing back the known palaeocoastline by over 600km. Finally, we will discuss implications for palaeoenvironmental reconstruction and challenges posed with regard to previous interpretations of the Messak Fm.



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Poster abstracts

Contourite sands

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Contourites are generally defined as “*sediments in relatively deep water, deposited or significantly reworked by the persistent action of bottom currents*” (Stow et al 2002). Much research has been carried out on these sediments and associated bottom currents since their first recognition almost 50 years ago. Using remote sensing and sea bed sampling techniques, contourites facies models have been developed, and it was noted that they are most commonly composed of muddy (<0.063mm) facies. In more recent years, contourite deposits containing a significant proportion of sand have been discovered. Clean sands and localised gravel accumulations have been found in the deep ocean basins, deposited by geostrophic currents reaching sufficiently high velocities to allow for the transportation and deposition of larger sediment grain sizes.

The largest known sandy contourite deposit is active in the eastern Gulf of Cadiz. Located on the Iberian continental slope, it extends from the Gibraltar Gateway towards the northwest at approximately 500 – 700 m water depth. The estimated regional extent of this contourite sand sheet is in excess of 4000 km². Thickness estimates state there may be as much as 800 m of sandy facies in a proximal location on the sheet. Sea bed sampling shows the sand content to be as much as 95% and composed of mixed terrigenous and bioclastic components. The sand sheet is the proximal component of the Gulf of Cadiz contourite depositional system which extends along the length of the Iberian continental margin, becoming progressively more mud-rich towards the north and west. This reducing grain size is in response to the decreasing transport capacity of the Mediterranean Outflow Water as it moves away from the Gibraltar Gateway.

The eastern Gulf of Cadiz sand sheet provides crucial evidence that bottom water currents are capable of transporting sandy sediments and deposit them in significant volumes. One can conclude that such bottom waters have been in existence throughout geological time and therefore sandy contourites are likely to also exist in the subsurface. Further understanding of these coarse deep ocean deposits could yield important paleoceanographic results and indeed may provide a future deep water hydrocarbon target.

Is Milankovitch cyclicity recognisable in carbonate sequences? Numerical experiments using the forward model CARB3D+

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Many workers have suggested that stacking patterns in platform carbonate sequences can be interpreted in terms of stationary Milankovitch-driven cyclicity in sea level. Indeed, this assumption often underpins conceptual models of many sub-surface carbonate sequences. Others have suggested that such patterns are illusory or related to auto-cyclic processes. Recently, Burgess (2008) has suggested that 29 % (16 out of 56) of platform sequences in a large data set of measured bed thickness data exhibited a Poisson distribution indicating that they were essentially random in nature.† However, 50 % (28 out of 56) showed non-random behaviour which could indicate they were driven by deterministic, or a combination of both deterministic and stochastic, processes. Here we have used CARB3D+, a numerical forward modeling programme, to generate synthetic stratigraphies for isolated carbonate platforms using both stationary Milankovitch cyclic and random sea level drivers.† The synthetic lithological successions generated were tested using two approaches, the exponential distribution test for Poisson related distributions used by Burgess (2008), and the layer thickness inventories (LTI) test devised by Bailey and Smith (2005). The synthetic bed thickness data generated using strictly stationary Milankovitch cyclic drivers showed both exponential and non-exponential distributions indicating that this technique is not capable of reliably identifying stationary cyclic behaviour. Furthermore, some of the non-cyclic simulations also yield non-Poisson distributions, suggesting some ordering was present. In contrast, the LTI technique generally detected cyclicity in the Milankovitch cyclic successions, and given a timescale calibration, the frequency of the main drivers.

Glacio-eustatic control upon sedimentation during the Namurian (Serpukhovian to Bashkirian) across northern England

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Over the past 30 years, sequence stratigraphic research on the Namurian (Serpukhovian to Bashkirian) has focussed on high frequency cyclicity (fourth-order cycles), confined to the Pennine Basin, North Staffordshire Basin of Northern England and the Western Irish Namurian Basin, Ireland. Through the collation of data from field observations, sub surface data and public domain literature, an interpretation of facies and parasequence stacking patterns has enabled the recognition of fourth-order sequences, whose own organisation allows a third-order stacking to be defined. Sand-prone sequences containing multiple internal incisions are recognised and interpreted to correlate with third order lowstand development. Mud prone sequences are also recognised lacking in sand, making sequence boundary recognition difficult. These have been interpreted to represent third order transgressive systems tract development.

In this study, seven third order cycles (from Pendleian substage to Yeadonian substage) have been identified. Regionally comparable patterns in sedimentations have been recognised suggesting that global sea level change was a controlling factor. In the early Namurian, sand prone sequences with highly erosive sequence boundary are identifiable in the Pennine Basin, whereas continuous sequences in the North Staffordshire Basin are mud prone and lack sandstone. During this time, the Pennine Basin was actively filled by a northerly sediment supply, unlike the underfilled North Staffordshire Basin, which lacked a coarser grained sediment supply with the exception of minor influxes from the south. Researchers have suggested a possible submerged high to have been located between the two basins causing the southerly North Staffordshire Basin to be restricted during the early to mid Namurian. This prevented the progradation of northerly supplied deltaic sands. In the late Kinderscoutian substage, a change in sedimentation is recognised; with the widespread progradation of northerly deltaic lowstand sands over most of the region once the Pennine Basin had become infilled

From this study it can be recognised there were several controls upon sedimentation during this time that included glacio eustasy, basin bathymetry and sediment supply, which affected the form of third-order sequences.

Downstream geomorphological channel changes on distributive fluvial systems and implications for interpreting the rock record

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Analysis of over 400 fluvial megafans in aggradational continental sedimentary basins reveals that downstream channel and floodplain changes on these distributive fluvial systems (DFS) tend to behave in predictable ways to climate in the catchment and receiving basins. The changes in channel dimensions can be explained in geomorphological and hydrological terms of the river's response to variation in discharge and valley slope in order to maximise the potential energy to transport the water and sediment supply. Contrary to the many examples discussed in hydrogeomorphological literature for tributary fluvial systems, observations suggest that intrinsic thresholds lead to the breakdown of the main trunk channel into smaller distributary channels and eventual disintegration of the majority of channelised flow at the DFS termination. These thresholds are related to downstream decreases in discharge and stream power, and downstream fining of sediment load. Lateral accretion deposits which are common components of the upstream sinuous channel and floodplain decrease in importance to a threshold point, beyond which vertical accretion deposits dominate the lower distal reaches of the system. In-channel and bank-top sediment accumulation increase as stream power declines, contributing to overbank and distributary flow losses and further loss of stream power leading to more avulsive behaviour in the system. Essentially, the underlying physical-processes, or hydraulic principles, of the channels on these distributive fluvial systems are identical to those for channels in tributary fluvial systems. However, current facies models based on our understanding of tributary fluvial systems are inadequate to interpret the apparently counter-intuitive downstream behaviour and signature of DFS as preserved in the rock record. New generic facies association models are presented derived from observations of remotely sensed imagery for the distribution of sedimentary facies on modern DFS in a range of environmental settings.

A down-system perspective of Neogene landscape evolution of the Rockies

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The Miocene to recent fluvial succession of the Great Plains, Nebraska, records a time-integrated history of denudation of the Rocky Mountains. The construction of major incisional surfaces and the delivery of coarse sediment to the Great Plains during Miocene-Pliocene times have been variably interpreted in terms of regional tectonic tilting, temporal variability in water discharge due to a fluctuating climate, and increased seasonality of discharge driven by summer snow melt. The majority of investigations attempting to understand the causes of this incision focus on the elevated regions of the southern Rockies, west of the Great Plains. Here, we offer a valuable down-system stratigraphic perspective on potential causative mechanisms.

The base of the Miocene succession is defined by a major unconformity that is overlain by up to 100 m thick succession of fluvial sands and gravels of the Ogallala Group (17-5 Ma). The top of the Ogallala Group is incised by a base-Pliocene surface that has 80 m of relief and is overlain by coarse cobble-grade fluvial deposits of the Broadwater Formation (ca. 4-2.5 Ma). The Broadwater Formation contains a lower unit known as the Remsburg Ranch unit (ca. 45 m thick), and an upper unit known as the 'classic Broadwater' (ca. 60 m thick). The Ogallala succession extends ca. 600 kilometres east of the Rockies Front Range and outcrops of the Remsburg Ranch unit can be traced down-system for over ca. 200 km. Subcrops of the Broadwater Formation can be traced for over ca. 700 km down-system. The Broadwater formation represents the coarsest sediment to have been exported onto the Great Plains in the last 60 million years.

We present data on timing, incision rates, transport gradients, sediment calibre, stream power and effective fluvial discharge for each unit, in order to critically evaluate the likelihood of tectonic and/or climatic control on the spatial and temporal evolution of the Neogene fluvial succession of the Nebraskan Plains. These data are in broad agreement with a climatically-driven system. The timing of fluvial incision and aggradation can be linked to local and global climatic changes. In addition, the level of uncertainty associated with the reconstruction of the original gradient of the base-Ogallala surface, and limitations of 1D flexural models of the region, allows the possibility that tectonic deformation has been minimal. Thus, flexural isostatic response to erosional unloading, due to a major climatic-shift, can account for all of the observed warping and tilting of the base-Ogallala surface, and suggests that this surface uplift probably conditioned the Great Plains, to the east of major isostatic surface uplift, for maximum incision.

Along strike variations in an ancient asymmetric wave-dominated delta: insights from a detailed virtual outcrop study

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Earlier models of wave dominated deltas assumed that the downdrift part of such a delta would contain thicker and more homogeneous sandstones than the updrift part. However, studies of largely modern systems show that the opposite is more likely to be true. A preserved deltaic deposit in the upper Star Point Formation of the Mesaverde Group, exposed along the western cliff face of the Wasatch Plateau, central Utah, serves as an ancient example of these results. A photorealistic virtual outcrop model of the deltaic deposits has been acquired using helicopter-mounted lidar scanning. This virtual outcrop model, spanning 3.5 km, allows for easy tracing of intra-parasequence boundaries, such as bed- and bedset boundaries, across the entire outcrop.

A 100 m wide and 10 meter deep distributary channel mouth is exposed in the centre of the outcrop. The area near the channel mouth is dominated by deposits of sandy mouth bars, while the area one kilometre south of the channel mouth has thinner sandstone beds and lower sand content than the area one kilometre north of the channel mouth. This is most likely due to the effluent acting as a groyne, or breakwater, inhibiting the southward longshore transport of sand, leading to deposition of muddy, river-transported sediment downstream of the river mouth, while sand is retained upstream of the effluent. This effect is not as strong as has been reported in the vicinity of the São Francisco and Paraíba do Sul strandplains of southern Brazil, as the bedsets are continuous across the entire outcrop. This is to be expected, since the preserved channel is one order of magnitude smaller than the present day channels in these systems. It is therefore likely that the preserved delta resembles the Costa de Nayarit strandplain of western Mexico.

