British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

BSRG Sedimentary Research

British Sedimentological Research Group AGM

Abstracts

British Geological Survey

21 – 22 December 2014

WELCOME

On behalf of the British Geological Survey it is my great pleasure to welcome you to Nottingham for the 53rd Annual General Meeting of the British Sedimentological Research Group. This year's AGM is the first to be convened entirely by a non-university and as such, we're looking forward to showcasing some of the skills and facilities that the world's first geological survey has to offer; for instance through the Carboniferous mudrock core workshop in the National Geological Repository and the conference field trip to the Neoproterzoic of Charnwood Forest.

This year's meeting features an extensive and varied technical programme, resulting from input from the BSRG membership; with a large and notable contribution from student members. Continuing this strong student focus, this year we convene a special session on Conventional and Unconventional Hydrocarbon Reservoirs, sponsored by the Petroleum Exploration Society of Great Britain (PESGB) – a session open to presentations from students in all manner of disciplines applicable to and associated with hydrocarbon exploration. In addition, we build upon the successes of previous years' meetings, once again featuring a jointly hosted session with the Clay Minerals Group (Clays, Mudstone and Shale – the Finest Sedimentary Rocks!).

Alongside the technical programme, this year we have a full social programme revolving around an ice-breaker in one of Nottingham's more unusual bars – in the form of the Canalhouse - and a conference dinner in the world famous Trent Bridge Cricket Ground.

We hope you enjoy the meeting and we would like to thank our sponsors for their financial support – which has been integral to running the event.

Oliver Wakefield
British Geological Survey

Convenor: *Oliver Wakefield*

Planning committee: *Linda Hetherington, Jackie Swift, Oliver Wakefield, Colin Waters*

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Core workshop: *Jan Hennissen, Ed Hough*

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Conference website: *Emma Ball*

Oral presentations – Sunday 21 December

	Lecture Theatre 4			Lecture Theatre 5		
09:00–09:15	Welcome address (M Stephenson)					
09:15–09:45	Plenary	*chair: Mike Stephenson*	KEYNOTE: Exploring the dark recesses of the Carboniferous sedimentary record (S Davies)			
09:45–10:15			KEYNOTE: 'Natural Fracking': hydrofracture systems in glacial environments (E Phillips and J Van der Meer)			
10:15–10:45			KEYNOTE: The weird world of the Brazilian Pre-Salt: gels, clay dissolution and a mantle source? (P Wright)			
10:45–11:00						
11:00–11:15	Sediments & the Biosphere	*chairs: Breandán MacGabhann and Jaco Baas*	How do biofilms alter the chemistry and fabric of a precipitate? (M Rogerson et al.)	Fluvial and Floodplain Environments in the Sedimentary Record I	*chair: Tim Kearsey*	Application of a quantified system scale analyses of a Distributive Fluvial System (DFS) to predicting basin scale facies distributions (A Owen et al.)
11:15–11:30			Can biogenic sediment modification trigger landslides and inhibit erosion from turbidity currents? (M Clare et al.)			Back-flow ripples: controls on their formation (C Herbert and J Alexander)
11:30–11:45			Mineral precipitates in modern microbial mats: carbonates, Mg-silicates and role of EPS (M Tucker and L Bowen)			The sedimentary architecture of an early Carboniferous ecosystem and the rise of tetrapod terrestrialisation (D Millward et al.)
11:45–12:00			Are flute cast-like structures in the Booley Bay Formation (Cambrian, Ireland) formed by down-slope creep of microbially-bound sediment? (B MacGabhann and J Murray)			Sedimentology of crevasse splay deposits in high- and low-accommodation greenhouse settings: examples from the Cretaceous Mesaverde Group (C Burns et al.)
12:00–12:15			New analytical approaches for characterising micro-soils and the weathering effect of cryptogamic ground covers (R Mitchell et al.)			Integrating outcrop and core studies to elucidate palaeoenvironments of subsurface successions (H Beaumont et al.)
12:15–12:30			Using well-preserved Mississippian brachiopod calcite for palaeoenviromental reconstructions of equatorial Britain (L Nolan et al.)			Seasonal wetland paleosols of the Ballagan Formation in SE Scotland and their link to tetrapod terrestrialisation in the earliest Carboniferous T Kearsey et al.)
12:30–13:15						
13:15–13:30	Deepwater Depositional Systems I	*chair: Joris Eggenhuisen*	Flow evolution and sedimentation processes across fine-grained deep-marine lobes an example from the Tanqua Karoo (I Kane et al.)	Fluvial and Floodplain Environments in the Sedimentary Record II	*chair: Tim Kearsey*	Large variations in sedimentary architecture in a Permian seasonal tropical, low-accommodation fluvial system (C Eide and J Howell)
13:30–13:45			New experimental approach shows morphodynamics at the inception of a submarine channel (J de Leeuw et al.)			Fluvial systems at the base of large igneous provinces – How predictable are they? (R Taylor et al.)
13:45–14:00			Mass transport complexes and the avulsion of submarine channels (A Ortiz-Karpf et al.)			Downstream control on fining in fluvial systems (N Meijer et al.)
14:00–14:15			Sedimentological and reservoir characterisation of thin bedded turbidites: Early Miocene outcrops, NW Borneo (I Puasa et al.)			Dunes and density currents: A re-evaluation of the dune phase-stability space (C Unsworth et al.)
14:15–14:30			Cryptic delamination beneath distal hybrid event beds: evidence for local substrate entrainment (M Fonnesu et al.)			Investigating the relationship between climatic cycles and the timing of fluvial incision in the Sorbas Basin, SE Spain (S Ilott et al.)
14:30–14:45			Hybrid event bed character across the Clare Shale – Basal Ross Formation contact, western Ireland – New insight from behind-outcrop cores (A Obradors-Latre et al.)			Internal sedimentary architecture and heterogeneity within fluvial point-bar successions (C Russell et al.)
14:45–15:00			Cores for concern: How well do seafloor deposits represent the flows that created them? (W Symons et al.)			Where are my fans? The onshore depositional record of widespread exhumation of southern Africa in the Cretaceous (J Richardson et al.)
15:00–15:15			An integrated model for inner bend deposition in submarine channels (J Peakall and E Sumner)			
15:15–15:30						
15:30–15:45	Deepwater Depositional Systems II	*chair: Joris Eggenhuisen*	Deposition of dual-source turbidites of the Aberystwyth Grits Group, Wales (L Gladstone et al.)	Source to sink: Recent Advances in Sedimentary Provenance Studies	*chairs: Rhodri Jerrett, Penelope Lancaster, Miqual Poyatos-Moré and Aoife Blowick*	INVITED SPEAKER: Provenance of Triassic sandstones in the Wessex and Cheshire basins: heavy mineral and zircon age constraints on the nature of the 'Budleighensis' river system (A Morton and D Frei)
15:45–16:00			A theory for the suspension capacity of geophysical turbulent flows (J Eggenhuisen and J de Leeuw)			
16:00–16:15			Influence of basin physiography upon the character and distribution of hybrid event beds (S Southern et al.)			Provenance and palaeoenvironments of Late Cretaceous-Miocene mixed terrigenous-carbonate sediments of the Arabian continental margin in SE Turkey: a record of ocean basin closure and continental collision (A Robertson et al.)
16:15–16:30			Depositional architecture of a deep-water sediment bypass zone (H Brooks et al.)			Deciphering sedimentary recycling via multi-proxy in situ analyses in the Millstone Grit, Yorkshire (P Lancaster et al.)
16:30–16:45			Variability in turbidity current frequencies in a central Portuguese margin canyon (J Allin et al.)			Detrital K-feldspar in modern river sands of the Mississippi Drainage Basin: A new perspective on continental-scale provenance (A Blowick et al.)
16:45–17:00			Healing the scars: Sedimentology and stacking patterns of intraslope lobe deposits related to sediment evacuation (Y Spychala et al.)			Multi-proxy sand provenance in the Lake Albert Basin, Uganda: Insights into the drainage evolution of the upper Nile (S Tyrrell et al.)
17:00–17:15			Classification of hierarchy in the sedimentary architecture of deep-marine systems: A review and a look forward (S Leadbeater et al.)			Rare earth elements as provenance discriminators of submarine mega-landslides in the Northern North Atlantic (M Watts)
17:15–17:30			Long term (20 Myr) tempo of long run-out turbidity currents in the Iberian Abyssal Plain: Persistent log-normal distribution and relationship to major climatic events (M Clare et al.)			Source to sink assessment of Oligocene to Pleistocene sediment supply in the Black Sea (J Maynard)
17:30–17:45			**AGM and Awards Presentation**			
17:45–18:40	Dedicated Poster Session					
18:40	Coach departs for Dinner 18:40					
19:00–23:00	Conference Dinner – Trent Bridge Cricket Ground *(postcode: NG2 6AG)*					

Oral presentations — Monday 22 December

	Lecture Theatre 4			Lecture Theatre 5		
09:00–09:15	Conventional and Unconventional Hydrocarbon Reservoirs (PESGB)	*chair: Chris Jackson*	Heterogenetic compaction and diagenesis of the fluvio-aeolian Lower Jurassic Etjo Formation, NW Namibia (M Kittel and H Stollhofen)			
09:15–09:30			Further insight into the depositional environment of the Holywell Shale (Carboniferous, northeast Wales) (L Newport et al.)			
09:30–09:45			Is clastic injection at deep-water stratigraphic traps predictable? (S Cobain et al.)			
09:45–10:00			Evolution of sand-body architecture influenced by large-scale remobilisation events in a deep-water setting: Britannia Field, UK North Sea (R Teloni et al.)			
10:00–10:15						
10:15–10:30	Clay, Mudstone and Shale the Finest Sedimentary Rocks! (CMG)	*chair: Simon Kemp*	Wave ripples in mixtures of cohesive clay and cohesionless sand (J Baas et al.)	Mixed-Processes in Coastal to Shallow-Marine Systems I	*Chairs: Marijn Van Cappelle, Daniel Collins, Marcello Gugliotta, Michelle Shiers, Gary Hampson*	Global classification of shallow marine systems (J Howell and B Nyberg)
10:30–10:45			Integrating microfacies typing and reservoir properties in the Haynesville-Bossier Shale, USA (P Dowey and K Taylor)			Origin of variations in mud-content in tide-influenced deltas: Delta lobe abandonment or maximum turbidity zone? (M Van Cappelle et al.)
10:45–11:00			Novel approach to dealing with the hardening of a clay-grade limestone: the Chalk of eastern England (C Jeans)			Recent shoreline change and sea level rise at a lagoon-barrier complex, Ghana (K Davies-Vollum and M West)
11:00–11:15			Using hydrocarbon reservoirs as analogues to assess shale seals for Carbon Capture and Storage (M Wilkinson and Y Shu)			The effects of flood-ebb flows and tidal bores on a large tidal bar within the river-estuary transition zone (C Keevil and D Parsons)
11:15–11:30			Characterisation of glaucony from the shallow marine Upnor Formation, London Basin (J Huggett et al.)			Lateral variability in stratigraphic transition from open shelf to non-marine deposition along a 70 km strike transect. Tanqua Depocentre, Karoo Basin, S. Africa (L Gomis-Cartesio et al.)
11:30–11:45			Lateral variation of deltaic sandstones in a shale succession from the Northwest Carboniferous Basin (R Raine et al.)			Detailed reconstruction of tidally influenced point-bar elements of the Campanian Neslen Formation, Utah (M Shiers et al.)
11:45–12:30						
12:30–12:45	Mixed-Processes in Coastal to Shallow-Marine Systems II	*Chairs: Marijn Van Cappelle, Daniel Collins, Marcello Gugliotta, Michelle Shiers, Gary Hampson*	Shelf margin variability in fine-grained prograding systems, Karoo Basin, South Africa (M Poyatos-Moré et al.)	Continental Sedimentology I	*chairs: Amy Gough and Adrian Hartley*	A 2.3 million year lacustrine record of orbital forcing from the Devonian of northern Scotland (S Andrews et al.)
12:45–13:00			Unravelling continental, shallow and deep marine facies distribution in passive margin basins: Early Cretaceous in Tarfaya Basin, Atlantic margin of Morocco (A Arantegui et al.)			Facies heterogeneity in the Triassic Sherwood Sandstone Group of the UK: Comparing and contrasting coeval depositional basins (J Thompson et al.)
13:00–13:15			The effects of mixed cohesive and non-cohesive sediment properties and hydrodynamics on ripple migration in the intertidal Dee Estuary (I Lichtman et al.)			Metre-scale polygonal dewatering structures and their mode of formation: Triassic Moenkopi Formation, Utah (S Banham et al.)
13:15–13:30			Stratigraphic record of river-dominated crevasse subdeltas with tidal influence (Lajas Formation, Argentina) (M Gugliotta et al.)			Mineralogical and geochemical analyses of the sideritic ironstones from the Weald Basin, southeast England (O Akinlotan)
13:30–13:45			Storm-wave dominated, fluvial influenced 'storm-flood' deltaic deposition in the eastern Baram Delta Province, NW Borneo (D Collins et al.)			Quantifying the controls on sediment fluxes and grain size export from catchments to basins: case studies from normal fault-bounded catchments in S. Italy (D Boluda et al.)
13:45–14:00			Pliocene-Early Pleistocene sedimentary response to early-stage tectonic uplift of the Kyrenia Range, northern Cyprus, in a collision-related tectonic setting (R Palamakumbura et al.)			Climatic controls on deposition within proximal continental basin margins (A Gough et al.)
14:00–14:15			Everything you wanted to know about fossil mangroves? (J Noad)			Facies distribution within aeolian sets related to large scale 3D outcrop architecture: A virtual outcrop case study from the Jurassic Page Sandstone, Arizona (C Pierce et al.)
14:15–14:30						
14:30–14:45	Sedimentology of Glaciated Margins	*chairs: Sarah Southern and Jonathon Lee*	Sedimentological insights into Cryogenian glaciation in Scotland: an integrated field-based analysis from the Port Askaig Formation of the Garvellach Islands (D Ali et al.)	Continental Sedimentology II	*chairs: Amy Gough and Adrian Hartley*	The dating of Late Quaternary fluvial and marine terrace sediments in south-west Iran and their use in determining Earth surface movements (K Woodbridge and D Parsons)
14:45–15:00			Dynamic glaciation during a Neoproterozoic 'Snowball Earth' event (E Fleming et al.)			Seismic geomorphology and sedimentology of a tidally-influenced, fluvio-deltaic succession: Late Triassic Mungaroo Formation (J Stuart and N Mountney)
15:00–15:15			The Late Devensian glacial history of the West Shetland Margin: a story of multiple ice advances, slope instability and bed rock control (S Davison)			Probing the sedimentary record of past climate change using alluvial fan stratigraphy (A Whittaker et al.)
15:15–15:30			Controls on Physical Property Distribution in the North of the Dogger Bank Tranche A – Results from a Pilot Study (K Blacker et al.)			The three-dimensional architecture and depositional environment of the Jurassic Kayenta Formation, Paradox Basin, Utah, USA (K Johnson)
15:30–15:45			Insights from high-resolution multibeam data on the Traenadjupet landslide on the Norwegian margin (A Mozzato et al.)			Relationships between floodplain aggradation rate and fluvial architecture: results of a meta-analysis and implications for fluvial sequence stratigraphy (L Colombera et al.)
15:45–16:00						
16:00–16:15	Primary and Secondary Volcanic Deposits	*chairs: Martin Jutzeler, Vern Manville, Mel Froude*	Facies analysis and floatation experiments from an unusual bed of pumice lapilli-and-ash offshore Montserrat (IODP 340) (M Jutzeler et al.)	The Proterozoic and 3D modelling	*chairs: Brian Burnham, Hazel Beaumont, Matthew Warke, Christian Haug Eide*	The Palaeoproterozoic Tongwane Formation (South Africa): transitioning from iron formation deposition to carbonate deposition on the Kaapvaal Craton prior to the Great Oxidation Event (M Warke et al.)
16:15–16:30			Antidunes from aggrading sediment-water flows in the Belham River Valley, Montserrat, West Indies (M Froude et al.)			Quantification of small-scale geobody architectures in carbonate platform settings using digital outcrop models (J Lavi et al.)
16:30–16:45			Giant rafted pumice blocks from the 1.8ka Taupo eruption, New Zealand (V Manville et al.)			Quantitative characterisation, analysis and modelling of a mixed-load fluvial system: A case study of the Huesca Fluvial Fan (B Burnham and D Hodgetts)
16:45–17:00			Volcanic forcing from two sides: Drainage and plant ecosystem development in the Columbia River Flood Basalt Province, Washington State (A Ebinghaus et al.)			Morphodynamics of cyclic steps: a depth-resolved numerical model (A Vellinga et al.)

Poster presentations — Sunday and Monday 22–22 December

Clays, Mudstone & Shale - The Finest Sedimentary Rocks!	1	The effect of interbedding on shale reservoirs properties (M Raji et al.)
	2	Diagenetic Evolution of The Eagle Ford Formation, SW Texas: Impacts upon Reservoir Quality and Rock Properties (R McAllister et al.)
	3	Thermal effects on an organic-rich mudstone and the implications of sill emplacement into carbon-rich sedimentary basins (K Summers and A Saunders)

Continental Sedimentology	4	Trends in the abundance of biotic sedimentary signatures in alluvium of the Maritimes Basin, eastern Canada: Pennsylvanian climax and Permian downturn (N Davies)
	5	The evolution models of a distributive fluvial system: the Parapeti, Bolivia (L Do et al.)
	6	Modern and ancient fluvial-aeolian interactions: sedimentary and stratigraphic expression examples from the Skeleton Coast of Namibia and the Triassic Helsby Sandstone Formation, UK (M Alkathery and N Mountney)
	7	A database approach to the characterisation of sedimentary architecture in mixed aeolian-fluvial successions: application to reservoir characterisation (M Al-Masrahy and N Mountney)
	8	Early Carboniferous depositional environments in the Northumberland Basin and implications for carbon-isotope stratigraphy (R Curtis et al.)
	9	An Early Carboniferous marine environment in the Northumberland Basin preserves a unique vertebrate assemblage (J Sherwin et al)
	10	Proximal to distal transition in the large-scale ephemeral fluvial system of the Kayenta Formation in western USA (M Watson et al.)
	11	Sedimentology of the Late Cretaceous in the Western Aude Valley, Southern France (D Satterfield and R Suthren)

Conventional & Unconventional Hydrocarbon Reservoirs - Sponsored by PESGB	12	Clay mineralogy distribution in modern estuarine environments as analogues for deeply buried sandstone reservoirs (J Griffiths et al.)
	13	Sandstone reservoir quality: The importance of a modern estuarine analogue in understanding the fundamental processes governing the distribution of clay-coated sand grains in petroleum reservoirs (L Wooldridge et al.)
	14	Unravelling timing, controls and distribution of Early Cretaceous sediments from source to sink along a complex passive margin: The Agadir-Essaouira Basin, Morocco Atlantic margin (T Luber et al.)
	15	Basin-scale mineral and fluid processes at a palaeo-platform margin, Lower Carboniferous, UK (C Breislin et al.)
	16	Chemostratigraphy of carbonate reef complexes of the Lennard Shelf, Western Australia - correlation and indication of environmental changes during the Frasnian and Famennian deposits of the Canning Basin (S Caulfield-Kerney et al.)

Crustal Faulting	17	Sedimentary fault rocks (N Woodcock)

Deepwater Depositional Systems	18	Using high-resolution datasets to improve understanding of submarine channel evolution (F Palm et al.)

Fluvial & Floodplain Environments in the Sedimentary Record	19	The internal architecture of a 3 dimensional point bar system in a sand dominated fluvial system in the Morrison Formation, Central Utah (A Swan et al.)
	20	Facies and palaeocurrent analysis of a braided fluvial system: a Carboniferous case study, Central Pennine Province, northern England (R Soltan and N Mountey)
	21	Why were the Early Carboniferous floodplains of southern Scotland key sites for preservation of the earliest four limbed vertebrates? (G Phillpotts et al)
	22	Dolomitic cementstones from the Early Carboniferous of Scotland: floodplains, lakes and marine transgressions (C Bennet et al.)
	23	Depositional models to account for stratigraphic complexity in fluvial point bars: integration of modern data from GIS studies with ancient outcrop data (C Russell et al.)

Mixed-Processes in Coastal to Shallow-Marine Systems	24	The Early Cretaceous sequence in Spitsbergen: the Festningen profile (M Vickers et al.)
	25	Spatial and temporal variability in the shallow-marine Favignana Calcarenite (Sicily, Italy) (A Slootman and A Moscariello)
	26	Floc depositional characteristics within the Sacramento–San Joaquin River (A Manning and D Schoelhamer)
	27	The Blisworth Limestone Formation (Middle Jurassic) at Roade Cutting, Northamptonshire, UK (A Barron and M Woods)
	28	Sequence boundary recognition in a tectonically-controlled shelf-margin delta (Lower Eocene, South-Central Pyrenees, Spain) (Poyatos-Moré et al.)

Sedimentology of Glaciated Margins	29	Quaternary unconformities in the making: examples from the UK continental shelf (C Mellett and D Dove)
	30	Palaeoproterozoic glacials in South Africa: age constraints and sedimentary context (Stefan Schröder et al.)
	31	The application of 3D geological modelling to visualise Late Devensian aged glacial sediments. An example from the Vale of York, UK (H Burke et al.)
	32	Ice advance in the Sturtian Sperry Wash succession: proglacial to ice-contact depositional processes (M Busfield and D Le Heron)
	33	Re-advancing ice sheets in the aftermath of a Sturtian glacial minimum: perspectives from the southern Kingston Range, California (D Le Heron and M Busfield)
	34	Controls on physical property distribution in the North of the Dogger Bank Tranche A – Results from a pilot study (K Blacker et al.)

Sediments & the Biosphere	35	Using well-preserved Mississippian brachiopod calcite for palaeoenviromental reconstructions of equatorial Britain (L Nolan et al.)
	36	Validating experimental bedform dynamics in cohesive sand-mud within a natural environment (M Baker et al.)
	37	Microbially mediated and authigenic carbonate formation in sabkha sediments (K Dutton et al.)
	38	Bedform dynamics in mixed sand-clay-EPS substrates (L Ye et al.)
	39	Is there sedimentological evidence for dinosaurs as geomorphic agents in Mesozoic rivers? A critical analysis (A Shillito)
	40	Flexure of microbial mats around holdfasts of epibenthic fronds: Ediacaran ecology in the Cambrian of Avalonia (Ireland) (B MacGabhann et al.)
	41	Facies and mass extinction controls on the ichnology of the Permian-Triassic succession of the Sydney Basin, New South Wales, Australia (S Lucas and N Davies)

Source to Sink: Recent Advances in Sedimentary Provenance Studies	42	Determining dune provenance of the Rub'al Khali desert, UAE; through heavy mineral analysis using ICP-AES and optical methods (I Mounteney et al.)
	43	Lower Cretaceous drainage systems of the north-western India Peninsular: Insights from petrographic, SEM and palaeocurrent studies (H Beaumont et al.)
	44	Tectono-stratigraphic framework and controls on sedimentation of the Lower Old Red Sandstone of the Midland Valley Basin, Scotland Z McKellar et al.)
	45	Provenance of Ordovician conglomerates in the South Mayo Trough, western Ireland (A Barry et al.)
	46	The West Burma Block – Origin of continental crust of western Myanmar: Insights from provenance of Triassic turbiditic sandstones in the Chin Hills (I Sevastjanova et al.)
	47	Mesozoic sediment dispersal patterns on the southwest Barents Shelf (E Fleming et al.)

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POSTERS

POSTER

MODERN AND ANCIENT FLUVIAL–AEOLIAN INTERACTIONS: SEDIMENTARY AND STRATIGRAPHIC EXPRESSION EXAMPLES FROM THE SKELETON COAST OF NAMIBIA AND THE TRIASSIC HELSBY SANDSTONE FORMATION, UK

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Fluvial-aeolian interactions are common at the margins of desert regions where drainage networks may penetrate tens to hundreds of kilometres into the inner parts of aeolian dune fields. Elsewhere fluvial systems may be dammed and ponded at outer dune-field margins. Some fluvial systems occupy long-lived fluvial corridors that partition dune fields; others temporarily exploit transient interdune corridors that open and close as aeolian-dunes migrate. This study documents the effects of temporal and spatial variability on preserved stratigraphic architecture of mixed fluvial-aeolian systems arising from: (i) morphological changes in aeolian dunes and interdune configuration; (ii) variability in processes of sediment transport across desert basins for both fluvial and aeolian systems; (iii) variability in the mechanism of sediment preservation. Controls on fluvial incursions into dune-fields include temporal and spatial changes in the frequency and magnitude of precipitation events, fluvial runoff distance from catchment to receiving basin, sediment yield, changes to regional water-table level in response to flood events, subtle variations in palaeotopography of the accumulation surface. These factors conspire to determine whether floods are confined within channelized networks or occur as unconfined sheet flows that inundate large areas of dune-field margins.

Active mixed fluvial-aeolian systems along the Skeleton Coast comprise dune networks that form major obstacles in the path of a series of ephemeral rivers that drain south-southwestward towards the Atlantic Ocean. Geomorphological relationships have been examined through analysis of high-resolution satellite imagery data from Google Earth Pro software. Recorded interactions include: (i) the maintenance of long-lived broad, through-going open interdune corridors along which well-established rivers pass; (ii) the damming of dry river courses by active aeolian dunes that form barriers to flow, thereby resulting in the ponding of flood waters and the development of large, slowly draining flood basins; (iii) the passage of flood waters as sheet flows into the outer margins of aeolian dune fields.

Outcrop analysis of the Helsby Sandstone Formation (Cheshire Basin) reveals the preserved stratigraphic expression of several types of ancient fluvial-aeolian interactions: (i) relationships indicative of systematic temporal change from an aeolian dune field characterized by small, isolated dry interdunes to one in which interdunes were large and interconnected such that they acted as conduits for fluvial flow whereby fluvial channels were able to penetrate into dune-field centre settings; (ii) evidence for fluvial reworking of aeolian dune deposits by erosive flows that resulted in temporary cessation in dune migration in the immediate aftermath of flood events.

A DATABASE APPROACH TO THE CHARACTERISATION OF SEDIMENTARY ARCHITECTURE IN MIXED AEOLIAN-FLUVIAL SUCCESSIONS: APPLICATION TO RESERVOIR CHARACTERISATION

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Geomorphological elements in desert settings tend to change systematically from the central parts of dune fields, where aeolian processes are dominant, to dune-field margins, where non-aeolian systems including ephemeral fluvial streams dominate. Aeolian and fluvial processes operate coevally in most desert-margin settings to generate a range of styles of sedimentary interaction that are documented from both modern arid systems and analogous ancient preserved outcrop successions. Such styles of system interaction give rise to considerable complexity in terms of sedimentology and preserved stratigraphy. The physical boundary between geomorphic systems in hot deserts is dynamic such that facies belts undertake considerable lateral shift over time with the result that preserved sequence architectures exhibit complexity arising from system interactions that operate at a range of spatial and temporal scales from local to regional. An improved understanding of factors that govern these multiple scales of interaction is important for prediction of preserved stratigraphic architecture. Across desert margins where fluvial and aeolian systems interact, the location of assemblages of surface landforms may change gradationally or abruptly. An improved understanding of contemporary interactions serves as the basis for a database of modern analogues that can be used to account for types of aeolian-fluvial interactions preserved in the stratigraphic record.

The database developed records the temporal and spatial scales over which aeolian and fluvial events operate and interact in a range of modern desert-margin settings and ancient preserved successions. Data from modern systems have been collated using high-resolution satellite imagery and field observation data. The database of case-study examples is employed to develop a series of quantitative facies models with which to account for dynamic spatial and temporal aspects of aeolian-fluvial system behaviour. Models can be used to predict the arrangement of architectural elements that define gross-scale system architecture in a variety of mixed aeolian-fluvial system types. Results demonstrate the significance of aeolian dune type and orientation relative to fluvial-system type and orientation in determining the style of fluvial incursion into dune fields.

This database approach serves as a tool for system classification and quantification. From an applied standpoint, quantitative depositional models arising from this database-driven approach serve to minimise uncertainties relating to stratigraphic heterogeneity in subsurface reservoir settings and aid inter-well correlation and prediction.

POSTER

VALIDATING EXPERIMENTAL BEDFORM DYNAMICS IN COHESIVE SAND-MUD WITHIN A NATURAL ENVIRONMENT

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For the first time, laboratory-based observations of bedform dynamics in mixtures of cohesive mud and cohesionless sand have been validated under field conditions. Both laboratory experiments and field observations in the Dee estuary now demonstrate that small quantities of clay and 'sticky' biological polymers within sandy substrates can dramatically reduce the development rate of sedimentary bedforms. These unique results build upon existing studies that focussed on bedform development, or the lack thereof, in pure sand or mud.

Previous laboratory flume experiments in the Hydrodynamics Laboratory at Bangor University showed that the winnowing of fine-grained cohesive sediment, containing clay minerals and biological stabilisers, is an important processes affecting the development rate, size and shape of cohesive bedforms in mixed sand-mud. Increasing the kaolin clay fraction in the sediment bed causes ripples to develop at an increasingly slower rate. The same relationship was found for xanthan gum, which is a proxy for biological polymers produced by microphytobenthos, such as diatoms, and bacteria. Yet, the xanthan gum was several orders of magnitude more effective in slowing ripple development than the kaolin clay at characteristic background concentrations found in nature. This implies that biological polymers provide more cohesive strength to mixed substrates than clay minerals.

Results from novel field experiments on an intertidal flat in the Dee Estuary (at West Kirby) mimic those found in the laboratory, in that the winnowing of fines occurs in conjunction with ripple development. Additionally, a strong relationship between increasing mud bed fraction and lower development rate of current ripples was found. This was inferred from an inverse relationship between percentage <63 particle size fraction and average wavelength of the ripples. There was also a strong change in ripple morphology from no ripples via two-dimensional (straight-crested) to three-dimensional (tongue-shaped) ripples as the percentage bed mud content decreased.

Despite that bedform prediction in natural mixed sediments remains a complex task due to the dynamic interplay between chemical, physical and biological factors, the favourable comparison between the laboratory and the field data found in this study takes us an important step closer to improving local and regional sediment transport models and process interpretations from sedimentary deposits in the rock record.

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THE BLISWORTH LIMESTONE FORMATION (MIDDLE JURASSIC) AT ROADE CUTTING, NORTHAMPTONSHIRE, UK

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The railway cutting on the West Coast Main Line at Roade, near Northampton, is 2.8 kilometres long and at 23 m the deepest on the British rail network. It cuts through an almost complete succession of Bathonian (Middle Jurassic) strata, and as such is probably unique in the East Midlands region, meriting its designation as a geological Site of Special Scientific Interest (SSSI). The succession was first described late in the 19th century.

Between 2005 and 2010, as a result of engineering works that would eventually obscure and restrict future access to the succession, the authors were given the opportunity to record the geology along nearly 1 km of the cutting. It soon became apparent that the only strata exposed belong to the Blisworth Limestone Formation of the Great Oolite Group. These form steep mural exposures up to 6.5 m high, and some hundreds of metres in length along the lower portions of both north-east and south-west faces of the cutting. The strata are more-or-less flat lying, and are generally not affected by any structural disturbances (faulting or folding).

The Blisworth Limestone Formation comprises a succession of bedded, fossiliferous, bioclastic and peloidal limestones, with subordinate mudstone beds mainly in the lower part. Vertical changes in lithology and macrofossil distribution, especially brachiopods, permit the subdivision of the formation into two formal members – the Roade Member below and the Ardley Member above. Unique access enabled us to collect lithological and biostratigraphical specimens and make a detailed description of the Blisworth Limestone Formation's stratigraphy, sedimentology and biostratigraphy along a total of over 1000 m of continuously-exposed cutting sides. At the same time, photographic panoramas were made, later superimposed with correlations and together these reveal lateral variations in the succession. The formation preserves evidence of particular environments developed around the northern fringe of the Anglo-Brabant Massif and is therefore important in developing our regional understanding of Mid Jurassic palaeogeography, depositional dynamics and shallow marine palaeo-ecology. Along with logs of nearby quarries and other exposures, these data will form the basis for a new regional appraisal of the stratigraphy and depositional development of the Blisworth Limestone.

PROVENANCE OF ORDOVICIAN CONGLOMERATES IN THE SOUTH MAYO TROUGH, WESTERN IRELAND

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Conglomeratic horizons in sedimentary successions form important archives, recording information on the evolution of both basin and hinterland. Determining the nature and provenance of such horizons from the Ordovician infill of the South Mayo Trough (SMT; north Connemara, western Ireland) is important as these sedimentary archives are potentially linked with the development of the Grampian Orogeny (c. 475 Ma).

This project utilised field work, clast counting, optical petrography and Pb isotopic analysis of K-feldspar crystals/grains in order to understand the supply of conglomeratic material into the SMT. Three geological units of Ordovician age were investigated – the Rosroe and Derryveeny formations and the Bunnacunneen Member of the Mweelrea Formation. The Rosroe Formation is a matrix-supported conglomerate, possibly a debris flow, and is dominated by granitic detritus. In contrast, both the Derryveeny Formation and Bunnacunneen Member are clast-supported, potentially represent alluvial fans, and comprise a more diverse range of clasts including metamorphic, basic igneous and granitic detritus.

Feldspar-bearing clasts were carefully chosen for Pb analysis which was carried out *in situ* using laser ablation multi-collector inductively coupled mass spectrometry (LA-MC-ICP-MS) at the National Centre of Isotope Geochemistry. Pb isotopic ratios act as a signature which can be used to identify different source terranes and their relative contributions.

A total of 153 Pb isotopic analyses were obtained from feldspars in twenty clasts from the three units. These data suggest that, with one exception, clasts in the Rosroe and Derryveeny formations are from a single, similar source. In contrast, feldspars in clasts from the Bunnacunneen Member yield a narrow range of Pb isotopic compositions, different to that recorded in the other formations. Comparison of these data with Pb isotopic compositions from the broad North Atlantic region suggest derivation from a southerly source for both the Rosroe and Derryveeny formations. Progressive development and modification of the hinterland, possibly linked to strike-slip faulting, potentially produced the provenance shift observed in the Bunnacunneen Member.

LOWER CRETACEOUS DRAINAGE SYSTEMS OF THE NORTH-WESTERN INDIA PENINSULAR: INSIGHTS FROM PETROGRAPHIC, SEM AND PALAEOCURRENT STUDIES

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The current understanding of the Lower Cretaceous drainage systems of Rajasthan, India is currently limited, despite the fact that their deposits represent part of the sedimentary fill of hydrocarbon prospective basins. By using petrographical, SEM and palaeocurrent studies to determine the source and palaeoflow direction of the probable Lower Cretaceous fluvial Ghaggar-Hakra Formation, Barmer Basin, India, we assess the implications of the evolution for the Lower Cretaceous palaeogeography of north-western India. This work has significant ramifications for the hydrocarbon prospectivity of the West Indian Rift System, including the Ghaggar-Hakra Formation within the subsurface of the Barmer Basin.

The Ghaggar-Hakra Formation comprises three distinct bedload-dominant stacked fluvial sandstone successions known as the Darjaniyon-ki Dhani Sandstone, the Sarnoo Sandstone and the Nosar Sandstone. These successions are interbedded with a significant thickness of strata dominated by overbank mudstones and siltstones. Petrographical studies and SEM analysis of the sandstone successions show rounded and moderate sorted sediments with detrital mineralogy that constitutes quartz grains, rigid rock fragments (of sedimentary, metamorphic and igneous origin), heavy minerals (zircon, tourmaline, rutile) and muscovite. The authigenic minerals comprise of quartz overgrowths, haematite cement, calcite cement, anatase and kaolinite booklets. All three sandstone successions are devoid of feldspar. Palaeoflow studies indicate that the Darjaniyon-ki Dhani and Nosar Sandstones flow dominantly to the south-west; while the Sarnoo Sandstone displays a dominantly westerly flow.

Petrographical and SEM analysis of the sandstone successions displays that the three sandstone successions are texturally and compositionally mature quartz arenites, composed of well-travelled detrital sediments all derived from the same provenance which is likely to be the Aravalli Mountain Range. The change in the palaeoflow directions may reflect regional tectonic activity, during in the Lower Cretaceous, likely to be related to formation of the eastern Barmer Basin margin.

DOLOMITIC CEMENTSTONES FROM THE EARLY CARBONIFEROUS OF SCOTLAND: FLOODPLAINS, LAKES AND MARINE TRANSGRESSIONS

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This study is a contribution to the TW:eed Project (Tetrapod World: early evolution and diversification), which examines the rebuilding of Carboniferous ecosystems following a mass extinction at the end of the Devonian. The project focuses on the Tournaisian Ballagan Formation of Scotland and the Borders, which contains rare fish and tetrapod material. The Ballagan Formation is characterised by sandstones, dolomitic cementstones, paleosols, siltstones and gypsum deposits. The depositional environment ranges from fluvial, alluvial-plain to marginal-marine environments.

Cementstones are a key component of the Ballagan Formation. Over 270 beds are recorded from the 500 metre Norham Core (near Berwick-Upon-Tweed) and 273 beds from the 520 metre field section at Burnmouth. The cementstones are flat-bedded, laterally extensive units, although individual units do not appear to correlate between the core and the field site. 17% of the cementstones contain marginal marine fossils: C*hondrites, Spirorbis, Serpula*, rare orthocones, brachiopods and putative marine sharks. More common fauna (likely non-marine) include ostracods, bivalves, plants, eurypterids, gastropods and fish. Rare units in the field section preserve large tree rooting traces. Secondary alteration is common; in the core 47% of cementstones are brecciated and 9% are pedogenically altered.

The cementstones are categorised by their sedimentary composition: Facies 1: Cemented siltstones, sandstones and microconglomerates; Facies 2: Homogeneous micrite; Facies 3: Bedded micrite and silts; Facies 4: Carbonate-bearing deposits (calcite); Facies 5: Dolomite containing gypsum. Facies 2 and 3 comprise ~60% of the cementstone beds and, along with Facies 4, contain the most marginal marine fauna. Cementstone formation processes are diverse, and include diagenetic cementation (Facies 1), deposition in saline lakes (Facies 2), deposition in floodplain lakes with clastic input (Facies 3), lagoonal to short-lived marine transgressions (Facies 4), and saline lake to sabkha environments (Facies 5).