Keywords: Wave dominated, Heli-Lidar, Wasatch Plateau, Virtual Outcrop, Groyne effect

The evolution of the Gollum Channels, Porcupine Seabight, NE Atlantic: A case of macro fill to spill?

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The Gollum Channel system is one of the largest seabed channel systems on the NW European Shelf extending over 200 km from shelf edge (~ 150 m water depth) to a submarine fan located deep (> 4000 m water depth) on the Porcupine Abyssal Plain. Despite being recognised in 1962 by Brenot & Berthois there have been very few published studies on the Gollum Channel system as a whole. Until the present study, no attempts have been made to chart the spatial and temporal evolution of the channel system by placing them within the established Cenozoic stratigraphic framework of the Porcupine Basin. Mid to late Cenozoic sedimentation in the Porcupine Basin was dominated by bottom-current controlled hemipelagic sedimentation, yet the Gollum Channel system has incised through this succession and was clearly supplied by an off-shelf sediment supply. The origin of this later offshelf sedimentation is as yet unknown and this study aims to establish when the channels became active and how they evolved in relation to the sediment drift succession.

The interaction between downslope gravity driven flows and the alongslope bottom current derived sediment drifts is something that is quite well understood with examples from several continental slopes e.g. Maury Channel in the Iceland Basin, NE Atlantic. In the Maury Channel example, the Gardar Drift acted as a barrier to turbidity current flows from the Icelandic shelf and promoted “fill to spill” behaviour of the turbidity currents (Elliott & Parson 2008). In this study we show that the Gollum Channels are the result of macro-scale “fill to spill” behaviour of turbidity currents controlled by contourite build-up in the basins. Using multibeam bathymetry data and by the application of an established Cenozoic stratigraphic framework to a suite of 2D seismic profiles we can show how post-Eocene contourite sedimentation annealed the post-rift basin topography thereby reducing the accommodation space. In addition, this infilling reduced the height of the Lugh High, a structural high located at the mouth of the Porcupine Basin which acted as a ‘sill’ to older sediment infill. Consequently, when the shelf-edge sediment supply initiated in the Miocene, the initial channels could supply further out into the basin and over the Lugh High, where the dramatic increase in slope out onto the Porcupine Abyssal Plain lead to rapid incision of the Gollum Channels through retrogressive knickpoint migration. This macro ‘fill to spill’ scenario resulted from the interaction of contourite sedimentation, a pre-existing bathymetry and off-shelf sediment supply on a scale much larger than seen in basins such as the Gulf of Mexico.

Is the sea surface the key to deeper goings-on on the ocean floor? Interaction of a mesoscale eddy with bathymetry in the Porcupine Seabight, West of Ireland

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The role of deep ocean currents in the moulding of continental shelf and deep basins of the world is well known and is evidenced by the presence of large sediment drifts which are commonly characterised by sediment waves at various scales. At the present time, these currents are largely sluggish in the open ocean with typical flow velocities below the threshold required to entrain seafloor sediment (fine to silty sand 30 - 40 cm s⁻¹ Stow et al 2009). Yet seafloor observations at a local scale reveal that ripple fields on drifts are active on a short timescale (< monthly), implying that episodic, intense high energy events occur in the deep ocean. These events have been known about for some time and the term "abyssal storms" was first coined by Hollister & McCave in 1984. The origin of these episodic, high energy events remains enigmatic although they have been related to the Gulf Stream (in North Atlantic examples), overflow events, instabilities in local currents and standing waves in the water column by previous workers.

In this work we propose a potential casual mechanism for the formation of benthic storm events. A time series of satellite chlorophyll imagery from the Porcupine Seabight (PSB), west of Ireland images the pathway of a mesoscale eddy over complex bathymetry. Eddies are circular rotating current systems capable of traversing ocean basins and regions of intense upper ocean biological activity. The movement of the eddy is strongly influenced by the bathymetric template of the basin suggesting that the eddy and the bathymetry interact despite water column depths being > 1000 m. The satellite imagery shows the eddy entering the PSB from the NW European shelf, cascading down the slope into the deepest part of the basin where it is then focused through a relatively narrow gap at the mouth of the PSB towards the deeper abyssal plain. The degree of interaction is backed by recent work by Biescas et al. (2008) using seismic reflection profiles of the water column to show that eddies can influence the water column, and thereafter the seabed, to depths greater than 1000 m.

Mesoscale eddies are episodic in nature with typical velocities of 50 cm s⁻¹ or more. If translated to the deeper sections of the water column such velocities would be above the threshold required to entrain seafloor sediment. Given the clear influence of bathymetry on the pathway of the eddy within the PSB we propose that mesoscale eddies, common in the world's oceans, play an important role in the transport of deep-sea sedimentation.

Architecture of a sand-prone fluvial succession: initial findings from the Moordenaars Member, Beaufort Group, Karoo Basin, South Africa

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The Triassic Moordenaars Member is located in the Abrahamskraal Formation, within the Lower Beaufort Group, Karoo Basin (Loock et al. 1994). The Moordenaars Member measures approximately 250 metres in thickness and consists of apparently sheet-like sandstones and mudstones. Previous work has been regional and largely lithostratigraphic with local biostratigraphic constraints from *Dicynodonts*. This study will mainly focus upon better process understanding of the Moordenaars Member by detailing the sedimentary characteristics, channel belt architecture, channel-belt terminations, and sand body connectivity in kms-scale exposures near Sutherland and Laingsburg. Initial work will involve detailed logging and constructing correlation panels, and the lithostratigraphic formation will be reconsidered in the sequence stratigraphic context of the surrounding Beaufort Group. Future work will look to integrate chemostratigraphy, magnetostratigraphy and radiometric dating in order to determine the controls of aggradation and degradation processes that shaped the landscape evolution preserved in the depositional architecture of the Moordenaars Formation.

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Integrated structural, sedimentological and diagenetic evaluation of hydrothermal dolomite, Cretaceous-Eocene, Hammam Faraun Fault Block, Gulf of Suez.

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In carbonate reservoirs, post-depositional modification usually strongly influences pore type distribution and connectivity, for example within fault-controlled dolomite bodies. Fluid flow along fault and fracture systems within carbonate reservoirs, particularly in the burial environment, is a complex process with the distribution of the resultant diagenetic products often controlling porosity and permeability architecture. The Hammam Faraun Fault is a major block-bounding normal fault that initiated in the early Miocene during the rift initiation phase of the Suez Rift (Gawthorpe *et al.*, 2003; Wilson *et al.*, 2009). Reconnaissance of the fault block (Sharp *et al.*, 2010) has proven exceptional pseudo-3D exposure of pre-rift Cretaceous-Eocene carbonates along the Sinai rift flank, Gulf of Suez. Sediments were deposited in a slope environment, with olistoliths, debris and grain flows preserved within a background of pelagic lime mudstones and wackestones. Dolomitisation appears to occur in three main bodies: (a) Vertical to sub-vertical discontinuous sheets along major normal fault zones (b) Laterally extensive stratabound bodies, within grain-rich carbonate facies adjacent to the Hammam Faraun bounding fault, (c) Adjacent to rift-related Oligocene volcanic dykes and sills.

This project forms part of a larger study to classify and map the spatial distribution, geometry and heterogeneity of dolomite bodies associated with the bounding fault, subordinate fault/fracture array and sedimentary facies. The project is focussed particularly upon description of the texture of the dolomite, and determination of the timing of dolomitisation, the fluid source and the mechanism for replacement of the host limestone. The relative timing of key diagenetic products within the context of the depositional and structural evolution of the fault block will be determined and their effect upon porosity and permeability assessed. This presentation will illustrate the results of initial reconnaissance fieldwork on the Hammam Faraun fault block, providing preliminary data on the vertical and lateral distribution of dolomite bodies.

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Sedimentological analysis of the Krossfjord and Fensfjord formations, Troll Field, northern North Sea

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The sedimentological character and distribution of shallow marine deposits are strongly controlled by physical processes at and near the shoreline (e.g. wave- vs. tide- vs. fluvial-dominated). These features can be further complicated by the interplay of tectonics in rift basins through fault block rotation, uplift, and subsidence. Such an example comes from the Krossfjord and Fensfjord formations (Middle-Upper Jurassic), Horda Platform, eastern margin of the Viking Graben, northern North Sea. The depositional setting of these sandstones and their architecture is poorly understood as they have not been the focus of any previous detailed sedimentological or sequence stratigraphic analysis. We report the preliminary results of core analysis and stratigraphic correlations concentrating on wells within the Troll Field area.

The Krossfjord and Fensfjord formations represent two prograding sandstone packages punctuated by transgressive marine shales of the Heather Formation. The Krossfjord Formation (~90 m thick) consists of three medium-to-coarse-grained, coarsening-upwards units (~20-30 m each). In contrast, the Fensfjord Formation (~140 m) is overall finer-grained (fine-to-medium-grained). The lower part of the formation consists of three coarsening-upwards units (~30 m), whereas in the upper part an overall fining upwards profile is identified (with evidence for transgressive pulses which are interpreted to represent the onset of a major flooding event). Further work will integrate 3D seismic data to analyse shoreline trajectories and seismic geomorphology of the Krossfjord and Fensfjord formations, with the aim of quantitatively characterising their stratigraphic architecture and sediment volumes. Our investigations will highlight the controls on shoreline variability and how these relate to the general tectono-stratigraphic evolution of the area.

Generation of training images for use in multi-point statistics-based reservoir modelling of fluvial systems

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Multi-point statistics (MPS) is a technique used in reservoir modelling which is based on the use of training images. Training images are used to capture the geological concept that is being modelled and to guide facies distribution patterns. MPS algorithms are able to capture 3-dimensional training images and consequently 3-D outcrop descriptions are required to test the MPS algorithms. A training image dataset, including digital photographs and detailed outcrop descriptions, was collected from Westphalian A aged sandstones at Seaton Sluice, Northumberland. A 3-D model based on the outcrop data was created. Selected photographs from the outcrop were imported into the "Paradigm GOCAD 2009" software. Photographs were manually rescaled and stretched to eliminate distortions and to fit the actual outcrop scale. Photographs were then aligned along the satellite image of the study area. A digital elevation model (DEM) derived from EDINA Digimap was imported. The topography, derived from the DEM served as the top boundary for the reservoir model and sea level was used as the bottom boundary. Erosion surfaces identified between these boundaries allow a separation of the sandstone into a number of different reservoir units that record the development of 3 aggradational phases within a mixed braided-meandering fluvial channel belt system, in contrast to previous work which has suggested the presence of 3 separate channel events.