Cementstones become thinner and slightly less common from the base to the top of the Ballagan Formation, with the only other distinct or systematic stratigraphic distribution being a decrease in the gypsum facies (Facies 5). This trend inversely correlates to palaeosols and desiccation cracks, illustrating a gradual increase in relative drier conditions through time. Aside from this sole trend, the stratigraphic distribution of lithologies indicates rapidly changing deposition between silts, sands and carbonates with many periods of pedogenesis and/or desiccation suggesting frequent switching from alluvial-plain to coastal environments. This temporal variability in the environments may have been an important factor in the evolution of tetrapods in the lower Carboniferous.

CONTROLS ON PHYSICAL PROPERTY DISTRIBUTION IN THE NORTH OF THE DOGGER BANK TRANCHE A – RESULTS FROM A PILOT STUDY

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The Dogger Bank is a large shallow topographic feature in the Central North Sea with water depths of 18–63 m. It is the proposed site for the largest of the offshore Round 3 windfarm zones, with a total area of 8660 km^2. The first survey area, Tranche A, comprises ~2000 km^2 and is located in the South West of Dogger Bank. Within this area a 110 km^2 pilot study area was selected and, using 2D high resolution multichannel sparker data, key seismic reflectors were picked and mapped in pseudo-3D. This allowed the identification of distinct seismo-stratigraphic packages that could be tied to the litho-stratigraphy sampled from geotechnical boreholes and wireline log data.

A distinct difference in seismic character between a younger upper unit and lower older unit within the Dogger Bank Formation is observed, believed to be the result of varying physical and acoustic properties of the sediment. This variation is present within wireline and CPT data, and discussed in this presentation. Where distinct seismo-stratigraphic features have been identified, the upper and lower Dogger Bank appear to have behaved differently; within this area the lower Dogger Bank behaves in a more brittle style, whilst the upper Dogger Bank behaves in a more ductile style. Controls on this variability are hypothesised to be the original distribution of sediment by glacial outwash, and post-depositional glacial processes leading to variations in strength of the sediment, such as differences in undrained shear strength, and physical properties between the two seismic packages. Within the pilot area it appears that repeated glacially-related processes had the greatest effect on the observed physical properties of the sediment. However, this may not be true for all of Dogger Bank, and ideas for further work are presented here alongside preliminary results.

BASIN-SCALE MINERAL AND FLUID PROCESSES AT A PALAEO-PLATFORM MARGIN, LOWER CARBONIFEROUS, UK

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The Derbyshire Platform is the westernmost expression of the East Midlands Platform, and is located on the southern margin of the Pennine Basin. The platform developed in the Lower Carboniferous (Visean) in response to back-arc extension north of the Variscan Orogenic Belt. Carbonate sedimentation focused upon the footwall highs of NW-SE trending Caledonian basement lineaments. During post-rift thermal subsidence in the Upper Carboniferous (Namurian-Westphalian), turbidite-fronted fluvio-deltaic systems buried the platform to depths of approximately 3 km. With the onset of the Variscan Orogeny, basement faults were reactivated and the Pennine Basin was inverted. Previous studies have proposed that this resulted in dewatering of overpressured, basinal sediments and massive fluid flux, leading to Mississippi-Valley Type mineralisation (fluorite-baryte-galena) and calcite cementation along faults and fractures.

On the south-western margin of the Derbyshire Platform, an area of approximately 50km^3 has been pervasively dolomitised. Dolomitisation is restricted primarily to the Brigantian Monsal Dale Limestone and, to a lesser extent, the Asbian Bee Low Limestone, occurring as halos surrounding northwest – southeast trending structural lineaments and is typically around 40 m thick. The dolomitised limestone is cross-cut by NW-SE and NE-SW trending, fluorite, galena and calcite cemented fractures, however. Since these fractures follow a Variscan trend, and have been dated as Late Carboniferous to early Permian in age, it seems reasonable to interpret the dolomitisation to be an earlier, Carboniferous, event.

Dolomitisation is typically fabric destructive with highly variable fabrics between localities, including idiotopic, hypidiotopic and xenotopic fabrics that are cross-cut by stylolites. Textural evidence suggests dolomitisation was multi-phase and occurred relatively early in the burial history. Fluid flow modelling indicates that sufficient fluid volumes were available in the basin to explain the volume of dolomite and mineralisation, but that the fluids did not contain sufficient Mg to explain the in situ volume of dolomite. Reactive transport models indicate that geothermal convection of seawater on the platform margin could have initiated dolomitisation during early burial, but preliminary geochemical data is consistent with dolomitisation from evolved basinal brines that have interacted with siliciclastic sediments and/or volcanics.

Following a site investigation at Carsington, borehole core from the platform margin has been made available to the British Geological Survey. This will be investigated alongside detailed field mapping, sampling and analysis to test the hypothesis that dolomitisation during early burial by seawater was overprinted by palaeofluids expelled from the Carboniferous basinal succession during the Variscan Orogeny.

THE APPLICATION OF 3D GEOLOGICAL MODELLING TO VISUALISE LATE DEVENSIAN AGED GLACIAL SEDIMENTS. AN EXAMPLE FROM THE VALE OF YORK, UK

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The last glaciation to affect Britain occurred during the Late Devensian, when ice of the Last British-Irish Ice Sheet occupied Northern Britain, Wales and offshore areas, including the North Sea, extending as far south as what is now the north Norfolk coast. A lobe of the British-Irish Ice Sheet extended around the North York Moors and southwards through the Vale of York. This ice advance through the Vale of York deposited till and formed a terminal moraine complex at its southern limit, the Escrick Moraine. Subsequent retreat resulted in the deposition of the York Moraine and a thick and variable succession, including laminated glaciolacustrine silts and clays and glaciofluvial sand and gravel.

Previous geological maps did not subdivide the sequence, and instead named it the '25 foot drift' To improve our understanding of the sedimentary (glacigenic) evolution of the area and to produce enhanced geological map coverage that sub-divided the glacial succession, a major mapping re-survey was undertaken by the authors. This re-survey was complemented by the construction of the York-Haxby 3D geological model, which covers an area of 50 km^2, corresponding with two 1:10000 scale geological map sheets of the northern part of the city of York and the village of Haxby. The York-Haxby model was constructed in 3D modelling software using an established workflow, and is underpinned by borehole data, surface geological map data, and field observations, such as geomorphology, logs of hand auger holes and lithology and grain size observations of the soil.

Seven Late Devensian geological units were modelled, together with Holocene aged alluvium and Late Permian aged Sherwood Sandstone Group bedrock. The glacial deposits include a sheet-like till unit, which forms the arc-shaped York Moraine ridge feature in the south of the model. Three separate laminated silt and clay units occur above and below the till, representing episodes of glacial lake conditions. Glaciofluvial sand and gravel occurs as a sheet-like unit at the base of the glacial succession and forms eskers at the surface. A surface cover of aeolian sand forms dune-like features.

Within this poster the glacial evolution of the Vale of York is described, focusing on the record provided by the landform and sedimentary records, aided by their 3D visualisation. This is placed within the wider chronological context of the Last British Irish Ice Sheet.

POSTER

CHEMOSTRATIGRAPHY OF CARBONATE REEF COMPLEXES OF THE LENNARD SHELF, WESTERN AUSTRALIA—CORRELATION AND INDICATION OF ENVIRONMENTAL CHANGES DURING THE FRASNIAN AND FAMENNIAN DEPOSITS OF THE CANNING BASIN

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The Canning Basin presents a perfect setting for developing alternative methods for high-resolution chronostratigraphic correlation, addressing problems such as subsurface data limitations and poor biostratigraphic resolution. Elemental data has been obtained by use of ICP OES and ICP MS for ca. 50 elements on over 2500 outcrop and core samples collected from field sections in the Canning Basin reef complexes of Western Australia. The study incorporates both attached and detached reef complexes, including back reef, reef core and fore reef facies. The samples range from Frasnian to Famennian in age and are taken from Windjana Gorge, the South Oscars Range, Casey Falls, Virgin Hills and the Horseshoe Range locations along The Lennard Shelf, Canning Basin.

The results show high-frequency trends in Cr/Al_2O_3, K_2O/Al_2O_3 and Zr/Al_2O_3 elemental ratios which infer changes in heavy metal compositions, clay mineralogy and siliciclastic input respectively. Thus the Cr/Al_2O_3 and K_2O/Al_2O_3 indicate clay mineral input from the weathering and transport of feldspar baring minerals and meteoric water in local settings, and the Zr/Al_2O_3 can be used as proxies for grain size and can reflect sea level and energy input changes at the time of deposition.

These elemental ratios allow for the inference of local to regional input into the basin, and can show correlational constraint boundaries that until now have not been recognizable in traditional sequence stratigraphy, making it a powerful tool in chronostragraphic correlation. Correlation of these sections is further aided when coupled with other methods of chronostratigraphy such as facies analysis, rock magnetics, biostratigraphy and stable isotope analysis.

EARLY CARBONIFEROUS DEPOSITIONAL ENVIRONMENTS IN THE NORTHUMBERLAND BASIN AND IMPLICATIONS FOR CARBON-ISOTOPE STRATIGRAPHY

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The fauna that survived the end-Devonian mass extinction have evolved to form the ecosystem that we recognise today. Core from the Hoddom No. 2 borehole in the western Northumberland Basin has recovered a continuous succession from the Early Carboniferous, which is time-equivalent to the neighbouring Tweed Basin where many new Early Carboniferous vertebrate fossils have been recently discovered. The main hypothesis of the project is to test whether the Northumberland Basin was more marine-influenced than the neighbouring Tweed Basin. This MGeol research is part of the TW:eed project (Tetrapod World: early evolution and diversification) which is studying recently discovered tetrapods from Romer's Gap in the Early Carboniferous.

A detailed log through a 77 m section of the core reveals an overall coarsening up succession with the proportions of gypsum and anhydrite decreasing upwards. The variety of textures observed including nodular anhydrite, chicken-wire anhydrite, laminated anhydrite, gypsum nodules, anhydrite cement and veins of gypsum and anhydrite indicate changing depositional environments and water depth. There is a clear upward change from the dominance of chicken-wire anhydrite and nodular anhydrite to later diagenetic anhydrite cement. Previous core descriptions found organic material, including plant fragments, root traces, megaspores and evidence of fauna, such as fish fragments, burrow traces and ostracods, in some of the mudstones and siltstones interbedded with gypsum and anhydrite. Two intervals with marine species have recently been discovered within the succession, containing Sanguinolites sp., lingulid, fish and Leiopteria sp. The lithologies are interbedded on a 0.05–0.6 m scale. The palaeontology combined with the sedimentary facies indicates a range of environments from marine-influenced fine-grained deposition through to environments with gypsum and anhydrite evaporites. The depositional environment appears most variable towards the base of the section, with repeated alternations of mudstone and anhydrite units.

Thin sections will be used to understand the mineralogy and relationship between anhydrite-gypsum textures and changing environmental conditions. Stable carbon isotope analyses, -13C, of the bulk organic matter and total organic carbon (TOC) measurements will help constrain the abundance and type of organic matter preserved, which will be linked to marine and non-marine environments.

POSTER

TRENDS IN THE ABUNDANCE OF BIOTIC SEDIMENTARY SIGNATURES IN ALLUVIUM OF THE MARITIMES BASIN, EASTERN CANADA: PENNSYLVANIAN CLIMAX AND PERMIAN DOWNTURN

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The alluvial sedimentary record of Euramerica during the Carboniferous and Permian contains evidence for marked climatic change associated with both the Late Palaeozoic Ice Age and the assembly of the supercontinent Pangea. This poster documents how this global climate change is reflected in the stratigraphic variation of biotic sedimentary structures within alluvium of the Maritimes Basin in eastern Canada, with special focus on the Pennsylvanian (Bashkirian, Langsettian) Tynemouth Creek Formation of southern New Brunswick and the lower Permian (?Asselian to ?Artinskian) Egmont Bay, Kildare Capes and Orby Head formations of Prince Edward Island. Within the Tynemouth Creek Formation, these signatures include (1) vegetation induced sedimentary structures (VISS) including upturned beds recording vegetation shadow effects, scour-and-mound beds, downturned beds and mudstone-filled hollows; (2) vertebrate and invertebrate trace fossils that demonstrate interaction between specific components of the Pennsylvanian ecosystem, such as very early folivorous grazing trails within Cordaites fronds; (3) an abundance of potentially microbially induced non-marine sedimentary structures (MISS) including Kinneyia ripples, elephant skin textures, and bubble marks; and (4) a bulk sedimentary architecture reflecting the culmination of the evolution of arborescent vegetation, with the presence of fixed-channel alluvial plains, potential log jam deposits, and evidence for floodplain stabilization. In contrast, the Prince Edward Island redbeds contain far fewer VISS, MISS and trace fossils, revealing a preserved sedimentary landscape dominated by abiotic processes. Changes in seasonality and aridity partially explain this trend, with the sedimentary record of the Permian semi-arid channel-braided river systems preferentially recording high-magnitude, low-frequency flood events, coupled with limited preservation potential for fossil material. Additionally, however, the major facies change also corresponds with significant vegetation turnover in central Pangea, from a lycopsid-and cordaitalean-dominated 'Carboniferous' flora to a conifer-dominated 'Permian' flora, and the mechanical properties of the different plant constituents may in part explain the absence of even indirect evidence of vegetation (i.e., VISS). The documented end-Carboniferous shift in Euramerican alluvial facies is partly analogous to a similar regional shift in alluvial facies around the supercontinental margins of Pangea at the Permian-Triassic boundary, observed in Siberia and Australia and previously attributed to reflect the effects of the end-Permian mass extinction.

THE EVOLUTION MODELS OF A DISTRIBUTIVE FLUVIAL SYSTEM: THE PARAPETI, BOLIVIA

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Recent work on fluvial depositional patterns in modern continental sedimentary basins indicates that large (>30 km radius) distributive fluvial systems (DFS) form important constituents. Despite their importance, studies based on modern DFS are relatively few in number. Here we use geomorphological observations from a modern DFS as an analogue for better understanding the continental rock record. The aim of the study is to utilise remotely sensed imagery to build a picture of depositional patterns over time, to develop a predictive model from these observations and then apply these to the rock record.

Spatial variations of channel pattern as well as avulsion occurrences were traced over the past 42 years using ASTER and Landsat time series satellite imagery (MSS, TM, ETM+, 1972–2014), and CBERS (China-Brazil Earth Resources Satellite) for Bolivia. We selected the less cloudy images for approximately the same hydrological period. Satellite imagery was pre-processed using basic procedures of image enhancement (Lillesand and Kiefer, 1994). Consequently, these images were georeferenced and orthorectified into ArcGIS. Then, to achieve a broader-scale geomorphic overview, the images were visually interpreted and map individual landforms. Visual interpretation incorporates colour, density and texture of the imagery, but also deduces information from elevation, vegetation and land-use patterns (Verstappen, 1977; Rosenfeld, 1984). Thus landforms, surface processes and their changes can be analysed for the investigated time period.

Two types of terminal channel evolution are defined based on the observations of progressive trends in the Parapeti system. Type 1 — where channel avulsion results in a channel that either cuts through older splay deposits or form a new splay system. This type occurs following a major flood event on a 15 year timescale. Type 2 — is where the channel and the associated splay prograded coevally resulting in the channel cutting progressively through older splay deposits. This type occurs on a 1–2 year timescale.

MICROBIALLY MEDIATED AND AUTHIGENIC CARBONATE FORMATION IN SABKHA SEDIMENTS

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Coastal sabkhas form under arid, hypersaline conditions to produce complex mixed carbonate-evaporite and/or siliciclastic-evaporite deposits. Carbonate sediments are sourced from adjacent shallow-marine carbonate factories and through the precipitation of microbial and non-microbial carbonate minerals. In addition, along the Abu Dhabi coast there is interaction with siliciclastic sediments, including eroded sediments from the aeolian Pleistocene Ghayathi Formation, transported by wind from the surrounding area. All of these individual processes interact to form the pristine Abu Dhabi sabkha coastline seen at present. Microbial mats thrive at various depths in coastal evaporite settings, but particularly the 'intrasedimentary brine tables' i.e. sabkhas. This study focuses on the Holocene development and near-surface processes of the Abu Dhabi sabkha environment and aims to determine the contribution of microbially-mediated carbonate minerals to the geological record. Initial results will be presented from surface and near-surface samples in the intertidal zone of the sabkha coastline with assessment of the role of microbes in the early lithification of sabkha sediments.

Samples were collected along a transect in a shoreward direction. Recently acquired XRD analysis of the bulk fraction identified the contribution of authigenic, allogeneic and microbially-mediated minerals to the sediment. The microbial communities associated with the mats and sediments were also characterised using culture-independent analysis of 16S rRNA genes demonstrating that the mats were dominated by cyanobacteria from the Oscillatoriales and Chrococcales. Sulfate-reducing bacteria and Haloarchaea were also detected. We aim to link the microbial communities to the minerals they produce, the subsequent lithification of the sediments and the diagenetic reactivity of the minerals. Sediment permeability and pore-water geochemistry will play a key part in this study, in analysing both the precipitation of microbial and non-microbial sediments and in examining the salinity of the water, which is a hostile environment for other marine organisms.

The next phase of this investigation will take place during fieldwork in the Abu Dhabi coastal sabkha during which samples, from both the surface and sub-surface, will be collected. Sediment and rock types will be documented throughout the intertidal and supratidal zones; phases of cementation, pore water geochemistry and microbial community composition will be analysed. By so doing, we aim to develop our understanding of the microbial communities involved and their relationship to the minerals precipitated.

MESOZOIC SEDIMENT DISPERSAL PATTERNS ON THE SOUTHWEST BARENTS SHELF

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During the Mesozoic, the Barents Shelf formed part of a large epicontinental seaway during which up to 8 km of predominantly clastic sediments were deposited. On the SW Barents Shelf thick accumulations of sand were deposited in predominantly deltaic and shallow-marine environments. The sedimentary source region for these sands was traditionally interpreted to be within the Caledonides and Fennoscandian Shield of northern Scandinavia. More recently, insights from wellbores and seismic surveys have revealed that a major deltaic system associated with the uplift of the Uralian Mountains may have spread northwest across the shelf and significantly affected sand dispersal patterns.

In this study, we present how a range of provenance techniques in combination with sedimentology and analysis of published seismic interpretations can be used to differentiate between, and map the extent of, 'Caledonide' and 'Uralide' sourced dispersal systems in time and space on the SW Barents Shelf. The provenance techniques utilised include petrographic data, heavy mineral abundance counts, mineral geochemistry and detrital zircon U-Pb geochronology. The results have implications for our understanding of source area exhumation, sediment dispersal patterns and interactions and the hydrocarbon prospectivity of the receiving basin.

CLAY MINERALOGY DISTRIBUTION IN MODERN ESTUARINE ENVIRONMENTS AS ANALOGUES FOR DEEPLY BURIED SANDSTONE RESERVOIRS

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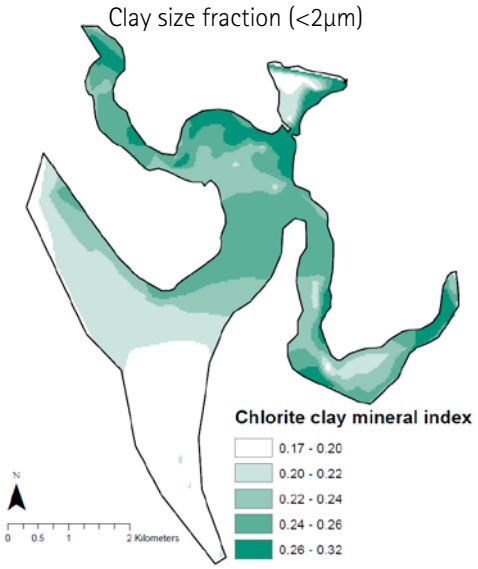
One of the major causes for porosity- and permeability-loss is the growth of authigenic quartz cements at depths >2.5 km (>80°C) in the subsurface (Worden and Morad, 2000; Paxton et al., 2002). However, grain-coating Fe-rich chlorite minerals preserve porosity by inhibiting quartz cement in deeply buried sandstone reservoirs. The dominant control on the type and occurrence of chlorite is the initial (depositional) mineralogy, as chlorite is considered to be largely isochemical during burial diagenesis (Chuhan et al., 200; Dowey et al., 2012). As spatial resolution of core is limited within tidally influenced petroleum bearing deposits, a modern high resolution analogue study of clay mineralogy is preferred.

This research focuses on the origin, abundance and distribution of clay minerals (specifically chlorite) within the Ravenglass estuary, UK. X-ray diffraction was performed on both fine clay (<2µm) and coarse-grained fraction (>2µm) of surface samples, to reveal the mineralogy and mineral proportions of the framework grains, bioclasts proportions and fine fraction (clay grade material).

Distribution maps of clay minerals show clear relationships between chlorite, illite and kaolinite abundance throughout multiple estuarine sub-environments. By incorporating clay mineralogy datasets within petroleum models, areas of enhanced and degraded reservoir quality can be predicted on a stratigraphic reservoir-scale basis.



Chlorite distribution and abundance within the Ravenglass estuary.

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RE-ADVANCING ICE SHEETS IN THE AFTERMATH OF A STURTIAN GLACIAL MINIMUM: PERSPECTIVES FROM THE SOUTHERN KINGSTON RANGE, CALIFORNIA

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The Kingston Peak Formation is a Cryogenian sedimentary succession that crops out in the Death Valley area, California. It is widely accepted to record pre-glacial conditions (KP1), followed by two glaciations of pan-global extent, the older Sturtian (KP2-3) and younger Marinoan glaciation (KP4). In the type area (the Kingston Range), detailed facies analysis of the Sturtian succession reveals a basal diamictite unit and an upper boulder conglomerate were deposited by proglacial subaqueous sediment gravity flows. An olistostrome unit punctuating the succession is interpreted to result from tectonically-induced downslope mobilisation during isostatic rebound, triggered by significant ice-meltback. Focussing on strata onlapping the olistostrome, this paper provides insight into the processes of glacial re-advance following an intra-Sturtian glacial minimum. These strata comprise at least 50 m of dropstone-free sediments that bear thin turbidites. A trend toward thicker graded beds upsection, in concert with the gradual appearance and then abundance of dropstones, testifies to the resumption of a direct ice sheet control on sedimentation. Stratigraphic organisation into thickening and coarsening upward bedsets over a multi-metre scale reveals a subaqueous gravity flow-dominated succession composed of a spectrum of high to low density turbidites, with thick graded boulder-conglomerates at intervals. The finer-grained facies assemblage is heterolithic: current ripple cross-laminated sandstones intercalated with shales that bear delicate granule to pebble-sized dropstones in abundance. Intervals of dropstone-bearing and dropstone-free strata are interpreted to record ice-stream switch on and ice-stream switch off, respectively. Thus, ice marginal processes gradually resume toward the end of the glaciation, rather than a dramatic and dominantly catastrophic emergence from a snowball Earth state.

UNRAVELLING TIMING, CONTROLS AND DISTRIBUTION OF EARLY CRETACEOUS SEDIMENTS FROM SOURCE TO SINK ALONG A COMPLEX PASSIVE MARGIN: THE AGADIR–ESSAOUIRA BASIN, MOROCCO ATLANTIC MARGIN

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This multi-disciplinary study is developing sequential gross depositional element maps across the margin by detailed logging, improved lithostratigraphy and new biostratigraphic age control for key stratigraphic sections. The aim is assess the controls (palaeotopographic, tectonic, climatic, eustatic and/or co-eval active salt movement) on the location and distribution of discrete feeder systems that sourced equivalent aged deepwater turbiditic deposits on the Moroccan passive margin. These offshore sandstone reservoirs are predicted but have yet to be located by exploration drilling. They are as yet only supported by amplitude analysis, some channel like morphologies on seismic data and indirectly confirmed by minor sands in wells and from exposed Early Cretaceous turbiditic deposits in Fuerteventura, Spain.

This margin was far from 'passive' during the Late Jurassic and Cretaceous. Recent studies (Bertotti & Gouiza, 2012) indicate Late Jurassic and Cretaceous exhumation of 2–3 km in the hinterland during this period, associated with enhanced subsidence in the developing deepwater basin.

Onshore in the Agadir–Essaouira Basin, extensive Early Cretaceous fluvio-marine deposits show lateral and temporal variability. They comprise dominantly fine-grained deposits with intervals of coarse-siliciclastic to mixed carbonate/siliciclastic deposits. Within the Agadir Area a gulf can be recognised, and preliminary palaeogeographic reconstructions have identified fluvial systems. To the north, more marginal marine to fluvial sections are recorded in the Essaouira and Doukkala Basins. Drainage pattern analysis suggests point source inputs for the main feeder systems, and sedimentary petrography suggests distinctive provenance areas, likely from the Moroccan Meseta and Massif Ancien. Initial results also highlight a period of high sediment discharge during Barremian to Aptian time, and simultaneous instabilities in the upper to middle shelf that are recognized by lateral-extensive soft sediment deformation structures along the margin. These deposits are further associated with longshore currents possibly redistributing coarser clastics along the margin.

All observations indicate that potential reservoir quality and sediment delivery varies spatially and through time. The results of this study and a linked study carried out in the Souss and Tarfaya basins to the south (A. Arantegui) will be combined with new apatite fission track analyses and (U-Th)/He data into source-to-sink conceptual and numerical models (R Charton). This large-scale project will serve as a valuable analogue for the conjugate margin of Nova Scotia and the entire Atlantic margin system.

FACIES AND MASS EXTINCTION CONTROLS ON THE ICHNOLOGY OF THE PERMIAN-TRIASSIC SUCCESSION OF THE SYDNEY BASIN, NEW SOUTH WALES, AUSTRALIA

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The Sydney Basin of New South Wales contains a complete sedimentary succession through the early Permian to Middle Triassic, an interval spanning the Earth's largest ever mass extinction event at the end-Permian. Mass extinctions have been shown to leave signals in the ichnological record at other locations worldwide; this poster seeks to analyse trends in the ichnological record of the Sydney Basin, in terms of ichnodiversity, bioturbation intensity and burrow size/depth, in order to unravel how the signatures of the two pulses of extinction at the end of the Permian are preserved in the sedimentary record. Fieldwork was carried out on both limbs of the main synclinal structure in the Sydney Basin, in the southern and northern Sydney Basin (Wollongong and Newcastle areas respectively). The wide variety of sedimentary environments recorded in the Sydney Basin formations (the Shoalhaven Group, Broughton Formation, Illawarra Coal Measures, Newcastle Coal Measures, Narrabeen Group, and Hawkesbury Sandstone), coupled with both the contemporaneous tectonic uplift of the regional source area (New England Fold Belt) and the strong end-Permian glacial signatures in eastern Australia, mean that controls on the ichnological signatures of the basin succession require careful unpicking. Despite the strong local controls, a broad ichnological trend can be observed, with a decrease in ichnodiversity, bioturbation index, burrow diameter and burrow depth observed throughout the late Capitanian formations which may be related to progressively worsening environmental stresses associated with the end-Guadalupian event. Furthermore, individual trace fossils change during the key interval with the disappearance of complex feeding structures such as *Zoophycos* and *Rosselia* in the late Capitanian potentially indicating a turnover from complex trace maker behaviour towards assemblages of more opportunistic organisms. After the Permian-Triassic boundary an unbioturbated interval persists until the early Anisian, though this is in part related to the fact that the local sedimentary record becomes dominated by the signatures of an increased influx of terrigenous sand and gravel alluvium associated with the evolution of the New England Fold Belt. Ultimately, although the largest control on ichnology remains sedimentary facies, close comparison between similar facies of different ages permits the unravelling of the effects of global mass extinction on bioturbation type and intensity.

POSTER

FLEXURE OF MICROBIAL MATS AROUND HOLDFASTS OF EPIBENTHIC FRONDS: EDIACARAN ECOLOGY IN THE CAMBRIAN OF AVALONIA (IRELAND)

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The Cambrian Explosion was accompanied by a fundamental shift in the nature of marine substrates. In shallow marine environments, characteristic Neoproterozoic microbial matgrounds gave way to typical Phanerozoic mixground substrates, concordant with the evolution of widespread bioturbation. In deep marine environments, the 'agronomic revolution' appears to have been delayed, as suggested by strata such as the microbially-bound middle Cambrian contourites of the Booley Bay Formation, southeastern Ireland.

Two sets of non-mineralised discoidal structures occur in this unit; millimetre-scale scratch circles, and centimetre-scale partial discs preferentially orientated in the palaeocurrent direction. We investigated the hypothesis that the larger discs were holdfasts of frond-like organisms, preferentially orientated by current pressure on their upper parts, numerically modelling the flexure of a microbial mat around such a holdfast. While highly speculative, the models predict profiles consistent with field observations. We conclude that one admissible interpretation is that the Booley Bay Formation preserves evidence of large stalked frond-like organisms, living in a contour-current environment, anchored to the microbially-bound substrate by discoidal holdfasts. The ecological similarity to deep marine Ediacaran environments such as Mistaken Point suggests that not just Ediacaran matgrounds, but Ediacaran community palaeoecology, survived in deep marine settings until at least the Middle Cambrian.

FLOC DEPOSITIONAL CHARACTERISTICS WITHIN THE SACRAMENTO–SAN JOAQUIN RIVER DELTA, NORTHERN CALIFORNIA, USA

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The Sacramento–San Joaquin River Delta (Delta) is where the rivers of the Central Valley of California merge to become the San Francisco Estuary. The rivers deliver sediment from the Central Valley watershed (approximately 96000 km^2) to the Delta. One of the major drivers of sediment transport and turbidity in the Delta is the supply of fine sediment from the watersheds, particularly the Sacramento River. Deposited sediment helps create and sustain the landscape in the Delta, including desirable habitats such as tidal marsh, shoals, and floodplains. Massive sediment supply during the period of hydraulic mining in the late 1800s caused deposition in Sacramento Valley rivers, the Delta, and San Francisco Bay. Today, a key management question is whether the existing Delta landscape can be sustained as sea level rises. The erosion and deposition processes are strongly dependent on the local sediment properties, particularly when cohesion and flocculation are important, as they are in the Delta.

The US Geological Survey (USGS) collects data that supports the development, calibration, and validation of numerical models of sediment transport and turbidity in the Delta. Research questions include: How much flocculation of sediment particles occurs in the Delta, and what are the settling velocities of the flocs? How do floc settling properties vary spatially and temporally? To address these questions, a Co-operative Agreement was established between the USGS and HR Wallingford (UK).

This paper presents preliminary findings from measurements of floc depositional properties throughout the Delta during 2010–2011. Individual floc properties and dynamics were measured with the LabSFLOC-1 instrument; a high resolution video-based device. Thirty-one floc population samples were obtained from 21 sites within the Delta. Flocculated particles were observed throughout the Delta including in freshwater. Suspended-sediment concentrations in the near-bed region ranged from 4-52 mg.l^{-1}. A combined total of more than 2,200 individual flocs were measured. Floc sizes (D) ranged from 27μm microflocs (D < 160 mm) to macroflocs (D > 160 mm) of 500 μm. Macrofloc settling velocities (Ws) were 0.7–5 mm/s (mean 2.25 mm/s) and macroflocs comprised 1–56% (mean 24%) of the suspended mass. Microfloc Ws was smaller (0.3–4.0 mm/s, mean 1.63 mm/s), but comprised more (44–99%, mean 76%) of the suspended mass and thus, mass settling fluxes (spanning 0.1–80 mg.m^{-2}s^{-1}) were dominated by microflocs, albeit Delta depositional fluxes were generally an order of magnitude less than within San Francisco Bay.

DIAGENETIC EVOLUTION OF THE EAGLE FORD FORMATION, SW TEXAS: IMPACTS UPON RESERVOIR QUALITY AND ROCK PROPERTIES

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The Eagle Ford Fm in southwest Texas is a self-sourced oil and gas reservoir currently stimulated through hydraulic fracturing to produce economic quantities of hydrocarbons. Both early and burial diagenesis has had a major impact upon the rocks and their resulting reservoir quality. In this presentation we infer mineral reactions and precipitation that took place during diagenesis through a combination of mineralogical and petrographic analysis using XRD, optical and electron microscopy and stable isotope geochemistry. We highlight how such an understanding can improve prediction of rock properties and reservoir quality.

Along with compaction and de-watering, we infer that bacterial sulphate reduction had a major impact during early diagenesis as it resulted in significant calcite cement precipitation. Calcite cements infill bioclasts and foraminifera chambers, thereby significantly reducing intra-granular porosity. Fine grained calcite cements the matrix and coccolith fragments that resulted in reduction in inter-granular porosity and its interlocking texture will likely lead to an increase in rock brittleness. Optical microscopy and cathodoluminescence (CL) highlight the extensive and invasive calcite precipitation that occurs within concretional features in the Eagle Ford Fm. Zonation within the calcite cements suggests evolution in pore water chemistry and this is interpreted to be caused by changes in microbial organic matter oxidation.

Foraminifera chambers are commonly infilled with kaolinite, as well as or instead of calcite. There is no clear petrographic evidence to suggest which came first, but based on the fact the foraminifera are not compacted we infer early diagenetic origin. Unlike the calcite infills, kaolinite infills preserve significant inter-crystalline porosity. Authigenic kaolinite is also present as multiple crystal grains within the matrix, and replacing 30–60 µm detrital grains- which we infer to be feldspars.

During late burial, authigenic quartz cement commonly precipitated around detrital quartz grains and calcite cements, further reducing inter-particle and inter-crystalline porosity. This source of this silica may have been clay mineral reactions or biogenic silica dissolution. Chlorite is present in the form of 5–15 µm wispy flakes in the most thermally mature samples. The precipitation of clay minerals during deeper burial leads likely to a decrease in rock brittleness and a further reduction in micro-porosity in the matrix.

TECTONO-STRATIGRAPHIC FRAMEWORK AND CONTROLS ON SEDIMENTATION OF THE LOWER OLD RED SANDSTONE OF THE MIDLAND VALLEY BASIN, SCOTLAND

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The 9 km thick Lower Old Red Sandstone (LORS) succession of the northern part of Midland Valley Basin ranges from Wenlock to Emsian in age and largely comprises conglomerates in the east, passing westwards into sandstones and siltstones. Predominantly of fluvial and alluvial origin, these facies accumulated across the Strathmore Basin, with associated deposition occurring northwards across adjacent areas of the Scottish Highlands. Despite decades of investigation, and several advances in provenance studies in recent years there are still some significant uncertainties in understanding the tectonic setting of the basin and the origin of the source terrain. Palaeocurrent data reveal conflicting evidence for a source to the north, east and west, grain size distribution indicates a proximal source potentially to the east and provenance data suggest a northerly and unknown easterly source. In addition, the relationship between the timing of tectonic and related depositional events in the adjacent Grampian Terrane to the north and the southern margin of the Midland Valley Basin associated with the closure of Iapetus and collision of Baltica are still poorly constrained. The aim of this work is to place the stratigraphy in the northern part of the Midland Valley Basin into a tectono-stratigraphic framework and to establish what the key controls are on sedimentation during deposition of the LORS in the Midland Valley Basin.

QUATERNARY UNCONFORMITIES IN THE MAKING: EXAMPLES FROM THE UK CONTINENTAL SHELF

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The UK continental shelf preserves a record of the erosional and depositional processes operating in the Quaternary over multiple glacial-interglacial cycles. Quaternary sediments in excess of 800 m thick within the North Sea and along the Atlantic margin document changing sedimentary and climate history over the last 2.7 Ma. However, over 20% of the UK continental shelf is characterised by bedrock exposed at seabed or a thin veneer of sediment (<5 m). In these areas, the record of sedimentary processes operating during the Quaternary is preserved as a composite erosional surface. Extracting process information and environmental history from a single bounding surface can be problematic as its formation is likely the product of several processes acting over multiple episodes, and only the morphological imprint is preserved. Despite these difficulties, an exclusively erosional record should not be ignored in stratigraphic studies. Here we demonstrate that information about environmental processes and controls can be extracted from erosion surfaces through the analysis of high resolution bathymetry and shallow sub-surface seismic data. We show that these erosion surfaces, in the absence of thick sedimentary successions, can provide information on the sedimentary response to changing climate and sea level at both local and regional scales, and help distinguish between 'background' and 'event' scale processes. Examples are given from the UK continental shelf of the erosional record left behind by glacial, fluvial and coastal processes operating at various times during the late Quaternary. Where chronostratigraphic controls are available, the timescales of erosional processes can be constrained revealing a bias towards the preservation of sedimentary products from the most recent glacial interglacial cycle. It is our aim to demonstrate that where depositional sequences are sparse, valuable stratigraphic information can still be obtained from the part of the record typically deemed as 'missing'.

DETERMINING DUNE PROVENANCE OF THE RUB'AL KHALI DESERT, UAE; THROUGH HEAVY MINERAL ANALYSIS USING ICP-AES AND OPTICAL METHODS

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Correlation and provenance of geological materials can be achieved through several techniques; a common and popular approach is by the analysis of heavy minerals (density > 2.85 g/cm^3). Traditionally this would involve the counting and identification of different mineral species using a petrological microscope. This can be time consuming and costly; geochemical analysis of heavy minerals by Inductively Coupled plasma-Atomic Emission Spectroscopy (ICP-AES) offers a faster and cheaper alternative. The ICP-AES approach establishes the relative or absolute abundance of key elements linked with specific heavy minerals; apatite, chrome spinel, monazite, titanium oxides (rutile, titanite, anatase etc) and zircon. Inherent difficulties with this method include the dissolution of highly resistant minerals and potential matrix interferences, both physico-chemical and spectral. Whilst this technique lacks the sensitivity of a traditional optical counting using a petrological microscope, it does provide unique mineral-chemical signatures, broad trends in major cation groups and the quantification of rare earth elements (REE).

To test the technique, we used both traditional optical methods and ICP-AES to determine the provenance of the Rub'al Khali desert sands, United Arab Emirates (UAE). 194 samples were collected from modern dune sands, palaeodunes and Miocene sandstones across the UAE. Heavy minerals were concentrated using a typical 'sink float' heavy media separation. Analysis was focussed on the 63–125 μm sand fraction. Samples for geochemistry were flash fused using a lithium-metaborate flux and analysed using a Perkin Elmer 7300 DV ICP-AES.

The results from both methods demonstrate that several distinct sources contribute sediment to the modern day dune sands of the Rub'al Khali desert, through mixing and reworking of existing Miocene and Quaternary sandstones. The dominant source of sand to the Rub'al Khali is the deflation of Miocene sandstones exposed along the Gulf coast and Quaternary palaeodune sediments derived from them. These are predominantly sourced from the Arabian shield, with a minor contribution from the Hajar Mountains to the east of the UAE. A smaller sand component is sourced from the deflation of deposits derived from Persian Gulf sediments (PGS), ultimately sourced from the Euphrates-Tigris-Karun river system. The Hajar Mountains in the east of the UAE supply a minor amount of sediment to the desert sands though deflation and reworking of both Miocene and Quaternary alluvial fans.

These results show that ICP-AES is a complimentary technique to the traditional optical microscopy employed in provenance studies based.

POSTER

USING WELL-PRESERVED MISSISSIPPIAN BRACHIOPOD CALCITE FOR PALAEOENVIROMENTAL RECONSTRUCTIONS OF EQUATORIAL BRITAIN

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Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) of biogenic calcite are commonly used as a proxy for assessing palaeoenvironment and palaeoclimate (seawater temperature, salinity etc). To validate isotope studies the preservation of the primary calcite needs to be assessed to ensure that data generated reflect original seawater chemistry, rather than secondary diagenetic fluids. Preservation analysis encompasses a range of techniques, including scanning electron microscopy (SEM), cathodoluminescence microscopy (CL), and analysis of trace element abundance (Mn, Mg, Fe, Sr, etc). Although it is best practice to use material which has passed most screening tests there are no fixed criteria for classifying biogenic calcite as pristine using these techniques. This study has developed a systematic procedure for the analysis of Mississippian biogenic calcite from *gigantoproductid* brachiopods collected from the Peak District National Park (Central England). From this, a set of criteria for the classification of well-preserved biogenic calcite were established and a method of high resolution isotope analysis is outlined. This analysis involves sampling individual growth bands (typically millimetre scale) to allow sclerochronology studies to be conducted. Where pristine calcite is identified we calculate seasonal sea surface temperatures through the organism's life-time. Supporting, detailed sedimentological investigations were conducted to help constrain palaeogeography and palaeoenviroments and establish the preferred environments of *Gigantoproductus* species. This integrated approach will further our understanding of why *gigantoproductids* dominate specific units. This study provides a practical methodology, linking quantitative and qualitative data that will allow a detailed palaeoenviromental reconstruction of this region of Mississippian palaeoequatorial Britain. Ultimately these studies contribute proxy data to improve estimates of the parameters required for data-climate model comparisons.

USING HIGH-RESOLUTION DATASETS TO IMPROVE UNDERSTANDING OF SUBMARINE CHANNEL EVOLUTION

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Submarine channels are important features to understand in terms of continental margin evolution, sediment and nutrient transport from continents to oceans, sea-floor hazard, and hydrocarbon exploration and production. Studying active submarine channels in nature is challenging because of their large-scale, and the limited successful monitoring of in-channel sediment transport processes. For these reasons various methods, such as geophysical data analyses, laboratory experiments, numerical models, and the comparison to fluvial systems are used to study submarine channels. It is known from these studies that evolutionary processes from submarine channels vary compared to fluvial systems. However, the detailed physiography of submarine channels using high resolution seabed data has not been widely investigated.

The evolution of sinuous, levee-confined, submarine channels is through a combination of lateral migration and vertical aggradation. The morphological parameters vary from bend to bend along the length of a channel, but in laboratory experiments and numerical models morphological parameters, such as channel bend height and width, radius of curvature, sinuosity, gradient and wavelength are fixed, and therefore deviate from nature. This is because detailed measurements of these parameters rarely exist because of the limit of high resolution bathymetry and seismic data. The increase in resolution and availability of high-resolution multibeam data, and 3D seismic data, now permit detailed analysis of morphological features within bends for the first time. In the future, the analysis of morphological parameters can be integrated into refined laboratory experiments and numerical models in order to improve understanding of the flow-deposit interactions around channel bends.

POSTER

WHY WERE THE EARLY CARBONIFEROUS FLOODPLAINS OF SOUTHERN SCOTLAND KEY SITES FOR PRESERVATION OF THE EARLIEST FOUR LIMBED VERTEBRATES?

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The early Carboniferous represents a key stage in the terrestrialisation of vertebrate life and has been the focus of recent tetrapod fossil discoveries. This MGeol research project is part of the TW:eed project (Tetrapod World: early evolution and diversification) which has been identifying and investigating key fossil sites. A detailed sedimentary log of just under 12 m of the 500 m thick Ballagan Formation exposed at Burnmouth in the Scottish Borders has been completed. The upper part of the logged sequence contains one of the rare tetrapod-bearing beds. During this research over 40 samples have been collected and will be examined to determine the types, abundance and diversity of the macro and microfauna as well as the flora to aid the environmental interpretation of this key section. Analysis of the samples is already underway and some initial observations have been made.

The section consists of fine grained rocks with a few more sandy intervals and is thought to represent an alluvial environment. It contains floodplain environments, river channels and extensive shallow floodplain lakes. Together with the sedimentology, microfossils extracted from the samples will be used to piece together the local ecosystem and contribute to our understanding why tetrapods were present in these basins of the Scottish Borders.

SEQUENCE BOUNDARY RECOGNITION IN A TECTONICALLY-CONTROLLED SHELF-MARGIN DELTA (LOWER EOCENE, SOUTH-CENTRAL PYRENEES, SPAIN)

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The landward expression of sequence boundaries that basinward separate delta front lobes to deeper turbidite systems, through the formation of submarine canyons, might be not easy to define, since they sometimes become least deepening and paraconformable when approaching the transfer areas of a depositional system.

The lower Eocene Castissent depositional sequences (Upper Ypresian-Lower Lutetian, South-Central Pyrenees, Spain) consist, in the Ainsa basin, in mouth-bars and delta front lobes in transition to slope turbidites, deposited in a flood-dominated river-delta system. Results of a recent field work suggest that deposition was strongly controlled by the interaction between hyperpycnal flows, shoreline processes and syn-sedimentary tectonics.

The bounding surface between the Castissent depositional sequences (CS1, CS2), separating shallow to deep-water settings, seems to be a combination of growth and incision, but it does not show erosional features clear enough to be easily recognized at outcrop scale. The surface is difficult to point out to the east due to its paraconformable and muddy-dominated nature, although the continental termination of the overlying delta front deposits is evident at regional scale and in the correlation panel, just a few kilometers downstream, to the west, where it becomes an onlap surface overlain by a submarine canyon fill, made of fine-grained turbidites. This surface belongs to the first stages of the formation of one of the most sandy turbidite systems of the Hecho Group: the Arro-Broto system.

Once demonstrated the existence of this boundary through detailed mapping and stratigraphic analysis, field evidences were integrated with the paleomagnetic study of a series of samples collected along several logged sections. The results, being compared with some previous cronostratigraphic studies, suggest that the contact separating the two Castissent depositional sequences is a clear by-pass surface, as it becomes demonstrated by the sedimentary hiatus found in the equivalent paraconformable contact westward of the Foradada fault, and thus can be considered a major sequence boundary, as it has been considered by some authors for a long time, but never demonstrated as in this work.

Results of this work therefore highlight the importance of integrating outcrop-based studies with chronostratigraphic techniques to expand our knowledge on the recognition of sequence boundaries in relatively conformable shallow-marine to continental successions in active tectonic settings, giving a powerful tool in order to predict the stratigraphic position and existence of sandy turbidite systems by studying carefully the character of sequence boundaries in their laterally associated proximal feeding systems.

THE EFFECT OF INTERBEDDING ON SHALE RESERVOIRS PROPERTIES

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North Sea oil has its source in shales, and following migration it accumulates in reservoirs of sandstone or carbonate. The shales from which the oils were sourced typically contain unexpelled petroleum. As a consequence such shales can form the targets in the exploration for what is termed 'unconventional oil'. Here we examine a part of the Kimmeridge Clay source rock of the South Viking Graben within which 'hot' shale and fine grained sandstone and siltstone intervals are intimately interbedded. The present study is based upon new organic geochemical and mineralogical analyses of core samples obtained from four wells drilled in UK Quadrant 16 of the South Viking Graben. The obtained data are used to determine oil saturation in interbedded sand-shale at peak oil maturity. The relationship between the estimated area percentages of sand and mudstone content on the one hand, and the free oil determined from Rock-Eval S1 yields on the other, is used to determine the amount of drainage of oil from source mudstone to reservoir sand at the decimeter scale. Higher values of free hydrocarbon (as evidenced by the S1 value in mudstone) suggest more oil is being retained in the mudstone, while higher S1 values in the interbedded sands suggest the oil is being drained to saturate the larger pore spaces. Both open and closed system expulsion models are proposed to explain this composite pore storage system.

DEPOSITIONAL MODELS TO ACCOUNT FOR STRATIGRAPHIC COMPLEXITY IN FLUVIAL POINT BARS: INTEGRATION OF MODERN DATA FROM GIS STUDIES WITH ANCIENT OUTCROP DATA

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There is a need to more closely integrate modern morphological data into sedimentological studies to more effectively interpret the significance of preserved fluvial point-bar successions. This work presents quantitative sedimentological models to account for the range of internal stratigraphic heterogeneities present within fluvial point bars and their preserved deposits, and to account for their origin by gaining an improved understanding of the mechanics of point-bar deposition and the agents that influence this process. This has been achieved through development of a quantitative database of point-bar shapes and their internal geomorphological and sedimentological form. Evolutionary behaviour has been reconstructed for point-bar elements in a range of environmental settings. A specific objective of this work is to identify common trends that allow the relative significance of allogeneic and autogenic controls to be discerned.

Quantitative measurements comprising >3600 data points have been collated to describe 120 point bars from 6 actively meandering fluvial systems using Google Earth Pro software: the Amazon (Peru), Qu'Appelle (Canada), Yukon (Alaska), Peace (Canada), Ob (Russia) and Omo (Ethiopia). For each studied system, meander-belt morphological maps have been drawn to demonstrate patterns of meander-loop and point-bar interaction and styles of truncation, overlap and overprinting. Individual meanders and their scroll bars have been examined to identify common patterns of evolutionary growth for individual elements, many of which record complex styles of interaction with neighbouring elements.

The principal findings are as follows: (i) direction of meander migration is controlled by interaction with older meander-belt deposits and especially by the presence of mud plugs associated with abandoned channel segments; (ii) the size and abundance of floodplain lakes varies between systems in different climatic settings and accommodation states in a manner that influences point-bar development by inhibiting bar growth; (iii) fluvial trunk-channel form and its relation to point-bar development is strongly controlled by density, abundance and type of vegetation in the Riparian zone; (iv) evolving meander loops tend to develop longer downstream sides such they become increasingly asymmetric in plan form as they grow.

Results from this work have applied significance: comparison of modern forms to analogous deposits preserved in the ancient record demonstrates that the style of point-bar evolution fundamentally controls both the site of accumulation of sand-prone mesoforms and the style and type of heterolithic strata present within individual architectural elements. This work serves as the basis for predicting internal heterogeneity in point-bar deposits that act as major hydrocarbon reservoirs.

SEDIMENTOLOGY OF THE LATE CRETACEOUS IN THE WESTERN AUDE VALLEY, SOUTHERN FRANCE

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The closure of the Tethys seaway between Iberian and European plates and early stage development of the Pyrenees produced continental sedimentation in the Western Aude Valley south of Carcassonne. Although timing is difficult in continental deposits, fluvial sedimentation occurred in much of Campanian time and changed gradually to lacustrine/palustrine by Maastrichtian time. The aim of this poster is to assess sedimentary changes laterally and over time. Sedimentary logs over an area of 16 x 30 km have been measured to correlate main bodies of sandstone and initiation of carbonate sedimentation.

Siliciclastic deposits can be grouped into 4 facies: trough cross-bedded conglomerate, massive conglomerate, trough cross-bedded sandstone and horizontally bedded sandstone. They suggest that they were formed in a high energy, low sinuosity braided river system with significant topography and coarse sediment supply. Breaks in coarse sedimentation, characterized by paleosols and fluvial stromatolites, suggest episodic high-energy sedimentation and are consistent with semi-arid climate hypothesized for the Campanian.

Above coarse Campanian sediments are Maastrichtian-aged thick marls and several-metre sandstone beds. Marl deposits indicate generally lower-energy conditions and contain dinosaur bones whereas sandy beds can be rich in dinosaur egg fragments and *Microcodium* associated with vegetation. Fine-grained carbonates and marls continue to the end of the Cretaceous. The presence of charophyte stems and gyrogonites, lack of desiccation cracks and medium gray colour with some preserved organic matter suggest lacustrine carbonates. Above and often interbedded with gray carbonate is mottled pink, yellow and cream limestone with roots, nodules and desiccation cracks interpreted to be marginal lacustrine to palustrine. The interbedded nature of these deposits suggests fluctuating water level controlling lacustrine/palustrine cycles and episodic high-energy clastic input. Relatively thin gray carbonate may mean perennial lakes were shorter-lived whereas palustrine conditions persisted over a longer time.

The Tethys seaway existed in the area until Santonian time, but was closed by the Campanian due to the Iberia-Europe collision creating a continental basin. Early stage of Pyrenean uplift and moderate topographic relief promoted fluvial deposition in the basin. Palaeocurrents and clast types will be assessed to differentiate among potential source mountains to the north (Montagne Noire), east (Massif de Mouthoumet) and/or south (Pyrenees). Over time, sediment transport energy decreased suggesting lower topography and, possibly, sufficient uplift to the south to confine lacustrine deposits. Infill logging next field season will attempt to define Campanian and Maastrichtian sediment sources, lake boundaries, dinosaur nesting areas and the transition to early Paleocene deposits.

PALAEOPROTEROZOIC GLACIALS IN SOUTH AFRICA: AGE CONSTRAINTS AND SEDIMENTARY CONTEXT

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The irreversible change from an anoxic atmosphere-ocean system to detectable levels of free oxygen in surface environments, the Great Oxygenation Event (GOE), occurred during the Archaean-Palaeoproterozoic transition (~2.5–2.3 Ga). It is linked with biological evolution, element cycling, and with possible snowball glacial events. However, correlations of Palaeoproterozoic glacials, their global vs. local nature, and their genetic relationship to oxygenation are debated, due to a lack of age constraints and uncertain stratigraphic context. The Transvaal Supergroup (South Africa, ~2.65–2.10 Ma) contains glacial diamictites in the Duitschland, Timeball Hill and Boshoek formations in the Transvaal sub-basin, and the Makganyene Formation in the Griqualand West sub-basin (Figure1 *overleaf*).

The Makganyene is commonly regarded as a snowball event at around 2.2 Ga, correlating with the Gowganda glacial or post-Gowganda in North America. Recent suggestions place the Makganyene at ~2.4 Ga, correlating it to a prominent unconformity in the Duitschland and with the Bruce glacial in North America. Similar detrital zircon signatures, the disappearance of mass- independent sulphur isotope fractionation, and supposed Makganyene 'diamictite' lenses within the underlying Koegas form the basis for this scenario. Each scenario has different implications for the genetic relationship between glaciation and oxygenation.

Maximum depositional ages from new detrital zircon analyses confirm existing age constraints, but still allow both correlations. Careful mapping has confirmed a distinct unconformity between Koegas and Makganyene strata on the basis of striated clasts, which is also supported by 2.2 Ga detrital zircons in the Makganyene. The Koegas 'diamictite' lenses are re-interpreted as intra-Koegas conglomerate lenses unrelated to Makganyene deposition.

New sections of the Duitschland Formation show the prominent intra-Duitschland unconformity. Ramp carbonates with gravity-driven sedimentation are interbedded with conglomerate beds reworking banded iron formation (BIF). The Duitschland Formation represents a tectonic sliver in stratigraphically older BIF, and both units are folded. This could reflect a ~2.4 Ga orogenic event, consistent with previous interpretations of the Duitschland Formation as a foreland basin deposit. In this context, the conglomerates may represent short-term sea level fluctuations and fluvial input, driven by tectonic subsidence, and/or development of mountain glaciers.

These new observations support a ~2.2 Ga, and thus post-GOE age for the Makganyene glacial. Both localities indicate that, at least in South Africa, local events may have played an important role in the stratigraphic development. Improving absolute age dates remains a priority for future research, and the stratigraphic and sedimentological context needs to be well understood before attempting global correlations.

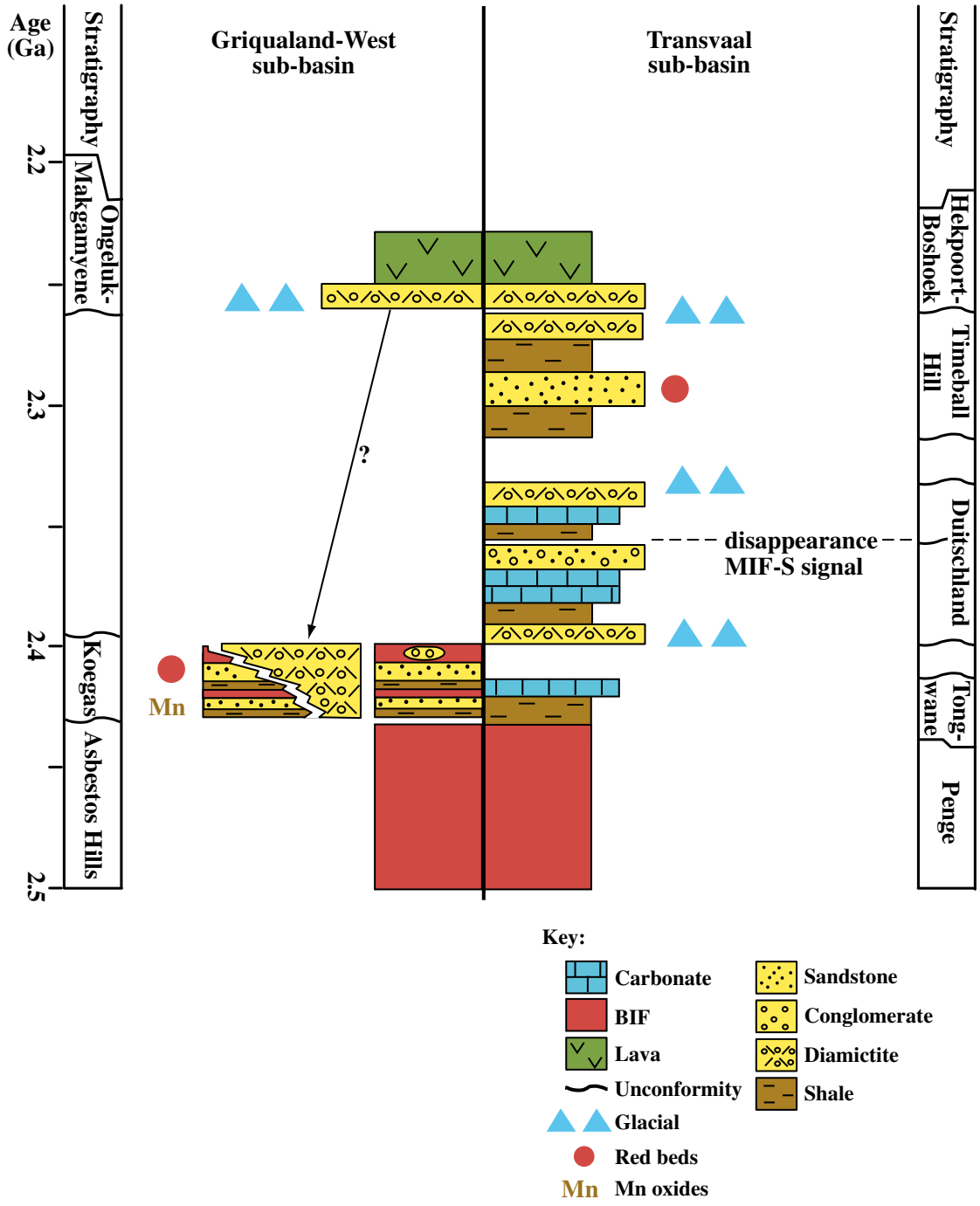

Figure 1 Overview of Transvaal Supergroup in the interval 2.5–2.2 Ga, with indications of major redox-relevant tracers. The arrow highlights the differing interpretations of the Makganyene glacial.

THE WEST BURMA BLOCK – ORIGIN OF CONTINENTAL CRUST OF WESTERN MYANMAR: INSIGHTS FROM PROVENANCE OF TRIASSIC TURBIDITIC SANDSTONES IN THE CHIN HILLS

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SE Asia is composed of continental fragments derived from Gondwana supercontinent by rifting events during the Palaeozoic and Mesozoic. It is well known that one fragment, the West Burma Block, now lies beneath the western Myanmar, but there are disputes about its initial position within the supercontinent and about its arrival in SE Asia. This study presents the first petrological, XRD diffraction, heavy mineral and detrital zircon U-Pb age data from six samples of the Triassic Pane Chaung Formation (PCF), which contains detritus from the areas surrounding West Burma Block and thus helps resolve arguments about its location until the Triassic.

PCF feldspathic litharenites contain quartz, plagioclase and lithics, which include phyllite, mudstone, chert, and intermediate to basic volcanic and granitic fragments. Heavy mineral assemblages are composed of zircon, apatite, tourmaline, rutile, chlorite, and epidote and minor anatase, titanite, monazite, hematite, Cr spinel, amphibole, and pyroxene. Garnet is present in five out of six analysed samples. Detrital zircon U-Pb ages in the analysed samples range in age from 3445±52 Ma to 195±4 Ma. They contain Archean, abundant Meso-Neoproterozoic, abundant Neoproterozoic-Cambrian, small Carboniferous, and abundant Permian-Triassic populations. Paleo-Mesoproterozoic and Ordovician-Devonian zircons are present, but do not form clear-cut populations. Abundant quartz, presence of sedimentary lithics, abundant zircon, tourmaline and rutile, all three of which show a wide range of shapes and common surface frosting, and a wide spread of zircon U-Pb ages in PCF all suggest reworking from multiple sources. Presence of foliated and platy metamorphic lithics, chlorite, fresh garnet and epidote, suggest contribution from local metamorphic basement of the West Burma Block. Fresh plagioclase feldspar, basic to intermediate volcanic lithics and Permian-Triassic zircons, show a first-cycle input from contemporaneous volcanism.

Detrital zircon U-Pb ages suggest that during the Proterozoic, West Burma was situated close to Sibumasu, Western Australia and the Carnarvon Basin in the Gondwana supercontinent, but away from Indochina. West Burma contains Archean zircon population derived from Western Australian cratons, which become less abundant moving outboard in Gondwana, towards Sibumasu. Abundant Permian-Triassic zircons are different to those in the Carnarvon Basin and are most probably derived from the SE Asian tin belt granitoids. These new data show that West Burma was part of SE Asia before the Mesozoic, although it is still unclear whether it was part of Sibumasu or Indochina.

POSTER

AN EARLY CARBONIFEROUS MARINE ENVIRONMENT IN THE NORTHUMBERLAND BASIN PRESERVES A UNIQUE VERTEBRATE ASSEMBLAGE

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In early Carboniferous successions exposed across the Borders region of Scotland and England, new tetrapod (first four-limbed vertebrates) and fish fossils are revolutionising our understanding of the recovery of life following the end Devonian extinction event. Among recent discoveries is a diverse vertebrate fauna from an inland exposure of the Ballagan Formation (Whitrope Burn in the Northumberland Basin). Remains include teeth from small elasmobranch sharks, tooth plates belonging to large bradyodont sharks, scales and teeth from actinopterygians, and lungfish material. This is a unique assemblage, no similar associations have been found in the earliest Carboniferous.

Most of the fossils have been recovered from a 20 cm-thick fining-upward carbonate-rich bed. The basal horizons of this bed are coarse grained and poorly sorted, with clasts of 0.5–1 cm in size. Clasts comprise lithic pieces, plant straps, fossil fragments and shelly material (ostracods and serpulids). Clasts decrease in size and density towards the top of the bed although shell fragments are abundant throughout. This bed is capped by a micaceous, intensely bioturbated limestone which also contains finer, poorly-sorted fossil and shelly material. Lungfish material has been recovered from this bed. Thin limestones (5-7cm thick) underlie the richly fossiliferous bed, each featuring repeated small fining-upward cycles, soft sediment deformation and fine micritic tops. These beds contain only small quantities of plant material, small lithic clasts (1-3 mm), some shelly material and occasional fossil fragments. There is no evidence for soil development or sub-aerial exposure. In adjacent exposures, crinoids, shrimps and further shark teeth have been recovered.

The sedimentological observations and fossil associations contrast with the more typical Ballagan Formation described from outcrops and cores across the Northumberland and neighbouring Tweed Basins. The grey siltstone- and cementstone-dominated formation is interpreted as deposition on extensive low-relief vegetated coastal-alluvial plains surrounding an upland area. In contrast, the sedimentology and the diverse bioturbation in some beds in the Whitrope Burn exposure indicate deposition from carbonate-bearing turbidity currents in a marine to marginal marine depositional environment. The depositional processes acting in this part of the basin have concentrated these diverse vertebrate remains. The animals would have been living elsewhere in the basin, although the geographical location is still to be determined. The depositional setting and associated sedimentary processes have preserved a diverse faunal assemblage that sheds new light on the existence and diversity of the earliest Carboniferous vertebrates.

IS THERE SEDIMENTOLOGICAL EVIDENCE FOR DINOSAURS AS GEOMORPHIC AGENTS IN MESOZOIC RIVERS? A CRITICAL ANALYSIS

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The sedimentological impact of present-day large animals such as elephants and hippopotami is well-documented. Amongst other examples, hippos behave as avulsion enablers in certain African distributive fluvial systems, and herding animals have trampling effects including sediment compaction and reorganisation of the depositional surface. It is clear that dinosaurs, as much larger creatures, would have also affected the geomorphology of their environments. As the geomorphic effects of other organisms, such as invertebrates and land plants, can be seen to have left indirect signatures in the sedimentary rock record, this research seeks to address whether the geomorphic impacts of dinosaurs may have also left recognisable sedimentary characteristics. This poster describes and critically assesses the sedimentary record of the proposed impact of dinosaurs on Mesozoic fluvial systems on a range of scales; (1) on a small scale as individual footprints and 'dinosaur induced sedimentary structures'; (2) on a meso-scale, looking for evidence of previously suggested dinosaur-induced avulsion (so-called 'dinovulsion', see Jones & Gustason, 2006) in alluvial architecture; and (3) on a global scale, through correlation of dinosaur-bearing alluvial successions and their sedimentary characteristics. Taking the Wealden Supergroup of the Wessex (Isle of Wight) and Wealden (Sussex) Basins as a case study, in depth fieldwork has been done to ascertain the likelihood of 'dinovulsion' occurring, and analyse the individual sedimentary perturbations that dinosaurs caused on a micro-scale. A semi-quantitative analysis of previously published studies of Cretaceous fluvial systems that bear dinosaur ichnoassemblages has been used to examine global patterns and identify correlations between these systems. From this, it can be seen that there is evidence for dinosaurs affecting sediment properties on a small scale, and a correlation between the styles of dinosaur bearing fluvial systems on a global scale. However, testing of the previously proposed idea of 'dinovulsion' on a meso-scale suggests that there is no hard evidence for this in the rock record; whilst there are potential avulsion indicators in many dinosaur bearing fluvial lithologies, the limitations of the sedimentary record mean it is impossible to identify a causative link between dinosaur activity and avulsion with certainty.

POSTER

SPATIAL AND TEMPORAL VARIABILITY IN THE SHALLOW-MARINE FAVIGNANA CALCARENITE (SICILY, ITALY)

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Favignana (18 km^2) is the principal island of the Egadi Archipelago located offshore from western Sicily in the central western Mediterranean. The geology of the island's eastern part consists of Lower Pleistocene, coarse grained calcarenites, composed mostly of a Heterozoan assemblage (e.g. red algae, bivalves, echinoids, bryozoans, benthic foraminifera) which is interpreted as the result of production and redeposition of skeletal debris in a coastal to shallow-marine system.

In Early Pleistocene times, the paleo-islands of Favignana and Levanzo were located on the outer shelf of the Sicilian western offshore, separated from Sicily by a 10 to 15 km-wide, N-S striking sea strait, in which deposition of the calcarenites took place. Based on palaeoflow analyses, the carbonate factory which produced the skeletal sand and gravel is inferred to have been located in a sub-marine sill between the two islands.

Upper shoreface deposits onlap the eastern side of the Favignana mountain ridge. During persistent (storm) winds, material was shed into deeper settings below wave base, giving rise to the formation of a ramp-slope descending ca. 50 metres into shelfal depths. Facies are dominated by decimetre to metre-scale dune cross-stratification dipping towards a prevailing southeastern direction, corresponding to ramp-slope progradation. On the flat offshore of the shelf, wind-driven currents through the strait generated cross-strata dipping either north or southward. Interaction with the ramp-slope toesets is apparent from the abrupt termination of dune beds against the prograding ramp. Cross-stratified deposits show intense *Thallasinoides* bioturbation.

The succession is interrupted by up to 10 metres-thick beds, characterised by supercritical flow and dewatering structures, erosive bases, the absence of *Thallasinoides* bioturbation, and the presence of rare *Ophiomorpha* escape burrows. Such beds were interpreted as catastrophic event beds, possibly linked to infrequent megastorms or tsunamis generated by active tectonic structures. The alternation of dune and event beds imposes a strong bimodal character on the deposits.

Here, we present some descriptions of key outcrops illustrating the spatial and temporal variability of this dynamic clastic carbonate system. Compared to siliciclastic environments, clastic carbonates achieved relatively little attention, despite a significant presence throughout the Mediterranean basin. We emphasise the catastrophic nature of the studied shallow-marine calcarenite, ca. 50% of which was deposited during short-lived, high-energy events.

FACIES AND PALAEOCURRENT ANALYSIS OF A BRAIDED FLUVIAL SYSTEM: A CARBONIFEROUS CASE STUDY, CENTRAL PENNINE PROVINCE, NORTHERN ENGLAND

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The Bashkirian Lower Brimham Grit of North Yorkshire (and adjacent regions), England is a fragmented fluvio-deltaic sandstone succession extending for ~700 km^2 that crops out in a variety of forms from disarticulated blocks to a complex series of pinnacles, the three-dimensional arrangement of which allows high-resolution architectural analysis of genetically-related lithofacies assemblages. Combined analysis of sedimentary graphic log profiles, architectural panels and palaeocurrent data have enabled three-dimensional geometrical relationships to be established for a suite of architectural elements so as to develop a comprehensive depositional model for the succession exposed at Brimham Rocks (the type section). Small-scale observations of facies have been related to larger-scale architectural elements to facilitate interpretation of the depositional palaeoenvironment to a level of detail that has rarely been attempted previously, thereby allowing reconstruction of formative processes. Detailed architectural panels and facies analysis form the basis of a quantitative technique for recording the variety and complexity of the sedimentary lithofacies present, their association within recognisable architectural elements and thus the inferred spatio-temporal relationship of neighbouring elements. Fluvial channel-fill elements bounded by erosional surfaces are characterised internally by a hierarchy of sets and cosets with subtly varying compositions, textures and structures. Simple, cross-bedded sets represent in-channel migration of isolated mesoforms (dunes); cosets of both trough and planar-tabular cross-bedded facies represent lateral- and downstream-accreting macroforms (bars) characterised by highly variable, yet predictable, patterns of palaeocurrent indicators. Relationships between sandbodies of strata bounded by third- and fifth-order surfaces, which represent in-channel bar deposits and incised channel bases respectively, chronicle the origin of the preserved succession in response to autocyclic barform development and abandonment, and major episodes of incision likely influenced by episodic tectonic subsidence, differential tilting and fluvial incision associated with slip along the North Craven Fault. Overall, the succession represents the preserved product of an upper-delta plain system that was traversed by a migratory fluvial braid-belt system comprising a poorly-confined network of fluvial channels developed between major sandy barforms that evolved via combined lateral- and downstream-accretion. Data and results from this study form a valuable tool for comparative study of analogous fluvial systems and preserved successions, in both modern and ancient settings, which do not possess the exposure and unique three-dimensional characteristics associated with the Lower Brimham Grit. A generalised depositional model demonstrates how such successions may accumulate in localised depocentres. This work has application to reservoir prediction in hydrocarbon provinces and sites considered for carbon sequestration.

THERMAL EFFECTS ON AN ORGANIC-RICH MUDSTONE AND THE IMPLICATIONS OF SILL EMPLACEMENT INTO CARBON-RICH SEDIMENTARY BASINS

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Contact metamorphism of organic-rich sedimentary rocks following sill emplacement into sedimentary basins has been proposed to increase the total carbon release from large igneous provinces, and cause contemporaneous negative carbon isotope excursions in sedimentary sections through the release of isotopically light-carbon compounds (CO_2 or CH_4) (e.g. Svensen, H. et al., 2009: Earth and Planetary Science Letters, 277, 490–500)

Basaltic Palaeogene sills intrude near-horizontal Jurassic mudstones on the Trotternish Peninsula, in northern Skye, Scotland. Organic-rich host shales from the lower contact aureole of an 8m thick dolerite sill near Bearreraig Bay have been sampled over a distance of 50cm from the contact, and analysed for major and trace elements, total organic carbon, and carbon isotopes. Progressive carbon loss from these shales (original composition approximately 5 wt % C) occurred over 40cm from the contact, resulting in approximately 50% carbon loss. Total carbon loss occurs within a few cm of hornfels at the contact. The loss of carbon is accompanied by an increase in $\delta^{13}C$ of approximately 1‰, indicating preferential loss of isotopically light-carbon compounds (CO_2 or CH_4). More importantly this study revealed an unexpected increase in total organic carbon, and decrease in $\delta^{13}C$, in a narrow interval ~25cm from the contact.

Thermogravimetic and differential thermal analyses will constrain the nature of reactions during contact metamorphism. Step heating and progressive measurement of total organic carbon and carbon isotopes will analyse changes in carbon isotopes associated with the heating.

Of particular interest is the peak in total organic carbon ~25 cm from the sill contact. This peak may represent a condensation front for fluids that contain isotopically light-carbon compounds generated closer to the contact during heating. The alternative explanation, that the peak in TOC represents an original feature of the sediments, is precluded because of the near constant concentrations of V, Mo and Zn throughout the sampled section, inconsistent with original variation in carbon content of the shales. Condensation of carbon compounds within contact aureoles has clear implications for estimations of potential gas release from large igneous provinces, because the gases produced during contact metamorphism are not vented to the atmosphere but instead remain within the contact aureoles.

THE INTERNAL ARCHITECTURE OF A 3 DIMENSIONAL POINT BAR SYSTEM IN A SAND DOMINATED FLUVIAL SYSTEM IN THE MORRISON FORMATION, CENTRAL UTAH

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Excellent exposure of a point bar in the Salt Wash Member, of the Morrison Formation, central Utah, allows a unique insight into the deposits and internal architecture of a large Upper Jurassic meandering river channel. A combination of plan-view and vertical exposures allows a full 3 dimensional understanding of point bar and associated channel deposits. The Salt Wash distributive fluvial system (DFS) was deposited during the initial stages of foreland basin development. Previous studies have allowed the point bar to be placed into a system context, with the point bar residing in the sandstone dominated proximal portion of the system, where at least 10 other exhumed point bar deposits can be observed. The dimensions of the bar outcrop being presented varies from 8–10 m high and from 35–45m wide at its thickest point.

Using photo-panels and satellite imagery, it is possible to build a 3D understanding of the internal architecture of the point bar system. It is hoped that understanding the architecture and formation of point bar systems in such an exceptionally well exposed outcrop will then allow better interpretations of meandering river systems in coarse grained deposits to be made in both 2D outcrop and core sections. It is clear from observations in the field that the dominant features of the point bar include, large scale bar accretion, roll-over structures and erosional chute structures. Preliminary results show the most upstream section of the bar is dominated by downstream accretion, further downstream the accretion stops and rollover and erosional chute structures dominate and towards the head of the bar downstream accretion and cross beds dominate.

Future plans for the project include using a LiDAR data set in conjunction with field observations to create a 3D model of the point bar outcrop. The modelling data will provide an understanding of the internal architecture of point bars. Once a strong understanding of internal bar architecture has been adapted it will then be possible to look at 2D exposures within the Salt Wash DFS, to reassess the previous assumptions that the Salt Wash had a braided plan-form based on the system being coarse sand dominated. The findings from this study will have future implications on recognising course grained sand dominated meandering fluvial systems in outcrop.

THE EARLY CRETACEOUS SEQUENCE IN SPITSBERGEN: THE FESTNINGEN PROFILE

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During the Early Cretaceous, Spitsbergen, Svalbard, was located at a palaeolatitude of ~60°N. Abundant fossil wood derived from conifer forests; dinosaur trackways; enigmatic deposits such as glendonite horizons and rare outsized clasts, and stable isotope data from the Early Cretaceous Rurikfjellet, Helvetiafjellet and Carolinefjellet formations of Spitsbergen suggest that the climate at that time was much more dynamic than the traditional view of 'invariant greenhouse' conditions on Earth. The purpose of this study is to test the veracity of using such proxies as climate indicators and to evaluate the climatic character of Arctic Svalbard during the Early Cretaceous. To this end, the sedimentological and sequence stratigraphic context of glendonites and outsized clasts within the Rurikfjellet, Helvetiafjellet and Carolinefjellet formations are being documented. This is being achieved through high resolution conventional sedimentary logging (bed-scale) of the Early Cretaceous succession at multiple locations, documentation of glendonites, outsized clasts, together with sampling (every < 0.5m) for stable isotope analysis, in order to constrain and elucidate the nature of environmental and possible climatic variations during this time. Preliminary results from a key targeted section at a location known as Festningen are presented on this poster.