Scale invariance and sediment body geometry in fluvial systems

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Length and width values of mid-channel bars, point bars, lateral (attached) bars, transverse bars and braid bars were measured in satellite images provided by GoogleEarth. The length (referred to as A-axis) of mid-channel and braid bars is the maximum visible extent of the bar parallel to the flow direction. The width (referred to as B-axis) of mid-channel and braid bars is the maximum visible extent perpendicular to the flow direction. The length (referred to as A-axis) of point bars and lateral (attached) bars is the maximum visible extent of the bar from one end to the other. The width (referred to as B-axis) of point bars and lateral (attached) bars is the maximum extent of the bar perpendicular to the A-axis. A data set consisting of 1007 data points from 38 rivers around the world was collected. The mean width:length ratio is 0.27 ± 0.0044 , with a standard deviation of 0.0709. The minimum value is 0.092 and the maximum value is 0.497. The correlation coefficient according to a power law regression line is, $r^2 = 0.9489$. The correlation coefficient r^2 is close to 1, which means that the data fit a power law and length and width values can be correlated. The frequency distribution shows that the majority (83.52%) of width:length ratio values range between 0.15 and 0.35. Therefore, fluvial systems and the related deposits have to be considered as scale invariant. The width:length ratio is not influenced by bar type, basin type, termination type, gradient, planform geometry, tectonic setting or climate.

Geochemistry and sequence of calcite cements in the chalk of eastern England, UK

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The exceptional fine-grained nature of the Chalk facies has been a major stumbling block for the investigation of its cementation. Exceptional material has become available from the Cenomanian Chalk of eastern England. This has allowed the full sequence of calcite cements to be investigated at various horizons throughout the Cenomanian sequence. Trace element studies on the calcite-spar infillings of terebratulid brachiopods demonstrate a sequence of cements ranging from Mg-rich (up to 5000 ppm), through Mn-rich (up to 24000 ppm) and Fe-rich (up to 5000 ppm) to cements poor in trace elements. Measured oxygen isotope values range from -5 to -11‰ and carbon isotope values range from 1.5 to -6‰. The varying geochemistry of the calcite cements reflects the interplay of the varying chemistry of the evolving pore fluids during the diagenesis of the Chalk and its burial history.

Onset of underfilled Himalayan peripheral foreland basin in southern Tibet: implication for timing of India-Asia initial collision

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The lack of the early stage, underfilled foreland basin resulting from the India-Asia continental collision has been intriguing. Combining stratigraphic, sedimentologic and provenance data for the Upper Cretaceous – Paleogene deposits at the Zhepure Mountain, southern Tibet, an early stage of Himalayan foreland basin development can be recognized. Detrital zircon U-Pb and Hf isotopic data indicate that terrigenous sediments of the Eocene Enba deposited in a foredeep depozone were sourced from an orogenic wedge (represented mainly by Lhasa terrain with minor contribution from Tethyan Himalaya). The first arrival of orogenic detritus occurred at ~ 50.6 Ma, when the siliciclastic turbiditic sediments of Enba Formation were laid down. The underlain Paleocene-Lower Eocene Zhepure Shan Formation represents establishment of a stable carbonate ramp, which began with deposition of oolitic bars at high-energy shoals, and progressively changed to a typical open marine ramp environment. This carbonate ramp developed on the northern flank of the peripheral foreland forebulge. The Zhepure Shanpo Formation (middle Maastrichtian - Lower Danian) and the overlying Jidula Formation (Upper Danian) show an overall shallowing-upward trend from the upper slope environment deposition to a terrigenous/ siliclastic-dominated delta plain deposition near the top. This shallowing-upward sequence is interpreted to be deposited during forebulge rise. The underlying Zhepure Shanbei Formation (Lower Coniacian to Lower Campanian) was deposited in an outer-shelf, pelagic environment. An erosional disconformity between the Zhepure Shanpo and Zhepure Shanbei formations we relate to a transition from Indian passive margin to an onset of Himalayan foreland basin deposition. Our data thus place the onset of Himalayan foreland basin development and therefore India-Asia initial collision in central Himalaya at ~ latest Campanian (~73 Ma).

Chaos in the abyssal: processes affecting distal abyssal plain sedimentation on the northwest African margin

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The quiescent environment of the abyssal plain is thought to be the site of deposition of distal turbidites with sheet geometries (Rothwell *et al.* 1992). However, flume experiments have shown that decelerating turbulent flows are not mechanically simple and can produce an array of depositional facies owing to mud content, grain size, flow velocity and sedimentation rate (Sumner *et al.*, 2008). This study aims to demonstrate an array of these complexities that govern the distribution of sediment in the deepwater realm. Specifically there are processes that profoundly influence the distribution of mudcap thicknesses of distal turbidites.

The volcanoclastic turbidites associated with the geologically recent El Golfo (15ka) and Icod (165ka) landslides show unusual dispersal patterns. Not only do these events appear to record multistage failures at source, but the mudcaps display atypical distributions.

A major control on the distribution of both the El Golfo and Icod volcanoclastic turbidites is syn-depositional remobilisation of the thick mudcap. The El Golfo turbidite has a 100-400cm thick mudcap in the Madeira Abyssal Plain. Where the mudcap thickness is accentuated in the basin centre. The apparent ungraded nature of the mudcap was attributed to deposition under laminar flow conditions (McCave and Jones, 1988; Jones *et al.*, 1992). However, geochemical studies of the mudcap showed Zr, Ti and Mg concentrations to decrease distally from north to south across the basin, a dispersal pattern attributed to turbulent flow (Pearce and Jarvis, 1992).

The present study focuses on the Icod turbidite, where there are similarities in its Madeira Abyssal Plain dispersal patterns to the El Golfo. The mudcap is ponded in the basin centre before tapering rapidly to the south. High resolution (1cm) grain-size analysis and facies analysis has been used to study the deposit. An additional study in the Agadir Basin shows mudcap isopachs of the Icod turbidite with excess thickening on the southern margin. The mudcaps also show contorted laminations of silt within an ungraded clay matrix. High resolution (1cm) grain-size analysis and facies analysis are supplemented by magnetic susceptibility, p-wave velocity, gamma-ray density and x-radiography.

This study shows that distal turbidite deposition involves a complex interplay of many mechanisms that can profoundly influence the final architecture of the deposits. This study also highlights a previously undocumented flow process of remobilised mudflow. This process can be potentially categorised amongst other processes that develop the hybrid bed or cogenetic linked debrite facies.

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Comparative development of deepwater turbidite systems along the NE Atlantic margin: variability in depositional facies and potential controls

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Due to the excellent core coverage and ability to correlate single event beds over 1000km the deepwater Northeast Atlantic basins pose a natural laboratory to test theories of flow processes. From the Canary archipelago to northern Spain these deepwater depositional systems include: South Canary Pathway, Moroccan Turbidite System, Horseshore Abyssal Plain, Tagus Abyssal Plain, Iberian Abyssal Plain and Biscay Abyssal Plain. These depocentres are located in >3800m water depths between 15-50km from the continental mainland. Though sheet-like in overall geometry these gravity flows present complexities in internal facies relationships and grain-size distributions. The first aim of this study is to build stratigraphic frameworks for the respective systems. Once these are in place, provenance and facies analyses can be undertaken to deduce source direction and methods of emplacement of the respective gravity flows.

The Moroccan turbidite system (MTS) is located on the northwest African margin north of the Canary archipelago. It is composed of three interconnected basins: Agadir Basin, Seine Abyssal Plain and the Madeira Abyssal Plain (Wynn *et al.*, 2002). The system here is the site of infrequent but large volume (>75km³) volcanoclastic (Tenerife and El Hierro) and siliciclastic (Moroccan margin) turbidity current events in the last 200ka. The turbidites display an array of architectures from single to stacked events. Furthermore, there is a prevalence of grain-size breaks, contorted mudcaps and well developed linked debrites.

The Horseshoe Abyssal Plain (HAP) is fed by the Sao Vincente and Portimão canyons from southwest Iberia. While the Tagus Abyssal Plain (TAP), immediately to the north, is fed by the Cascais, Lisbon and Sebúbal canyons. Here the Tagus and Sado rivers release sediment laden outflows directly into the canyons feeding the TAP; while along-shore drift is primarily responsible for sediment reaching the Sao Vincente canyon to the HAP. High turbidite sedimentation rates are facilitated by high sediment flux to the basins and intermittent high magnitude earthquake activity. The deposits are atypical to textbook turbidite models with a dominance of ripple-laminations, prevalence of grain-size breaks and thick contorted mudcaps.

The Iberian Abyssal Plain (IAP) represents the site of a number of large volume organic-rich siliciclastic turbidites and debrites. The IAP is fed by the Nazare, Aveiro and Porto canyons with a number of intervening sub-basins. Like the turbidites of the TAP and HAP biotite, muscovite and quartz are the dominant grain types. However, many turbidites contain an abundance of silt to granule-sized organic carbon particles. There is an increasing influence of laminar flow processes here with highly contorted muds and sands, principally owing to the higher mud content.

This study presents a culmination in decades of core recovery in the Northeast Atlantic. This has allowed detailed event histories and sediment budgets to be calculated for the respective depocentres. However, in providing bed-scale correlations invaluable information can be gleaned in regards to the depositional processes. The present study highlights the prevalence of linked debrites and the strong influence of mud content on the depositional mechanism along the entire margin.

Dating the onset of Neogene basin incision in SE Spain using in situ cosmogenic exposure dating

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Neogene sedimentary basins in Iberia underwent uplift and inversion during the Late Pliocene and Quaternary. Many basins record this in a transition from marine to continental conditions in their sedimentary infill, followed fluvial incision and basin erosion. The timing of the switch from basin infilling to basin incision is poorly constrained. Within this paper we present preliminary results of cosmogenic exposure dating of a basin fill surface in the Sorbas Basin in SE Spain.

The Sorbas basin has two clear phases of infill aggradation represented by the G₁char Formation, which is the final stage of basin infilling during the Miocene/Pliocene and the dissection represented by the quaternary drainage system. The switch from aggradation to incision in the Sorbas Basin is marked by several terrace levels. The terrace record is well preserved and is represented by four main terrace levels which are inset into the top basin fill surface (the G₁char Formation). The preservation of the top basin fill surface is fragmented with residual hills and dissected fan surfaces. A section which is thought a residual hill has been sampled for dating with a cosmogenic exposure dating method.