The Early Cretaceous succession at Festningen is 750 m thick and is considered to have been deposited between the Berriasian and late Aptian/early Albian. The basal Rurikfjellet Formation comprises a normally regressive water to wave/storm dominated shoreface. A forced regression (expressed as a regional unconformity) marks the base of the overlying Helvetiafjellet Formation. The Helvetiafjellet and overlying Carolinefjellet Formation represent a strongly aggradational, weakly transgressive succession characterised by delta plain deposits, containing abundant terrestrial woody material and with ornithopod footprints, passing upward into deep water mudstones and rare storm beds. Glendonites occur within the shoreface deposits of the upper Rurikfjellet Formation, and in the Carolinefjellet Formation.

The occurrence of glendonites in sediments recording a relative sea-level fall may suggest a direct cooling control (i.e. eustatic sea-level signature) on relative sea-level. At the top of the succession, glendonites are found in the aggradational Carolinefjellet Formation. The expanded nature of the sedimentary deposits suggest high subsidence rates and high sedimentation rates, implying that the main signature here is that of higher rates of tectonic subsidence, rather than a eustatic control possibly evident in the lower part of the succession.

PROXIMAL TO DISTAL TRANSITION IN THE LARGE-SCALE EPHEMERAL FLUVIAL SYSTEM OF THE KAYENTA FORMATION IN WESTERN USA

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The deposits of continental depositional systems provide good hydrocarbon reservoirs but the quality is strongly influenced by interactions between competing environments and allocyclic controls upon the system. Ephemeral fluvial systems are common in arid continental environments as a result of seasonal flash flooding. The successions produced by these seasonal flash floods represent deposition by a rapid sediment-rich flow succeeded and preceded by dry conditions resulting in series of erosional surfaces. Fluvial style, source area (and lithology), gradient, reworking, underlying formations and basin tectonics all play roles in the rapid variation of facies both laterally and vertically. Climatic cyclicity in the arid continental basin results in alternations of fluvial and aeolian deposition relating to periods of relative humidity and aridity respectively. The study of these cycles and their influence on deposition is crucial to understanding these facies variations and erosional surfaces in the broader context of the sedimentary basin.

In this work we present the results of initial investigations into variation in sedimentology between proximal and distal deposits of the Kayenta Formation, which is an ephemeral fluvial depositional system from the Colorado Plateau, USA. The proximal sand-rich facies of the Kayenta Formation are well studied, but the distal silt-rich facies are poorly documented. Using sedimentary logging and 3D panel photograph interpretations of proximal and distal outcrops, we investigate the variations in the complete Kayenta fluvial system. Logging and detailed analysis provide data on facies, associations, and architecture and 3D photographic constructions provide relationships between elements, and insights into the broader depositional system.

The Kayenta Formation was derived from flash-flood events creating multichannel ephemeral streams on a broad floodplain. Multi-storey sandstone channel bodies are recorded proximally, with smaller, isolated streams developing downstream. Rapid flow in the proximal highland source area creates upper flow regime bedforms in fine to medium sands. Due to the relative tectonic quiescence of the Paradox Basin during the Jurassic Period, the multiple channels reworked overbank deposits thus preserving stacked channels in preference to silty overbank. The eroded overbank material was carried downstream in suspension and was subsequently deposited as the stream systems become smaller and lower in energy, resulting in significantly more argillaceous distal deposits. Further to this, reworking of different underlying deposits contribute to these downstream variations. Future work will examine the sedimentological interactions between the ephemeral fluvial system and contemporaneous arid continental environments, and place all findings in the regional context of the allocyclic controls upon the depositional system to provide analogues for hydrocarbon reservoirs from the North Sea and beyond.

SEDIMENTARY FAULT ROCKS

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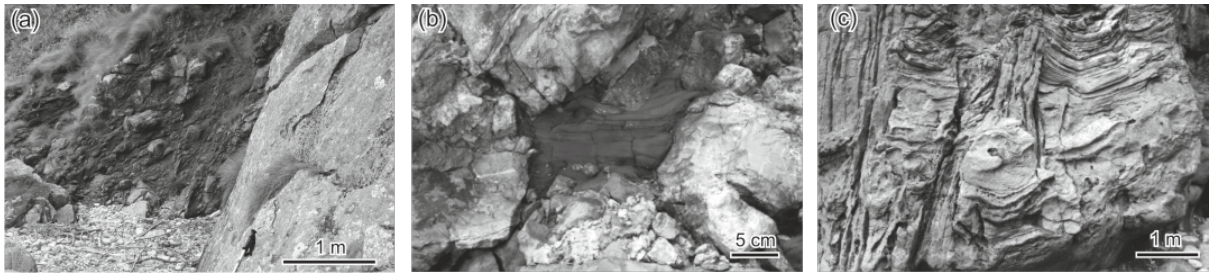
Upper crustal *fault rocks* – such as cataclasite or breccia – are typically explained by deformation processes: attrition of one fault wall against the other or hydraulic fracturing of wall rock due to high fluid pressures. However recent field studies have shown that some fault rocks result from sedimentation into open *fault fissures.* This talk reviews the formation and significance of these 'sedimentary' rather than 'deformational' fault rocks.

No fault is perfectly planar, so any displacement creates potential voids as irregular fault walls ride over other. If the wall rocks are weak, for instance in shale-rich units, these spaces are filled by plastic flow of the walls. By contrast strong rocks – such as cemented limestones and lavas – can support persistent voids, especially if an extensional regional deformation regime leads to dilational faulting. Voids or 'fault fissures' in the top few kilometres of the crust, where crustal stress in low, are then available for filling by sediment.

The best UK examples of fault fissures are hosted in Carboniferous limestone. We have documented examples in Cumbria (Dent Fault) and south Wales, and Wall & Jenkyns (2004) described fissure fills from the Mendips. Walker et al., (2011) documented sedimentary fills from faults in the Palaeogene basalts in the Faroes. Fill sediments are typically breccia or mud, and less commonly purely of sand. Breccias, often crudely bedded, are mostly due to collapse of walls rocks into the fault void (Fig. a). They are classified in the same way as cave collapse breccias into *crackle, mosaic and chaotic breccias.* Fine-grained fault fills are mostly washed down from higher in the fault system or from the contemporary land surface. They form local matrix between breccia clasts (Fig. a, b) or catenary-laminated units in larger fissures (Fig. c).

Characteristics of fault fissure fills compared with karstic cave fills are their association with hydrothermal veins and cements and their potential deformation by repeated displacement on the host fault. Consequently, clasts of fissure fills are commonly found in later fault breccias. Sedimentary fault rocks are an important marker of dilational faults, which form highly permeable conduits through otherwise low permeability sequences. Even when filled with breccia, dilational fault fissures can have permeability some orders of magnitude greater than host rocks.



SANDSTONE RESERVOIR QUALITY: THE IMPORTANCE OF A MODERN ESTUARINE ANALOGUE IN UNDERSTANDING THE FUNDAMENTAL PROCESSES GOVERNING THE DISTRIBUTION OF CLAY-COATED SAND GRAINS IN PETROLEUM RESERVOIRS

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Porosity and permeability generally decrease with increasing depth; however a significant number of deep sandstone reservoirs worldwide, express anomalously high porosity and permeability values, most commonly linked to the inhibition of authigenic silica cement through the presence of clay- coated quartz sand grains (Bloch *et al.*, 2002; Ajdukiewicz and Larese, 2012). The key factor controlling the effectiveness of quartz cements inhibition being the extent and completeness of the detrital precursor clay coating (Billault *et al.*, 2003). However the production of an encompassing reservoir quality predictive model of clay coat origin, mineralogy and distribution on a stratigraphic basis remains lacking.

This study focuses on the Ravenglass estuary, NW England, providing a modern reservoir-scale analogue, offering a wide range of depositional environments, removing the often limited spatial distribution and stratigraphic coverage of exclusive core based studies. The overall research aim is to establish a fundamental understanding of the processes governing the origin, mineralogy and distribution of clay coating, facilitating application to ancient deeply-buried petroleum reservoirs.

Datasets incorporating grain size, bioturbation and the distribution of clay coat quality and quantity have been determined by scanning electron microscopy of loose sediment grain mounts and extensive surface mapping.

The early results from on-going research have identified:

1 The textural and mineralogical characteristics of modern day clay coats.

2 Variations in grain coat quality and quantity distribution related to specific modern depositional environments.

3 Possible physical and biological processes responsible for clay coat formation and distribution.

Understanding the nature, origin and distribution of clay coats on a stratigraphic basis has important implications for understanding the fundamental processes controlling clay-coated sand grains, enabling the production of a high resolution analogue model to aid subsurface Reservoir Quality Prediction.

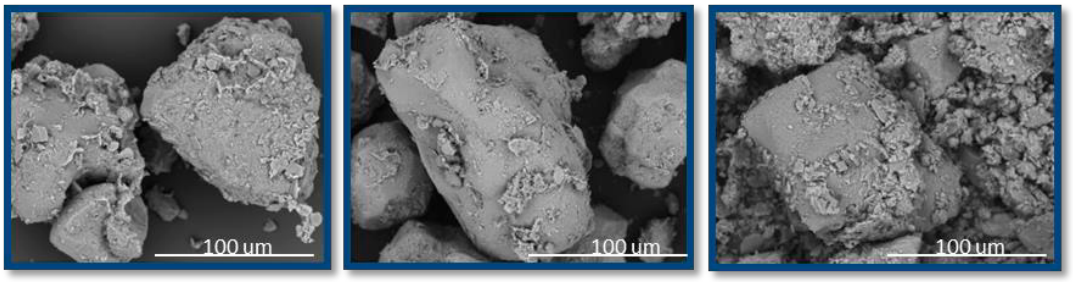

Figure 1 SEM images of modern surface estuarine clay coats.

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BEDFORM DYNAMICS IN MIXED SAND-CLAY-EPS SUBSTRATES

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The quantification of sediment dynamics in coastal and estuarine environments remains a distinct challenge, particularly in terms of including the complexities of sediment mixtures, such as sand and clay along with their biological components. Quantifying such biological mediation is key to parameterizing physical processes at the flow bed interface, which ultimately controls morphodynamics at local and regional scale. Moreover, understanding sediment movement is also vital for monitoring water quality, fate of pollutants, and the success of coastal dredging operations. Fine sediments, which commonly exist in natural estuarine flow systems and are composed of fine silts and clays, with biological agents that have cohesive properties that modulate the complex interactions between flow, sediment transport and morphological evolution. Our existing flow and transport predictions for these environments are seriously impeded by an almost complete lack of process based knowledge of sediment behaviour consisting of complex mixture of cohesionless sand and biologically active cohesive muds. The work presented here forms a part of the UK NERC COHBED project which aims to fill this gap in knowledge. Herein results from a set of controlled laboratory experiments, conducted using mixed cohesive and non-cohesive sediment and Xanthan gum (as a proxy for the biological stickiness of Extracellular Polymeric Substances (EPS)), are presented and discussed.

Experiments were undertaken at the University of Hull's Total Environment Simulator flume/wave tank facility (www.hull.ac.uk/tes). The tank was sectioned into a 10 x 2 m flume channel and filled with varying ratios of fine sand and kaolin clay, and varying amounts EPS (Xantham gum, a natural biopolymer) and varying ratios of sand, clay and EPS. Saline water (at 15 PSU) was used throughout the experimental set and was pumped to produce a constant unidirectional current with a depth-averaged flow velocity and depth. The depth and velocity were set such that, in the test section, conditions occupied the known dune regime for non-cohesive sands. A total of 16 individual runs were conducted lasting ~10.5 hours for each, with continuous acoustic monitoring of the flow current and bed topography via automated traverse and profilers, with water and bed samples also taken every 30 minutes during the run.

Results show that bedform development was influenced by clay and EPS component in substrate of each run because clay and EPS affect the timing of first occurrence of bedforms on a flat sediment bed, bedform development rate and equilibrium bed morphology. And sediments transport between bed and flow was analysed by floc and suspended sediment concentration (SSC) data.

TALKS

MINERALOGICAL AND GEOCHEMICAL ANALYSES OF THE SIDERITIC IRONSTONES FROM THE WEALD BASIN, SOUTHEAST ENGLAND

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Sideritic ironstones have an extensive occurrence on a basin-wide scale in the Weald Basin, southeast England. They occur as nodules, tabular ironstone bands and sometimes as spherulites. The most common sideritic horizons are very important stratigraphic units at base of the Wadhurst Clay Formation (Berriasian-Valanginian) and represent important marker beds. Despite their well-known nature and wide occurrences, mineralogical and geochemical data on these ironstones are scarce in the literature. Three ironstone samples from the base of the Wadhurst Clay Formation at Cliff End near Hastings, Houghton Green, Rye and West Hoathly quarry, Sharpthorne in southeast England were subjected to mineralogical and geochemical analyses using XRD and XRF methods respectively.

Mineralogical and elemental compositions of the Wealden ironstones confirmed the presence of early diagenetic siderites that have strong geochemical correlation with their hosts. The trace elements assemblage demonstrated that the siderites are chemically pure confirming their freshwater origin. The siderites indicate shallow burial depth of the Wealden sediments and confirm reducing and anoxic conditions in the Weald Basin. These siderites also provided information about the sea level changes and the alkalinity of the palaeo and depositional environments of the Weald Basin. Although the Wealden siderites are likely to have been precipitated from the interstitial meteoric pore waters beneath the sediment-water interface in a freshwater environment, their detailed formation mechanisms require further investigations.

TALK

SEDIMENTOLOGICAL INSIGHTS INTO CRYOGENIAN GLACIATION IN SCOTLAND: AN INTEGRATED FIELD-BASED ANALYSIS FROM THE PORT ASKAIG FORMATION OF THE GARVELLACH ISLANDS

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The Neoproterozoic Port Askaig Tillite Formation is a glaciogenic succession, probably representing the Scottish record of the Sturtian global glaciation. This paper provides initial results stemming from a 2 month field study undertaken on the Garvellach Islands. The exposed nature of the coastlines affords spectacular and continuous exposure, allowing the nuanced advance-retreat behaviour of ice sheets to be determined. A total of 1400 m of strata were logged and correlated, allowing lateral facies variations to be determined at a total of 16 separate horizons, and a preliminary facies model to be produced. The predominance of diamictites within the succession has led some previous authors to propose that they were deposited through slope instability and mass movement rather than under a direct glacial influence. Careful facies analysis, however, renders this interpretation inappropriate. Lonestones recur at intervals with impact structures, implying a dropstone origin, and hence a direct glacial influence on sedimentation. Furthermore, some levels show well-expressed soft-sediment deformation structures including *en echelon* normal faults passing laterally into reverse-sense microfaults. These are tentatively proposed to result from ice keel turbation. A series of at least 6 stratigraphically separated sandstone sheets or wedges crosscut diamictite beds at intervals. Given the occurrence of well-preserved, polygonal patterned ground at some levels, these wedges may either originate as periglacial contractional structures or, alternatively, subglacial injectites. Intriguingly, dolostone accumulations are well developed within the lower part of the succession and some of these exhibit contemporary reworking as intraclasts. These puzzling intervals either imply a syn-glacial carbonate factory, or refluxed carbonates shed from a source area during the glaciation.

VARIABILITY IN TURBIDITY CURRENT FREQUENCIES IN A CENTRAL PORTUGUESE MARGIN CANYON

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Submarine canyons constitute one of the most important pathways for sediment transport into ocean basins. For this reason, understanding canyon architecture and sedimentary processes has significance for reservoir characterisation, carbon budgets and geohazard assessment. Canyon sedimentation in the form of turbidity currents is known to operate on a variety of scales and result from a number of different processes, including landslides, river-derived hyperpycnal flows and tidal resuspension. Despite our knowledge of turbidity current triggers, the spatial variability in turbidity current frequency within most canyon systems is not well defined.

Here, new chronologies from cores in the lower reaches of Nazaré Canyon illustrate changes in turbidity flow frequency linked to sea-level controlled sediment redistribution. Flow frequencies suggest considerable activity during the last glacial maximum and the last deglaciation, with an average recurrence interval of 70 years. Mid to early Holocene slowdown in activity (1625 yr recurrence) appears to occur later than other systems along the Iberian margin. Cores from the Iberian Abyssal Plain (IAP) also provide the first recurrence interval estimates for large run-out turbidity currents from the central Portuguese margin. These large turbidity currents have an average recurrence interval of 2750 years, broadly comparable to modern turbidity flow events in the lower canyon. This indicates that Nazaré Canyon acted as a depocentre, capturing large volumes of sediment during glacial periods prior to large scale canyon flushing events. However, this sediment capture has largely been restricted to the middle and upper canyon since stabilisation of Holocene sea level. Recurrence intervals suggest that large turbidity flows which flush the canyon operate on a timescale independent of the sea level forcing evident in the lower canyon. While landsliding due to sediment instability and tidal/storm resuspension are likely responsible for canyon restricted turbidity flows, a different trigger may exist for long run-out turbidity flows.

Canyon flushing events in other canyons have been suggested as being the result of landslides triggered by regional earthquakes. However, turbidites from the IAP do not correlate well with suggested earthquake-triggered landslides in the Tagus Abyssal Plain (TAP) to the south. The inability to test for synchronous deposition makes identifying a seismic trigger problematic. The Nazaré fault, which intersects the canyon head, may have a distinct return time for large earthquakes that is different from seismically active areas to the south. This further suggests the need for caution in the use of turbidites as a palaeo-seismological indicator along the Iberian margin.

TALK

A 2.3 MILLION YEAR LACUSTRINE RECORD OF ORBITAL FORCING FROM THE DEVONIAN OF NORTHERN SCOTLAND

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Detailed sedimentological examination of well exposed onshore sections through the continental Middle Devonian succession of northern Scotland have been augmented with offshore well data to allow the construction of a continuous 2.3 million year record of orbital forcing. The Middle Devonian of Northern Scotland comprises a succession of cyclic lacustrine deposits. The onshore exposures of this succession, although well exposed, are disrupted by faulting. Hand held gamma logging of onshore exposures has allowed direct ties to be made to adjacent offshore well data which provides a continuous record through the lacustrine succession. Further onshore sections, shown to be representative of those identified in the offshore data, help define the orbital periodicities influencing sedimentation and furthermore, provide insights in to the response of the lacustrine system through time.

Periodicities reflecting the Precessional (19 886 years) and Eccentricity (100 000 years) cycles are shown to be dominant by the direct measurement and extrapolation of depositional rates in well exposed sections as well as the analysis of ratios between primary and, modulating, secondary cycles. The demonstration of a robust link between gamma log response and lithology in the onshore cycles allows the offshore data to be to be interrogated for evidence of the long term climatic forcing of sedimentation. Fourier analysis has confirmed the presence of regular cycles throughout the succession which vary in thickness similarly to the onshore records. Variations in cycle thickness and symmetry are related to a trend from an underfilled to a balanced fill lacustrine basin. Of further importance is the period of each cycle during which lacustrine conditions, and therefore lake level controlled accommodation, existed.

UNRAVELLING CONTINENTAL, SHALLOW AND DEEP MARINE FACIES DISTRIBUTION IN PASSIVE MARGIN BASINS: EARLY CRETACEOUS IN TARFAYA BASIN, ATLANTIC MARGIN OF MOROCCO

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The breakup of Pangaea and opening of the Central Atlantic between present day Morocco and Nova Scotia during the Mesozoic led to the development of an extensive passive margin. During the Early Cretaceous, basins were filled mainly with clastic sediments that offer potential hydrocarbon reservoirs. Assessing the provenance, delivery and character of sediments on the coastal basins has significant implications for understanding the evolution of the Atlantic passive margin and nature of deepwater systems.

We present detailed field observations of the coastal outcrops of southern Morocco (Sidi Ifni and Tan Tan areas) and the associated deep marine deposits outcropping in Fuerteventura (Canary Islands, Spain), including stratigraphic logs, field gamma-ray and petrographic analysis. The results suggest a complex facies distribution, abrupt changes in depositional environments both temporally and spatially along the margin.

Two depositional environments are observed in the north (Sidi Ifni area). The first consists of locally derived coarse continental alluvial deposits of red sandstones and polymictic breccias, with clasts ranging in size from fine sand to boulders. A few kilometers to the south, shallow marine to deltaic deposits comprise laminated siltstones, muds, calcareous sandstones and oolitic limestones. Further south (Tan Tan area) thick siliciclastic-dominated successions comprise dominantly fluvial sequences of cross-bedded sandstones, passing basinwards to shallow marine sandstones, sand-rich carbonates and dark clays.

In Fuerteventura, the distal basinal equivalents of the southern Moroccan sections have been inverted and exposed, although now structurally overturned and highly intruded by igneous rocks. The thick Early Cretaceous succession consists of, deepwater turbidites and calcturbidites.

The results suggest highly variable input along the margin, controlled by local palaeotopography and pre-existing structure, defining drainage divides, resulting in variable composition from different provenance areas. Improved understanding of the controls on delivery, input points and timing of sediments into these Cretaceous basins is allowing the construction of improved palaeogeographic and facies distribution maps. These results will reduce risk for evaluating reservoir type and location in the deep basins offshore Morocco and are a valuable analogue for the conjugate margin of Nova Scotia and the entire Atlantic margin system.

This study is linked with a similar project being carried out further north in Agadir-Essaouira Basin (T Luber). The outcome of both studies will be combined with thermal history of the Precambrian basement inferred from apatite fission track and (U-Th)/He analyses and integrated into source-to-sink conceptual and numerical models (R. Charton).

TALK

WAVE RIPPLES IN MIXTURES OF COHESIVE CLAY AND COHESIONLESS SAND

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Novel large-scale flume experiments show that regular water surface waves require longer to reshape a flat bed into wave ripples if the bed consists of mixed cohesive clay and cohesionless sand than if the bed consists of pure sand. Yet, the equilibrium height and length of these bedforms are unaffected by the initial bed clay fraction. The delay in wave ripple growth rate increases exponentially with increasing initial bed clay fraction. This can be explained by the cohesive clay particles binding the sand grains together, thus increasing the critical shear stress required for bed erosion and reducing the bed sediment erosion rate. The constancy of equilibrium ripple height and length is related to the highly efficient entrainment (i.e. winnowing) of clay particles from the clayey sand through wave shear, which eventually produces wave ripples that comprise 100% clean sand and therefore have dynamic similarity to equilibrium ripples in sand that never contained clay. These findings imply that empirical equations for the prediction wave ripple dimensions, which are essential for sediment transport modelling in the marine environment and the reconstruction of wave climates from wave ripples in the rock record, are valid for mixed sand-clay beds only if it can be proven that these bedforms are in equilibrium with the wave conditions. This requirement needs greater awareness amongst scientists and practitioners, given that long delays in the formation of equilibrium wave ripples are associated with sand that contains only 4.6% clay.

METRE-SCALE POLYGONAL DEWATERING STRUCTURES AND THEIR MODE OF FORMATION: TRIASSIC MOENKOPI FORMATION, UTAH

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Although soft-sediment deformation and water-escape structures are relatively common within continental successions, well exposed examples of large-scale sandstone extrudites generated in response to catastrophic dewatering of over-pressured horizons are relatively uncommon in the stratigraphic record and are poorly documented. Here we document exceptionally well-preserved examples of metre-scale polygonal sandstone extrudites hosted within a predominantly heterolithic succession, the Tenderfoot Member of the Triassic Moenkopi Formation, a predominantly fluvial succession present in the Salt Anticline Region of South East Utah.

Differential rates of weathering have resulted in the partial exhumation and exposure of these structures in three dimensions. This allows for detailed analysis of the internal form and structure of the features and associated study of the style of deformation of the surrounding host sediments. In planform, the structures form a polygonal network of water-escape fissures that typically join at triple junctions, with inter-fissure areas measuring 3 to 5 metres in diameter. In cross-section, the structures form downward tapering wedges composed of sandstones with a vertical height of 0.75 to 2 m and cross section widths up to 2 m. Internally, these structures are characterised by laminae that are parallel to the vertical axis and radiate from the base, increasing in thickness upward toward the apex of the structure. In some cases, the laminations at the centre of the structure exhibit stepped-extension above the outer laminae by up to 0.5 m.

These structures grew at, or near the ground surface, where confining pressure of the overburden diminished sufficiently to allow accretion of medium-grain sand onto the walls of open water-escape fissures and dilatory growth of the structures. The structures grew in a polygonal pattern predominantly at a single stratigraphic level at or close to the ground surface. The structures demonstrate polyphase growth, as recorded by the stepped-extension between the outer-most and inner-most laminae, which indicate episodes of renewed growth during the history of formation following temporary cessations in the aftermath of burial by fluvial flood deposits. Accretion episodes are expressed as upward (vertical) growth of the dilatory structures. Many of these dewatering structures are confined to a single stratigraphic level, which implies generation in response to a high-magnitude (seismic?) event. However, the presence of smaller structures approximately 3 m higher in the stratigraphy but linked to the larger structures below suggests the operation of subsequent lower-magnitude dewatering events, which apparently exploited the pre-existing conduits to facilitate renewed water escape.

TALK

INTEGRATING OUTCROP AND CORE STUDIES TO ELUCIDATE PALAEOENVIRONMENTS OF SUBSURFACE SUCCESSIONS

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The preserved deposits of continental sedimentary environments are inherently three-dimensional and highly varied: properties that make subsurface interpretations of such environments difficult to interpret from core alone. To provide an understanding of subsurface continental successions, extensive field studies are required to appreciate the geometry and scale of the system in three-dimensions, and to develop quantified models to use as guides in core interpretation.

In this work, we present the development of quantified sedimentary models from outcrp of the Lower Cretaceous Ghaggar-Hakra Formation, Barmer Basin, India, as an example of the deposits of a spatially and temporally varied fluvial system, as a means to aid interpretation of subsurface core. At outcrop, three channel-dominated sandstone successions are evident comprising architectural elements of channel fills, braid bars, in-channel bars, point bars, sheetfloods and chute channels. These successions are interbedded with claystones and siltstones which contain architectural elements of floodplain and ephemeral ponds. The lowermost succession contains braid bars highly suggestive of a bedload-dominant low sinuous fluvial system. The middle sandstone succession contains points bars, sheetfloods and chute channels all indicative of a mixed-load high sinuosity fluvial system. The uppermost fluvial sandstone succession contains braid bars, in-channel bars and channel fill which elucidates a well-developed bedload-dominated fluvial system. The interbedded claystones and siltstones are the associated floodplain environments of the fluvial systems.

Detailed examination of core through the same succession within the subsurface of the Barmer Basin reveals facies and facies associations consistent with those observed at outcrop. The relative proportions of channel and overbank facies suggest a system comparable with the middle and uppermost sandstone successions as the facies associations of in-channel bars, braid bars, point bars and channel-fills are noted. However, differences include the thickness of the sediment and the core data contains facies associations of a lake margin. These differences are likely due to the relative position of the outcrop which is proximal when compared to the distal core datasets, as the dataset was likely controlled by faulting at the time of deposition.

This work demonstrates the value of detailed, scaled and three-dimensional, quantified field based models to aid the interpretation of subsurface core. Whilst channel and overbank dominant successions can be observed in core, element dimensions and relationships can only be determined to from outcrop studies and may significantly impact reservoir characterisation of hydrocarbon prospects, particularly within the Barmer Basin.

CONTROLS ON PHYSICAL PROPERTY DISTRIBUTION IN THE NORTH OF THE DOGGER BANK TRANCHE A — RESULTS FROM A PILOT STUDY

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The Dogger Bank is a large shallow topographic feature in the Central North Sea with water depths of 18–63 m. It is the proposed site for the largest of the offshore Round 3 windfarm zones, with a total area of 8660 km^2. The first survey area, Tranche A, comprises ~2000 km^2 and is located in the South West of Dogger Bank. Within this area a 110 km^2 pilot study area was selected and, using 2D high resolution multichannel sparker data, key seismic reflectors were picked and mapped in pseudo-3D. This allowed the identification of distinct seismo-stratigraphic packages that could be tied to the litho-stratigraphy sampled from geotechnical boreholes and wireline log data.

A distinct difference in seismic character between a younger upper unit and lower older unit within the Dogger Bank Formation is observed, believed to be the result of varying physical and acoustic properties of the sediment. This variation is present within wireline and CPT data, and discussed in this presentation. Where distinct seismo-stratigraphic features have been identified, the upper and lower Dogger Bank appear to have behaved differently; within this area the lower Dogger Bank behaves in a more brittle style, whilst the upper Dogger Bank behaves in a more ductile style. Controls on this variability are hypothesised to be the original distribution of sediment by glacial outwash, and post-depositional glacial processes leading to variations in strength of the sediment, such as differences in undrained shear strength, and physical properties between the two seismic packages. Within the pilot area it appears that repeated glacially-related processes had the greatest effect on the observed physical properties of the sediment. However, this may not be true for all of Dogger Bank, and ideas for further work are presented here alongside preliminary results.

TALK

DETRITAL K-FELDSPAR IN MODERN RIVER SANDS OF THE MISSISSIPPI DRAINAGE BASIN: A NEW PERSPECTIVE ON CONTINENTAL-SCALE PROVENANCE

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Large and long-lived continental-scale river systems like the Mississippi and its tributaries dominate sediment supply to passive margin slopes and deep-water basins. Both the flux and character of the sediment delivered to the shoreline will reflect the evolving geomorphic, climatic and tectonic controls on sediment production, storage and transfer. 'Big' rivers potentially collect and mix sediment from large areas and they can tap diverse sourcelands. There is a need to better understand how sand is collected, mixed and fed through modern large river systems to guide interpretation of older passive margin basins where sediment supply is a key control.

The Mississippi River drains over 40% of the lower United States and extends northwards as far as northern Minnesota, over 3760 km upstream. U-Pb zircon geochronology of modern Mississippi sands (Wang et al., 2009) reveals distinct age peaks that can be broadly related to different hinterland source components. Zircons extracted from sandstones fed by the ancestral Mississippi and other coastal plain rivers have identified major shifts in the positon of tectonic divides, particularly during the Palaeocene when much of the modern drainage network was initially shaped (Blum and Pecha, 2014). In attempting to budget contributions from different source areas through time, the origin of the framework minerals needs to be considered alongside the heavy mineral populations. The restricted framework mineralogy of many sands and sandstones means that this is a challenge. However, K-feldspar grains may give useful insight as the common Pb isotopic composition of potential source terranes can vary systematically and the Pb signal can be retained in individual grains and retrieved by laser ablation MC-ICPMS.

Characterisation of common Pb isotopes in detrital K-feldspar collected from sand bars along the full length of the Mississippi and the main tributaries is underway. Preliminary results show at least four distinct Pb isotopic populations, each correlating to discrete source domains in the hinterland. The common Pb signal of the uppermost Mississippi (above any major confluence) has been resolved as a single population, while the other three Pb populations are present in variable proportions in the sands studied to date and record tributary contributions, mixing and dilution with distance downstream. The diversity of feldspar Pb isotopic compositions and changing proportions of the different populations along the river system is in marked contrast to the relatively constant overall feldspar abundances identified in previous studies of sands in the lower drainage basin.

QUANTIFYING THE CONTROLS ON SEDIMENT FLUXES AND GRAIN SIZE EXPORT FROM CATCHMENTS TO BASINS: CASE STUDIES FROM NORMAL FAULT-BOUNDED CATCHMENTS IN SOUTHERN ITALY

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The sedimentary record is the only physical evidence we have of mass transfer across the Earth's surface. In order to understand and ultimately decode this record, it is of key importance to characterize the sediment fluxes that generate stratigraphy. Sediment fluxes from catchments to basins, and their grain size distribution, may be highly sensitive to tectonic, geomorphic and lithological boundary conditions. However, the way in which these variables interact to determine the volume, locus and calibre of sediment released from catchments to basins remains unclear.

Here we use a combination of DEM analysis and fieldwork to quantify the controls on sediment export from catchments crossing two tectonically active faults in the Southern Apennines over timescales of 102—106 years, where fault throw rates along strike, landslide abundances and hanging-wall stratigraphies are well-constrained. We first use fault throw rate measurements, catchment drainage areas and channel transport capacities as the main variables to estimate the likely grain sizes, volumes and spatial distribution of sediment supply along the fault footwalls using three complementary methodologies: 1) the assumption of topographic steady-state; 2) the BQART model1; 3) Shields stress-based approaches. We compare these predictions with field data of the grain size distributions exported along the fault footwall catchments; the sediment volumes and grain sizes supplied by landslide populations in the field area; and the volumes and grain sizes of sediments stored in the hanging-wall basins.

Our analysis shows that: 1) fault throw rates strongly influence channel and hillslope gradients and hence they exert a critical control on the calibre of the sediment released from footwall catchments; 2) grain size distributions correlate with the magnitudes of the sediment fluxes exported from catchments, and both vary significantly along the strike of active faults, 3) bedrock lithology modulates the grain size and locus of sediment export by influencing landslide abundances and input sediment supply.. These data suggest that hangingwall stratigraphies in areas of active normal faulting fundamentally reflect landscape responses to tectonics.

[1]Syvitski, J P and J D Milliman. 2007. 'Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean.' The Journal of Geology 115(1): 1–19

TALK

DEPOSITIONAL ARCHITECTURE OF A DEEP-WATER SEDIMENT BYPASS ZONE

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The timing and location of sand bypass in submarine settings is important for constraining the distribution of sediment on basin margins. Deep-water sediment bypass zones are rarely identified in outcrop and therefore the sedimentary processes and resulting architecture of these zones are poorly understood. Regional mapping of sedimentary characteristics and stratigraphic architecture of a completely exhumed slope to basin floor fan lowstand sequence set (Unit E, Fort Brown Formation, Karoo Basin, South Africa) has allowed the recognition of a sand-rich lobe system down-dip of a zone of sand bypass. The 80 km continuous dip section outcrop shows the physical connection of an updip slope channel-levee feeder system through perched transient intraslope lobes and bypass-dominated channels to basin-floor lobes. This architecture is consistent with a stepped slope profile, where lobe deposition occurs on low gradient steps and channels dominate on higher gradient ramps. Three 20 km long parallel, oblique-dip oriented sections, 3–5 km apart, have been constructed in order to detail the sedimentological record and 3D architecture in this exhumed bypass zone.

Sediment bypass indicators in this zone include shale clast lag conglomerates with clasts up to 15 cm long, within slope mudrocks plus composite erosional surfaces and megaflutes with easterly (down-dip) oriented palaeocurrents. The spatial transition from bypass-dominated channels to lobe deposits is abrupt with local thickening at a rate of 7 cm/m. This thickening and increased proportion of sand in the unit is accompanied by evidence of high rates of deposition, such as stoss side-preserved climbing ripples. Overall a rapid change in flow behaviour and therefore depositional facies is observed over a relatively short distance of <1 km.

This outcrop example allows the examination of bed-scale processes preserved in a sand-bypass zone of a seismic-scale system. The characterisation of these sub-seismic scale elements and prediction of down-dip sands is crucial in understanding the stratigraphic trap potential of stepped slope profiles. Application of these results to subsurface data sets should provide better constrained geological models.

QUANTITATIVE CHARACTERISATION, ANALYSIS AND MODELLING OF A MIXED-LOAD FLUVIAL SYSTEM: A CASE STUDY OF THE HUESCA FLUVIAL FAN

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The Huesca fluvial fan in the northern extent of the Ebro Basin, is an Oligocene—Miocene age distributive fluvial system that was deposited in an endorheic setting with minimal tectonic deformation, which allowed hundreds of metres of sediment to accumulate. Through stratigraphic aggradation and hinterland valley back-fill, the basin centre level rose consistently enough to maintain a constant slope across the fluvial profile (Fisher and Nichols, 2013). The well exposed outcrops found throughout the Huesca system provide an excellent opportunity to integrate traditional field and digital acquisition techniques to further improve the understanding of the system, and its use as an outcrop analogue for reservoir modelling purposes.

This project utilises techniques developed for acquiring, processing and analysing large quantitative datasets and integrating them with traditional field measurements to build high resolution, accurate 3D geologic models of a medial portion of the Huesca fluvial fan. By using a combination of lidar, photography and Differential Global Navigation Satellite Systems (DGNSS), the authors were able to create sub-metre (spatially) accurate geologic models of the studied sections, near the town of Piracés. Traditional sedimentary logs collected throughout the mapped area offer further control on facies variability and lithostratigraphy represented within the models. The analyses and interpretations derived from the integrated models provide workers with a quantitative tool to further understand the spatial physiognomy of the depositional architecture, geometric relationships and lithologic characteristics across the study area.

Outcrop analogue studies provide detailed information about object geometry, architecture and structural elements found within a system, which is often difficult to obtain from traditional subsurface datasets and modelling techniques when creating reservoir models (Perez et. al., 2010). With the advent of novel acquisition techniques [lidar, photogrammetry, DGNSS], introduced with traditional field work studies, it is becoming easier for geoscientists to model, analyse and visualise the types of features required to create accurate model realisations of various sedimentary systems.

Utilising the inherent quantitative nature of the geologic models in combination with the traditional field data collected, geobody interpretations and architectural data has been collected along with the appropriate geostatistics required to create an accurate geocellular model from outcrop data. This modelling approach leads to more accurate, quantitative geologic and depositional models of the fluvial system, and further emphasises the necessity of using outcrop analogue studies to improve model building for subsurface reservoirs.

TALK

SEDIMENTOLOGY OF CREVASSE SPLAY DEPOSITS IN HIGH- AND LOW-ACCOMMODATION GREENHOUSE SETTINGS: EXAMPLES FROM THE CRETACEOUS MESAVERDE GROUP

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Crevasse splay deposits represent an important component of the stratigraphic record of fluvial overbank systems. Preserved sand-prone splay bodies commonly constitute volumetrically significant parts of otherwise predominantly fine-grained floodplain successions. In addition, splay deposits yield important information about the size, form and behaviour of formative fluvial systems, including adjacent major trunk channel bodies.

This work presents depositional models to account for the variability of crevasse splay body sedimentology and architecture, based on a quantitative facies and architectural-element analysis of the Campanian Castlegate and Neslen formations, Mesaverde Group, Utah.

Crevasse splays in high- and low-accommodation settings thin and fine away from major trunk channels. Preserved elements internally comprise sandstone and siltstone facies associations: proximal parts are dominated by sharp and erosional sand-body bases, upper-stage plane beds and erosional gutter casts; medial parts comprise climbing-ripple strata and small scale deformed beds; distal parts comprise lower-stage plane beds and exhibit complex styles of lateral grading into fine-grained floodbasin silts and coals. The distal parts of overlapping splay elements tied to either separate but adjacent master channels or to the same master channel may merge together within the central parts of flood-basins. This is significant because, in higher accommodation settings, laterally tied and linked splay elements act as connections that enhance sand-body connectivity in otherwise floodplain dominated successions.

In higher accommodation settings, preserved splays deposits stack sub-vertically such that successive bodies thicken- and coarsen-upwards before being overlain by an erosional channel element at the top of a cycle. This trend records the progressive migration of a master channel towards the site of deposition. By contrast, in lower accommodation settings multiple, stacked crevasse splay elements are amalgamated. In low-accommodation settings, progressive migration of the master channels towards the site of splay deposition acts to lower the preservation potential of overbank elements; the exception to this is where master channels avulse to leave an abandoned channel fill with associated attached splay deposits. Contrasting the sedimentology and architecture of crevasse splay deposits preserved low- and high-accommodation floodplain successions serves as a tool for determining both distance from and direction from a major trunk channel sandstones.

CAN BIOGENIC SEDIMENT MODIFICATION TRIGGER LANDSLIDES AND INHIBIT EROSION FROM TURBIDITY CURRENTS?

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Large submarine landslides can mobilise thousands of km^3 of sediment, yet geotechnical modelling often struggles to explain why they occur on remarkably low angle slopes (<2°). One hypothesis is that destructuring of sediment during shallow burial leads to generation of excess pore-pressures, which in turn promotes failure. Their run-out may cause only minor amounts of seafloor erosion, despite traveling hundreds of kilometres at speeds of several m/s. Bacteria and benthic organisms can create micro-structure within cohesive deep-water sediments and we suggest that these relatively small-scale modifications in sediment properties may be an explanation for this lack of erosion and destructuring.

Deep-water sediments typically feature very low undrained shear strengths, high water contents and low unit weights due to high bioclast content. Despite this, many deep-water areas feature a shallow zone of biogenic modification with apparently overconsolidated clay sediments; termed a 'crust'. In-situ geotechnical testing show dramatic (often ten-fold) increases in undrained shear strength within the top 1–2 m below seafloor and an increase in unit weight, before returning to a normally consolidated profile. The 'crust' underlies a water saturated 'slurry' layer (<10 cm thick) at the water-sediment interface. As these sediments have not been loaded other than by self-weight consolidation, the 'crust' is deemed to have a high Yield Stress Ratio (YSR) rather than being overconsolidated. The 'crust' is caused by interparticle bonding from extracellular polymeric substances (EPS) related to bacterial and/or benthic activity. EPS bonding strengthens sediment by inducing structure, creating a honeycomb-type structure of clay particles and preserve void spaces. Similar structure may be caused by weak cementation of bioclastic-rich fine grained sediments during early diagenesis. Under burial the loss of this structure can lead to a dramatic loss of porosity and generation of excess pore-water pressures.

Several field studies indicates that erosion at the base of high density turbidites is often limited to a few centimetres, and rarely extends below this depth. We suggest that this is due to the contrast in YSR at the slurry-crust interface, at which a markedly higher critical shear stress is required for erosion. If the critical shear stress is exceeded, the 'crust' rapidly breaks down due to its high sensitivity (S_t>10). This may explain where scoured features are locally pronounced (e.g. linear grooves). If loss of structure can also occur under low rates of strain or earthquake loading, sediments with biogenically-induced structure may be candidate 'weak' layers for large slope failures.

TALK

LONG TERM (20 MYR) TEMPO OF LONG RUN-OUT TURBIDITY CURRENTS IN THE IBERIAN ABYSSAL PLAIN: PERSISTENT LOG-NORMAL DISTRIBUTION AND RELATIONSHIP TO MAJOR CLIMATIC EVENTS

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Distal basin plains act as records of long run-out turbidity current deposits which represent unusually large-scale sediment transport events, with the largest volume events most likely triggered by submarine landslides. Such events transport globally significant volumes of sediment to deep-water, potentially causing damage to strategic and expensive seafloor infrastructure, and may cause hazardous tsunamis. Understanding their future recurrence and potential triggers is important - particularly in light of future projected climate and sea level change. Submarine landslide and turbidity current hazard has been forecast by some studies to increase during rapid global warming and may even contribute towards future warming through methane release from gas hydrates. Here we analyse an unusually large number (N=1571) of distal turbidite recurrence intervals from the Iberian Abyssal Plain during the late Cretaceous to mid Eocene. This record covers several major climatic excursions over a period of 20 Myr and hence provides unique insights into how the frequency of turbidity currents and their initiating processes related to major climatic events. We identify a persistent log-normal distribution for the entire record and also for sub-sets of the analysed period. This, and the results of non-parametric and rescaled range statistics, indicates a high degree of temporal order in turbidite recurrence. The common log-normal distribution indicates that mean recurrence varies between clusters; however the parameter that governs the shape of the distribution does not vary.

Therefore the controlling mechanism(s) for turbidity current generation is inferred to be broadly the same throughout the sequence. We compare our results to those of previous studies that identified an exponential distribution for distal turbidite recurrence and provide possible explanation for the difference in relation to sediment input source(s), pathway(s), triggering mechanism(s), and transport distance. A trend of increased frequency is observed to be coincident with long-term global warming in the mid-Eocene; however clusters of anomalously long recurrence intervals occur during the much shorter-term, intense warming at the Early Eocene Climatic Optimum and Initial Eocene Thermal Maximum. Intensification in turbidity current activity appears to show a lag of ~1 Myr after periods of sea level highstand. This suggests that predicted future sea level rise and global warming may not necessarily result in significantly increased submarine landslide or turbidity current on human (<100 year) timescales.

IS CLASTIC INJECTION AT DEEP-WATER STRATIGRAPHIC TRAPS PREDICTABLE?

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Clastic injectites are widely recognised in deep-water stratigraphic successions, and impact hydrocarbon reservoir connectivity and fluid flow. Their stratigraphic and geographic distribution in the subsurface is largely unpredictable, however documenting the distribution of exhumed injectites from known palaeogeographic positions can help to reduce subsurface uncertainty. Three examples of injectite complexes exposed in the Karoo Basin, South Africa have been studied in detail. The excellent palaeogeographic and stratigraphic context and three dimensional constraints permit the relationship to the original depositional architecture of the parent sands to be investigated. Each example occurs where there is an abrupt pinchout of relatively clean sands and has a particular style and geometry of clastic injection. Several near vertical dykes extend down from the erosive base of the parent body and feed a main sheet or sill, which steps upwards and outwards, following the thinning direction of the parent sand, with net injection propagation direction being horizontal rather than vertical. In cross-section the geometries of injectites observed are comparable to those imaged on seismic sections of known injected units in the subsurface, including cone-shaped sheet injections and large scale steps. Each example occurs at the up-dip fringe of a lobe complex. The reason for this association is thought to be due to the higher proportion of clean and erosively based sands compared to the more distal, heterogeneous deposits. The common presence and character of injectites at locations analogous to deep-water stratigraphic traps suggests that there is scope to improve our predictive understanding of their distribution, but that their presence will complicate simple stratigraphic trap architecture.

TALK

STORM-WAVE DOMINATED, FLUVIAL INFLUENCED 'STORM-FLOOD' DELTAIC DEPOSITION IN THE EASTERN BARAM DELTA PROVINCE, NW BORNEO

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Offshore sediment delivery requires flows to overcome the net landward bottom stress induced by fairweather shoaling waves. Storm waves are the dominant offshore transporting flow interpreted in basic models of clastic coasts, commonly generalised as a 'shoreface': the two-dimensional coarsening and shoaling upwards succession dominated by wave-formed sedimentary structures. Yet this model is just one end-member in a continuum of shoreface and delta front models, which reflect fundamental differences in shoreline processes, energy level and textural character.

We interpret abundant upward coarsening successions in the mid-late Miocene Belait Formation, eastern Baram Delta Province of NW Borneo, to reflect mixed-process storm- and river-flood influenced delta front deposits. High rates of sediment input attributed to combined fluvial and storm influence, is reflected in the pervasive 0.5–2 m-thick, very-fine grained sandstone beds. The abundance of swaley, to locally hummocky, cross-stratification, with exquisitely preserved mm-scale laminae, and internal discontinuity surfaces indicates repeated erosion and deposition during predominantly aggradational sedimentation. In addition, there is significant anisotropy within the swaley cross stratification, indicating a subordinate unidirectional flow acting with the inferred dominant oscillatory storm-generated component. Common mud drapes at the top of beds/bedsets and the observed gradients in ichnofauna diversity and abundance attest to a return to ambient, low-energy conditions. In some cases, angular carbonaceous material, including cm-scale wood clasts, indicate minimal reworking of fluvial-derived sediment. As large tropical storms invariably cause both increased fluvial discharge and sediment delivery ('storm floods'), as well as increased wave energy, we propose a combined storm-dominated and fluvial-influenced delta front environment.

This is further supported by the size and frequency of erosional gutter casts that commonly define the bases of these beds. These features are uniquely abundant throughout the study area and display both exceptionally large dimensions, with thicknesses up to 2 m and widths >10 m, and a wide range of geometries. Isolated gutter casts, often up to 1–2 m deep, occur with steep to overhanging walls. The abundance, dimensions and wide-variability of gutter casts observed is unlike those documented in traditional wave-dominated shoreline successions and also attests to high-energy, erosive storm-flood flows with large sediment supply. We suggest the basinward progradation, coalescence of several small delta fronts, which may show updrift versus downdrift asymmetry, are responsible for a 'ragged blanket' of river- bypassed sand. Subsequent marine reworking may increase lateral sand continuity resulting in more typical 'shoreface-like' successions.

RELATIONSHIPS BETWEEN FLOODPLAIN AGGRADATION RATE AND FLUVIAL ARCHITECTURE: RESULTS OF A META-ANALYSIS AND IMPLICATIONS FOR FLUVIAL SEQUENCE STRATIGRAPHY

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The abundance, geometry and arrangement of lithosomes interpreted as the product of deposition by channels in fluvial depositional systems are commonly believed to be dependent on floodplain aggradation rate. In the so-called Leeder-Allen-Bridge (LAB) models of fluvial architecture, channel density is generally expected to increase with decreasing accumulation rate, thereby also affecting the geometry and connectedness of channel bodies. This principle dominates thinking in continental sequence stratigraphy, despite the lack of a definitive test of its prevalence in the rock record. Here, we study relationships between floodplain aggradation rate and fluvial architecture through a meta-study of architectural data from several ancient successions.

A comparative study is made based on architectural data collated from 20 fluvial depositional systems into a relational database (the Fluvial Architecture Knowledge Transfer System; FAKTS), which digitizes architectural characters of sedimentary units that sit in a hierarchical scheme. At the largest scale, FAKTS characterizes fluvial architecture in terms of depositional elements classified as 'channel complex' or 'floodplain' units; the subdivision of stratigraphic volumes into these units is partly established on geometrical criteria that aim to achieve an objective distinction of amalgamated channel bodies. Stratigraphic volumes are then classified on a range of attributes, including their average aggradation rate or the relative change in aggradation rate as compared to directly lower stratigraphic intervals.

FAKTS has been used to perform a quantitative comparison of sedimentary architectural features between various suitable depositional systems, some of which are also characterized in terms of temporal evolution. Quantities describing the proportion, geometry and connectedness of channel deposits have been analysed as a function of aggradation rates or of their relative variations, in a way that takes into account the time-scale dependency of rates of sediment accumulation.

No evident relationships are observed between accumulation rates (or variations thereof) and measures of fluvial channel-complex proportion, size or vertical connectivity (or variations thereof). These results suggest that, counter to what expected by common models of alluvial architecture, combined observations on channel-body density, geometries and stacking patterns cannot be considered as reliably diagnostic of accumulation rates, or rates of creation of accommodation. Therefore, the use of channel-body characteristics alone for the identification of high- and low-accommodation 'systems tracts' and 'settings' does not appear to be justified, calling into question fluvial sequence stratigraphy models and practices that are firmly based on the LAB-model principle.

TALK

EXPLORING THE DARK RECESSES OF THE CARBONIFEROUS SEDIMENTARY RECORD

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Fine-grained sedimentary rocks, mudstones, have been an overlooked part of the geological record and yet are an abundant sedimentary rock type, preserve key fossil assemblages and contain long-term records of climate and environmental change. The sedimentological analysis of mudstones deposited in deep water basins, on shallow-water shelves and on floodplains during the Carboniferous, has revealed a variety of facies and shed new light on mechanisms for preserving organic matter of different types and abundances. Our recent research analysing Carboniferous mudstones from UK basins suggests systematic variations in total organic carbon (TOC) content are related to the dominant delivery process (hemipelagic suspension settling vs sediment gravity flows). There is evidence that some muds deposited during significant marine transgressions may have been deposited as multiple event beds with reworking during widespread transgressions associated with glacioeustatic sea level changes. This is significant because the high sedimentation rates proposed provide a mechanism for the rapid burial and preservation of significant quantities of organic matter. There are also specific associations of thin-bedded carbonate-bearing mudstones, with high total organic carbon that were deposited during marine transgressions. These organic-rich lithologies contain hydrogen-rich kerogen type II and have a significant potential for hydrocarbon generation. This process contrasts with previous interpretations of these intervals as exclusively suspension deposits formed during periods of slow sedimentation. A comprehensive analysis of the $\delta^{13}C$ composition of sedimentary organic matter from these successions indicates that the source and delivery mechanism of the sediment contribute to the type of organic matter preserved at an individual location and this, in turn, influences the measured $\delta^{13}C$. Some of our most recent data, however, indicate that there may be significant shifts in $\delta^{13}C$ through the Mississippian and into the Pennsylvanian that may provide information about the global carbon cycle during this icehouse climatic period.

RECENT SHORELINE CHANGE AND SEA LEVEL RISE AT A LAGOON-BARRIER COMPLEX, GHANA

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Lagoon-wetland systems are common environments of low-lying coastlines. They are often separated from the sea by beach barriers or bars that receive sediment through long shore currents. The barriers/bars are susceptible to erosion related to sea level rise and extreme sea level rise events. The Muni-Pomadze lagoon in Ghana is a protected Ramsar site and presents an opportunity to study how recent sea level rise has impacted a relatively undeveloped lagoon-bar system. The lagoon is separated from the ocean by a narrow beach bar, fronted by a steeply sloped beach face, which is breached at times of high discharge. Breaching creates an intermittently open connection to the ocean, which causes hydrological and physico-chemical variation in the lagoon and provides a conduit for sediment transport. Field observation, digital mapping and GIS analysis reveals that shoreline retreat and erosion is occurring along the whole barrier. GIS analysis of the current high-water (HWM) mark on the beach bar face compared to that detected on aerial images from 1972 indicates approximately 9 metres of shoreline retreat (average retreat rate of 0.22 metres per year). Maximum change has occurred at the western end, where breaching occurs, with significant erosion of the more stable bar and the development of an unstable spit. Comparison of GIS data for 2014 with topographic map data from 2005 reveals that the bar has decreased in length by 36 metres during this time. Wash-over fans along the length of the bar are evidence that sediment from the beach face has been transported lagoonwards, effectively shifting the beach-bar landward. Location of fans appears to be stable with similar washover locations evident in 1972 and 2014 images. Other sediment probably enters the eastward-moving long shore current transport system. Model projections for a one-metre rise of sea level reveal fragmentation and breaching of the barrier and an increasingly permanent connection to the ocean, creating a more open estuarine environment.

TALK

THE LATE DEVENSIAN GLACIAL HISTORY OF THE WEST SHETLAND MARGIN: A STORY OF MULTIPLE ICE ADVANCES, SLOPE INSTABILITY AND BED ROCK CONTROL

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The continental margin in the area west of Shetland was subjected to repeated and extensive ice sheet advances during the Late Pleistocene. Geophysical and borehole core data held by the British Geological Survey (BGS) suggest the Late Devensian ice sheet on the continental shelf west of Shetland underwent two phases of expansion to the shelf edge. In addition, a late phase of localised expansion occurred during the last major retreat from the shelf edge. This reworked much of the earlier glacigenic sediment sequence, generating large moraine banks and burying features on the shelf beyond.

Deposits on the inner shelf are limited to thin sediments from the last retreat together with exposed bedrock surfaces. On the mid to outer shelf, extensive glacigenic deposits are preserved, especially where there are local shallow basins. Sediments include lodgement tills, melt-out and water-lain till sheets and a series of recessional and terminal moraines. Towards the shelf edge, these deposits can be separated into two phases. At the shelf edge, there is a transition from the till sheets and moraines of the shelf to glacigenic debris flows which dominate deposition on the upper and middle slope. Deposition on the lower slope is marked by either large debris flow lobes of glacigenic sediment or thin glacimarine muds deposited from suspension.

The scarcity of tills and moraine banks in the shallower areas of the inner and mid-shelf is closely related to underlying bedrock type. Acoustic survey data indicates that where rocks of sedimentary origin are present, the seabed is comparatively smooth and the sediment cover is of glacigenic diamicts and muds. In areas underlain by high grade gneiss, the acoustic profile is generally rough or irregular and sediment cover is very thin or absent.

The large moraine banks associated with the third ice expansion lie just beyond the western margins of the gneiss exposure and their formation is interpreted to be the result of the release of basal friction between the ice and gneiss bedrock. This was probably caused by increased buoyancy provided by rising sea-levels as the overall ice retreat progressed, allowing a rapid, but local advance which pushed previously deposited sediment in to the large preserved mounds.

INTEGRATING MICROFACIES TYPING AND RESERVOIR PROPERTIES IN THE HAYNESVILLE–BOSSIER SHALE, USA

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The Haynesville-Bossier Shale in Western Louisiana and Eastern Texas continues to be a major target for shale gas exploration with the USGS estimating a gas resource of up to 75 tcf. The study documents petrographic and mineralogical observations from one basin margin and two basin centre Haynesville-Bossier cores. It includes samples from silica-, carbonate and organic-rich sections to develop a microfacies scheme. From this scheme, a study of the petrophysical and reservoir characteristics of each microfacies is undertaken with the aim of understanding the contribution of microfacies units to larger-scale reservoir structure and properties.

The detrital assemblage within the studied samples comprises quartz, feldspars, clay minerals and bioclastic grains. Brachiopods, bivalves, foraminifera, peloids and undifferentiated bioclastic debris are present in most microfacies. The five microfacies present are: (i) clay-rich siltstone (>50% silt content), (ii) silt-rich mudstones (20–50% silt), (iii) silt-bearing mudstones (5–20% silt), (iv) clay-rich mudstones (<5% silt) and (v) cement-dominated mudstones. Clay-rich siltstones account for 8% of the studied samples and consist primarily of silt-size quartz and feldspar grains, with a significant proportion of fine-grained matrix composed primarily of clay minerals. Silt-rich mudstones (59% of samples) and silt-bearing mudstones (21% of samples) are similar in terms of composition: silt-size quartz and feldspar, clay minerals, brachiopods, bivalves, foraminifera and clay- and silt-rich peloids. The key distinction between the two facies is that the silt-rich mudstones contain more silt. Clay-rich mudstones (3% of samples) generally occur as thin (<50 cm) isolated sections in core. They are comprised of a very fine-grained groundmass of clay minerals, clay size lithic grains and bioclasts. Cement-dominated mudstones (9% of samples) occur as thin units (<50 cm). The cemented units replace primary sedimentary features and are composed variably of apatite-cored pyrite, calcite and dolomite cements.

Petrophysical analyses of representative microfacies samples indicate differences in the characteristics of each microfacies. These characteristics will impact the production, storage and transport of gas on both geological and production timescales. Using a microfacies approach to understanding the behaviour of shale gas reservoirs may enable the development of predictive models for reservoir characterisation.

TALK

VOLCANIC FORCING FROM TWO SIDES: DRAINAGE AND PLANT ECOSYSTEM DEVELOPMENT IN THE COLUMBIA RIVER FLOOD BASALT PROVINCE, WASHINGTON STATE

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Large Igneous Province (LIP) volcanic activity has been implicated to have had significant environmental effects throughout Earth's history. However, the impact that LIP evolution has had on drainage and plant ecosystem development in the immediate vicinity of volcanic activity is poorly constrained. Here we present an integrative approach to better understand the relationships between LIP volcanic activity and inter-lava field drainage and plant ecosystem development in the Miocene Columbia River Basalt Province (CRBP), Washington State.

The CRBP stratigraphy comprises numerous basaltic lava flows which are intercalated with fluvio-lacustrine sediments formed during periods of volcanic quiescence. These interbed intervals become longer as volcanic activity wanes during CRBP LIP evolution. Detailed facies analysis of the sedimentary interbeds indicates intra-basaltic establishment of fluvial systems associated with various types of lacustrine and wetland settings. The distribution of sedimentary settings and pattern of drainage development is reflected in CRBP effusion frequency, and correlates with lava field topography and lava flow emplacement patterns.

The vegetation that inhabited the fluvio-lacustrine environment is expected to reflect drainage development and to become more mature during longer volcanic hiatuses. The palynological record of the sedimentary interbeds however shows that plant succession does not correlate with CRBP evolution. The analysis of pyroclastic deposits within the interbeds and sediment geochemical investigations suggest that plant succession in the CRBP was largely controlled by extrinsic volcanism of the Yellowstone hotspot.

While CRBP LIP evolution had significant impact on drainage system development and the distribution of sedimentary settings, it has less influence on the intra-basaltic plant ecosystem. Response of the CRBP palynoflora to Yellowstone hotspot volcanism demonstrates that intra-LIP vegetation may be largely controlled by extrinsic forces, and argues against global climate and environmental changes solely driven by LIP volcanism. Nevertheless, LIP parameters and dimensions vary between individual LIPs and may modify the magnitude of environmental impact.

A THEORY FOR THE SUSPENSION CAPACITY OF GEOPHYSICAL TURBULENT FLOWS

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Suspension of sediment particles by geophysical turbulent flows is one of the most widely occurring physical phenomena at the earth's surface, yet no theory so far predicts how much sediment can be transported in suspension by wind, avalanches, pyroclastic flows, rivers, in estuaries and shallow seas, or along the seafloor into the deep oceans.

In 1937, Rouse presented a landmark solution for the distribution of suspended sediment concentration in turbulent flow over a solid wall, resulting from the interplay between kinematic dispersal due to turbulence and settling under gravity. The limitation of this kinematic approach was immediately recognized: it could not predict the absolute concentration anywhere in the flow, but merely described the relative concentration with respect to the near-bed concentration, and therefore lacked the ability to predict the quantity of sediment in suspension. In the absence of theory for this near-bed concentration, fully empeiric formulations have been used to close the sediment concentration field in suspension modelling studies. The kinematic approach with empeiric closure has been widely applied in hydraulic-, civil- and coastal-engineering, in sedimentology, and in oceanography. Bagnold regarded 'any kinematic approach to be inherently self-defeating' and argued for a dynamic approach that deduced the capacity of turbulent flows to maintain sediment in suspension from turbulent stresses and buoyancy considerations. The dynamic approach called for by Bagnold has remained all but anonymous [Leeder et al., 2005].

A new dynamic theory for the suspension of sediment is presented here; this theory predicts the infamous 'near bed reference concentration Ca' based on scale-invariant turbulence characteristics and buoyancy and gravity forces of the immersed sediment. The deductive theory performs at least equally well as fully empirical predictors of sediment concentration. Application of the theory to turbidity current flow through submarine channels illustrates how the theory facilitates new insights in sediment transport and deposition by suspension.

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LARGE VARIATIONS IN SEDIMENTARY ARCHITECTURE IN A PERMIAN SEASONAL TROPICAL, LOW-ACCOMMODATION FLUVIAL SYSTEM

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Fluvial systems are important recorders of palaeoenvironmental variables, as fluvial style, architecture and texture is highly dependent on parameters such as climate, discharge, gradient and subsidence rate. Fluvial style also has a critical importance on reservoir modelling and drainage strategies. Large variations in fluvial style have been observed in a small stratigraphic interval of Permian rocks. One of the few outcrops (c. 200 m x 10 m) of this formation has been studied using a combination of photorealistic virtual outcrops and sedimentological logs.

The lower part consists of c. 4 m thick deposits of a basal sandstone overlain by rooted, downstream-dipping inclined heterolithic stratification, interpreted as the deposits of the fine-grained, downstream part of point-bars which were preferentially preserved in a river that migrated by point bar translation. Steep and shallow lateral accretion surfaces indicate a channel width of c. 30 m and depth of c. 4 m.

The middle part of the outcrop consists of 2–4 m thick, sandy channel stories wider than the outcrop. These contain thick cross-bedded sets overlying relatively planar, downstream-dipping bar surfaces, interpreted as bars deposited in the primary channels of braided rivers. These stories contain localized intervals c. 20 m wide, with more complex bedding surfaces, and transported blocks of floodplain up to 4x1 m. These are interpreted as the deposits of secondary, or low-flow, channels in the braided rivers. In-situ floodplain deposits are preserved locally the top of some stories, but are scarce and make up much less than 5% of the deposits.

The upper part of the outcrop exposes several fluvial sandbodies c. 1 m thick and wider than the outcrop, interbedded with floodplain deposits which make up c. 40% of the deposits, and crevasse splay deposits that can be traced from the channels into the floodplain. These are interpreted as the deposits of point bars that migrated by expansion in an aggrading river system.

Translating and braided river systems and scarce floodplain are associated with steep gradients and little accommodation, while aggrading fluvial systems with extensive floodplains and crevasse splays are associated with lower gradients and high accommodation. Without larger outcrops or correlated well data, it is hard to say whether variations in fluvial styles reflect purely autocyclic variation in a complex fluvial system with high variation in discharge, or that the variation is mainly due to allocyclic (glacio-eustatic?) mechanisms.

DYNAMIC GLACIATION DURING A NEOPROTEROZOIC 'SNOWBALL EARTH' EVENT

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The Neoproterozoic Wilsonbreen Formation in the Svalbard archipelago records some of the best exposed and best preserved examples of Neoproterozoic glaciation in the North Atlantic region. The Formation has been interpreted in terms of a Snowball Earth Model which postulates complete or near freezing of the Earth's surface. Under these conditions, a distinctive advance-melt back cycle would be expected. More recently, new observations of current glacial environments and the development of new techniques have enhanced our understanding of glacial sedimentation. Therefore, excellent opportunities exist for these deposits to be re-examined and snowball earth hypothesis tested.

Lithofacies of the Wilsonbreen Formation can be grouped into distinct glacial-depositional environments (glacioaqueous and subglacial) as well as non-glacial (terrestrial, lacustrine and fluvial). Palaeo-iceflow, deduced through clast fabric analysis and the novel application of anisotropy of magnetic susceptibility (AMS) indicate that transport was dominantly N-S to NW-SE oriented during both subglacial and glaciomarine deposition. This suggests deposition in a roughly N-S orientated basin with glacier flow dominantly to the N or NW.

Our observations and results reveal a complex interchange of depositional environments ranging from non-glacial to subglacial. This architecture shares many characteristics with ice marginal locations in the modern day Polar Regions which show similar variability related to Holocene climatic fluctuations. This style of deposition could provide some challenges if a classic 'Snowball Earth' model was envisaged as, in contrast to a single advance-meltback cycle, the Wilsonbreen Formation is composed of a series of oscillations between different depositional regimes in different environments. This evidence suggest that whilst the 'Snowball Earth' hypothesis provides insight into how extreme climate perturbations can occur, a simple advance-melt back cycle cannot explain the variability and dynamism exhibited in the Neoproterozoic glacial deposits of Svalbard and instead a more complex story is evident.

CRYPTIC DELAMINATION BENEATH DISTAL HYBRID EVENT BEDS: EVIDENCE FOR LOCAL SUBSTRATE ENTRAINMENT

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Hybrid event beds (HEBS) are increasingly recognised as an important component of the stratigraphy of many deep-sea fan and sheet systems. Previous models have attributed their origin to vertical and/or longitudinal segregation of co-genetic turbidite and debritic flows in a downcurrent direction, triggered by mud acquisition in up-dip channels or channel-lobe transition zones.

Sedimentological analysis of the deep-water Cretaceous-Paleocene Gottero Sandstone (NW Apennines, Italy) has revealed large substrate delamination features at the bases of mudclast-rich HEBs in the distal sector of the basin. The delamination features are generally bedding-parallel and can be shallow (15–20 cm deep and few 10s of meters wide) or deep (c. 1–2 m deep and several hundred meters wide). Such features can remain completely undetected without a careful sedimentological analysis and bed by bed correlations, and the minimum amount of stratigraphy removed can be estimated only in a few cases where at least part of the original stratigraphic succession is preserved laterally. The deepest features are overlain by thick hybrid event beds containing large rafts derived from the underlying substrate and composed of mudstone and intervening thin sandstone beds, passing rapidly along both downstream and lateral facies tracts into chaotic or mud-clast-rich HEB debrites. Similar bed types are present in other deep-water systems (Castagnola, Marnoso Arenacea, Ventimiglia flysch, Ross Formation), usually associated with more conventional HEB types. However, their significance and association with substrate delamination has not been demonstrated before.

The field observations suggest that in the Gottero system incorporation of muddy substrate occurred when dense sandy flows were able to extend sand injections into the shallow substrate and detach large slabs, carrying them for short distances before they broke up due to sand injection and internal shearing. The substrate entrainment was therefore not due to turbulent processes that could not have picked up and carried such large rafts. Remnants of undetached sea floor 'flaps' are only occasionally preserved. Similar process at smaller scale may have accompanied the widening of tiered down-cutting surfaces seen elsewhere in the Gottero and these may have contributed smaller mudclasts to down-dip HEBs.

An angular gradient change between the proximal fan-lobe area and the distal basin plain sectors, possibly accentuated by distal basin confinement, could have promoted substrate delamination and the development of raft-bearing and mudclast-rich hybrid event beds in this and other basins.

ANTIDUNES FROM AGGRADING SEDIMENT-WATER FLOWS IN THE BELHAM RIVER VALLEY, MONTSERRAT, WEST INDIES

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Drainage catchments around active dome-building volcanoes receive primary sediment from pyroclastic flows and tephra fall during eruptive episodes and to a lesser extent during pauses in eruption. Depending on the volume and composition of this sediment, and discharge characteristics, channels may aggrade and sedimentary structures can be preserved. A camera installed to monitor a section of the lahar-prone Belham River Valley, Montserrat captured a large lahar on 13–14th October 2012. Stationary and upstream migrating trains of water-surface-waves were a prevalent feature of the flow. The wavelengths ranged from 0.3 m to 8.33 m, indicating max flow velocity of 3.6 m s^{-1}, in 1.3 m of flow. The wave behaviour varied with changing flow conditions and with the passage of bores which propagated downstream during peak discharge. When a bore approached (within ~10 m) a wave train, the waves tended to break all together generating a localised short-lived upstream surge. In the absence of a bore, waves persisted without breaking for longer, growing and diminishing in height, and breaking individually. Sometimes, breaking of individual waves triggered adjacent waves to break. Deposits from the October 2012 lahar and previous events include clast-supported gravel beds organised in lenses with sharp erosional boundaries delineated by beds of massive sand. These are interpreted as resulting from upstream migrating and breaking water-surface-waves. Transitions from upstream migration to breaking water-surface-waves is inferred from preserved trough-shaped bedsets. These are composed of a series of concave-up truncated lenses with concordant laminae that had an erosional lower boundary, cutting into low-angle downstream-dipping planar to sub-planar sand and pebble-gravel with low-angle upstream dipping laminae. The vertical and lateral changes in sediment structures and character, reflected intra- and inter- flow variations, particularly in the context of volcanic activity and sediment availability.

DEPOSITION OF DUAL-SOURCE TURBIDITES OF THE ABERYSTWYTH GRITS GROUP, WALES

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The Silurian Aberystwyth Grits Group is a deep-marine clastic sequence exposed along the coastline of Cardigan Bay, Wales. Sediment-laden gravity currents were sourced from the southwest and travelled in an arc towards the NE before gradually swinging towards north. The western margin of the extensional tilt-block basin was constrained by the steeply-dipping Bronnant Fault.

At Aberarth a 90 m thick section is exposed, gently dipping to the northeast. Facies include cm-scale thin turbidites ($T_{D,E}$), graded Bouma-type beds ~10–30 cm thick ($T_{C,D,E}$) and thicker Lowe-style and hybrid beds with a range of sedimentary structures, grading patterns and clasts. Complex beds containing large rafts of folded turbidites, termed 'prolapsed' beds in the seminal work by Wood & Smith (1959), are a defining feature at Aberarth. These metre-thick beds typically comprise (i) a basal coarse sand grading sharply into (ii) a thick region of weakly normally-graded high-matrix sand with the contorted rafts typically found towards the top, often capped by (iii) turbidite sand which may deform downwards and can detach to produce loadballs (Figure 1). Some rafts are large slabs of relatively undeformed turbidites. The ragged edges of these slabs with the adjacent high-matrix sand can be located by downstream tracking of individual beds over many tens of metres.

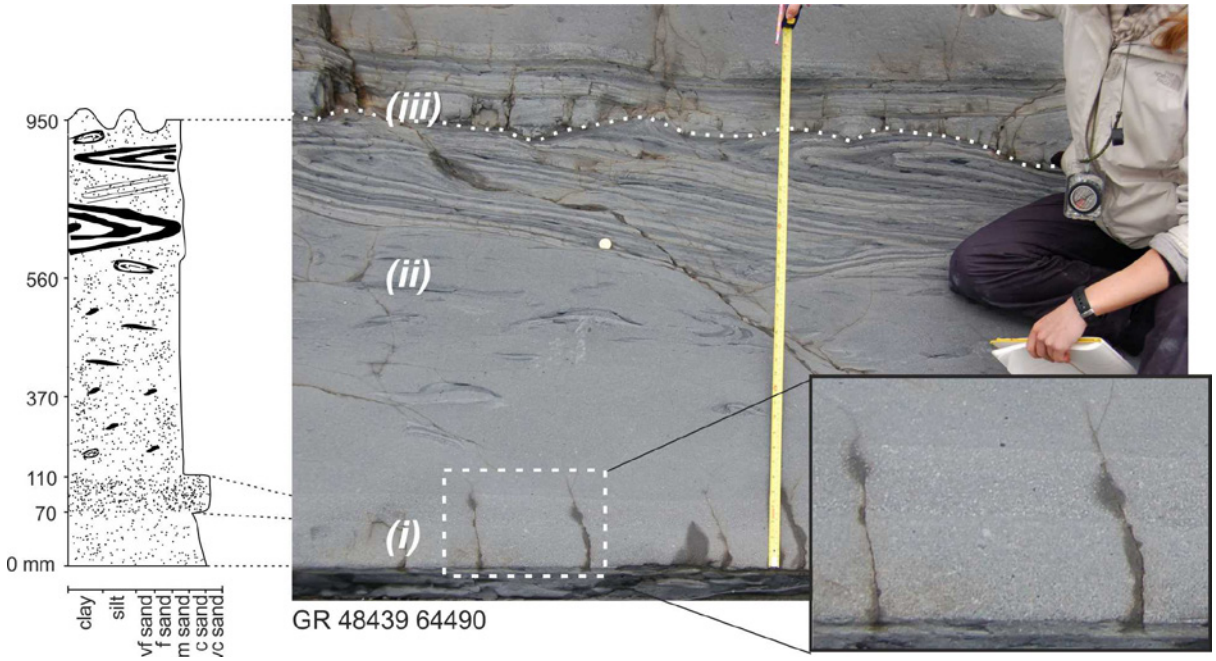

Figure 1 A complex bed with basal sand (i), overlain by raft-bearing high-matrix sand (ii), and capped by deformed sand (iii).

Sole marks and cross-lamination indicate that the basal sands, the capping sands and indeed the background turbidites are all axially-derived, flowing from southwest to northeast. In contrast, the rafts are laterally-derived from the southeast, deduced from fold hinge and axial plane measurements and assuming that the raft transport direction was perpendicular to the mean fold axis. We suggest that the rafts represent localised slides due to undercutting of the steeper western slope by the axial-flowing currents. The complex beds are thus dual-source. There is no evidence that the capping sands are part of the same flow event: they are more likely to have been deposited later over uneven topography and/or deformed under gravity. Without the rafts, the complex beds resemble many of the background beds, and would perhaps be interpreted as standard fine-grained turbidites representative of the Lower Palaeozoic. The lateral variability of a single complex bed—from deformed rafts, into tabulate undeformed raft, then into high-matrix sand—illustrates the potential perils of interpreting turbidites from core. These three examples would lead to very different conclusions.

TALK

LATERAL VARIABILITY IN STRATIGRAPHIC TRANSITION FROM OPEN SHELF TO NON-MARINE DEPOSITION ALONG A 70 KM STRIKE TRANSECT,TANQUA DEPOCENTRE, KAROO BASIN, SOUTH AFRICA

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The precise stratigraphic transition from open shelf conditions to non-marine environments can be difficult to constrain despite very different depositional processes in operation. This is further complicated by lateral changes in coastal configuration. However, resolving the transition is important to understand how the process regime of basin-margins evolves in space and time.

In the Tanqua depocentre, Karoo Basin, South Africa, a 200 km-long NW-SE continuous exposure through a 500 m thick basin margin succession permits the study of lateral changes in stacking patterns and facies variability. Nine 500 m-thick logged sections spaced 4–15 km apart along a 70 km outcrop belt were measured, and correlated with field observation and detailed panoramic photopanels. More than 2700 sedimentological measurements show a dominant N-NW unidirectional value in the lower part that changes to NE in the upper part of the stratigraphy with a dominant E-W to NE-SW bidirectional trend (symmetrical ripple crests). These observations confirm that the section is strike to oblique-strike oriented.