The cosmogenic exposure dating method involves measuring the concentration of cosmogenic nuclides (¹⁰Be/²⁶Al) within a landform or rock surface. The cosmogenic nuclides are produced as cosmic rays (from super novae and the sun) hit the surface of the landform and interact with quartz clasts within the landform. In this project we use ¹⁰Be and ²⁶Al to date the top basin fill surface to attempt to constrain when aggradation within the Sorbas basin ended. These two isotopes are used because their half lives allow us to date a longer time period and it covers the time in which we expect the date of the basin fill surface to be.

In order to date the top basin fill surface with cosmogenic exposure dating, a profile through the top of the basin surface needed to be located. A suitable site was located in a road cut which provided a three meter section through the G₁char Formation from the top of the basin fill surface. The site consisted of a cut through the top surface with a soil and hardpan calcrete along with fluvial coarse clastic gravel deposits. It is important that the section cuts through the top of the surface because the cosmogenic nuclides only form in the top three meters of the landform.

The date for the top basin fill surface is expected to be late Pliocene in age. The date will provide the timing of the switch from aggradation to incision which is currently poorly constrained and also an opportunity to model landscape evolution within the Sorbas Basin.

Sedimentological and Structural Controls on Dolomite Distribution and Timing: an Example from the Great Orme, Llandudno, UK

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Porosity enhancing dolomite facies within platform carbonates form major hydrocarbon reservoirs and are the subject of exploration targets world-wide. However, not all dolomitisation events result in favourable reservoir characteristics. In order to fully understand and predict the diagenetic processes (e.g. dolomitisation) controlling porosity and permeability evolution, outcrop analogue studies are essential. This study focuses upon the Lower Carboniferous fractured carbonates of The Great Orme, Llandudno, UK. Through a multiscale outcrop, petrographical and isotopic investigation, The Great Orme provides the opportunity to understand the relationship between depositional facies, structuration and dolomitisation.

Diagenesis on The Great Orme is represented by the gradual, pervasive destruction of primary fabrics and porosity within the shelf margin carbonates by early marine/ meteoric calcite cementation and several dolomitisation events. Diagenetically early stratabound dolomitisation took place preferentially within skeletal wackestones-packstones. The primary depositional facies allowed dolomitising fluids to move laterally and preferentially through the more porous shelf-margin during shallow burial. Interbedded mudstones and shales behaved as aquitards often resulting in the ponding of diagenetic fluids beneath them and controlling the limited vertical extent of the dolomitisation. Faults, fractures and to a lesser extent primary depositional facies dominated late burial diagenetic fluid flow and controlled the stratigraphic distribution of successive dolomitisation events (replacement and cementation). The faults and fractures provided effective conduits for the flow of diagenetic fluids, whereas, the variable and often limited porosity and permeability of the host rock hindered fluid-rock interaction. The combined structural and sedimentological controls on late burial dolomitisation have resulted in a variety of diagenetic body geometries.

The faults and fractures provided important pathways for the circulation of dolomitising fluids within otherwise tight limestones. Furthermore, the primary texture, porosity and composition of the carbonate host rock dictated the extent of dolomite replacement. The results of this study are important for understanding fluid flow within fractured and dolomitised reservoirs and provide a framework for the prediction of diagenetic bodies.

Distributive fluvial system behaviour and resulting sandbody architecture, Huesca System, Ebro Basin, Spain

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The Ebro Basin in northern Spain was an endorheic foreland basin in the late-Oligocene to early Miocene where water and sediments from the Pyrenean orogenic belt formed distributive fluvial systems. The Huesca fluvial system is a fan-shaped body of sediment comprising channel and overbank facies that formed a radial pattern across the system. The sandstone body geometries and their stacking relationships have been considered at three locations in a proximal to distal transect across the system. In the more proximal to medial regions, the sandstone body geometries indicate that both laterally unstable and stable channel forms were common.

Sandbodies formed by stable channels are characterised by pronounced incision and deposits of medium to coarse sand, granules and pebbles. Evidence for lateral accretion is limited, suggesting low sinuosity of the channels.

Sandbodies formed by unstable channels have a sheet-like geometry and may be more than 100m across. The presence of heterolithic lateral accretion complexes indicates deposition by laterally migrating meandering channels. Grain size variations within these bodies suggest variable flow regimes.

In the medial/distal part of the system sandbodies formed by stable channels are more common than others. They have been filled to bank-full level with sand and are capped by a thin sandstone sheet, indicating that high-discharge, high-bedload events resulted in choking and abandonment of the channel.

Floodplain deposits range from mud-rich fine-grained sediment, which may have influenced the lateral stability of channels, to thin sheet-like sandstones that are interpreted as lateral splays from the channels.

In the distal parts of the system, where the fluvial deposits are intercalated with ephemeral lacustrine mudstone and limestone beds, sandstone bodies formed by deposition in channels form a low proportion of the succession. Distal sandy deposits are mainly thin sheets with slightly erosional bases, interpreted as unconfined flow deposits where flow is dechannelized on the low-gradient alluvial plain.

The stacking pattern of the sandstone bodies is determined by the processes of avulsion and lateral migration of the channels. More proximal and medial deposits have a higher proportion of channel sandstones in the succession, but they tend to be laterally and vertically amalgamated. However extensive sheets produced by the meandering channels have limited vertical connectivity. Some of the sandbodies are laterally and vertically isolated and tend to be stacked vertically suggesting an avulsion process that favours reoccupation of the same channel paths.

Field spectral gamma-ray profiles through the deposits illustrate that sandstone units and the floodplain mudstones can be readily distinguished, making the distinction between the distal mud-rich and proximal/medial sand-rich facies easy to establish. However, the heterogeneity of the succession, both in terms of lateral extent of the sandstone bodies and their non-uniform distribution, makes characterisation of the architecture on the basis of gamma-log profiles uncertain.

The geomorphology of Antarctic submarine slopes

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The accelerating flows of ice streams around West Antarctica are today contributing to approximately 10% of the observed increase in global sea level (Rignot et al. 2008). Ice streams are responsible for up to 90% of all ice and sediment drained from the Antarctic ice sheet and so have a profound effect on sediment delivery to continental margins whilst also influencing ice sheet dynamics. Understanding the processes operating on Antarctic continental margins is essential for interpreting the depositional record and ice dynamic history which has the potential to be used for testing and refining numerical models that will predict Antarctic contributions to future sea-level rise. Sedimentary deposits around Antarctica contain a record of varying ice-sheet extent, sub-glacial processes, past erosion and climate change. Slope processes modify this record through erosion, remobilisation and deposition. It is evident from multibeam swath bathymetry data that different morphological styles exist along the Antarctic continental margin. Quantitative methods are used to distinguish these morphological styles, with the aim of determining whether morphological styles relate to different processes on Antarctic submarine slopes. This will allow past routes of sediment delivery to be mapped, which in turn will help constrain where palaeo-ice sheets extended to the continental shelf edge, and permit interpretation of past subglacial processes and ice dynamic history from the depositional record. Knowledge of how the Antarctic ice sheets responded to past climate change is critical in understanding and predicting ice sheet sensitivity to future change.

Fluvial systems: a limit to depositional models

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Fluvial deposits are common in sedimentary basins and form important hydrocarbon and water reservoirs. For decades fluvial sedimentologists have categorized fluvial architecture into two main end-members (braided and meandering rivers), sometimes discussing the possibility of simultaneous channel activity and therefore interpreting an anastomosing component to the fluvial system. Interpretations of sedimentary succession as braided river deposits are very common but the variety of allegedly braided architectural styles is immense.

Many studies have tried to improve depositional models of braided rivers, but lack of knowledge of the three-dimensional architecture of fluvial bedforms has limited the development of satisfactory models. Recent work has developed models based on modern braided rivers using ground-penetrating radar (GPR), multibeam echo sounding (MBES), aerial photographs and satellite imagery. They have given new insights and proposed new depositional models (e.g. Best et al., 2003; Bridge and Lunt, 2005) which need to be taken into account by geologists when interpreting ancient deposits and building new reservoir models. However, application of these modern-based depositional models in ancient deposits is not straightforward. Geologists are confronted with specific issues like estimating the amount of erosion versus preservation potential and the scarcity of data, which are rarely three-dimensional, all of which can make interpretation fraught with difficulties.

The approach of the geologist is to only consider the two end-member styles of river system and assume that the characterization of those two systems is simple. However, in modern environments, river architecture varies greatly downstream and channel belts show many transitional architectures between braided and meandering (e.g. Hartley et al. 2010). In the rock record, equivocal bedforms and stacked bedform architecture can be observed and are hardly “characteristics” of either braided or meandering channels. In addition, geologists mainly observe stacked sandy bedforms and yet try to reconstruct individual depositional channel geometries which can be measured only in rare occasions. Channel dimensions are generally guessed or calculated. We finally end up with models based on very speculative sand-body (channel) objects. The sand-bodies to consider should be what we observe: sandstones sheets or packages that represent amalgamation of non contemporaneous channel fills.

The purpose of this paper is to discuss 1) the applicability of modern depositional models to predict ancient sedimentary fluvial deposits, addressing the difficulties with regard to extracting realistic data from outcrops, 2) examples of preserved architecture, and 3) the implications for building accurate reservoir models.

A relational database for the digitization of fluvial architecture: conceptual scheme and overview of possible applications

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Alluvial architecture is defined as the ensemble of geometry, proportion, internal organization and spatial distribution of genetic bodies within fluvial successions. Fluvial architecture records the preserved product of complex interactions of allogenic and autogenic controls acting upon river systems and the heterogeneity inherent in such architecture determines the distribution of natural resources such as water, hydrocarbons and metals.

A relational database has been devised as a tool for translating numerical and descriptive data and information about fluvial architecture coming from both modern rivers and their ancient counterparts in the stratigraphic record. The database is presently being populated with literature-derived examples; the stratigraphy of preserved ancient successions is translated into the database schema by subdividing it into geological objects belonging to different scales of observation, nested in a hierarchical fashion: each order of objects is assigned a different table and each object within a table is given a unique identifier that is used to keep track of the relationships between the different objects, within the same scale (transitions) and across different scales (containment). Each single dataset is split into a series of stratigraphic windows (subsets) characterized by homogeneous attributes, such as internal and external controls (e.g. outcrop panel stratigraphy can be subdivided into subsets on the basis of inferred basinal climate type and planform river pattern). Each subset is broken down at the largest scale into depositional elements defined as channel-complexes and floodplain segments with distinct geometrical properties. Each depositional element can be subdivided into a suite of architectural elements, which in turn can be further subdivided into the depositional facies from which they are constructed.