The overall coarsening-upwards trend in the 500 m-thick interval of interest indicates a shallowing-upwards succession. The lower stratigraphy is dominated by thin-bedded sandstones, siltstones and claystones that form at least six ~25 m-thick coarsening upward units. These are interpreted as slope turbidites and as hyperpicnites with distal mouth bar deposits, which are overlain by a 50 m-thick highly aggradational similar succession that are locally cut by scours and channels. The second major cycle show higher lateral-variability and are composed of 5–15 m-thick cycles that coarsen/thicken upwards with the top showing a fining/thinning upward trend. Cleaner sandstones, with convex-up lamination, and wave ripple top thin beds indicate wave-dominated deposition. Widespread soft-sediment deformation is common. The upmost studied succession contains channel-forms with cross-bedding that incise into green, dark blue emerald and purple mudstones with tabular climbing ripple laminated sandstones, interpreted as a delta-coastal plain and fluvial succession with splays and floodplain fines.

The Tanqua-Karoo succession is interpreted as a record of a relatively abrupt transition from mixed-influence shoreline systems to marginal and non-marine deposits in a moderate to high latitude non coal bearing setting. As such this study provides an alternative outcrop analogue to constrain architectural heterogeneities in paralic reservoirs.

CLIMATIC CONTROLS ON DEPOSITION WITHIN PROXIMAL CONTINENTAL BASIN MARGINS

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Proximal alluvial fan environments are long-lived throughout the evolution of continental basins, and often interact with segregated and archetypal arid continental environments within the distal extent of the basin. Alluvial fan deposition is influenced by varying autogenic and allogenic controls, including variations in tectonics, climate, sediment supply and base level. Of these, climatic cyclicity affects deposition consistently throughout the proximal to distal extent of the basin. The interaction between the alluvial fan and contemporaneous deposits in the distal extent of the basin can affect basin-scale fluid flow, and can lead to; 1) pathways that connect isolated distal reservoirs 2) thief zones away from potential reservoirs 3) a bypass to charge these potential reservoirs or 4) an introduction of additional seals into the system.

The alluvial fan sediments of the Permian Cutler Group are well exposed in the Paradox Basin, Utah, western U.S.A. The Cutler Group sediments grade from alluvial fan deposits in the proximal basin, through to contemporaneous deposits of typical continental environments in the distal extent of the basin. The zone of interaction between the proximal and distal parts of the Paradox Basin is informally referred to as the 'Arkosic Facies'.

Longer-term allocyclic changes in climate are identifiable throughout the deposits of the distal part of the Paradox Basin. The signature of these allocyclic changes are overprinted by shorter-term autogenic alterations through both the alluvial fan deposits of the Cutler Group and the zone of interaction. The observed sedimentary response of these depositional systems to climatic change allows identification of correlatable horizons throughout the proximal extent of the Cutler Group. Recognising the climate-driven sedimentology can aid in the prediction and correlation of subsurface stratigraphy at a basin scale to understand potential flow pathways throughout the alluvial fan and the zone of interaction.

This research has falsified the general assumption that these basin margin clastic bodies are relatively impermeable, by highlighting a complex network of flow conduits and pathways. The work demonstrates that the analysis of both the longer-term allocyclic and short-term, fan-scale, climatic cyclicity can help map potential flow zones through basin margin deposits and has application within lesser exposed basins, such as the Brockram Facies of northern England.

TALK

STRATIGRAPHIC RECORD OF RIVER-DOMINATED CREVASSE SUBDELTAS WITH TIDAL INFLUENCE (LAJAS FORMATION, ARGENTINA)

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Crevasse subdeltas develop on modern river-dominated delta plains, and may be affected by the interaction of river currents and marine processes. However, their sedimentology and stratigraphic architecture is poorly-constrained leading to simplistic depositional models of delta plain systems in the ancient record. Extensive exposures of the Middle Jurassic Lajas Formation permit the architecture, main stratigraphic surfaces, and lateral and vertical facies variations of crevasse subdelta deposits to be constrained. Lower delta plain successions studied in the Lajas Formation consist of up to 5 m thick distributary channels and interdistributary bay deposits, interpreted as crevasse subdeltas. Crevasse subdelta deposits in the Lajas Formation consist of small-scale lenticular units (~1–2 m thick) interpreted as crevasse channels and upward coarsening/thickening packages (~2 m thick) with clinothems interpreted as crevasse mouth-bars. These deposits preserve interbedding of coarser and finer sediments that are interpreted as river flood and interflood couplets associated with variations in river discharge. River flood beds are commonly structureless, erosionally based and show little evidences of tidal action and brackish water conditions. Interflood deposits show rhythmically distributed mudstone drapes, bimodality and brackish trace fossils. This study highlights an important, but largely undocumented component of interdistributary deposits consisting of tide-influenced, but strongly river-dominated, prograding depositional bodies. An implication is that some coarsening upward, forward accreting, units previously interpreted from the rock record as inter-channel 'tidal bars' may instead represent minor mouth-bars of tide-influenced crevasse subdeltas. Furthermore, present-day crevasse subdeltas are restricted to river-dominated delta systems that flow into semi-enclosed or enclosed seas and lakes with microtidal conditions and limited wave action, which is comparable to paleogeographic reconstructions for the Neuquén Basin during the Middle Jurassic.

BACK-FLOW RIPPLES: CONTROLS ON THEIR FORMATION

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Back-flow ripples are formed downstream of dunes and unit bars by the return flow within flow-separation zones and can be preserved in the rock record. Back-flow ripples were generated in the lee of unit bars within a recirculating flume. They formed over a wider range of mean flow velocities than previously suggested, notably occurring at lower minimum flow velocity than anticipated.

Wavelet analysis (to identify periodicity within time series) of velocity time series recorded within the flow separation zone identified peaks in normalised power close to the periods associated with three processes: vortex shedding, wake flapping and migration of superimposed bedforms (causing changes in the separation zone size and turbulence intensity). The influence of these three processes was less pronounced outside the flow separation zone. High speed packets generated by these three processes control back-flow ripple development at lower mean flow velocities, whereas at higher mean flow velocities they are the primary cause of back-flow ripple wash out. These processes control both ripple persistence and morphology.

Back-flow ripples form over a wider range of flow conditions in association with unit bars than in association with dunes. This is because of differences in the conditions in which unit bars and dunes form and because of the time taken for these bedforms to adjust to changing flow conditions. With unit bars flow unsteadiness can lead to variations in deposits in the lee and flow along their downstream troughs may be more common than with dunes, influencing the formation and orientation of back-flow ripples.

GLOBAL CLASSIFICATION OF SHALLOW MARINE SYSTEMS

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Shallow marine systems are traditionally classified on a ternary diagram that compares the relative importance of tidal, wave and fluvial processes at the coastline. The different processes produce markedly different shoreline types with distinct sandbody geometries, which in turn have a significant impact on hydrocarbon reservoir performance. The advent of modern remote sensing data (GoogleEarth and similar) has revolutionsied modern analogue studies allowing reservoir geologists to very quickly access high quality satallite imagary of depositional systems which can be used to improve reservoir models of the subsurface. Identifying the correct analogues remains a challenge.

Global data on mean wave height and mean tidal range have been combined with estimates of fluvial discharge from watershed analysis to classify the World's coastline in 5 km increments by dominant and secondary process. This database can then be filtered by parametres such as climate, latitude and tectonic setting to identify potential reservoir analogues.

The data can also be analysed from a more academic perspective. The first order classification is whether the shorelines are erosional (rocky shorelines) or depositional. 36% of the Earth's shorelines are depositional. Within the depsotional shorelines 65% are wave dominated of which 8% are fluvial influenced and 14% are tidally influenced. 34% of shorelines are tide dominated of which 4 and 11% are fluvially and tidally influenced respectively. Fluvial domainted shorelines make up 1% of the global depositional coastlines.

The distribution of process appears to correlate with a variety of controlling parametres. Wave dominated systems are more common at higher latitudes and in regions with narrow shelves. A far greater abundance of tidal systems occurs close to equator. Wave dominated systems are most abundant on erosional coastalines. Extensional and foreland basins show the highest proprotion of tidal infleunce.

The database that has been compiled aloows suitable analogues to oil fields to be quickly indentified. In addition a robust emprical description of the current distribution of moden systems is the first stage towards a detailed predictive model for the ancient.

CHARACTERISATION OF GLAUCONY FROM THE SHALLOW MARINE UPNOR FORMATION, LONDON BASIN

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Glaucony comprises up to 50% of the Upnor Formation, a grey to green sandstone, of variable thickness and composition that was deposited in a shallow marine to estuarine environment, ~55.6–56.2Ma. Using morphological criteria and % K_2O, the Upnor glauconite may be defined as evolved. The absence of any trends in major element chemical composition, swelling clay content or oxygen isotopic composition, either vertically or laterally, suggests that the glaucony has been extensively reworked. This is consistent with the high proportion of glaucony that is granule fragments rather than whole granules, and with its occurrence in high-energy depositional environments. However the REE data suggests more than one source for the sediment from which the glauconite formed. The highly fractured, delicate nature of some granules indicates that some maturation of the granules has occurred *in situ*, after reworking. Oxygen isotopic analysis of Upnor Formation sharks teeth and glaucony have yielded compositions that point to a low salinity water with a temperature of 21–23°C. The variations in $\delta^{18}O$ values that do occur suggest fluctuations in bottom water temperature and or salinity. The estimated precipitation temperature range and the shallow, brackish environment of deposition suggest that there is not a clear distinction between the environmental requirements of verdine (or odinite) and glaucony (or glauconite).

TALK

INVESTIGATING THE RELATIONSHIP BETWEEN CLIMATIC CYCLES AND THE TIMING OF FLUVIAL INCISION IN THE SORBAS BASIN, SE SPAIN

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Long term fluvial incision spanning the Late Cenozoic is recorded in many fluvial systems around the world by terrace landform sequences. The incision manifests itself as inset sequences of river terraces which form terrace staircases. The timing of the onset of incision and subsequent periods of incision and aggradation are poorly constrained due to the difficulties in dating river terraces.

This study set out to investigate the relationship between climatic cycles and fluvial incision in the Sorbas Basin, SE Spain using cosmogenic exposure dating. Terrace deposits in the Sorbas basin comprise coarse clastic fluvial gravels sequences with sand lenses deposited by braided processes. Terraces can be up to 20 m in thickness and are capped by red soils and cemented calcrete crusts. There are four main terrace levels (labelled A [oldest to D [youngest]) inset into a top basin fill surface of the Góchar Formation representing 160 m of Plio-Quaternary(?) incision. Currently, the river terraces have been dated using U-series techniques producing ages of 280 Ka (Terrace B) and 100 Ka (Terrace C). However, these ages are derived from pedogenic calcretes that cap the terrace surfaces and thus represent time for soil formation after terraces have been incised. Furthermore, U-series dating is limited to ~300 Ka and therefore the application of cosmogenic exposure dating by this study provides an opportunity for a more accurate and long term absolute chronology.

Cosmogenic exposure dating involves measuring the concentration of cosmogenic nuclides ($^{10}Be/^{26}Al$) within a landform or rock surface. The cosmogenic nuclides are produced as cosmic rays (from super novas and the sun) hit the surface of the landform and interact with quartz clasts within the landform. In this project two methodologies are used, burial dating and profile dating, to date the terrace sediments. Profile dating produces a date for the timing of surface abandonment whilst burial dating provides a date for terrace aggradation. Using this time framework of long-term drainage evolution, we can explore more fully the relative controls on fluvial system development (climate, tectonics, river capture etc).

The fluvial deposits in the Sorbas Basin record 1.0 Ma of incision by the Río Aguas. The timing of aggradation and incision in the Sorbas basin has been linked to both tectonics and climate cycles. The abandonment of terrace surfaces has been linked to both warming transitions and interglacial periods.

NOVEL APPROACH TO DEALING WITH THE HARDENING OF A CLAY-GRADE LIMESTONE: THE CHALK OF EASTERN ENGLAND

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The regional hardening of the late Cenomanian to early Turonian Chalk of the Northern Province of eastern England has been investigated by examining the pattern of trace elements and stable carbon and oxygen isotopes in the bulk calcite of two extensive and stratigraphically adjacent units each 4 to 5 metres thick of hard chalk in Lincolnshire and Yorkshire. These units are separated by a sequence, 0.3–1.3 metres thick, of variegated marls and clayey marls. Modelling of the geochemistry of the hard chalk by comparison with the soft Standard Louth Chalk, combined with associated petrographic and geological evidence, indicates that (1) the hardening is due to the precipitation of a calcite cement, and (2) the regional and stratigraphical patterns of geochemical variation in the cement are largely independent of each other and have been maintained by the impermeable nature of the thin sequence of the clay-rich marls that separate them. Two phases of calcite cementation are recognised. The first phase was microbially influenced and did not lithify the chalk. It took place predominantly in oxic and suboxic conditions under considerable overpressure in which the Chalk pore fluids circulated within the units, The second phase of calcite precipitation was associated with the loss of overpressure in late Cretaceous orTertiary times as the result of fault movement in the basement penetrating the overlying Chalk and damaging the seal between the two chalk units. This greatly enhanced grain pressures resulting in grain welding and pressure dissolution, causing lithification with the development of stylolites, marl seams, and brittle fractures. Associated with this loss of overpressure was the penetration of the chalk units by allochthonous fluids, rich in sulphate and hydrocarbons, derived probably from the North Sea Basin.

TALK

THE THREE-DIMENSIONAL ARCHITECTURE AND DEPOSITIONAL ENVIRONMENT OF THE JURASSIC KAYENTA FORMATION, PARADOX BASIN, UTAH, USA

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Fluvial systems are known to make good hydrocarbon reservoirs (Leman sandstone, SNS; Raude Member of the Statfjord Fm and the Skagerrak Fm, Viking Graben). Meandering and braided systems, typically those accumulating clean, homogeneous sand-bodies with laterally extensive alluvial plains tend to be the standard models used, resulting in little attention being paid to systems containing more abnormal sediment loads, where stream capacity is at, or near its limit. Thus there is a need to create non-standard models based on more atypical systems, such as those displaying a more 'flashy' nature of deposition, such as that exhibited in ephemeral systems.

The Jurassic aged Kayenta Formation located in the Colorado Plateau is known to be an ephemeral to perennial braided river-system with highly mobile channels which accumulated in semi-arid to arid settings. The Kayenta Formation is dominated by sandy facies in the proximal section to the east (Utah and Colorado), becoming progressively more argillaceous towards the distal fringes to the west, into Nevada and Arizona. Outcrops of the formation within the vicinity of Seven-Mile Canyon along the UT-313, north of Moab, Utah – which is situated within the proximal portion of the palaeodrainage basin – were investigated with regards to facies type, facies associations and architectural elements, with the aim of ascertaining the formation's three-dimensional architecture and in order to model spatial and temporal changes.

Detailed sedimentological logs and interpreted photo-panels were used to measure changes in palaeocurrent direction and architectural element sizes throughout the Kayenta in order to draw up three-dimensional schemes.

The work presented details how the Kayenta Formation was deposited by a 'flashy' ephemeral regime, rather than perennial regime, which is evident from the frequently occurring mud-drapes deposited during the waning phases of floods and soft-sediment deformation, caused by rapid loading of water-saturated sediments by subsequent flood deposits. The fluid's capacity limit is often reached during these flooding events, leading to preferential deposition over erosion, with argillaceous material being deposited during the waning flood stage creating partitions between sandier bedforms. These partitions can come in the form of vertical baffles as laterally extensive draping argillites and horizontal baffles in the form of mud-drapes on bar-forms or dune-forms. Where erosion takes place however, these divisions may be scoured sufficiently to restore connectivity between sandy elements.

The Kayenta Formation can be used as an analogue to model interconnectivity of architectural elements within hydrocarbon reservoirs deposited by similar fluvial systems, where interplay between accumulation of argillaceous baffles, and interceding erosive events can create complex connectivity scenarios between adjacent sandy architectural elements.

FACIES ANALYSIS AND FLOATATION EXPERIMENTS FROM AN UNUSUAL BED OF PUMICE LAPILLI-AND-ASH OFFSHORE MONTSERRAT (IODP 340)

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An unusual 1.2-m-thick bed of pumice lapilli-and-ash occurs at ~122 mbsf at Site U1396, IODP Expedition 340. The substantial thickness and unusual facies of this interval on a bathymetric high brings questions on how it was erupted, transported, and sedimented. The pumice lapilli is ~4 Ma, unconsolidated, and is present with the exact same facies in both Holes U1396A and U1396C, separated by only 40 m laterally. The pumice lapilli-and-ash interval is stratified into two main units, named 1 and 2 upward stratigraphy, and subtly differ in colour, grading, componentry, fines content, and grain size distribution. Unit 1 is clast-supported, whereas unit 2 is matrix-supported and is further subdivided into several sub-units, some of them entirely made of ash. Both units contain the same types of clasts, with abundant sub-angular pumice clasts, glass shards, crystal fragments, lithic clasts and foraminifer tests. Componentry shows perfect density grading, with increase of pumice clast content to the expense of crystal fragments up stratigraphy. Lithic clasts occur everywhere apart from the uppermost part of the interval; coarse lithic clasts are restricted to unit 1. Foraminifer tests occur at the base of unit 1 and in the uppermost part of unit 2. The coarse clasts are dominated by pumice, with subdominant crystal fragments. Crystal fragments are dominant in the fine fraction. The pumice glass shows homogeneous dacitic composition, and Pb isotopes suggest a Soufriere Hills (Montserrat) origin. Weighing, SEM and micro-tomography data on pumice clasts reveal a high porosity, two types of bubble size distributions and that most vesicles are extremely small (<20 um). Floatation experiments at 20°C show unusually high rate of waterlogging, and a correlation between floatation time and clast porosity, in contrast to published data that correlate with clast size. Interestingly, the floatation time of these pumice clasts correlates with clast size length for hot (600°C) floatation experiments. The pumice lapilli-and-ash interval has a clear pyroclastic origin, however the vent water depth, and transport and sedimentation processes associated with this interval remain poorly constrained. Several preliminary contenders are proposed: (1) proximal deposit derived from density currents and submarine pyroclastic fall from an unconstrained submarine volcano; (2) submarine density currents originated from Montserrat seamount; (3) submarine density current derived from pyroclastic flows sourced on Montserrat island; (4) Montserrat island-sourced pyroclastic surges that travelled over water, followed by suspension settling and transport by vertical density currents that swept laterally on the sea floor.

TALK

FLOW EVOLUTION AND SEDIMENTATION PROCESSES ACROSS FINE-GRAINED DEEP-MARINE LOBES AN EXAMPLE FROM THE TANQUA KAROO

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Today's ultra-deep-water subsurface exploration targets are typically associated with sedimentary systems that are up to orders of magnitude larger, and often significantly finer grained, than those of 'classical' outcrops from relatively small, coarse-grained foreland basin-fills. The Skoorsteenberg Fm., Tanqua Karoo, offers an excellent opportunity to study fine-grained deep-marine lobes in near continuous quasi-3D exposure. The spatial and stratigraphic distribution of the various facies of Fan 3 (one of the Skoorsteenberg Fm. lobe complexes) are presented and characterized to develop a picture of flow evolution and sediment transport across deep-marine lobes. The stratigraphy of Fan 3 is exceptionally well-exposed and well-constrained in distal areas, making it an ideal place to observe this variability. The dataset includes helicopter-based photomosaics, 20 measured sections, logs from cored research boreholes and 49 thin sections from oriented samples. QEMSCAN® (Quantitative Evaluation of Minerals by SCANning electron microscopy) analysis, including mineralogical and textural analysis of different bed types, was undertaken to support outcrop observations. Grain-size distributions, including quantification of clay content, can be established from these data and, in conjunction with the outcrop data, demonstrate a progressive enrichment of clay and fine grained particles towards the distal and lateral fringes of Fan 3. Predictable 'gross' spatial and stratigraphic facies distributions can be recognised, from turbidites in proximal areas to transitional flow deposits in distal areas; locally these deposits are complicated and composite. This gross distribution is here attributed to an increase in near bed flow concentration due to flow deceleration and collapse in response to flow expansion and mud entrainment; this is recorded in the deposits, from axis to off-axis positions, by increased clay content, decreased erosional capability of flows and progressively stronger internal deposit heterogeneity. The model differs from previous models as the flow transformation is thought to be highly localized, occurring due to autocyclic flow evolution in medial to distal localities. The model and quantification of flow transformation distance has important implications for estimating the spatial and stratigraphic distribution of such beds in deep-marine lobes, which in many areas form important hydrocarbon reservoirs, and for interpreting the significance of these deposits in core and outcrop datasets.

SEASONAL WETLAND PALEOSOLS OF THE BALLAGAN FORMATION IN SE SCOTLAND AND THEIR LINK TO TETRAPOD TERRESTRIALISATION IN THE EARLIEST CARBONIFEROUS

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The link between floodplain evolution and major changes in the evolution of life has become of seminal interest in recent years. New localities within the Lower Carboniferous (Tournaisian) Ballagan Formation in SE Scotland are yielding early terrestrial tetrapod fossils that provide fresh insights into this pivotal period when tetrapods first became fully terrestrialised. The TW:eed Project (Tetrapod World: early evolution and diversification), is a major research programme that is investigating the rebuilding of ecosystems in the early Carboniferous, following the mass extinction events towards the end of the Devonian. Interpretation of the coastal floodplain and related facies of the Ballagan Formation is key to understanding the palaeoenvironments in which these tetrapods lived. The paleosols can provide a wealth of information about the range of habitats present and of the palaeoclimate, as well as helping to understand the overbank sedimentary architecture.

More than 200 separate paleosols have been identified in a single, 500 m thick section through the Ballagan Formation in the Norham Borehole, sited near Berwick-upon-Tweed, UK. They range in thickness from 0.02 to 1.85 m. The types of paleosol present are diverse; most are entisols and inceptisols, indicating relatively brief development times. Gleysols and vertisols are less common (37%). The gleysols contain siderite nodules and some have O horizons containing up to 5% TOC. The vertisols are the thickest paleosols seen in the Ballagan Formation and have vertic cracks up to 38 cm in length. Evidence of rooting is abundant through all the paleosols, from shallow rootmats and thin hair-like root traces to the thicker root traces typical of arborescent lycopods. A very dynamic flood plain is inferred.

Geochemical analyses of paleosols indicate a range in soil alkalinity which has controlled the type of paleosol that formed. Estimates of mean annual rainfall from paleosol compositions are in the range of 1000–1500 mm per year. High mean annual rainfall and variable soil alkalinities alternating with the presence of deep vertic cracks and deposits of gypsum and anhydrite together suggest a sharply contrasting seasonal climate with repeated cycles of wetting and drying. The paleosol story provides a unique insight into an early Carboniferous tropical coastal floodplain and its habitats, and furthers our understanding of the evolution of fluvial seasonal wetland facies and their links to the evolution of life.

TALK

THE EFFECTS OF FLOOD-EBB FLOWS AND TIDAL BORES ON A LARGE TIDAL BAR WITHIN THE RIVER-ESTUARY TRANSITION ZONE

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All river-estuary systems contain a transitional zone between fully fluvial and fully tidal environments. This river-estuary transition zone is highly complex with fluvial and tidal currents interacting on daily, seasonal and annual cycles, which are superimposed upon each other. These varying cycles and the resultant daily shift in the position and magnitude of the transitional zone make the measurement and definition of flow processes and sediment transport often difficult to define. Quantification of these processes will allow a fuller model of the flow, sediment transport and sedimentary architecture of this complex zone to be developed.

The Severn Estuary, UK has the second highest tidal range in the world and contains a large fluvial-estuarine transition zone. The system also exhibits one of the most impressive bores in the world. The flow around a large bar located within the river-estuary transition zone, which was fully submerged at high tide, was measured in detail during a spring tidal cycle. Measurements of flow were made at the seaward end of the bar and along a central transect across the bar using an acoustic Doppler current profiler (ADCP) on a small research vessel. The fieldwork coincided with spring tides and measurements were made of the incoming tidal bore and the following flood tide, at a fixed position in the channel. An electromagnetic current meter with conductivity temperature and depth profiles (ECM+CTD) was deployed across two tidal cycles to measure current speed, conductivity, temperature and pressure at this fixed point. Finally, a total of 4 vibrocores were recovered, at the upstream and downstream ends of the bar and a further two across the central ADCP transect obtained during the flood tide. The core furthest seaward was located close to the position of the current meter.

The data shows the variation of flow on the flood and ebb tides around a region of complex bed morphology, allowing the influence of flow and the tidal bore on sediment movement and deposition to be quantified. Sediment transport in the channels both around the bar and across the bar top can be compared to the flow patterns identified and the resultant deposits. These results, including the sedimentary sequences identified in core, can be compared to measurements made in other river-estuary transition zones.

HETEROGENETIC COMPACTION AND DIAGENESIS OF THE FLUVIO-AEOLIAN LOWER JURASSIC ETJO FORMATION, NW NAMIBIA

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The Fluvio-Aeolian Lower Jurassic Etjo Formation forms the topmost of sedimentary unit of the Karoo Supergroup in Namibia. Key outcrops of the Etjo Formation sandstones in NW-Namibia are comprising (a) Mt. Etjo, (b) Waterberg, (c) the Erongo region and (d) the Gamsberg area, where they form pronounced plateaus. Although principal sedimentological interpretations have been made, the burial history of the Etjo Formation is rather uncertain. Classic modal analysis including point-counting, together with scanning electron microscope (SEM), cathodoluminescence (CL) and microprobe analysis of quartz cements is used for the interpretation of the diagenetic and compaction history. In the course of Triassic/Jurassic and early Cretaceous rifting episodes prior to South Atlantic opening, the Namibian margin developed a pronounced tectonic zonation. With this background, the Etjo Formation experienced heterogeneous compaction and diagenesis. Gamsberg is sitting on the Triassic-Jurassic rift shoulder whereas Mt. Etjo and Waterberg, 200-250 km farther north, are associated with an active halfgraben basin, attached to the Waterberg-Omaruru transtensional fault zone. Compaction and cementation effects include remarkable variations in grain contact types, quartz cement abundance and porosity. Gamsberg sandstone is characterized by high intergranular volumes (IGV), averaging 32 Vol.%, low OPDMC (original porosity destroyed by mechanical compaction and intergranular pressure solution), low ICOMPACT (compaction index) values (average 0,3), low amounts of overlap quartz (average 1,5 Vol.%), and floating to tangential grain-to-grain contacts. No stylolites and fractured grains occur at Gamsberg locality. The amount of overlap quartz is not in equilibrium with quartz cement volumes and therefore characterizes the Etjo sandstones as silica importer. Low average porosity values of 3.3 Vol.% are related to remnant intergranular porosity besides less important feldspar dissolution porosity. Samples collected at Mt. Etjo and Waterberg are significantly different from the Gamsberg samples and characterized by lower IGV (averages 12 Vol. % and 25 Vol.%), moderate to high OPDMC and ICOMPACT values (averages 0,83 and 0,65), and tighter, dominantly tangential and sutured grain-to-grain contacts. The amount of overlap quartz (averages 5 Vol. % and 4 Vol %) is in equilibrium with the quartz cement. Preserved porosities at Mt. Etjo are as low as 2.9 Vol.% but reach up to an average of 9.1 Vol.% at Waterberg, where less pervasive quartz cementation is due to the presence of early diagenetic illitic "dust rims" that acted as inhibitors during silica precipitation. The Etjo Formation turns out as a good reservoir analogue example illustrating heterogeneous compaction and diagenesis, dependent on the geodynamic setting.

TALK

DECIPHERING SEDIMENTARY RECYCLING VIA MULTI-PROXY IN SITU ANALYSES IN THE MILLSTONE GRIT, YORKSHIRE

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Sediments and sedimentary rocks together sample large volumes of the Earth's crust, and preserve units that vary greatly in age and composition. These deposits are critical to many disciplines, including petroleum geology, crustal evolution and archaeology, so understanding the source(s) of their component minerals is fundamental to their interpretation. However, provenance determinations are complicated by the ability of some minerals to be recycled through multiple sedimentary cycles, so minerals from completely unrelated sources may end up in the same sedimentary basin. To untangle these multi-stage signals, two or more signatures measured in minerals with different stability are required, such as K-feldspar and zircon.

In situ common Pb analysis of individual K-feldspar grains from throughout the Upper Carboniferous Millstone Grit Group clearly indicate two $^{206}Pb/^{204}Pb$ isotope peaks between 12.5 and 15.5 and c. 18.4, consistent with previous work [1], and with derivation from Archaean–Proterozoic basement and Caledonian granites, respectively. The proportions of each group are unchanged throughout the sequence. *In situ* U–Pb analysis of individual zircon grains group into three main populations at c. 430, 1000–1800 and 2700 Ma. The proportion of younger ages increases up section, while the new data also indicate a much greater contribution from Archaean material than was previously observed in parts of the sequence [2]. However, *in situ* Hf model ages measured in the same zircon growth zones indicate only two broad groups at 1500–2300 and 3000–4500 Ma, making this technique too imprecise for provenance work in the N Atlantic region, but indicating contributions from both juvenile and reworked crust.

Combined, these data create a statistically significant database covering c. 14 Ma of deposition in the Pennine Basin. Ultimate source areas most likely include the Caledonian belts of Scotland, western Scandinavia and Greenland, where younger granitoids intruded older sediments and basement gneisses. The contrasting distributions of zircon ages and Pb ratios throughout the sequence reflect the different recycling potentials of labile and refractory minerals, with ramifications across many research applications. Combining these results with ongoing HMA work, as well as published garnet, monazite and muscovite data, will provide a much clearer picture of provenance routes through this tectonically and geologically complicated region, and highlights the power of multi-proxy provenance work.

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QUANTIFICATION OF SMALL-SCALE GEOBODY ARCHITECTURES IN CARBONATE PLATFORM SETTINGS USING DIGITAL OUTCROP MODELS

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The large variety of sub-seismic geobody architecture and facies distribution in many hydrocarbon reservoirs hosted within carbonate platform deposits are difficult to properly assess using the traditional combination of core, borehole logging and seismic surveys. This poses a major challenge for the industry, as such elements may be the cause of flow-controlling heterogeneities in the subsurface and thus to increased reservoir risk. To address this problem, reservoir models need to be supplemented with geometrical data from outcrop analogues. The construction and study of digital outcrop models provides a method for extracting quantitative geometrical data as well as lithological and petrophysical data on these small scale architectures. However, extracting the complex geometries that represent facies transitions (i.e. clinoforms, bioherms, biostromes and other sedimentary surfaces) from digital outcrop datasets is problematic, both due to the limited resolution of mesh data and the lack of appropriate tools to digitise 3D curves.

Here, we present an approach which utilises optical ray tracing from calibrated images to extract sub-seismic scale sedimentary architecture from Structure from Motion (SfM) derived digital outcrop models of Upper Cretaceous carbonate platform deposits exposed in the South-Central Pyrenees of Spain. This approach has many of the advantages akin to 2D interpretation of sedimentary architecture from conventional digital images (i.e. CAD based b-spline curves and edge detection), whilst producing a continuous 3D representation of contacts.

In this example of the Santonian Sant Corneli Platform, several different types of geobodies can be observed in the outcrop, including metre-scale patch-reefs, laterally extensive bioherms and biostromes, as well as several tens of metres wide grainstone clinoform bodies. These individual geobodies can be found in specific positions within the carbonate platform, as the dominating environmental parameters — including relative sea-level, water energy and carbonate producing factory — control their deposition.

The surfaces extracted using the presented method allow comprehensive quantitative interrogation of the sedimentary architecture of such sub-seismic geometries, enabling bedding orientation, bed thicknesses and their lateral variation to be constrained. Together with geological interpretations made in the field and petrophysical data gained through sample analysis, this quantitative data can be integrated into future stratigraphic and seismic forward models, which help to optimise subsurface reservoir models and to better understand the spatial distribution of the small-scale elements present in carbonate platform deposits.

TALK

CLASSIFICATION OF HIERARCHY IN THE SEDIMENTARY ARCHITECTURE OF DEEP-MARINE SYSTEMS: A REVIEW AND A LOOK FORWARD

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The main purpose for a hierarchical classification of sedimentary architecture is to aid the user's ability to interpret a depositional system through its division into discrete units, which can then be compared and analysed against other systems. However, comparisons between deep-marine systems, and thus analogue-based interpretations, are difficult due to the range of scales of approach commonly used, as well as the growing disparity of terminology.

For example, Sprague et al., (2005) liken their seismic-based hierarchy to the sequence stratigraphy framework as well as Mutti and Normark's (1987) outcrop-derived hierarchical scheme, but problems arise when independently comparing Mutti and Normark's scheme against the sequence stratigraphy framework as inconsistencies are shown with Sprague et al.'s hierarchical comparisons. Furthermore, otherwise similar Exxon-funded seismic studies made by Sprague et al., (2005) and Campion et al., (2011) on confined basins in West Africa show a lack of coherence in their nomenclature, irrespective of their similarities. These problems are not exclusive to these studies but have been shown to be mirrored across deep-marine hierarchical classifications through a detailed review of common terminology and classification methodology. This lack of translation that exists between classifications complicates and limits the ability for reliable analogues to be identified, inhibiting data sharing and thus bringing to question the efficiency of such schemes.

All deep-marine hierarchical classifications do share the same basic criteria to denote their hierarchical orders, criteria also utilised by the sequence stratigraphy framework. The central focus to all deep-marine classification systems is also based around the 'architectural element' and the relationship this has with the rest of the depositional system in regards to the scale of the study taking place. Thus, the focus of a classification system becomes a function of the types of data collection methods used relative to the architectural element, which therefore determines the classification style displayed. For example seismic-based hierarchical classifications focus around the large-scale stacking patterns of seismically resolvable architectural elements, while outcrop-derived hierarchies focus on the facies associations within architectural elements.

Therefore, the need for a hierarchical classification that can be easily applied to all scales of approach avoiding overcomplicated terminology could be resolved through a directed focus on the universally applicable architectural elements and the familial relationships it displays within a depositional system. Recognition of a common thread throughout all systems would then permit the growth of multi-analogue studies as a standard way of storing and analysing data, pushing interpretation.

NEW EXPERIMENTAL APPROACH SHOWS MORPHODYNAMICS AT THE INCEPTION OF A SUBMARINE CHANNEL

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Submarine channels form efficient conduits for sediment transport from the continental margins to the deep oceans and they are ubiquitous on continental slopes that are traversed by turbidity currents. The inception and further evolution of these channels is a result of interaction between flows and the seafloor. Comprehensive datasets that record both the morphological evolution and the flow field in nature are not available because of the remote location, the infrequent occurrence of turbidity currents and the relatively long timescales involved in morhodynamics. The laboratory provides a controlled environment in which flow and bed evolution can be monitored in great detail. However, realistic depositional geometries associated with channels were not produced in most previous work because of scaling issues. Here we apply Shields scaling, which consists of two additional scaling constraints that ensure that experimental flows are able to bypass most of their sediment on an unconfined slope and are able to re-entrain sediment from the bed. In order to fulfil the scaling requirements, we use steeper slopes, higher sediment concentrations and coarser sediment than in most previous experiments.

A suspension with sand-grade sediment (D50=135 microns) was released onto an 11 degree featureless slope. The first current deposited two sub-parallel ridges. During the subsequent runs, the confinement relief grew due to further deposition on the ridges. In addition, the confinement is deepened by erosion in between the ridges. Velocity measurements using four UVP probes indicate that the current was strongly influenced by the evolving topography: As the confinement relief grew, the axial flow velocity increased while the flow velocity outside of the confinement decreased. Comparison of bathymetric surfaces and flow dynamics illustrates that erosion of the channel floor was only initiated in the second run after initially aggradational confinement contained the flow up to the velocity maximum.

From the experimental results a model for the early stage of submarine channel evolution is derived. First, a low-relief, high-aspect ratio confinement is created by deposition from a flow which is relatively uniform along its width. Second, the partially confined flow starts to erode in the centre of the confinement. Finally, both erosion in the axis and deposition on the sides contribute to the increase in channel relief resulting in further flow confinement and increasing erosion rates in the channel axis.

TALK

THE EFFECTS OF MIXED COHESIVE AND NON-COHESIVE SEDIMENT PROPERTIES AND HYDRODYNAMICS ON RIPPLE MIGRATION IN THE INTERTIDAL DEE ESTUARY

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Accurate sediment transport models are essential for the management of coastal erosion, maintenance of navigation channels and understanding the impacts of climate-induced habitat change. Many of these coastal environments are dominated by mixtures of sand and mud. While reasonable sediment transport predictors are available for pure sands, this is not the case for mixed cohesive and non-cohesive sediments. Existing predictors mostly use a median sediment grain diameter, assuming a narrow unimodal particle size distribution. Under natural conditions, deposited beds may be comprised of mixed sediments affected by both physical and biologically-mediated cohesion (biogenic stabilisation).

This natural complexity severely limits the applicability of standard predictors. Indeed, recent laboratory experiments mixing cohesive and non-cohesive sediments and adding bacterial polymers as a proxy for natural biogenic stabilisation have shown that bedform dimensions decrease with increasing bed clay content and that the bedform development rate is reduced by biological action. In the field, it is expected existing predictors will match data for well-sorted sands closely, but will be inaccurate for mixed sediments containing cohesive sediments and natural biota. This paper reports on an extension of laboratory work to examine mixed sediments in the field.

Over a two week period, 21 May to 4 June 2013, a field study was carried out on tidal flats in the Dee Estuary, on the NW coast of England. As part of the fieldwork, a suite of instruments was deployed collecting co-located measurements of the hydrodynamics and bed morphology. The instruments occupied three sites across the tidal flats. Site 1 was located higher on the intertidal flats than site 3, and site 2 was the lowest and located in a creek. The experiment covered a tidal cycle from springs to neaps, and the weather during the sampling window provided onshore and offshore winds of varying strength.

Bedform measurements were taken every half an hour using an Acoustic Ripple Profiler that covered an area of about a 10 m^2. Dynamic measurements of tides and waves were made using an Acoustic Doppler Velocimeter at 8 Hz. Bed sediment samples were collected for laboratory particle size analysis when the tidal flats became exposed at low water.

This paper will present results that show comparisons of ripple migration, under different hydrodynamic conditions, with measurements of the percentage of bed mud content. The aim is to assess how the bed dynamics of ripple migration are affected by cohesive sediment.

ARE FLUTE CAST-LIKE STRUCTURES IN THE BOOLEY BAY FORMATION (CAMBRIAN, IRELAND) FORMED BY DOWN-SLOPE CREEP OF MICROBIALLY-BOUND SEDIMENT?