Each object, at any given scale, can be geometrically characterized in terms of dimensional and shape parameters, and internally in terms of the objects belonging to lower-order scales which form them. The spatial relationships between these elements are stored as transitions along the vertical, cross-valley and along-valley directions. The database can then be used as an instrument for the quantitative description of the geometry and internal organization of geological objects and of their reciprocal relationships. Thus, the database has the potential to provide new insights into the complex controls on fluvial architecture and their interplays, by disentangling the relative role of the fundamental intra- and extrabasinal controls through the quantitative comparison of a large base of data/information, eventually leading to the compilation of synthetic depositional models. Furthermore, the correspondence between the scales of observations considered and the main scales of heterogeneity which need to be recognized within subsurface fluvial successions makes the database a powerful source of information for the characterization and modelling/simulation of fluvial hydrocarbon reservoirs and aquifers, and for the quantitative determination of their most suitable modern or ancient analogues.

The role of salt tectonics in controlling fluvial system evolution: the Triassic Moenkopi Formation (SE Utah) as an analogue for the Triassic hydrocarbon province of the central North Sea

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The mechanisms by which ongoing salt tectonics acts to influence the development of active fluvial systems and to control the preserved nature of resultant fluvial architecture within salt-walled mini-basins remains poorly understood. The Triassic Moenkopi Formation within the salt anticline region of the South East Utah, USA, represents the preserved expression of a mixed sheet- and channel-dominated fluvial succession that developed over a broad low-relief plain under the influence of a semi-arid climate. Throughout its development, this fluvial succession was influenced by ongoing salt uplift in a series of mini-basins that developed in the foreland of the Paradox Basin in the area to the east of Moab, Utah. The onset of movement of Pennsylvanian salt at depth occurred in response to sediment loading during the Permian, with movement continuing throughout the Triassic and well into the Jurassic. A range of sedimentary logs and architectural panels across neighbouring mini-basins demonstrate the influence of the pre-, syn- and post-sedimentary salt movement and the ensuing effects the movement had on preserved sand-body geometries and stacking patterns. Key tectono-sedimentary relationships include: (i) growth strata, whereby a combination of salt-wall uplift and mini-basin subsidence maintained topographic relief at the basin margins, onto which fluvial sediments overlapped; (ii) lateral channel migration and avulsion away from the basin margin in response to uplift, resulting in preferential stacking of channels at the base of the uplifted slopes; (iii) the presence of strata bearing fluvially reworked gypsum clasts indicative of rates of salt uplift that surpassed sedimentation rates, thereby allowing salt walls to breach the ground surface, resulting in the erosion of gypsum detritus and its reworking and preservation as lags within fluvial channel elements. † This outcropping fluvial succession is of value as a field analogue for subsurface Triassic hydrocarbon reservoir intervals of the Central North Sea, especially the Skagerrak Formation and associated J-Block sands, because both represent similar palaeoclimatic and palaeoenvironmental settings and both developed in salt-walled mini-basins of a similar size and geometry. A series of predictive models developed using the field analogue is being applied to demonstrate the likely style of channel-body connectivity and lateral continuity within a range of subsurface hydrocarbon reservoirs.

The Sedimentology "Bucket List"

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How many times have you been on a field trip at a conference and heard the words "This is without doubt a world class outcrop"? Many times this sentiment could hardly be further from the truth, with your field trip leader trying to paper over the cracks of a less than stellar set of outcrops. However there are definitely some outcrops that every sedimentologist should visit before they die. To find them one first needs to ask what makes a world class outcrop?

In this presentation we will explore what factors are critical to defining a world class outcrop. Though obviously subjective, there are clear indicators (beyond sunshine) of outcrops which will literally take your breath away. These factors read like an estate agent's shopping list and include location, size and uniqueness, as well as technical quality and most importantly beauty.

There may also be historical aspects of note. Following on from this I will introduce sedimentologically outstanding localities that cover each of the "main" sedimentary environments. These will range from glacial to aeolian, from shallow to deep water, from clastic to carbonate and beyond. They will be complimented by classic modern examples to provide a counterpoint. Expect ripples, dunes, deltas, towering cliffs and tiny trace fossils, and much more. Even such theoretical aspects as sequence stratigraphy will have their day.

I will draw upon papers, websites, personal correspondence and my own subjective experiences to try and give a flavour of the range of outcrops available. No stone will be left unturned in the search for the key outcrops to see before you die. Though no doubt controversial, it is hoped that this list will at least be enough to inspire extended conversation on the merits of outcrops across the world, and lead each of you to consider your own Sedimentology Bucket List.

Seismic architecture and topographic controls on Pliocene deepwater deposits, offshore Angola, West Africa.

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Analysis of 3D seismic data from the slope to proximal basin-floor of the Pliocene succession, offshore Angola, provides an opportunity to better understand the sedimentary processes and kinematics in the deposition of submarine Mass Transport Deposits (MTDs). 73 km² of 3D seismic are used to investigate: (i) the external morphology of MTDs; (ii) the geometry, scale, distribution and kinematic importance of structures in the MTDs; and (iii) the effect of MTD topography on the distribution of subsequent deposition.

The study area is dissected by NW-SE-trending normal faults. In the upper- to mid-slope, these faults bound a graben that passes downslope into a salt-cored horst on the lower-slope; this divides the basin floor into two depocentres. Four units are identified within the study area. The 1st unit, which comprises low amplitude, inclined seismic reflections, is interpreted as an MTD. The northwest margin is bounded by a steeply-dipping surface which passes downslope into a flat, SW-dipping surface with NE-SW-trending grooves; this surface is interpreted to be the basal shear surface associated with the 1st unit). The 2nd unit, which is characterised by chaotic seismic reflections, is also interpreted as an MTD and is partly controlled, in terms of its areal distribution, by the salt-cored horst. NNE-SSW-striking kinematic elements in the 2nd unit include normal faults located upslope to the north, and an anticline located downslope to the south; together, these structures imply a westerly transport direction for this unit. Rugose relief of ca. 120 m is developed along the top surface and this relief controls thickness variations in overlying units. The upslope edge of the 2nd unit is overlain by a 3rd unit which onlaps relief along the top of the 2nd unit. The uppermost 4th unit is characterised by laterally continuous seismic facies cut by numerous channels, and terminates on the eastern flank of the horst. In the upper part of this unit the bathymetric control of the horst diminished and deposits overstepped and capped the horst.

This study demonstrates that seismic facies analysis from 3D seismic data can provide useful insights into the external geometry and internal anatomy of MTDs, and their role in creating and destroying slope accommodation and in controlling subsequent depositional units. The analysis also indicates the significance of kinematic indicators in unravelling the magnitude and transportation direction of MTDs.

Keywords: Mass Transport Deposits, salt-influenced horst, seismic facies, kinematic elements.

Progradation and development of a distributive fluvial system in the Jurassic Morrison Formation, Colorado Plateau, USA.

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The Jurassic Morrison Formation occurs over an area of more than 150,000 km² of the Colorado Plateau in Utah and Colorado, USA. The fluvial Saltwash Member within the formation can be traced over hundreds of kilometres, allowing the pattern of fluvial channel and overbank deposits to be traced from proximal areas near the source in the southwest to more distal parts of the system to the north and east. Previous work has already established the Saltwash Member as the product of a radial, distributive fluvial system (DFS). This current study seeks to establish the development of the fluvial system, by documenting the transition from underlying continental deposits and changes in the patterns of fluvial channel deposits through time across the area.

Measured sections from 4 locations across the area are used to chart the onset of fluvial deposition in the Morrison Formation. The underlying unit, the Tidwell Member, is variable in thickness and facies, but in all locations displays some characteristics of a lacustrine environment (algal limestone beds, common wave ripple lamination in sandstones and absence of well-developed palaeosols in mudrocks). In all locations studied the onset of Saltwash fluvial conditions is marked by the presence of channelized sandstone bodies. These have erosional bases and are predominately medium to very coarse cross-bedded sands with local pebbly layers. They are associated with thinly interbedded floodplain sandstones and mudstones which show palaeosol development.

Changes throughout the Saltwash fluvial system can be seen in the four locations studied. In the three most proximal successions studied, a sudden coarsening up from the underlying Tidwell unit is observed, after which a general fining up succession (in both grain size and percentage of overbank fines present) is recorded to the top of the logged Saltwash succession. In the most proximal location the sandstone bodies are highly amalgamated, with the successions being slightly less amalgamated as you move further north and east. The characteristics observed could be the result of low accommodation, leading to the lateral cannibalisation of streams, or may purely be the result of their proximal location.

In the most distal location visited a coarsening up succession can be seen from the Tidwell Member through to the top of the logged Saltwash succession. This change in grain size is matched with a change in the architecture of the sandstone bodies, which become much more laterally amalgamated at the top of the succession. Possible explanations behind the changes seen at this location could be due to its more distal location and thus may be recording the progradation or avulsion of the system or the succession may be recording a change in accommodation over time.

Effects of topography on lofting gravity flows: implications for the deposition of deep-water massive sands

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Hyperpycnal flows are generated in the marine environment by sediment-laden fresh water discharge into the ocean. They frequently form at river mouths and are also generated in proximal ice-melting settings and are thought to be responsible for transporting a large proportion of suspended river sediment onto and off the continental shelf. Hyperpycnal flows are an example of gravity currents that display reversing buoyancy. This phenomenon is generated by the fresh water interstitial fluid being less dense than that of the ambient seawater. Thus after sufficient particles are sedimented the flow can become positively buoyant and loft, forming a rising plume. Here we present results from physical scale-modelling experiments of lofting gravity currents upon interaction with topography. Topography, in the form of a vertical obstacle, triggered a localised lofting zone on its upstream side. This lofting zone was maintained in a fixed position until the bulk density of the flow had reduced enough to allow lofting along its entire length. The obstructed lofting zone is associated with a sharp increase in deposit thickness. By inference these experimentally established lofting dynamics are applied to improve understanding of the potential for hyperpycnal flows to deposit deep-water massive sands. This study provides a depositional mechanism by which large volumes of sand can be deposited in the absence of traction and the fines removed, leaving thick deposits of structureless sand with a low percentage of mud. This conceptual model for the first time provides a framework by which the geometries of certain deep-water massive sands may be predicted within specific depositional and basinal settings. This is crucial to our understanding of massive sand deposits in modern and ancient turbiditic systems and in the commercial evaluation of hydrocarbon potential of such sedimentary successions.

Early Cretaceous tectonics on the eastern Canadian passive continental margin interpreted from geochronology of detrital muscovite, monazite and zircon.

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In the passive margin Scotian Basin, more than 45 million years after the onset of sea-floor spreading, Early Cretaceous sandy deltas prograded tens of kilometres seawards. Sand supply was 3–4 times higher than in the early history of the basin. Multiple sedimentary petrology methods show that the dominant source of the sand was from the local Appalachians, supplied by at least three different rivers.

Geochronology of detrital minerals provides a first-order assessment of the source of detrital sediment. The detrital minerals muscovite, monazite and zircon have been dated from different parts of the basin. Almost all detrital muscovite grains are Late Paleozoic in age. Mass-balance calculations require a few hundreds of metres of exhumation of the inner continental shelf during the Early Cretaceous. The paucity of older ages results from abrasion during transport from older, more inboard Appalachian terranes.

Most detrital monazite grains are Devonian, but Lower Paleozoic, latest Neoproterozoic, Mesoproterozoic and Paleoproterozoic grains each make up about 10% of the total assemblage. Although monazite is relatively resistant to mechanical abrasion, it is readily broken down chemically under acid conditions. There is no systematic variation of morphology with age, except that euhedral grains are over-represented in middle Paleozoic ages, characteristic of the outboard Appalachians, and involving short transport distances. This variation indicates that most monazite is of first cycle origin.

Most detrital zircon grains are of Precambrian age, with peaks at 1.0 Ga and 1.7 Ga that are characteristic of reworked zircons in inboard Appalachian rocks of Laurentian provenance. A few samples show peaks at 0.6 and 2.0 Ga, characteristic of outboard Appalachian rocks of Gondwanan provenance. All samples have a few 300–550 Ma zircons, representing Appalachian crystalline basement. Comparing abundance of monazite and zircon grains of different ages in the same sample provides estimates of the importance of polycyclic reworking. Samples with similar distribution of monazite and zircon ages suggest that most zircons are first cycle, and only a few zircons are rounded or broken. Samples with many zircons older than the monazites have many rounded and broken zircon grains. In such samples, bulk chemical analyses show a good correlation of Zr and Cr. These elements are principally in zircon and chromite, derived from quite different rock types, but resistant minerals concentrated by polycyclic reworking. In contrast, Zr correlates with Ti only at low concentrations, above which the abundance of Ti is largely constant as Zr abundance increases. Ti is transported principally in ilmenite, an abundant first-cycle mineral in proximal fluvial sediments, but very susceptible to chemical weathering. Ce, which is principally present in monazite, shows no correlation with Zr but correlates well with Ti, suggesting that mostly first cycle monazite and ilmenite are concentrated together by sedimentary sorting.

Late-Permian volcanism of Southern Gondwana as recorded by tuff deposits of the Tierberg Formation, South Africa.

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Throughout the Karoo Basin, South Africa, there are abundant volcanic tuff horizons intercalated with late Permian siliciclastic strata. The volcanic arc that sourced the ash tuff horizons does not crop out present day, and there is no evidence of volcanic vents in Southern Africa until the late- Triassic. A comprehensive and targeted geochemical analysis through a single stratigraphic succession has been undertaken at Bloukranz Pass, near Calvinia, which provides excellent outcrops for logging the mud-rich Tierberg Fm, Tanqua depocentre, Karoo Basin, and sampling multiple ash tuff beds. The succession is the distal expression of the Permian turbiditic strata exposed in the Laingsburg and Tanqua areas. Previous spot-sample analysis of late Palaeozoic tuffs around southern South Africa has provided some insights into the likely composition and provenance, which was likely located along a volcanic arc at the Panthalassan margin of Gondwanaland to the south (palaeowest) of the Cape Fold Belt. Geochemical bulk sample analysis will give percentages of major elements and trace elements present, as well as minerals. The origin and subsidence mechanism in the Karoo Basin remains controversial. The approach taken here aims to relate ash geochemistry to volcanic provenance and likely tectonic setting, providing evidence to aid the interpretation of the sedimentary basin-fill and subsidence history.

SEM analysis of injected sands from the Namurian of C/ounty Clare

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The Namurian of County Clare not only encompasses some of the world's finest coastal outcrop of the infill of a Carboniferous sedimentary basin, but some of the world's best preserved examples of sedimentary intrusion and volcanism from 3 localities. The study uses back-scattered electron images to study the mineralogy and microtexture of injected sands, or sedimentary dykes, extrusive sands (sand volcanoes) and the relationship between these structures and the host sediment. Analysis has shown the clear mineralogical differences between injected and host sediments as a result of fluidisation processes. Microtextural variations include differences in lamination style and the nature of the clay-lined contact between injected sand the host sediment. Assemblages of heavy minerals including Cr spinel provide evidence for a basic igneous provenance for the later stages of basin infill.

Fluorescence characterization of organic matter released from surface sediments collected from a traverse at the Messiniakos Gulf, SW Peloponnese, Greece

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The present work aims to the evaluation of the fluorescence spectra of dissolved organic matter aqueous extracts isolated from surface sediment samples collected from a traverse (with a direction from northeast to southwest) at the Messiniakos gulf, located in the SW Peloponnese in S. Greece. The samples are classified as fine clayey silt and they are considered as recently deposited sediments. DOM has a significant effect on sediment biological activity, metals and organic pollutants transportation and toxicity.

DOM was extracted under gentle extraction conditions and characterized by applying the rapid, sensitive and non-destructive method of fluorescence spectroscopy. The fluorescence of DOM is a property of the material that may reveal important information about its composition and biogeochemical cycling. Conventional mono dimensional fluorescence spectra in the three modes of emission, excitation and synchronous-scan excitation spectra were recorded, measuring fluorescence at a single set of excitation and emission wavelengths. Humification Indexes according to both Ohno (HIX) and Zsolnay (HI) were calculated. Also, tridimensional in the form of excitation/emission matrix fluorescence spectra were recorded. EEMS (contour plots) give excitation/emission Wavelength Pair and respective Relative Fluorescence Intensity. Results show the presence of humic like material of a marine rather than terrestrial origin, low degree of aromatic polycondensation and low levels of conjugated chromophores. Also, it is suggested the presence of the benzopyrone coumarin and the polyphenols flavones and isoflavones.

Towards the remote measurement of cohesive sediments dynamics: developing acoustic and optical measurements via *in situ* particle visualization

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Cohesive particles in marine and coastal waters remain a significant challenge to sediment transport predictions. Given the relevance to water quality, pollution, benthic ecology and coastal engineering our ability to develop process-response models of cohesive sediments is poor. Suspended cohesive particles rarely exist in their primary state but form flocs which are aggregated, heterogeneous assemblages of mineral grains, biogenic debris, bacteria and organic material. Floc formation is thus a function of numerous variables whose inter-related processes are yet to be fully elucidated.

This complexity is exacerbated by a lack of suitable data, notably in characterizing floc populations. A floc may constitute over 1 million individual particles and size can range over 4 orders of magnitude within one population; effective densities and settling velocities can therefore span several orders of magnitude. The challenge is to develop data acquisition techniques that will allow accurate quantification of floc characteristics for the determination of SPM concentration and settling velocities for mass settling flux calculations.

Particle size ranges and concentrations are not adequately measurable by physical sampling which break up fragile flocs. Remote methods offer the potential to greatly enhance our understanding of floc particle dynamics. However, the responses of light and sound to floc particles remain uncertain. Differences in derived mass concentrations of flocculated and non-cohesive suspensions occur because OBS measures projected area concentration not mass concentration. Laser interferometry (e.g. LISST) is only applicable in relatively low concentrations, can disturb fragile flocs and requires a smooth size distribution and near-spherical particles. Acoustic backscatter methods are limited by a lack of data from floc-dominated environments which has restricted the development of suitable acoustic inversion algorithms.

Recent innovations of *in situ* visualization of floc size and settling velocity using INSSEV & LabSFLOC mean we are now in a position to make simultaneous measurements of cohesive SPM populations using *in situ*, remote and physical sampling to aid development of methods that account for the flaws in remote measurements. We present selected data collected in the meso-tidal Tamar Estuary, Devon, UK over several tidal cycles. INSSEV and LabSFLOC data were acquired at multiple heights and complimented by physically sampled SPM later analysed for mass and organic content. A suite of ABS and OBS sensors were used to provide multi-frequency vertical response profiles, and a LISST-XT was positioned at INSSEV height. These measurements were augmented by vertical ADV and ADCP profiles of velocity and regular CTD profiles.

Examples are shown that reveal different responses of acoustic and optical methods across the tidal cycle. These differences are compared to changes in floc characteristics, SPM concentration, organic content, hydrodynamics and water density over the tidal cycle in an attempt to determine the key parameters affecting the way in which sound and light interact with flocs. Ultimately, this information will be used to develop inversion algorithms that will allow the recovery of cohesive sediment mass concentrations using combinations of acoustical and optical instruments without the need for extensive field calibrations.

Provenance analysis of Devonian-Carboniferous sandstones from the Clair Basin, West of Shetland using heavy mineral and detrital zircon age data

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An integrated heavy mineral and zircon age study was conducted on the sedimentary succession from the Clair Basin, which has been divided into ten lithostratigraphic units. Heavy mineral data reveal a major change in provenance at the boundary between the Lower (Units I-VI) and Upper (Units VII-X) Clair Groups and subtle changes in and between all of the stratigraphic units. The analyses of detrital zircons from ten sandstone samples by sensitive high resolution ion microprobe (SHRIMP) provide additional information about possible source terrains. Detrital zircon ages in the Lower Clair Group range from ~450 to 3650 Ma. Derivation from Lewisian basement has been suggested for Unit I based on clast composition and heavy mineral content, whilst the heavy mineral data from Units II - lower VI do not suggest much input from Lewisian gneisses. The zircon age data on the other hand show a group of Archean ages in all samples of the Lower Clair Group. Most samples also have a major group of Caledonian aged zircons, the exception being the sample from Unit IV which is almost exclusively Archean and in conjunction with abundant high-Mg, low-Ca garnet indicates a change in provenance to high-grade metamorphic rocks. Archean zircons are more abundant in the upper part of Unit VI suggesting increased input from the Lewisian at this time. Three Lower Clair Group samples show small additional older Archean peaks suggesting a source in Greenland. Zircons from the Upper Clair Group Unit VIII are almost exclusively Archean, but the heavy mineral assemblage reflects a moderate- to high-grade staurolite- and garnet-rich metasedimentary source rock similar to the Neoproterozoic to Early Palaeozoic Moine and Dalradian successions. This suggests derivation from a metasedimentary source which was itself supplied from an Archean terrane. The sample from Unit X shows an age spectrum ranging from 400 Ma to 3700 Ma, similar to the age spectra found in the Lower Clair Group samples. The combination of heavy mineral data and detrital zircon ages indicate a complex history of provenance in the Clair Basin, with multiple sources supplying detritus at different times, some probably including reworked material from older terranes.