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The Booley Bay Formation is a Cambrian deep marine succession in south-eastern Ireland. In the type area at Booley Bay, the succession primarily consists of a mixture of well-sorted and poorly-sorted siltstones interbedded with grey mudstones (Fig. 1A). Coarser poorly-sorted sandstone beds are also present, including some containing rolled-up coherent fragments of laminated bedding resembling 'Swiss rolls' (Fig. 1A–B), with long axes parallel to the palaeocurrent direction of siltstone deposition. Metre-scale black mudstone horizons also occur.

Previous interpretations regarded the Booley Bay Formation as distal turbidites. Instead, we interpret the sandstone beds as downslope debris or slurry flows, with siltstones and grey mudstones reflecting contourite-modified turbidite deposition, and black mudstones representing hemipelagic deposition during periods of contour current inactivity. Wrinkle textures, scratch circles, organic tool marks and other common sole structures suggest that the substrate was firm, and probably microbially bound.

One curious set of structures on well-sorted siltstone bed soles are palaeocurrent-parallel tubular-like forms, generally 10–30 mm in width, 100–500 mm in length, and with up to 20 mm of positive hyporelief from the bedding plane (Fig. 1 C–E). Some appear to emerge and broaden from a point; others are of constant width along their entire length. Most examples are asymmetrical; many are twisted (Fig. 1D–E), with some approaching a Z-shape, occasionally intermingling with underlying mudstone (Fig. 1E). On at least two beds, examples are superimposed by scratch circles.

Whilst these structures have previously been figured as classic examples of flute casts, superimposition by scratch circles rules out an erosional formation. Instead, their asymmetry, twisting, and particularly intermingling with underlying mudstone, together suggest a post-depositional origin.

We propose that these represent post-depositional structures formed by down-slope creep of microbially-bound sediment on a seismically-influenced slope. Common convolute bedding in siltstones is consistent with local seismic activity; debris/slurry flows could also have been seismically initiated. In this scenario, microbial binding could have prevented full disruption, suspension, and formation of debris flows from recently-deposited sediment. However, reduction in bed stability due to seismic tremors may have allowed gravitational forces trigger limited downslope motion. As motion initiated, the differences in sedimentological properties and rate of motion between silt and mud, combined with microbial binding, may have led to irregularities forming along sedimentological interfaces. Where instability was sufficient to initiate significant downslope motion, microbial binding may have been sufficient to retain coherence in fragments of bedding which ultimately became the 'Swiss rolls' in the debris/slurry flow beds.


A
200mm
B
50mm
C
150mm
D
0.5m
E
50mm

GIANT RAFTED PUMICE BLOCKS FROM THE 1.8 KA TAUPO ERUPTION, NEW ZEALAND

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An unusual sedimentary facies is exposed along a former transgressive shoreline of intracaldera Lake Taupo, New Zealand. Giant blocks of vesiculated grey rhyolite glass, or pumice, some of which are >10 m long, show complex jointing patterns indicative of both surface chilling and continued interior expansion, as well as heterogeneous vesicularity, with dense rims, grading via a transitional zone into a more highly vesiculated interior. Thermal remnant palaeomagnetic evidence indicates significant reorientation of the blocks as they cooled through a series of blocking temperatures, with up to three orientations recorded: one in the dense pumice rim; another in the transition zone; and the third in the clast interior that matches the modern geomagnetic field. The blocks are believed to be derived from one or both of a pair of rhyolitic lava domes that developed on the bed of the lake over the inferred vent area several decades after the climactic Taupo eruption.

Adjacent sediments are indicative of a transgressive shoreline depositional environment, accumulated as Lake Taupo refilled following the paroxysmal 1.8 Ka Taupo eruption. These sediments represent a shoreface succession, comprising in increasing depth-order: (i) planar-laminated, swash zone winnowed, crystal/lithic sands; (ii) tabular cross-beds formed by large-scale asymmetric ripples developed in pumice granules and fine gravel in the breaker zone; (iii) small-scale asymmetric rippled fine pumiceous sand; (iv) symmetrical rippled fine pumiceous sand; and (v) laminated and massive fine pumiceous sands containing foundered pumice clasts. Effective wave base is estimated at 8–10 m, equivalent to c. 1 year of lake level rise. Locally, sediments enclosing the pumice blocks show signs of elutriation of fines, suggesting boiling of pore water by the still-hot clasts.

Overall, the giant rafted pumices show a number of interesting features. Firstly, they are a rare example of floating rocks: mean density varies from rim (917 kg/m^3) to interior (815 kg/m^3). The prolonged floatation of such outsized clasts of hot vesiculated pumice contrasts with the rapid flooding and sinking of smaller fragments of plinian pumice under laboratory conditions. Secondly, at individual sites, the megaclasts occur over narrow elevation ranges (less than 1 m), implying emplacement during a single, short-lived stranding event. Correction for post-1.8 Ka tectonic movements and grounding-line variations suggests emplacement occurred over a few months, implying dome emplacement at a higher rate than the historically observed range for modern subaqueous rhyolite dome growth, or more prolonged dome growth and a restricted (?single) spalling event. Thirdly, these, and similar giant rafted pumice blocks in other marine and lacustrine settings raise questions about how volatile-rich felsic magma can be erupted underwater without thermal fragmentation occurring.

TALK

SOURCE TO SINK ASSESSMENT OF OLIGOCENE TO PLEISTOCENE SEDIMENT SUPPLY IN THE BLACK SEA

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Despite having at least one major river (Danube) supplying sediment into the Black Sea the presence of significant deepwater clastic reservoirs has always been viewed as the major exploration risk. Source to sink concepts have been used to examine this risk. Reconstruction of plausible palaeo-drainage scenarios combined with knowledge of the palaeogeography, climate and hinterland geology have been used to estimate palaeo-sediment budgets and provide an assessment of reservoir quality in the basin. Analysis of the basin fill interpreted from extensive seismic coverage calibrated by wells allows further refinement of the rates of sediment supply. A forward model of the basin fill has been created that successfully produces a postulated fill that matches the observed geometry of the fill of the basin.

The analysis shows that fluvial drainage into the Black Sea from the Oligocene through to the Pleistocene has been dominated by small local mountainous hinterland drainage formed in the many surrounding orogens and volcanic arcs. The resulting sediment supplied is predicted to be of low quality. Likely routes for large long lived fluvial systems draining the continental shields to the north and west include many up-dip basins on the way to the Black Sea and mean sediment entered the basin in volume only in the latest Pleistocene.

Therefore the risk of finding large volumes of sandstone in the form of large deepwater fan complexes pre-Pleistocene is high. However, smaller volume local sources forming fan-aprons may be common throughout the succession around the margins of the basin.

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DOWNSTREAM CONTROL ON FINING IN FLUVIAL SYSTEMS

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Downstream fining in fluvial systems is often ascribed to changes in upstream parameters such as sediment supply and water discharge, and relative sea-level fluctuations. Using analogue models, we examine whether basin water depth provides an additional downstream control on fluvial aggradation and downstream fining. The elevation of the longitudinal profile is measured at fixed time steps. Additionally, the distribution of coarse-grained sediment along the fluvial profiles is recorded.

In Scenario 1, an overflow is located downstream of the experiment to prevent progradation. This experiment serves as an analogue to continental fluvial system development upstream of a buttress in the absence of marine base level control. Successive longitudinal profiles show that the initial system has a low gradient, is concave upwards and gets steeper and more linear as time progresses. This development coincides with an increasing volume of coarse-grained sediment bypassing the overflow. The coarse-grained sediment fraction is equally distributed along the longitudinal profile at the end of the experiment, indicating ineffective downstream fining. Scenario 2 involves progradation in a shallow basin. The elevation profile remains concave during the entire experiment. The coarse fraction accumulates at the steep proximal part, indicating downstream fining.

Our results imply that the ability to prograde affects the shape of the longitudinal profile, and affects downstream fining. This can be related to the ability of fluvial systems to approach equilibrium conditions, during which no aggradation occurs. Continental systems without progradation show steep longitudinal profiles with low fluvial aggradation rates and no downstream fining. Systems prograding into deep water are characterized by slow progradation that allows them to generate steep longitudinal profiles with limited downstream fining and low aggradation rates in the fluvial domain. Systems prograding into shallow water are characterized by a low gradient, strongly concave up profile, high fluvial aggradation rates and strong downstream fining. Our experimental results are compared to modern fluvial systems, where they offer an explanation for the mechanism governing downstream fining.

TALK

THE SEDIMENTARY ARCHITECTURE OF AN EARLY CARBONIFEROUS ECOSYSTEM AND THE RISE OF TETRAPOD TERRESTRIALISATION

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Recently discovered vertebrate fossils from the lower Carboniferous (Tournaisian) succession in SE Scotland provide insights into the evolution of life on Earth following mass extinction events towards the end of the Devonian. Tetrapods first became fully terrestrialised during the subsequent rebuilding of ecosystems in the early Carboniferous. An understanding of the sedimentary environments in which these tetrapods lived is a key remit of the TW:eed Project (Tetrapod World: early evolution and diversification). The break-up of the 'Old Red Sandstone' continent in the late Devonian and early Carboniferous saw the development of sedimentary basins in the equatorial Midland Valley of Scotland and Northumberland – Solway Basin. Fluvial sandstones and well developed calcretes of the Kinnesswood and Clyde sandstone formations are separated stratigraphically by grey siltstone- and cementstone-dominated sequence of the Ballagan Formation, interpreted as a coastal alluvial plain succession and host to the tetrapod faunas.

Cores from a 500 m borehole drilled in 2013 near Berwick-upon-Tweed provide millimetre-scale detail of the sedimentary facies of the Ballagan Formation. More than 200 paleosols, 270 cementstones, 140 microconglomerate siltstones, and 23 units of gypsum and anhydrite, along with fluvial sandstone bodies testify to a dynamic floodplain environment. The broader picture of the sedimentary architecture across the basins is assembled from logs of selected boreholes across the region. The succession thickens SE across the Midland Valley and into the Solway–Northumberland basin. The proportion of sandstone varies, from <10% along the northern margin of the Midland Valley to >40% in East Lothian and north Northumberland. Rooted horizons and paleosols are only sparsely recorded in these logs. Many others may have gone unrecognised, but descriptions in the logs showing substantial thicknesses of 'laminated siltstone' would seem to preclude the ubiquitous presence of paleosols. The importance of supra-tidal evaporite deposits in the succession is only appreciated from the borehole logs. Nodular gypsum occurs widely across the Midland Valley whereas anhydrite is dominant in the Norham Borehole and in other boreholes in the Northumberland Basin. However, evaporites are notably absent in East Lothian. Further evidence for the extent of marine influence is indicated by shallow marine facies of siltstones and cementstones, and by the sporadic repeated occurrence of shallow marine fauna. The emerging picture is of a complex floodplain architecture with stratigraphical and geographical interplay between a set of distinct facies. This has implications for our understanding of marginal marine environments in the early Carboniferous.

NEW ANALYTICAL APPROACHES FOR CHARACTERISING MICRO-SOILS AND THE WEATHERING EFFECT OF CRYPTOGAMIC GROUND COVERS

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Cryptogamic Ground Covers (mosses, liverworts, lichens, algae, fungi) are important early colonizers of fresh, unstable, sometimes inhospitable, and potentially nutrient-poor ground surfaces. A growing body of data from the early fossil record indicates that comparable associations of organisms were the first early colonisers of the land during the Palaeozoic, where they played an important role in the development of soils and had a major impact on palaeoclimate and the carbon cycle. We are investigating how modern Cryptogamic Ground Covers colonize, interact and bind with their substrates in order to understand the structure of early soil ecosystems and how communities of organisms work together to contribute to the stabilization and weathering of land surfaces.

Our approach uses x-ray micro CT to characterize the spatial structures of the soils and substrates and then to apply a range of analytical techniques, particularly SEM and EDS to further characterize their physical and chemical properties. Here we present preliminary results of x-ray micro CT of micro-soils produced by modern Cryptogamic Ground Covers collected from Iceland. We collected small ~8 cm soil cores and rock samples from a variety of habitats.

What is particularly unique about Iceland is that soils are not thick or very well developed (evident from the general lack of higher plants and trees), and Cryptogamic Ground Covers are widespread on loose mineral and volcanic-fragment substrates; consequently, cryptogams can thrive without much competition. To visualise the spatial structure of these micro-soils, we employed x-ray Micro-CT. The advancement of this technique for geological material in recent years as well as the development of material-specific CT rendering and volume reconstruction software has enabled us to look at the in-situ mineralogical and organic interactions specifically associated with cryptogams on a micro-scale in ways which have not been studied before. Imaging the cores also keeps a visual record of the soil structure, something that we can re-visit once (and if) the sample has been pulled apart for other laboratory purposes. We are able to characterize the spatial distribution of mineral, clasts, clay, soil porosity, and to show how these elements interact with the organic components to a resolution of approximately 23 um. Importantly, key components (e.g. sedimentary components, organics) can be extracted from the volume for individual analysis. Results enable the characterization of the structure of thin Cryptogam Ground Cover micro-soils in 3D facilitating the targeted use of other destructive methods such as thin sectioning and chemical analysis.

PROVENANCE OF TRIASSIC SANDSTONES IN THE WESSEX AND CHESHIRE BASINS: HEAVY MINERAL AND ZIRCON AGE CONSTRAINTS ON THE NATURE OF THE 'BUDLEIGHENSIS' RIVER SYSTEM

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A large northward-flowing axial fluvial drainage system, termed the 'Budleighensis River', is believed to have been responsible for deposition of the Sherwood Sandstone Group in a series of linked basins from the Wessex Basin in the south to the Irish Sea Basin in the north. On the basis of a variety of data, including clast compositions, reworked brachiopod faunas, paleocurrents, detrital mica ages and Pb isotope compositions in feldspar, the main sourceland for this river has been identified as the Variscan mountains of northern France, possibly extending as far south as the Massif Central.

Heavy mineral and detrital zircon age data from the southern (Wessex Basin) and northern (Cheshire Basin) parts of the Budleighensis River system reveal significant differences in provenance characteristics both within and between basins. At least four different transport systems can be distinguished in the Wessex Basin. Sandstones in the west of the basin were predominantly derived from Neoproterozoic metasediments and granitoids, with metasedimentary sources more conspicuous in the older part of the succession (Budleigh Salterton Pebble Beds Formation) compared with the younger (Otter Sandstone Formation). In the central and western Wessex Basin, Variscan granitoid sources are dominant, and on the western margin, recycled Old Red Sandstone detritus is recognised.

Zircon ages in the Sherwood Sandstone Group of the Cheshire Basin contain the same components as those in the Wessex Basin, with conspicuous supply from Variscan granitoids and Avalonian/Cadomian basement together with subordinate older Proterozoic and Archaean sources. Zircon data are therefore broadly consistent with the model of axial-derived sediment from the Variscan belt. However, heavy mineral characteristics of the Cheshire Basin succession contrast with those of the Wessex Basin. Some of the variation can be attributed to differences in diagenetic history, but other parameters, especially the markedly lower monazite:zircon ratio in the Cheshire Basin, are considered to have provenance significance. There is, therefore, a mismatch between the heavy mineral and zircon age evidence.

Zircon age data from the Kinnerton Sandstone Formation of the Cheshire Basin, which comprises aeolian sandstones deposited prior to the establishment of the Budleighensis River system, offer one possible solution to this apparent conflict. The presence of Variscan and Avalonian/Cadomian zircons in this formation indicates that recycling of Late Carboniferous Variscan-derived sediment was important during deposition of the lower part of the Sherwood Sandstone Group. The low monazite:zircon ratios associated with northerly-sourced Late Carboniferous sandstones are also consistent with the recycling hypothesis.

INSIGHTS FROM HIGH-RESOLUTION MULTIBEAM DATA ON THE TRAENADJUPET LANDSLIDE ON THE NORWEGIAN MARGIN

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Submarine landslides are among the largest mass flows on Earth and can be far larger than landslides on land. They can generate tsunami and therefore represent a significant geohazard. Many huge submarine landslides have been discovered and studied along the Norwegian continental margin including Storegga and Traenadjupet. Storegga in particular has been the most studied so far. The slide has been dated 8.2k BP and is thought to have moved 3000 km^3 of sediments. A tsunami up to 20 m high has been identified from deposits found on the Norwegian and Scottish coasts. Traenadjupet is the second largest slide on the Norwegian margin with a volume of about 900 km. It has been dated to 4 k BP. The volume, comparable to Storegga, suggests that there should be an associated tsunami, but as yet no deposit linked to the event have been found.

The purpose of our investigation is to obtain new insights on Traenadjupet's tsunamigenic potential from the MBES bathymetry. We present high-resolution multibeam data acquired during the 64PE391 expedition on July 2014 together with data acquired during the JCR51 cruise. These datasets cover a large part of Traenadjupet slide and give an unprecedented insight into the mechanism of the slide failure. The Traenadjupet morphology is very different to other landslides on the Norwegian margin, particularly Storegga. Storegga disintegrated generating turbidity currents propagating for hundreds of kilometres into the North Atlantic basin. This disintegration caused a massive movement of sediment, which in turn caused the tsunami. Traenadjupet, on the other hand, appears not to have disintegrated in a similar manner, but rather left mounded deposits at the foot of the slope. Several distinct lobes are visible from the multibeam data at the foot of the slide. Those lobes are made of sediment blocks highlighting a low sediment disaggregation. The top of the slide presents several scars and internal headwalls. A possible explanation is a multistage character of the slide, which could also explain the formation of the lobes at the bottom. The mounding, and possible multistage failure mechanism, could suggest that the slide was slow with limited breakup, that could explain a reduced tsunami potential. Further investigations are necessary to understand the mechanism that lead to this behaviour.

TALK

FURTHER INSIGHT INTO THE DEPOSITIONAL ENVIRONMENT OF THE HOLYWELL SHALE (CARBONIFEROUS, NORTHEAST WALES)

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The Carboniferous Bowland Shale Formation of northwest England has been identified as one of the largest potential shale gas targets in the UK. The Holywell Shale is part of the Bowland Shale Formation and represents a succession of marine, brackish and non-marine mudstones at the southwest edge of the Pennine Basin. Five outcrop locations of the Holywell Shale across northeast Wales were sampled to investigate variations in mudstone deposition and organic matter input/ preservation throughout the Namurian (326.4–313 Ma). A multidisciplinary approach was adopted relating organic and inorganic geochemistry, petrographic imaging, and SEM imaging of micro-scale fabrics to determine the range of depositional environments and organic matter types which occur within the Holywell Shale.

At outcrop, the Holywell Shale is immature to early oil mature and has organic matter contents (TOC) ranging from 0.12 wt % to 10.31 wt %. Carbon and nitrogen isotopic data combined with RockEval™ analyses indicate that the organic matter ranges from type II/III kerogen in the lower Holywell Shale to type III kerogens in the middle and upper shale. This can be related to a temporal shift in the source of organic matter, from a more marine influenced signature to a more terrestrial influenced signature. There is only a weak relationship between the quality and quantity of organic matter, suggesting quite complex controls on organic matter supply and preservation. Similarly, there is a broad range of mineralogies and depositional fabrics at a wide range of spatial scales. In the context of a potential shale gas reservoir, these data indicate that the Holywell Shale has highly variable reservoir quality. The identification of 'sweet spots' will have to be underpinned by detailed geological investigations.

EVERYTHING YOU WANTED TO KNOW ABOUT FOSSIL MANGROVES?

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Ancient mangrove deposits have been studied in Eastern Borneo, Spain and other locations, having been identified through newly-developed recognition criteria. A classification scheme has been erected to separate them into clastic and carbonate dominated depositional systems, which are interpreted to be related to contrasting climatic signals. Clastic dominated systems represent humid conditions with significant runoff and sediment supply, while carbonate dominated mangroves typically occur in arid climates with little sediment supply. The dimensions and morphologies of sedimentary (architectural) elements such as channels, bars and sheets also vary depending on the climatic signature relating to the depositional systems. Modern mangrove analogues have been studied in detail to support these observations.

Criteria for recognising mangrove environments in the fossil record feature a variety of sedimentological data. In humid mangroves these include: isolated channels and sheet-like sandstone beds encased in mudstones; an association with tidal and shallow marine sandstone deposits; trace fossils including mangrove lobster and other trackways. In arid mangrove systems these include: rooting, which may be cemented; associated karst and shales relating to periods of exposure. In addition diagnostic body fossils occur such as mangrove lobsters, certain gastropods and rooted trees bored by teridinids.

A new model, explaining the process of mangrove colonisation, will also be discussed, with implications for interpreting changes in relative sea level. From an initial 'blank page', a muddy tidal flat, typically developed during a minor fall in relative sea level, will be dissected by tiny meandering channels. Despite the ephemeral appearance of these channels, gradual colonisation by mangrove plants along their margins will stabilise them, allowing the channels to incise vertically while the extensive mangrove root systems discourage lateral migration. This is in contrast to their meandering morphology. In humid climates the interfluve regions will either be colonised by mangroves or, in the presence of strong winds, remain open forming 'reaches', where sheet-like deposits, made up of coarser grained sediment, will be deposited. In contrast, in arid systems these interfluves will comprise featureless sabkha or desert deposits.

TALK

USING WELL-PRESERVED MISSISSIPPIAN BRACHIOPOD CALCITE FOR PALAEOENVIROMENTAL RECONSTRUCTIONS OF EQUATORIAL BRITAIN

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Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) of biogenic calcite are commonly used as a proxy for assessing palaeoenvironment and palaeoclimate (seawater temperature, salinity etc). To validate isotope studies the preservation of the primary calcite needs to be assessed to ensure that data generated reflect original seawater chemistry, rather than secondary diagenetic fluids. Preservation analysis encompasses a range of techniques, including scanning electron microscopy (SEM), cathodoluminescence microscopy (CL), and analysis of trace element abundance (Mn, Mg, Fe, Sr, etc). Although it is best practice to use material which has passed most screening tests there are no fixed criteria for classifying biogenic calcite as pristine using these techniques. This study has developed a systematic procedure for the analysis of Mississippian biogenic calcite from *gigantoproductid* brachiopods collected from the Peak District National Park (Central England). From this, a set of criteria for the classification of well-preserved biogenic calcite were established and a method of high resolution isotope analysis is outlined. This analysis involves sampling individual growth bands (typically millimetre scale) to allow sclerochronology studies to be conducted. Where pristine calcite is identified we calculate seasonal sea surface temperatures through the organism's life-time. Supporting, detailed sedimentological investigations were conducted to help constrain palaeogeography and palaeoenviroments and establish the preferred environments of *Gigantoproductus* species. This integrated approach will further our understanding of why *gigantoproductids* dominate specific units. This study provides a practical methodology, linking quantitative and qualitative data that will allow a detailed palaeoenviromental reconstruction of this region of Mississippian palaeoequatorial Britain. Ultimately these studies contribute proxy data to improve estimates of the parameters required for data-climate model comparisons.

HYBRID EVENT BED CHARACTER ACROSS THE CLARE SHALE – BASAL ROSS FORMATION CONTACT, WESTERN IRELAND – NEW INSIGHT FROM BEHIND-OUTCROP CORES

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The 490 m thick Ross Sandstone Formation in western Ireland is a well-exposed and instructive example of a deep-water system that has been extensively used as a subsurface analogue and training resource. The sea cliffs facing the Atlantic and along the Shannon estuary record the sandy deep-water part of a major shallowing-upwards Pennsylvanian succession that filled the cratonic Clare Basin. A recent behind-outcrop drilling program targeting the Ross Formation has focussed on the Loop Head peninsula in west Clare. This has provided a fully-cored composite Ross section (490 m thick) that underpins a new understanding of bed-scale variability and the vertical evolution of the system. The work programme has now been broadened to include the key Ballybunion section on the south side of the Shannon which sits obliquely down-dip (to the east) of Loop Head (c. 18 km away). This area is important in that outcrop studies have suggested that the character of the lowermost Ross with its abundant hybrid event beds (HEBs) may reflect a lateral fringe to the early Ross system and that the HEBs which are common there might thus be diagnostic of a fringe position.

A re-analysis of the basal Ross draws on three new borehole sections, one at Ballybunion and two on the Loop peninsula, all three coring the same Clare Shale to Ross Formation transition. The cores can be tied using both major and subordinate goniatite-bearing condensed sections and reveal a widespread precursor unit involving many stacked thin mudflow deposits (fluid mud deposits released from up-dip HEBs?) that can be traced through all three boreholes. These form the upper part of the Clare Shale although they are more logically grouped with the Ross and make up an expanded first cycle of Ross deposition comprising this and a pair of overlying sandier units. The latter are characterised by unusually coarse grained (coarse to very coarse sand) event beds, all of hybrid character, and reaching up to 4 m thick. The earliest of these sandstones show little change in character laterally, but the younger and thicker sandstones show marked lateral facies changes and only half of the event beds recognised in the Loop subsurface extend down-dip to Ballybunion. The sandy event beds are encased in similar mudflow deposits to the precursor unit, and the lateral facies transitions support a down-dip and axial position for the Ballybunion section rather than any link to a lateral slope.

TALK

MASS TRANSPORT COMPLEXES AND THE AVULSION OF SUBMARINE CHANNELS

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The avulsion of submarine channels is a fundamental process in the stratigraphic evolution of submarine fans. In passive margins avulsion is related to in-channel aggradation and/or peak volume flows. This study explores an active margin, and the role of mass transport complex erosion and emplacement in controlling the location of avulsion nodes, the architecture of avulsion lobes, and the evolution sediment pathways. The study area is focused in the southern Magdalena Fan at the northern tip of the Southern Sinú Fold Belt, offshore Colombia, and is based on the near surface mapping of a 1900 km^2 three dimensional seismic volume.

In the study area, the emplacement of a large mass transport complex (MTC) that entrained kilometre-scale blocks of substrate resulted in net degradation of the seascape and the development of a bathymetrically irregular seabed. A consequence of this seabed bathymetry is the unusual geometry of an external levee of a younger submarine channel that tried to build out over the MTC pathway. Discontinuities in the levee above an elongate erosional remnant of a pre-existing levee are interpreted to have formed a failure surface leading to the collapse of a discrete area of the levee that triggered the full avulsion of the channel. Detailed mapping of the reflectors overlying the failed levee and seismic amplitude extractions indicate the presence of erratically distributed low amplitudes at the base, and lobe-shaped high amplitudes at the top. This interval is interpreted as an avulsion lobe complex that developed upward from patchily-distributed, mud-prone packages to sand-prone and well-defined lobes. The distribution, morphology and evolution of the avulsion lobe complexes were strongly influenced by the local bathymetric highs formed by blocks protruding above the mass transport complex top surface.

Mass transport complexes can significantly modify the seascape instantaneously, but their impact is long-lasting. Channel levee systems that propagate over complex inherited bathymetries are more susceptible to avulsion. Therefore a relationship between the emplacement of mass transport complexes and changes in sediment dispersal patterns is to be expected.

APPLICATION OF A QUANTIFIED SYSTEM SCALE ANALYSES OF A DISTRIBUTIVE FLUVIAL SYSTEM (DFS) TO PREDICTING BASIN SCALE FACIES DISTRIBUTIONS

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A system-wide study on the Salt Wash distributive fluvial systems (DFS), Morrison Formation, SW USA, was conducted in order to test the presence of trends cited in published generic DFS models. Common trends such as a downstream decrease in the sand:mud ratio and proportion of amalgamated channel-fill deposits and a downstream increase in floodplain proportion were quantitatively determined. Analyses of the occurrence and thickness of ribbon fluvial channel fills indicate a relatively uniform presence across the DFS. A consistent change in fluvial architecture was qualitatively identified, with proximal regions dominated by stacked channels belt deposits with a high degree of amalgamation and distal regions dominated by floodplain muds and sheet sandstones and sparse ribbon channels, with little to no amalgamation of channel deposits. Results obtained were found to be in-line with generic trends cited within models and quantitative data obtained from the Salt Wash DFS that is deemed to be generic has been added to the DFS model.

Observations from the Salt Wash DFS have been utilised to aid mapping efforts at the basin scale within the Bighorn Basin, Wyoming. Multiple sections across an E-W trending transect in the northern portion of the basin were analysed in order to map individual systems within the sedimentary basin. Preliminary observations show the northern portion of the basin to possess several small (<15 km from apex to toe, <5 km radius) transverse systems flowing easterly away from the Beartooth uplift. A much larger scale (approximately 25 km radius) northerly flowing axial system has been identified within the basin centre. Deposits within the central axial system possess amalgamated channel-fill deposits with thicknesses of up to 30 m that are separated by intervals of equally as thick floodplain packages. Based on observations from the Salt Wash DFS and trends cited within generic models these deposits are tentatively interpreted to be medial-distal DFS deposits. Further work within the central and southern portion of the basin aims to identify further systems within the basin, allowing insights into how fluvial systems fill continental sedimentary basins to be gained. The preliminary analyses shows the DFS model to be a powerful predictive tool at both the system and basin scale demonstrating the robustness and predictability of the DFS model, with clear implications in resource exploration efforts.

TALK

PLIOCENE–EARLY PLEISTOCENE SEDIMENTARY RESPONSE TO EARLY-STAGE TECTONIC UPLIFT OF THE KYRENIA RANGE, NORTHERN CYPRUS, IN A COLLISION-RELATED TECTONIC SETTING

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The Kyrenia Range forms part of a broadly east-west lineament, which extends through northern Cyprus and offshore into southern Turkey. New facies provenance and isotopic age data from the sedimentary basin directly south of the Kyrenia Range (Mesaoria Basin) shed provide insights on the setting and timing of the initial stages of surface uplift. In general, the Early Pliocene-Early Pleistocene sequence (Nicosia and Athalassa Formations) represents a shallowing-upward marine environment, prior to the major uplift of the Kyrenia Range. A progressive change took place from open-marine, to marginal-marine, to lagoonal and finally to continental. At the base of the sequence, above localised Messinian evaporites, interbedded chalks and marls of the Nicosia Formation are rich in Pliocene planktonic foraminifera, which indicate an open-marine environment. Conglomerate lenses containing well-rounded clasts derived from the Kyrenia Range (e.g. marble, dolomite, chert, basalt) appear within the upper part of the Nicosia Formation, and indicate the earliest emergence of the Kyrenia Range during the Mid-Pliocene (approximately). The Nicosia Formation is transitionally overlain by lithified carbonate sands (grainstones) of the Athalassa Formation, which include planar-bedding, cross bedding and foreset bedding. The sedimentary structures, combined with petrographic analysis, indicate the development of a south-facing carbonate ramp along the southern margin of the emerging Kyrenia Range. Based largely on the carbonate biota present, three water-depth zones are inferred: 1) littoral, with a shelly fauna including the shallow-water solitary coral, *Cladocora*; 2) ramp-slope, dominated by calcareous red algae; and 3) offshore, with an abundance of benthic foraminifera and some planktonic foraminifera. In some proximal, northerly areas (in the NW), the upper part of the Athalassa Formation includes lenticular conglomerates (Kalkanlı Member; new name), with well-rounded clasts that are interpreted as prograding fan deltas. Strontium isotopic dating of the grainstone facies (whole-rock sample) suggests that shallow-marine conditions persisted into the Early Pleistocene. The intact sequence culminates in oyster- and oncolite-rich lagoonal deposits, aeolinites and palaeosols. In addition, poorly dated non-marine sedimentary breccias, dominated by metacarbonate rocks (Karka unit), accumulated along the proximal flank of the Kyrenia Range. The breccias are interpreted as the result of rapid tectonic uplift during Early-Mid Pleistocene. The uplift continued during the Mid-Late Pleistocene, probably more slowly, as recorded by non-marine terrace deposits along the southern flank of the range. In addition, both marine and non-marine terrace deposits accumulated along the northern flank of the range. The ultimate driving mechanism of the uplift is likely to be a combination of collision of the Eratosthenes Seamount (a crustal edifice) with the subduction zone to the south of Cyprus, and left-lateral strike-slip related to the westward movement of Anatolia towards the Aegean.

AN INTEGRATED MODEL FOR INNER BEND DEPOSITION IN SUBMARINE CHANNELS

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The nature of deposition at inner channel bends in submarine channels has remained rather mysterious, both in terms of products and their formative processes. Clinoforms resembling fluvial point-bars have been observed but their composition and ubiquity are unclear. The thickness of these clinoforms, where present, is however typically much smaller than the channel depth, in marked contrast to fluvial systems. Given that channels may be 150 m or more deep, and clinoforms may only account for a small fraction of this depth, what fills this 'space' above the 'point-bar-like' clinoforms at the inner bend, and what processes control this? Here these questions are addressed, and an integrated model of inner bend deposition in submarine channels is postulated for the first time.

In modern and ancient channels a number of studies have identified high-amplitude point-bar deposits overlain by low angle inclined sediments at inner bends, where bends have undergone progressive lateral migration and bend expansion. The results of submarine channel experiments suggest that these inner-bend accumulations are formed by two separate and temporally distinct processes. The lower coarse-grained component is formed from traction-dominated flows as occurs in classical point-bars, or as inter-leaved deposits from traction- and suspension-dominated processes, whilst the upper clinoforms or low-angle dipping surfaces are formed entirely by suspension dominated flows; grain-sizes appear too fine to undergo significant tractional reworking. These upper clinoforms may either be related to flow separation as seen in laboratory experiments, or to zones of lower flow velocity with a more diffuse velocity gradient to the main flow, as likely occurs in fluvial oblique accretion deposits. However, the resultant deposits from these two different velocity flow fields are likely very similar in form and facies. This proposed model of inner bend accumulations in submarine channels exhibits striking similarities with oblique accretion deposits above point-bar sediments as observed in fine-grained mixed-load rivers. Such fluvial oblique accretion deposits can also form in the absence of coarse-grained point-bars, again analogous to suspension-dominated submarine channels where classical point-bars appear to be absent.

TALK

FACIES DISTRIBUTION WITHIN AEOLIAN SETS RELATED TO LARGE SCALE 3D OUTCROP ARCHITECTURE: A VIRTUAL OUTCROP CASE STUDY FROM THE JURASSIC PAGE SANDSTONE, ARIZONA

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Recent work in ancient aeolian sediments has highlighted a suite of relatable empirical relationships which exist between facies dimensions and distribution, larger scale architectural elements and original parent-dune morphology and migration (Romain and Mountney, 2014). These relationships generally link smaller- and larger-scale aspects sedimentary architecture. Several parameters are thought to closely approximate the morphology and geometry of aeolian bedforms and their preserved bedsets. For example, a positive correlation has been demonstrated between preserved original bedform height (and therefore size) and preserved grainflow thickness (grainflows are the deposits generated by lee-slope avalanching down dune slipfaces). Quantifying the proportions of wind ripple and grainflow strata and the distribution of their occurrence within preserved sets is thought to be key to understanding the three dimensional configuration of aeolian packages. Reservoir quality and connectivity in the subsurface is closely tied to the distribution and individual porosity/permeability properties of these facies (grainflows frequently exhibit permeabilities orders of magnitude above those of wind ripples). Many of the above interdependent relationships may be better constrained through detailed comparison to a broad variety of outcrop examples.

A new study undertaken on the Colorado Plateau investigates these predictive empirical relationships across differing aeolian environments (wet and dry). The study is underpinned by terrestrial laser scanning (TLS) through-which 3D virtual-outcrop models from four different aeolian systems ranging from Permian to mid-Jurassic in age have been generated. For each model the internal facies associations and geometries are mapped highlighting their 3D spatial distribution in relation to aeolian dune and interdune elements. The first of these to be analysed is the mid-Jurassic Page Sandstone Fm. The Page Sandstone Fm. has been well studied and is thought to exhibit a diverse range of parent dune morphologies, lithofacies and migratory behaviours (Kocurek et al. 1992) and so forms a suitable test site for the investigation of these empirical relationships. Permeability and behind outcrop core data has also been gathered in the vicinity of the study area (Chandler et al., 1989). A detailed virtual outcrop model within a 600 m x 800 m x 45 m-high outcrop volume has been populated with internal facies from high resolution outcrop logs. In addition data collected on grainflow thickness versus average foreset dip angle, grainflow width, slipface length and set height are examined with respect to the larger stratigraphic architecture. This data is compared to the predicted trends between small and larger-scale aspects of sedimentary architecture.

'NATURAL FRACKING': HYDROFRACTURE SYSTEMS IN GLACIAL ENVIRONMENTS

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Hydrofracture systems, also referred to as water-escape features or clastic dykes, are being increasingly recognised within subglacial to ice marginal settings and represent a visible expression of the passage of pressurised meltwater through these glacial environments. Such structures provide a clear record of fluctuating hydrostatic pressure, leading to brittle fracturing of the host sediment/bedrock/or overlying ice and penecontemporaneous liquefaction and introduction of the sediment-fill. Detailed macro- and microstructural, and sedimentological studies have revealed that they range from simple features in which initial fracture propagation was immediately followed by the injection of the fluidised sediment fill (cut and fill), through to highly complex multiphase systems which were active over a prolonged period and accommodated several phases of fluid flow and sedimentation. Depending on the consolidation of the host sediment or bedrock found beneath or at the margins of contemporary and former glaciers, closed fractures (joints), bedding or faults may already exist prior to hydrofracturing, with the elevated hydrostatic pressures leading to the reactivation of these pre-existing structures. Due to the pressurised nature of the meltwater, the infill can be introduced from structurally above (downward injection) or below (upward injection) the developing hydrofracture system. They range from relatively minor features just a few millimetres across, through to much larger structures up to several metres in width which can be traced laterally for several tens of metres. The more complex systems are typically composed of one or more feeder conduits linked by shorter transgressive sections. Comparison of the data obtained from hydrofractures developed in glacial environments with published engineering hydraulic fracturing data indicates that the various stages of sediment-fill deposited within the natural systems during a flow event can be directly related to the fluctuation in overpressure during hydrofracturing. The development and repeated reactivation of subglacial hydrofracture systems are believed to have a dramatic effect on the permeability of the bed of former and contemporary glaciers, influencing the potential for overpressure build-up within the subglacial hydrogeological system, and facilitating the migration of meltwater beneath glaciers and ice sheets. It is also becoming increasingly apparent that the introduction of pressurised meltwater can have a profound effect on subglacial to ice-marginal deformation, for example aiding in the development of water-lubricated detachments within the sediment pile which can promote rapid ice movement and/or facilitate the initial detachment and transport of sediment and/or bedrock rafts.