Ealirly infill of the confined Edale sub-basin of the South Pennine Basin

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The Kinderscoutian deep-water Mam Tor Sandstones (MTS) and Shale Grit (SG)† respectively represent basin floor fan and channelized slope successions of the Edale sub-basin and together record a downslope reduction of sandstone bed thickness, grain size, sand proportion, erosive character (e.g., channelization and amalgamation), and a corresponding increase in mud content. The deposits represent the initiation of a turbidite-fronted delta following southwest progradation of the clastic system across the complex sub-basin bathymetry of the Pennine Basin further updip. These deposits mark the earliest infill within the Edale basin prior to subsequent fill, then spill into the Staffordshire Basin to the south. The Edale basin has been a classic forcing ground for the development of ideas in deep marine clastic sedimentology. Here Walker (1966) interpreted the MTS and overlying SG as coeval, genetically linked distal and proximal depositional divisions, respectively, within his classic turbidite fan model. These early models, though groundbreaking, interpreted the entire basin infill sequence to represent a single but significant system progradation during an episode of relatively constant sea level. More recent sequence stratigraphic models have challenged this coeval fill model (Hampson, 1997). We hypothesise that the Shale Grit may not simply be the proximal, upstream time equivalent of the Mam Tor Sandstones, but that channel erosion, which often characterises the former may pre-date the deposition of the Mam Tor Sandstones, and that, in turn, the subsequent channel fill may postdate them.

This implies the potential for local out-of-sequence deposition of these deep water sediments compared to the basinal-scale pattern of southward younging. Recent recognition of hybrid event beds within the MTS has also highlighted the operation of gravity transformation processes operating during basin infill, perhaps linked to channel erosion. The interaction of gravity currents with confining basin bathymetry – present as a shale draped carbonate platform bounding the Edale basin to the south – has not yet been closely studied, and may offer insight into the origins of significant proportions of clay found within MTS relative to the SG. Potential exists for the application and expansion of findings from other detailed studies focused on such topographic interactions in order to characterise deposits and their formative processes around the Edale Basin’s southern margins. Thus, having remained relatively understudied for the last decade – a time during which understanding of deep marine processes and architecture has been significantly advanced – this basin is emerging as a promising location to re-evaluate the spatio-temporal evolution of different depositional elements along the gravity current pathway, as well as to differentiate the competing effects of local bathymetric confinement and allogenic system evolution.

Sedimentary architecture and connectivity of reservoir-quality facies in fluvial overbank successions

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The deep-ocean marine isotope record and the Antarctic and Greenland ice caps record numerous glacial and interglacial cycles since the Middle Pleistocene, yet evidence for similar numbers of ice-sheet advances over the continent and shallow shelves of NW Europe is absent. Here we present seven generations of regionally correlatable subglacial tunnel valleys that record the geomorphic imprint of ice sheets traversing the North Sea basin between ca. 500 and 40 Ka, consistent with the pattern predicted by proxy records of glacial and interglacial climate change. Over 180 subglacial tunnel valleys that incise into Pleistocene sediments in the North Sea basin were mapped over ~60,000 km² of 3-dimensional seismic reflection data. Using a subset of these data we have identified seven separate episodes of subglacial erosion which can be correlated regionally in the UK sector of the central North Sea. The characteristics of the valley morphologies, orientations and infill stratigraphy indicate that each set of tunnel valleys formed during a separate ice sheet advance and retreat cycle. Stratigraphic data suggest that the tunnel valleys formed significantly later than the Brunhes-Matuyama reversal event at 780 Ka and before the Last Glacial Maximum (marine isotope stage [MIS] 2; 21 Ka). These results imply a more complicated glacial history for mainland NW Europe with more glaciations than the three-glaciation model traditionally interpreted from the terrestrial record for the last 500 k.y.† Our data provide the most complete documentary evidence for repeated advance and retreat of the NW European ice sheets since the Middle Pleistocene and for the first time indicate that terrestrial ice-sheet advances in the North Sea can be matched in number with the cold events recorded oceanic and/or ice-core proxies of climate change in the last 500 k.y.

The 3D microscopic ,signature' of strain within glacial sediments revealed using X-ray computed microtomography (μCT)

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X-ray computed microtomography (μCT), a non-destructive analytical technique, was used to create volumetric three-dimensional (3D) models representing the internal composition and structure of undisturbed pro- and subglacial soft sediment sample plugs for the purposes of identifying and analysing kinematic indicators. The contrast resolution achievable depends on the compositional elements and the consolidation of the sediment. Analysis of a plug acquired from a (proglacial) 'ideal' specimen permitted the 3D geometry of a suite of micro-faults to be analysed and the strain history reconstructed. Conversely, a plug containing a deformed intraclast enclosed within a clay-silt rich matrix could be only partially differentiated within the associated scan images. However, the lack of contrast resolution indicates a very low void ratio within the matrix, a product of overconsolidation under normal loading, the diamicton conclusively demonstrated to have undergone subglacial deformation subsequent to deposition within a glaciomarine environment. An overconsolidated diamicton sample of known subglacial origin also displays poor contrast, because of the autochthonous nature of the groundmass. μCT reveals the extensive, small-scale (<20μm) network of fractures delineating a 'marble-bed' structure, brittle failure contrasting with the millimetre scale thin-section evidence of ductile deformation. Thus a polyphase deformation history is proposed. A volcanic lithic clast contrasts well with the surrounding matrix in a sample acquired from 'lodgement' till. μCT and thin-section evidence indicate that the clast initially ploughed through the soft, wet matrix followed by dewatering, brittle failure of the groundmass and subsequent emplacement of the grain. μCT analysis of a specimen acquired proximal to a 2D (thin-section) type example of clast rotation, reveals that the clast has a proximal décollement surface orientated parallel to the plane of shear. Once again a polyphase (brittle/ductile) suite of processes is indicated. The lenticular morphology of the rotational structure defined suggests an unequal distribution of forces along two of the principal stress axes. The metalliferous grains contained within a specimen of till eroded from an orebody contrast well with the surrounding sediment, highlighting the considerable potential of the technique in permitting the rapid (semi-)quantitative analysis of undisturbed sediment sample characteristics datasets. It has been demonstrated that μCT offers significant potential for elucidating glacial soft sediment kinematics. The subglacial sample evidence presented indicates that complex polyphase (brittle/ductile) deformation histories are common in such diamictic soft sediments and that local (microscale) parameters (composition, structure, shear forces and effective pressure) controls rheology.

Diagenetic Processes in a Foreland Basin Mudstone Succession: The Mancos Shale, Book Cliffs, Utah

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An understanding of the nature and scales of diagenetic variability within organic-rich mudstones is critical to the accurate assessment of shale-gas reservoir properties, as well as for elucidating chemical evolution pathways within mudstones.† Here we integrate large-scale (>10km) field observations with thin section descriptions, and petrographic and mineralogical data for the Blackhawk Member time-equivalent Mancos Shale in Book Cliffs, Utah.†The detrital assemblage in the Mancos Shale is quartz-silt, feldspar, clay minerals, dolomite and organic matter (TOC of 1 to 2.5%). Biogenic silica is negligible. Field mapping reveals laterally continuous (km-scale) brittle ferroan dolomite cements ($\delta^{13}\text{C} = +1$ to -2 per mil, $\delta^{18}\text{O} = -2$ to -5 per mil), up to 30 cm thick, marking coarsening-upward units 1-3m thick, and stacked coarsening-upward units 5-15m thick, which correlate to bedsets and parasequences in updip settings. These are early diagenetic in timing and are interpreted to result from enhanced bacterially-mediated diagenesis at sediment hiatus during marine flooding events. In more distal settings these cements become isolated, septarian concretions which contain generations of dolomite, calcite and kaolinite cements, thereby containing a record of chemical mobility during burial. The dominance of dolomite cements in these units may be linked to the recently recognised low-sulfate seas of the Western Interior Seaway and highlight the importance of macroscopic-scale diagenetic carbonate mobility in these mudstones. †Diagenesis between these surfaces is characterised by early diagenetic pyrite, early kaolinite precipitation into shelter porosity, quartz overgrowths and micro-quartz precipitation. These latter three phases highlight that microscopic-scale diagenetic mobility of silica is important even within mudstones lacking biogenic silica.

Fine-grained sediment records of climatic variation and ice margin recession within Paleolake Rawtenstall, a Quaternary ice-dammed lake in NW England

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The identification of former ice-dammed lakes associated with Quaternary ice sheets is important for two reasons.† Firstly, these lakes can contain varved sediments which can be used to establish a chronology related to ice margin position, and also provide a high-resolution (sub-annual) record of meltwater discharge from the ice sheet, which in turn can be related to climate.† Secondly such lakes are commonly associated with sporadic outburst floods, which are an important geomorphic agent and can affect ice dynamics.† This poster presents sedimentary evidence for the existence of a lateral ice-dammed lake, Paleolake Rawtenstall, which was ponded within the upper Irwell Valley shortly after the Glacial Maximum (c. 22ka BP) by the late Devensian British Ice Sheet.† The position of palaeolakes has been reconstructed from a combination of borehole records of laminated silts and clays and associated sands, and morphological evidence, including shorelines and meltwater channels.† A number of shorelines were identified, indicating that lake level dropped as the ice margin receded and the lake surface area expanded.† Borehole records, coupled with newly collected cores demonstrate that long sequences of rhythmically laminated sediments occur in distal lake deposits.† We use a combination of techniques, including microscale logging, thin sectioning, SEM fabric analysis, μ -XRF and particle size analyses, to reconstruct depositional processes and examine temporal variation in lake sedimentation.† The rhythmites are interpreted as varves and indicate that the Paleolake Rawtenstall may have existed for a considerable period of time (>1,000 years) and contains a record of changing meltwater input and lake water level changes reflecting both climatic variation and ice margin recession.

Turbidity currents over muddy substrates: Evidence for flow acceleration over a horizontal bed

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The bed surface of many sedimentary environments is soft and muddy, but this has largely been ignored in process-based sedimentological models, despite the fact that this is expected to have a significant impact on flow properties and the ability of flows to erode, transport and deposit sediment. In turn, this is believed to affect the sedimentary facies, spatial distribution and architecture of sediment deposits. Therefore, it is timely to establish the differences between flows over hard, sandy substrates and soft, muddy substrates and to determine how this is expressed in sedimentary successions.

New laboratory flume experiments on the interaction of turbidity currents with soft, muddy substrates revealed several unique feedback processes that are related to the ability of such substrates to be soft and fluid-mud like, hard and consolidated or plastically deformable, depending on degree of consolidation. In the experiments, which were carried out in Hydrodynamics Laboratory at Bangor University, the degree of consolidation of the substrate, the turbidity-current velocity and the current density were varied to investigate the criteria for bed erosion versus coherent deformation without erosion and suspension collapse (c.f. Winterwerp 2001) versus continuity of the flow, with possible flow deceleration or acceleration.

The specific aims of the experiments were to determine: (1) what happens to turbidity currents when they move over a soft, muddy bed, both in terms of their velocity profile and turbulence structure; (2) what happens to the muddy substrates in terms of deformation and erosion, when they are subjected to shear by turbidity currents; (3) whether thresholds can be determined for erosion, plastic deformation and flow deceleration/acceleration. The laboratory experiments showed evidence for erosion, mixing and formation of shear waves at the interface between muddy bed and turbidity current. Moreover, under certain combinations of flow density and bed consolidation state, flow acceleration across the horizontal muddy substrate was observed. This unexpected result might be caused by plastic deformation of the substrate in front of the turbidity current and closely linked streamlining of the head of the current.

To be able to formulate diagnostic criteria for flow over muddy substrates, fieldwork was carried out in the Annot Sandstones of Peira Cava (S. France). Observations of the different boundaries between sandstones and underlying mud/siltstones were used to characterise different forms of interaction between turbidity currents and their soft, muddy substrates. Variations in the thickness of mudstone layers underneath turbidite deposits were inferred to be a possible indication of the preservation of these interactive processes.

Winterwerp, J.C. (2001) Stratification effects by cohesive and noncohesive sediment. Journal of Geophysical Research-Oceans, 106, 22559-22574

Volcanic island flank collapse and associated seafloor sediment failure: emplacement dynamics and implications for tsunami hazards

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Landslides associated with volcanic island flank collapse are among the largest-volume events on Earth's surface, and could potentially generate ocean-wide tsunamis. Debris avalanche deposits around ocean islands show that large flank collapses have occurred widely. However, we are yet to observe such an event. The dynamics and timing of landslide emplacement is the major unknown factor for predicting tsunami hazards, and understanding these emplacement processes relies on detailed mapping and structural interpretation of landslide deposits.

Seafloor mapping around several island arcs indicates the occurrence of blocky flank collapse deposits adjacent to more extensive, smoother-surfaced failures. This relationship suggests emplacement complexities, potentially involving seafloor sediment failure. Here we outline the main results from arguably the most detailed seismic reflection data set yet collected around a volcanic island, from Montserrat in the Lesser Antilles. Our aim is to determine how landslides are emplaced around volcanic islands and the implications of emplacement processes for tsunami generation. Studies of Montserrat have generated a benchmark dataset for andesitic island-arc volcanoes since the Soufrière Hills volcano began to erupt in 1995. The eruption has included the largest recorded volcanic dome collapse, which generated a tsunami that reached neighbouring islands. Seafloor mapping shows that far larger and deeper seated landslides have occurred in the past, with volumes of up to 10 km³, fifty times larger than the largest historical dome collapse.

Landslide deposits around Montserrat result from a range of failure types, across a broad range of magnitudes. We show that the largest events are dominated by seafloor sediment failure, and that landslide deposit volumes cannot simply be related to failed volcanic material. Additionally, internal structures show that deposit emplacement commonly occurs in multiple stages, with substantial time gaps indicated within deposits that appear simple based on surface mapping alone. The association of seafloor sediment failure with volcanic collapse appears to modify landslide mobility and produce elongate deposits. The distal margins of these deposits are associated with relatively little downslope material motion, and do not display prominent accumulation fronts. Although the seafloor sediment failure component of these landslides may be of much larger volume, it is the volcanic collapse components that are of the greatest significance, at least locally, in terms of tsunami hazard. Due to the relatively deep water, low slope angle, and thin failure geometry, the seafloor sediment failures produce only relatively small tsunamis.

Debrite and turbidite sand relationships as observed in the Britannia Sandstone Formation, Early Cretaceous, UK North Sea and the Vocontian palaeomargin, south-east France.

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Non-reservoir debrites alternating with turbidites can introduce significant heterogeneity in deep-marine reservoirs and can impact on the geometry and connectivity of the producing sandstones. The deep-water Aptian Britannia Sandstone Formation hosts the extensively cored Britannia gas-condensate field in the Outer Witch Ground Graben, UK North Sea.

Although occupying a distal and basin floor position, the sea floor was prone to large-scale gravitational failure, particularly during deposition of the lower and middle reservoir zones where inter-well correlation of the reservoir sandstones can be problematic at short length scales.

The aim of this work is to highlight the relationship between these debrites, their associated topography and the subsequent deposition of turbidite sands. Some of the largest debrites occur within failure-excavated topography which they only partly heal. Mapping of the platform area shows that the failures transect and modify pre-failure sandbodies via incision and substrate deformation - the debrites were probably sourced further upslope as they are relatively well mixed. Subsequently, younger turbidite sandstones fill the remaining accommodation space with facies controlled by local bed topography that influenced flow uniformity, with continuing local instability at the failure margins. Destabilised banding at the margins and in situ massive sands in central areas is observed and distinct multiple flow events observed within the infill deposits.

From core analysis it has been possible to look in detail at the debrite/turbidite relationship. The interpretational foci is; 1) The mechanisms for failure at different scales in the Britannia area, 2) Whether the debrites lining the excavation surfaces are themselves responsible for the excavated topography, 3) The facies that are key in identifying such sediment interactions in Britannia and elsewhere. Within the Aptian Vocontian palaeomargin deposits in SE France, a similar debrite topography and sand infill relationship can be observed, although the system is somewhat muddier. Field studies of this system allow insights into the relationship between turbidites and underlying debrites at the inter-well scale. Facies comparisons with the Britannia Sandstone Formation provide a test of the general applicability of Britannia-derived models linking substrate topography, infill history, and facies architecture heterogeneity.

Fluvial sand body architecture in the Lower Beaufort Group, Karoo Basin, South Africa

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The Beaufort Group is the oldest fluvial component of the Karoo retro-arc foreland basin fill, comprising up to 3900m of relatively sand-rich and sand-poor terrestrial deposits which vary both along strike and up section. Point bar dominated meandering rivers have previously been interpreted for the plan view fluvial style of the lower Beaufort Group and fluvial megacycle interpretations for this stratigraphic interval have been popular.

A detailed study of approximately 700m of the stratigraphy in the lowermost Abrahamskraal Formation of the southwest Karoo has involved detailed logging and photographic interpretation of near-vertical river cliffs and steep hillside sections. The sedimentary architecture of the sandstone bodies has been analysed on photopanel and sedimentary structures mapped by walking out accessible sections.

Our analyses reveal that fluvial style is not as simple as previously thought. Aggradational sandstone bodies, which have basal (cumulative) incisions of up to ~20 m, contain multiple storeys with a range of stacking patterns. These laterally extensive sandstone bodies do not exhibit dominant lateral accretion. Instead the internal architecture of many sandstone bodies indicates mixed lateral and downstream accretion modes with considerable variability locally. In some outcrops widespread erosion surfaces truncate the tops of channel sand bodies and may relate to times of regional system degradation. Overbank deposits include splay complexes with well exposed connections to channels. Floodplain sediments show a characteristic alternation of red mudstones and green siltstone but mature palaeosols are absent, suggesting near continuous aggradation. Widespread units of green siltstones may represent non-marine flooding surfaces or be linked to local avulsion-related water table behaviour.

We discuss possible controls on the formation of the architecture we report with reference to external forcing factors and autogenic behaviour of the fluvial system.

Ultrasonic Velocity Doppler Profiling of the boundary layer in a fine sand laden river estuarine transition zone (RETZ)

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In recent years Ultrasonic Velocity Doppler Profiling (UVDP) has begun to gain acceptance as a valid method for fluid velocity measurement. UVDP offers significant improvements in the field of fluid velocity measurement over traditional equipment such as ADCP. Using a series of probes, all of which measure along 1D, aligned in parallel it is possible to create a 2D flow field of a fluid. The small surface area of each probe ensures that there is minimal effect on the flow, allowing the probes to be placed directly into the flow. This allows the probes to accurately measure close to a boundary surface. Within a laboratory environment UVDP has been used to measure the bottom 0.10 m of a body of water with induced currents.

River estuarine transition zones (RETZ) have begun to attract a lot of attention from the scientific community, because as an area of interaction for fluvial currents, tides and waves, the RETZ is particularly vulnerable to environmental change. The Cletwr is a canalised RETZ, with the mouth bordered by extensive sand marshes, on the southern shore of the Aberdyfi Estuary in Mid-Wales. It is characterised by mountainous and estuarine sediment sources, with a fine sand bed, making it susceptible to extreme weather conditions.

The aim of this experiment was to determine the vertical velocity profile of the boundary layer (0 – 0.27 m) of the Cletwr River and how this varies over a tidal period under the influence of varied weather conditions. Measurements of the vertical velocity profile of the Cletwr were taken at 15 minute intervals over a nine hour period in April 2010 and again in September 2010. Field-based experiments followed a period of drought and a period of flooding respectively.

The vertical profile of the lower 27 cm, from the September campaign, follows a logarithmic profile as expected. The corresponding measurements from the April campaign do not indicate a logarithmic profile. This may be a result of the significantly lower river input and may have consequences for sediment transport.

3D Seismic Imaging of Methane Hydrates, Offshore of Mauritania

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Gas hydrates are crystalline compounds of gases and water that are common along continental margins and stable at specific temperatures and pressures. Below a few hundred meters of burial, gas hydrate becomes unstable and gas and water exist in a free gas zone (FGZ). In deepwater continental margins this transition, known as the base of the gas hydrate stability zone (BHSZ) is commonly marked by a high amplitude seismic reflection that is parallel to the seabed but has the opposite seismic polarity.

The BHSZ moves in response to sedimentation or erosion at the contemporaneous seabed, or due to changes in ambient temperature. Rather than venting to the seabed, dissociation of gas hydrate caused by upward resetting of the BHSZ can be stored in the FGZ which is sealed by the hydrate. Many FGZs are thought to be critically pressured, so any additional free gas could be sufficient to reactivate faults within the hydrate, allowing methane release to the seabed. Methane may be repetitively recycled between the hydrate and the FGZ by upward and downward resetting of the BHSZ. This process is known as hydrate recycling. However, dissociated gas could also be stored in stratigraphic traps sealed by surrounding low-permeability sediment, until these are filled sufficiently for the seal capacity to be reached.

We describe seismic reflection data from a world-class example of a gas hydrate reservoir offshore of Mauritania. The BHSZ reflection is unusual because it shallows with reducing water depth and intersects the seabed. The data are also characterized by hundreds of vertical chimneys, which are indicative of methane migration from critically charged free gas reservoirs below the hydrate. There is very little evidence for methane leak to the surface, but it does occur where there are through-going faults that cut through the hydrate. These faults are permeable to gas and vents are aligned on the seabed. The aim of the project is to provide the capability to discriminate between gas trapped at the base of the hydrate (i.e. the FGZ) and free gas sealed stratigraphically by surrounding low-permeability sediment. Furthermore we aim to understand how methane is stored and leaks to the seabed.