TALK

SHELF MARGIN VARIABILITY IN FINE-GRAINED PROGRADING SYSTEMS, KAROO BASIN, SOUTH AFRICA

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A number of factors, such as sediment supply, shelf physiography and lateral variability of dominant process regime control the long-term progradation of deltaic shelf margin systems and delivery of sand to deep water settings. Three-dimensional datasets that bridge the resolution gap between seismic scale and facies scale analysis are required to unravel the complicated interplay of these factors.

The exhumed Karoo basin margin provides such an opportunity and regionally-distributed sedimentary logs, from basin-floor to shelf, along a 150 km+ strike section have constrained the stacking of clinothems, the position of the shelf-edge rollover and the base-of slope through time. A striking result is that progradation of the Karoo Basin margin was dominantly by the accretion of silt. The sandy part of each clinothem did not reach the shelf-edge rollover, resulting in fine-grained accretion at the shelf margin and generation of thick clinothems with sand-starved bottomsets.

Field and age data suggest that shelf margin deposition initiated earlier in the Tanqua depocentre, with a thinner and ramp type progradational geometry, whereas differential subsidence along strike explains the thicker slope succession found in the Laingsburg depocentre, 80 km to the east. The downdip correlation of shelf edge deltas shows that their associated slope deposits are generally mud-rich. This contrasts with the underlying sand-rich basin-floor stratigraphy, and points to a physiographic change in the basin margin architecture and/or process regime through time.

Detailed field observations have provided criteria to define a muddy shelf to slope transition, offering a basis for equivalent seismic expressions in the case of margin progradation via fine grained material. This work demonstrates that basin margin progradation can occur without deltas or shorelines reaching the shelf-edge rollover, and with the development of basin-floor fans. Future work aims to address the exact processes responsible for transporting large volumes of fine grained material across the shelf and beyond the shelf edge rollover.

SEDIMENTOLOGICAL AND RESERVOIR CHARACTERISATION OF THIN BEDDED TURBIDITES: EARLY MIOCENE OUTCROPS, NW BORNEO

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The Miocene to Recent deep-water successions of the central part of the Baram Delta Province are located within an active deltaic toe-thrust setting. Reservoir successions within the Province are dominated by fine-grained deep-water sediments, characterised by the dominance of relatively monotonous mudstone and siltstones with subordinate but hydrocarbon-bearing, thinly-bedded fine-grained sandy turbidites. These beds are commonly discounted as potential reservoir zones due to their 'shaly' display on conventional logs.

This study focuses on thin-bedded turbidites from the Oligocene-Lower Miocene Temburong Formation, which crop-out on the island of Labuan, NW Borneo. The outcrop comprises 150 m of alternating mudstone, siltstone and sandstone. Detailed, cm-scale sedimentary logging of the succession documented bed-scale facies characteristics. Three main facies are identified: Facies-1 form 40–60 cm –thick beds of alternating T_{B-1} and T_C intervals deposited by multiple surge-like flows, with varying capacity. Facies-2 and -3 consists of beds dominated by T_C deposits, distinguished by changes in the angle of climb within individual beds. This analysis concludes that deposition occurred within a distal-external-levee environment, an interpretation that is supported by the lack of erosional scours, and multi-directional current-ripple cross-lamination. This interpretation also suggests that, while individual beds may be laterally extensive, overall effective reservoir properties would be severely reduced due to the low degree of vertical connectivity. The continuous outcrop enables the sand percentage (c. 50%) and bed thickness characteristics to be evaluated and compared with conventional well log analysis results from the offshore, hydrocarbon-bearing deposits.

This outcrop study provides the only Neogene-aged outcrop analogue for several recently discovered fields in offshore NW Borneo, with subsurface examples display similar signatures on conventional well logs. The reservoir potential of external-levee thin beds may represent an important upside offshore NW Borneo due to better lateral continuity and a higher net sand content that would typically be assumed.

TALK

LATERAL VARIATION OF DELTAIC SANDSTONES IN A SHALE SUCCESSION FROM THE NORTHWEST CARBONIFEROUS BASIN

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The Lough Allen and Sligo–Donegal sub-basins form part of the much larger Northwest Carboniferous Basin: a structural and sedimentary basin that lies in an analogous tectonic position to the Midland Basin of Scotland. The basin is a graben, associated with faulting in Silurian to Devonian times. Carboniferous rocks crop out in a large tract of the counties Sligo, Leitrim, Cavan and Monaghan (Republic of Ireland) as well as counties Fermanagh, Tyrone and Armagh (Northern Ireland). A thick limestone–shale–sandstone–shale succession (up to 1750 m) is represented by the Ballyshannon Limestone, Bundoran Shale, Mullaghmore Sandstone and Benbulben Shale formations. The lower shale unit, the Bundoran Shale Formation commonly has a gradational base with the underlying limestones and contains a number of related, but separate sandstone members, which were deposited as localised deltaic facies prograded into discrete parts of the basin. This occurred prior to the initiation of a more regionally extensive deltaic episode, recorded by the Mullaghmore Sandstone Formation (c. 200 m thick). The Bundoran Shale Formation is the most prospective for shale gas in the basin, but it displays variable source rock richness and distinct facies variation and understanding the causal factors attributing to facies variation can help to identify the more prospective areas.

On seismic data the Mullaghmore Sandstone Formation resembles a single sand unit and can be correlated between most wells. At outcrop scale there is a significant amount of lateral variability in lithology, architecture and ichnology and it can be observed that the facies in the shale succession are closely linked with the overlying sandstones. Detailed sedimentary logging of sections at Bundoran show that the facies in the Bundoran Shale Formation appear to be directly influenced by deltaic sediment supply, albeit from a distant but emerging delta. In what is commonly thought of as just a 'shale unit' a number of previously unrecorded toesets of clinoforms of the overlying deltaic event are identified. The boundary between the Bundoran Shale Formation and the Mullaghmore Sandstone is clearly shown to be diachronous and the top of the Bundoran Shale Formation contains laterally extensive coarsening upward bars overlying thick prodelta facies. These sandstones grade laterally into carbonate-rich siltstones and mudstones of more typical 'Bundoran Shale' facies.

WHERE ARE MY FANS? THE ONSHORE DEPOSITIONAL RECORD OF WIDESPREAD EXHUMATION OF SOUTHERN AFRICA IN THE CRETACEOUS

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Exhumation of southern Africa, associated with the African superplume, primarily occurred during the Cretaceous. The onshore depositional record of the Cretaceous is limited to the hanging-wall basins of several non-volcanic syn-rift extensional faults that trend WNW-ESE. Deposits in the Worcester and Oudtshoorn Basin, the Uitenhage Group, were investigated in detail. The group is dominated by conglomeratic deposits with varying amounts of sandstone layers. Clast analysis highlights a different erosional and landscape development history of each basin. Clast composition in the Worcester sedimentary basin mainly represents the Ecca or Dwyka groups, with no deeper stratigraphy quartzite found, despite this being the dominated local bedrock type. Exhumation was deeper within the downdip of the Oudtshoorn sedimentary basin, where Palaeozoic quartzites (Table Mountain group) represent the majority of the clast composition. No Uitenhage Group deposits are found within the main tributary of the Gouritz basin (the Gamka River), indicating that perhaps at the time of large scale deposition within a tributary, the Gamka acted as a bypass zone or the present day tributary was not connected to the Gamka River. Previous apatite fission track thermochronology analysis indicates two peaks of erosion were experienced within the Western Cape, with 2.2–0.72 x 106 km^3 sediment removed, more than the Amazon Fan. However, there are no major submarine fans offshore South Africa meaning that there is an order of magnitude difference between the volumes of material eroded from the onshore record and the volumes of sediment in the offshore record. The age and palaeocurrent direction of the Uitenhage Group and palaeogeographic reconstructions of the Cretaceous period suggest that much of the exhumed sediment was transferred across the Atlantic Ocean separating the source from its sink by >6000 km.

TALK

PROVENANCE AND PALAEOENVIRONMENTS OF LATE CRETACEOUS–MIOCENE MIXED TERRIGENOUS–CARBONATE SEDIMENTS OF THE ARABIAN CONTINENTAL MARGIN IN SE TURKEY: A RECORD OF OCEAN BASIN CLOSURE AND CONTINENTAL COLLISION

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Provenance studies are most effective when a multidisciplinary approach is adopted. The present study links clastic and carbonate sediments to potential source areas, taking account of sediment routing and evolving palaeogeography. Mixed terrigenous-carbonate systems are useful for such studies. Also, passive continental margins are ideal, as they provide an excellent record of changing sediment provenance and palaeoenvironments though time. Such basic principles are exemplified by the mid-Cretaceous to Late Miocene sediment provenance and palaeoenvironments of the Arabian continental margin in SE Turkey. Changing sediment provenance relates to suturing of the Tethyan ocean (S Neotethys), to the north. After Permian to Early Cretaceous rifting and passive margin development, the Tethyan ocean basin closed in two main stages. The first stage involved southward emplacement of ophiolitic (oceanic) rocks onto the Arabian margin during latest Cretaceous. The second stage relates to ocean suturing during Early Miocene. The first closure stage began with tectonically controlled subsidence and the deposition of lithoclastic and bioclastic turbidites along the northern margin of the Arabian carbonate platform during Campanian time. Clastic sediments were mainly derived from the Arabian continent to the south during this time. During latest Campanian-early Maastrichtian, a flexurally controlled foredeep formed, related to the emplacement of ophiolitic (oceanic) rocks onto the Arabian continental margin. Sediment provenance switched from south to north when the allochthonous rocks over-rode the continental margin and emerged near, or above, sea level during latest Campanian-Early Maastrichtian time. During Palaeocene time, the northerly edge of the continental margin uplifted relative to more inboard areas, which subsided, generating southward-flowing, high-density, subaqueous gravity flows. Areas in the north, and also in the southwest, emerged during the Early-Middle Eocene, creating alluvial fans that prograded, both southwards and northwards in different areas. Uplift was possibly driven by far-field compression, as a northerly Tethyan ocean basin sutured in central Turkey. During the second, Early Miocene, stage of ocean basin closure, the northern edge of the Arabian margin subsided strongly to form a further flexurally controlled foreland basin. This infilled with terrigenous sediments, including metamorphic detritus, mostly derived from the north. This basin was finally over-ridden by the northerly continental margin of the ocean basin (Anatolian continent) during Early-Mid Miocene, associated with voluminous, southward supply of coarse clastic sediments in the form of alluvial fans.

HOW DO BIOFILMS ALTER THE CHEMISTRY AND FABRIC OF A PRECIPITATE?

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It is generally accepted that biofilms play an important part in the precipitation of authigenic minerals in a wide variety of settings. Some of the most spectacular and important biofilm-influenced deposits are formed of calcium carbonate – tufas, travertines and associated deposits. In these settings, biofilms are recognised to increase the amount of calcite precipitation [1] and alter the geometry and coarse scale petrography of the precipitate [2]. They determine at what water marginal water chemistries calcite starts to precipitate and microbialites give way to chemical limestones [3]. Biofilms also interact with ambient water, controlling chemical accumulation transport [4].

New evidence, drawn from unique experimental approaches, is demonstrating that biofilm influence extends to control of calcite trace element composition, and crystal scale fabric. Under tightly controlled temperature and chemical conditions, fully replicated experiments show that Mg incorporation into tufa carbonate defies the expected thermodynamic control. However, there is a pronounced influence on $(Mg/Ca)_{calcite}$ from precipitation rate, so that rapidly forming precipitates develop with very low magnesium content indicating kinetic control on fractionation. Calcite precipitation rate in these experiments is controlled by biofilm growth rate and reflects kinetic fractionation arises from the electrochemical activity of extracellular organic acids. These effects are therefore likely to occur wherever these molecules occur, including stromatolites, soil and lake carbonates and (via colloidal organic acids) speleothems.

The presence of Extracellular polymeric substances (EPS), even without the presence of cells, also alters precipitation style. Spherular and shrubby calcite growths are well known from the geological record, but their environmental significance is not clear. Sterile, microcosm experiments have shown that these forms occur in saline, hyperalkaline settings – but only in the presence of organic acid molecules in solution. The presence of inorganic materials (hydrated magnesium clays) does not impact on precipitate morphology, and reduces the precipitation rate of calcite.

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TALK

INTERNAL SEDIMENTARY ARCHITECTURE AND HETEROGENEITY WITHIN FLUVIAL POINT-BAR SUCCESSIONS

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Point-bar elements that represent preserved remnants of meandering fluvial channel systems are widely recognized in the rock record. Although the fundamental mechanisms responsible for determining the facies architecture of these bodies have long been known, the specific processes that give rise to the wide variability in internal facies compositions and arrangements remain poorly constrained. This study documents and accounts for the facies architectures of a range of exhumed point-bar successions via comparisons to a GIS-based analysis of the morphology of modern point bars in similar modern environments.

Ancient lateral accretion architectural elements representing point-bar deposits have been studied in the Pennant Sandstone Formation, a Bashkerian delta-plain succession exposed along the West Pembrokeshire coastline, UK. Individual point-bar elements are 2 to 10 m thick and can be traced for up to 400 m laterally. The internal architecture of one especially well-exposed example has been studied in detail. Thirty sub-components comprise the internal anatomy of the preserved point bar and these are represented by sets and compound cosets of strata that are each 0.5 m to 2 m thick and are delineated by various types of erosional bounding surfaces. Internally these components themselves comprise a variety of sand-prone strata with subordinate proportions of gravel, silt and clay; 11 primary lithofacies and 19 sub-facies types are recognized and 2000 palaeocurrent readings highlight subtle yet predictable variations in ripple, dune and bar migration directions. Many sandstone packages are delineated by muddy and organic drapes on surfaces inclined up to 12° in the direction of point-bar propagation. These drapes vary in composition, thickness, spacing, lateral and downslope continuity as a function of both position within individual point-bar components and position along the alluvial profile represented by the curved point bar surfaces.

Comparisons between this detailed outcrop study, on-going studies of analogous Campanian successions in the Mesa Verde Group, Utah, and studies of the morphology of modern point-bars highlight the preserved stratigraphic record of common aspects of fluvial system behaviour. For individual point-bar elements, the abundance, thickness and lateral continuity of mud drapes tends to be greater on the downstream side of the apex of reconstructed meander bends, especially in high-accommodation systems. Regionally, the incidence of mud-draped surfaces is greater in the lower parts of alluvial plains. Results from this work have implications for understanding both the controls on point-bar growth and the origin and style of internal stratigraphic heterogeneity that governs reservoir quality in hydrocarbon provinces.

DETAILED RECONSTRUCTION OF TIDALLY INFLUENCED POINT-BAR ELEMENTS OF THE CAMPANIAN NESLEN FORMATION, UTAH

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Tidally influenced fluvial deposits record the transition in process regime from fully fluvial to open marine conditions. Heterogeneities in tidally-influenced point bars have been the focus of recent research. Widespread exposures of the lower part of the Neslen Formation, Upper Mesaverde Group, Utah provide three-dimensional outcrop control. This enables the reconstruction of point-bar architectural elements via detailed analysis of their internal sedimentology, ichnology, reconstruction of inferred palaeoflow and bar-form growth trajectory. Ten separate point-bar elements have been examined along a 70 km-long dip-oriented transect. Data from each element has been recorded using a combination of stratigraphic panels and sedimentary logs to enable both vertical and horizontal changes in the sedimentary architecture and the internal arrangement of facies components and their bounding surfaces to be assessed.

The evidence for tidal influence in the studied point-bar elements generally decreases in prevalence towards the west (i.e. palaeo-landward). Some elements are dominated by sandstone, whereas others are heterolithic and comprise interbedded sandstone, siltstone and mudstone units in bundled sediment packages delineated by bounding surfaces inclined up to 12 degrees; this stratigraphic style is commonly referred to as 'inclined heterolithic stratification' (IHS). IHS deposits are defined by alternating beds of relatively clean sandstone and flaser bedded and interlaminated very fine sand, silt and mud, or by alternating thicker and thinner sandstone beds. Although sand bodies become progressively more partitioned by IHS in settings that possess increasingly abundant indicators of tidal and brackish-water in more distal settings, exceptions abound. This is interpreted to reflect factors such as position on the point-bar surface on inner channel bends, radius of curvature and style of migration of the meander bend, fluvial discharge, variations in tidal and wave forces, and the rugosity of the coastline.

Results suggest that the style of developed heterogeneity and architecture within preserved point-bar elements is predictable. The outer edges of the point-bar elements are commonly composed of finer sandstone and are less heterolithic. Middle sections are characterised by IHS in which alternating units of sand and silts and muds, lenticular and flaser bedding are common. A depositional model is proposed that enables the position within a preserved point bar to be predicted from limited spatial data. The construction of a quantitative depositional model serves as a tool that can be applied to analogous subsurface reservoir settings.

TALK

INFLUENCE OF BASIN PHYSIOGRAPHY UPON THE CHARACTER AND DISTRIBUTION OF HYBRID EVENT BEDS

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Confinement of sedimentary gravity currents and the deep-water depositional systems they emplace by sea-floor topography is commonplace in a number of settings (e.g., salt mini-basins, intra-cratonic basins, passive margins with gravity-driven tectonic systems). Distinct sedimentary gravity flow deposits, containing co-genetic matrix- mud-clast-rich and matrix-poor sandstone, are recognised in a range of deep-water depositional systems, including topographically complex settings where gravity flows can be confined and or contained (ponded) by sea floor topography. In the latter settings HEBs can exhibit systematic development and variation in their depositional character with increasing proximity towards their confining topography.

New research from the Castagnola Basin (Miocene, Northern Italy) and the Pennine Basin (Namurian, Northern England) has begun to highlight contrasts between sedimentary systems that are confined and contained (CC) and those which are confined but uncontained (CU). In CC settings HEBs are less likely to be localised to their topographic confinement and exhibit no systematic variation in depositional character in respect to palaeoflow direction or proximity towards the confining slope. Compared to CC settings, HEBs in CU settings are more likely to be localised to confining topography and exhibit systematic variation in depositional character over short length-scales; however systematic variation in depositional character can occur over longer length-scales where HEB extend further upstream and are not locally restricted to the confining basin margin. These contrasts are considered to arise due to flow containment which restricts flow expansion and promotes a number of factors. Specifically significant erosion of muddy substrate, high sedimentation rates and the extensive complex 3D flow dynamics following interaction with multiple basin margins. This work highlights a range of boundary conditions which influence the character and distribution of HEBs, and thus that of depositional reservoir quality, in topographically complex settings. Awareness of these boundary conditions may provide insight when attempting to reconstruct basin geometries and evolutions using the character of their sedimentary infill.

HEALING THE SCARS: SEDIMENTOLOGY AND STACKING PATTERNS OF INTRASLOPE LOBE DEPOSITS RELATED TO SEDIMENT EVACUATION

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Intraslope, or perched, lobes develop in areas of transient accommodation, and have been identified from reflection seismic datasets on many continental margins (e.g. the Gulf of Mexico, Niger Delta). Mechanisms to generate slope accommodation include dynamic processes such as tectonism and diapirism, or static processes such as differential compaction. Intraslope lobes are seldom identified at outcrop due to insufficient palaeogeographic context and the origin of accommodation is rarely constrained.

Extensive exposures of a tabular sand-prone package in Unit E2, Fort Brown Formation, Karoo Basin, South Africa have been studied in an area dominated by overall net sand bypass across a palaeoslope setting and development of a thick terminal lobe complex downdip. 125 bed-by-bed sections were logged along an oblique dip section, physically correlated by key surface tracing, and combined with palaeocurrent measurements. Unit E2 is divided into 3 packages along an 8 km-long outcrop. The basal subunit (E2.A) is characterised by deposits from turbidity currents with opposing flow directions and abundant erosional surfaces which, when combined with horizontal datums, indicate a highly confined setting. Subunit E2.B has a highly erosive base in its axis, cutting out E2.A up-dip, and is dominated by thick bedded amalgamated structureless sandstones that become more bedded laterally. Subunit E2.C is the most extensive of the subunits up-dip and shares close facies affinities with terminal lobes, which suggests a final, relatively unconfined phase of deposition. The subunits show overall aggradational stacking, although there are changes in dominant palaeoflow direction from E (E2.A), to ENE (E.2B), and back to E (E.2C). Overall the subunits shift slightly to the NW during deposition. A 0.4 m-thick debritic bed within mudstones underneath the E2 unit can be traced out close to the area in which E2 has maximum thickness, where it stops abruptly due to truncation. Juxtaposed thin-bedded coarse siltstones and silty claystones form a ~30 m-thick wedge that thins out over a distance of ~700 m to the E. These relationships are interpreted as the preserved expression of an underlying slide scar that led to evacuation of material and generated sufficient accommodation on the slope to initiate the deposition of intraslope lobes.

TALK

SEISMIC GEOMORPHOLOGY AND SEDIMENTOLOGY OF A TIDALLY-INFLUENCED, FLUVIO-DELTAIC SUCCESSION: LATE TRIASSIC MUNGAROO FORMATION, EXMOUTH PLATEAU, AUSTRALIA

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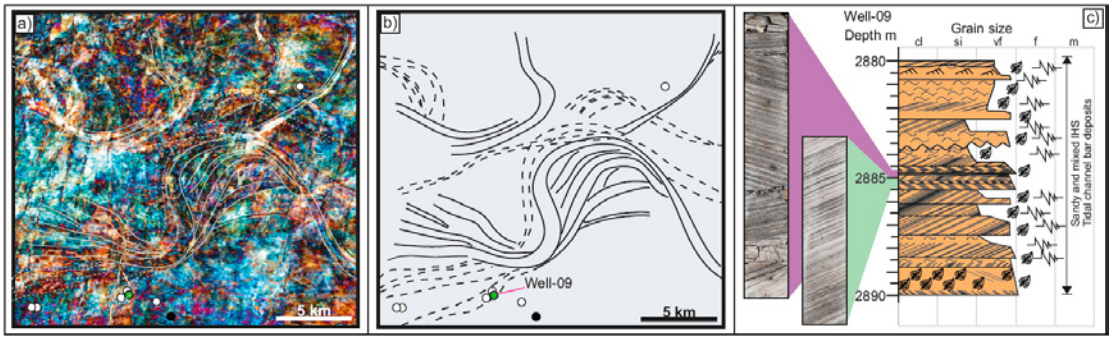
Linking seismic geomorphology to sedimentology is an important step towards understanding past depositional settings and the likely controls on depositional style and preservation of deposits. Tidally-influenced fluvial deposits are of current interest due to currently producing hydrocarbon reservoirs such as the McMurray Formation. Previous seismic and sedimentological studies of the fluvio-deltaic, Late Triassic Mungaroo Formation have established a stratigraphic and sedimentological framework for the formation, and have explored the varying dimensions of channel geobodies within the formation. Previous work by the authors has created a series of depositional environment maps for the formation, incorporating sedimentology, seismic facies and seismic geomorphology.

This study is focussed on a 3D seismic survey and several wells (two with core) from the Exmouth Plateau, NW Shelf, Australia, and uses a variety of seismic attributes, stratigraphic techniques and frequency decomposition, in conjunction with lithofacies interpretations, in order to image and interpret the detailed, internal architecture of channel belt deposits from the Mungaroo Formation.

Specific objectives are: (i) to identify channelised deposits using stratal slicing and spectral decomposition, and interpret, where possible, the internal architecture of the channel belt deposits; (ii) to link the seismic geomorphology to sedimentary core logs (where available) in order to interpret depositional environment; (iii) to examine the possible allogenic and autogenic controls on the varying depositional style encountered.

Four distinct intervals from the formation are presented, exhibiting a range of styles: (i) seasonally-influenced, entrenched, multi-storey valley fill; (ii) sinuous, channel and splay belt deposits with weak tidal influence; upper delta plain distributary networks; (iv) tidally-influenced, lateral accretion deposits. The example shown below incorporates stratal slicing, spectral decomposition and sedimentary logging. This interval exhibits 'McMurray-style' tidally-influenced lateral-accretion deposits, the planform geomorphology of which can be traced from the stratally-sliced frequency decomposition cube. Core photos and logs from the interval show IHS and tidal bundling.



Above: (a) Large-scale, moderately sinuous channel bodies are imaged, with evidence for lateral migration of channel belts over time: identified from a stratigraphically flattened, frequency decomposition cube. Likely large-scale lateral accretion channel-belt deposits. (b) Final interpretation of fluvial point-bar and channel architecture; (c) Core log and photographs from the interval show sandy and mixed IHS with tidal bundling of mud laminae. The imaged deposits are interpreted as tidally-influenced, lateral accretion deposits.

CORES FOR CONCERN: HOW WELL DO SEAFLOOR DEPOSITS REPRESENT THE FLOWS THAT CREATED THEM?

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Submarine canyons act as major conduits of sediment from shallow- to deep-sea regions, yet the sedimentary processes operating within them are very poorly understood. This stems from the relative inaccessibility of such complex environments and therefore the difficulty of making direct observations. As a result much of our understanding of the dynamics of sediment-laden flows in submarine canyons results from making inferences from the deposits that they leave behind in the geological record. This study tests how well geological deposits in the canyon represent the flows that created them by comparing the sedimentary record on the floor and walls of Monterey canyon with the sediments collected in sediment traps during flow events. The project makes use of systematic transects of precisely located push cores and vibracores that were collected using a remotely operated vehicle (ROV). The cores were collected by the Monterey Bay Aquarium Research Institute (MBARI) at 300 m, 500 m, 800 m, 1000 m, 1200, and 1500 m water depth, with three of these in the vicinity of sediment traps deployed in 2002 by the US Geological Survey. Laser particle size analysis was used to analyse the grain sizes present in the push cores and was directly compared to deposits from the sediment traps, previously analysed using the same techniques. Preliminary results suggest that using deposits to reconstruct flows may not be as robust as previously assumed. For example the size and type of sediment found draping the canyon walls can be very different from that collected in sediment traps at the same heights and locations. Three hypotheses are outlined to suggest reasons for this unexpected sand distribution: (1) evolution of flows as they travel down system, (2) flows superelevating, and (3) flows being in a critical state whereby they bypass sad down system.

TALK

FLUVIAL SYSTEMS AT THE BASE OF LARGE IGNEOUS PROVINCES—HOW PREDICTABLE ARE THEY?

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Large Igneous Provinces (LIP's) are associated with the emplacement of anomalously high volumes of magma throughout the crustal profile and onto the earth's surface. During the initiation of volcanism, sedimentary systems which exist prior to and during the emplacement of the LIP are irreversibly altered due to the interplay between uplift, subsidence and occupation of available accommodation by volcanics. Although the initiation of LIP's are associated with high eruption rates and high volume eruptions, ponding of fluvial systems with large external catchments can cause rapid aggradation of clean, siliciclastic channel filling sandstones which intercalate with the volcanics. Proven reservoir potential of this nature exists in the Faroe-Shetland basin within the Rosebank field therefore there is a need for analogue study to improve understanding of this unusual play type.

The Clearwater Embayment within the Columbia River Basalt Province of Miocene age was selected as a case study area to document the response of fluvial systems during the initiation of the LIP and assess the predictability of the preserved sediments along the reach of the system and in successive cross valley profiles. Pre-LIP fluvial catchment areas were impounded by a series of thick (typically 20-50 m) fissure fed basalt lava flows which raised the elevation of the palaeo-valley base and transformed these catchment areas into aggradational alluvial plains. The stratigraphic interval studied was the Grande Ronde Formation which formed between 16.5 and 15.6 Ma and has a maximum thickness of 600 m within the study area. Sedimentary interbeds range from 0.1–70 m in thickness and have a maximum across valley distribution of 15 km.

The fluvial successions comprise both within channel and flood basin sediments. Within channel facies associations include cross-channel bars, confluence scour fills and point bar deposits. Flood basin packages included crevasse complexes, sheet-flood sands, diatom lakes, swamp and paleosol facies associations. Interbeds typically show coarsening up profiles, with the base of the sequence dominated by carbonaceous rich fines overlain by sheet flood sandstones. The channel complexes are typically confined to the upper parts of the sequences and generally consisted of multi-lateral stacked stories. The very top of the sequences are typically represented by an abandonment package most likely caused by headwater capture from an advancing lava flow front upstream. At the end of Grande Ronde time, subsidence of the sequence proximal to the volcanic source forced the sedimentary systems basin-ward which caused the study area to be uplifted relative to the basin, such that it formed part of the catchment once more.

EVOLUTION OF SAND-BODY ARCHITECTURE INFLUENCED BY LARGE-SCALE REMOBILISATION EVENTS IN A DEEP-WATER SETTING: BRITANNIA FIELD, UK NORTH SEA

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Mass-failure events may affect the deep-water bathymetry of the sea floor by remobilising or removing sediments, whilst their deposits (MTDs) may further change the bathymetry. Jointly, these effects may influence subsequent turbidite deposition. The extensively drilled Aptian deep-water succession of the Britannia Field, Outer Witch Ground Graben, North Sea provides an opportunity to study the relationship between bathymetry created by mass-wasting processes and the character of later sandstones. This work aims to combine new and previous data from the Britannia Sandstone Formation in order to describe the evolution of large-scale mass-failures and subsequent emplacement of associated sandstones. The focus is on the 35 km^2 Platform Area of the Britannia Field, where well-data from 47 wells and sedimentary analyses of core from 13 of those wells (this study plus earlier studies) provide a unique subsurface case study comprising detailed characterisation of reservoir architecture variability in relation to different slope-failure magnitudes.

Four mass-transport events (R1-R2-R3-R4) originated from the southernmost extension of the Fladden Ground Spur, a high that formed the local northern margin to the basin. They were likely triggered by tilting and over-rotation of the earlier tabular turbidite deposits linked to large-scale differential subsidence (tectonic and compactional) of the Witch Ground Graben. Well correlations within the Platform Area identify two classes of remobilisation on the basis of the maximum depth of evacuated topography and related deposit thicknesses. In the lower part of the Britannia stratigraphy, R1 and R2 rest on an irregular topography formed by evacuation and only partial infill of a failure surface with between 50 and 100 m of relief. Most-failure topography of the order of 50 metres was subsequently healed by sharp-based, medium/fine-grained, clean, amalgamated sandstones. Within the central reservoir, R3 and R4 represent smaller-scale remobilisation events. These events left a less pronounced topography, which excavated local accommodation of between 10 and 50 m deep that was then healed by muddier sandstone beds including subsidiary hybrid-event beds that pinch out and lap onto relatively subtle confining slopes. Towards the top of the central interval, a smooth sea floor had been re-established with a return to a tabular sandstone architecture.

These depositional trends can be understood in terms of the impact of varying scales of remobilisation (decreasing with time) and induced sea floor rugosity. The documented spatial variation in turbidites in this deep-water setting illustrates how sandstones deposition in association with MTD-created accommodation can be quite different from that in conventional architectural models.

TALK

FACIES HETEROGENEITY IN THE TRIASSIC SHERWOOD SANDSTONE GROUP OF THE UK: COMPARING AND CONTRASTING COEVAL DEPOSITIONAL BASINS

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The primarily fluvial Triassic Sherwood Sandstone Group is found at outcrop fringing the northern part of the Needwood Basin (between Stoke-on-Trent and Nottingham) then northwards along the western margin of the East Midlands Shelf (Figure 1). The offshore lateral equivalents of the group in the East Irish Sea and North Sea (Ormskirk and Bunter sandstones) are reservoirs for oil and gas. Additionally, the Sherwood Sandstone Group is of regional importance in eastern England as the principle groundwater aquifer that supplies water for potable and industrial use. In some areas the aquifer has become contaminated by a variety of pollutants including Non-Aqueous Phase Liquids (NAPLs) and nitrates. Some pathways through the aquifer are via intergranular flow and this is partly influenced by variations in porosity and permeability, of which lithofacies is a major control. As such, further understanding of the spatial relationships between different lithofacies and associated properties at outcrop can be used to augment predictive models applicable to both the water and hydrocarbons industries.

Data collection for this study focussed on 6 field localities covering the East Midlands Shelf and Needwood Basin. From these field localities numerous lithofacies have been identified and these include: i) clean homogeneous massive sandstones, ii) sandy conglomerates, iii) poorly- to moderately- sorted cross-bedded sandstones, iv) fine to very-fine cross-laminated sandstones, and v) thin horizontally laminated siltstones. Data from these field localities comprises a series of pseudo-three dimensional architectural panels which illustrate the relationship and three-dimensional configuration of observed lithofacies types. Cores from eight boreholes were also logged and provide information on the spatial distribution and relative abundance of the identified lithofacies where outcrop is sparse.

Figure 1 Onshore outcrop of the Sherwood Sandstone Group in central and Northern England

This study allows a comparison of the Sherwood Sandstone Group between depocentres separated by the Charnwood palaeo-high. The dataset is being used to create qualitative and quantitative models that depict the variations in lithofacies types and configurations in the Sherwood Sandstone Group spatially; contrasting lithofacies from linked contemporaneously depositing basins. Preliminary results suggest more lateral and vertical variation in lithofacies types than has been previously described, which implies that a greater complexity of lithofacies architecture needs to be captured to improve models of fluid flow in the Sherwood Sandstone Group.

MINERAL PRECIPITATES IN MODERN MICROBIAL MATS: CARBONATES, MG-SILICATES AND ROLE OF EPS

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Much research in recent years has focused on the role of microbes and their associated EPS (mucilage) in the precipitation of dolomite. This study of modern high-intertidal microbial mats from Qatar reveals that in addition to dolomite and calcite, Mg-silicates are also precipitated within the mat. They take the form of a felted mat of palygorskite-type fibres, which appear to have the undulating, sheet-like form of EPS with holes resembling EPS alveolar structures. Dolomite is present in the mats as micron-sized rhombs, and submicron spheroids of various sizes, reflecting the honeycomb texture of EPS wherein they originally formed. These nanospheroids may well be the initial precipitates that eventually develop into rhombs. Calcite crystallites commonly form fanning bundles, "wheatsheafs", occurring in groups, fans and coating grains. Terminations are observed developing on top of such bundles.

These Qatari microbial mats are covered by the sea at very high tides. Exposed for much of the time, evaporation leads to elevated salinities in the porewater in excess of seawater. The source of silica for the Mg-silicates is likely to be wind-blown dust, which in the region is composed of 33% SiO_2. The dust consists of particles chiefly in the size range 1-4 microns. The Mg^{2+} is probably derived from seawater, and it may have been 'mopped up' by the EPS. Silica dissolution-Mg silicate precipitation is likely to have been driven by pH changes within the mat related to micro-environmental changes induced by the microbes and their degradation, and that of the EPS. Mg-silicates are unstable in a system of fluctuating pH and temperature, and eventually silica may be precipitated within the mats, releasing Mg^{2+} for further dolomite. Many ancient microbial mats / stromatolites have laminae of silica or are wholly silicified, wherein microbial microfossils may be preserved.

TALK

MULTI-PROXY SAND PROVENANCE IN THE LAKE ALBERT BASIN, UGANDA: INSIGHTS INTO THE DRAINAGE EVOLUTION OF THE UPPER NILE

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The Lake Albert Basin, NW Uganda, comprises proven reservoir sandstone intervals of Late Miocene–Pliocene age, variably representing fluvial, deltaic and lacustrine environments. Originating as part of an intra-continental rift system, the basin and its constituent lake marks the modern confluence between the Victoria and Albert Nile.

This study aims to identify and distinguish the source areas supplying sediment to the basin during the Neogene and ultimately constrain regional palaeodrainage pathways and scales. These types of insight can contribute to understanding the broad-scale evolution of the upper Nile drainage system. On a more local scale, such information can help in the prediction of reservoir sandstone distribution and quality.

To these ends, a multi-proxy provenance approach, integrating heavy mineral analysis, U-Pb zircon geochronology and Pb isotopic analysis of detrital K-feldspar, has been used to constrain the sources of reservoir sandstones in sand prone intervals from three exploration wells along the margins of Lake Albert. By incorporating provenance techniques based on framework and accessory minerals of variable stability, this approach aims to understand both the provenance of the sands and the processes/factors which can influence and modify sediment composition and, ultimately, reservoir quality.

This approach has revealed contrasting provenance for sediments developed on the northeastern and southern margins of the basin respectively, confirming that two independent, unconnected drainage systems operated during the Neogene. Provenance data suggest basin-axial derivation in the north, with sediment dominantly sourced from the poorly-constrained Ugandan Craton and minor input from more distal basement to the northeast. Supply was via a proto-Albert Nile which, in contrast to today, flowed from northeast to southwest. Drainage scales appear to be in excess of 250 km. Further south in the basin, the integrated data suggest derivation of sand from the Tanzanian Craton (likely the 2.7–2.8 Ga Victoria Terrane) with some input from the far west (the Mozambique Belt or equivalents), suggesting drainage scales in excess of 500 km. This basin-lateral supply appears to have been via the palaeo-Nkusi river, which had a significant regional catchment prior to the capture of the upper Nile by the Victoria Nile. Rift flank uplift and regional tilting can account for the rearrangement of drainage since the Neogene. Although pedogenesis appears to be a key control on reservoir quality in the area, there is a clear link between primary mineralogy and susceptibility to post-depositional alteration.

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DUNES AND DENSITY CURRENTS: A RE-EVALUATION OF THE DUNE PHASE-STABILITY SPACE

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The past 100 years of research on fluvial dunes and their deposits has produced bedform scaling laws based on flow depth, grain size and flow velocity. Such flow-form-deposit scaling is used ubiquitously for a wide range of paleo-environmental interpretations and in parameterising river bed roughness for flood models. Recent research from the density current community, where flow velocity can be significantly different to open-channel flows, shows that these laws are often extrapolated beyond the limits of the original research. In turbidity deposits, for example, paleo-hydraulic reconstructions commonly predict dune forming flow conditions, but preserved dune cross strata are rarely found. One particular difference between these geophysical flows is the mean downstream velocity profile shape, which is known to alter bed shear stress and sediment transport rates.

In a series of novel laboratory experiments the shape of the mean downstream velocity profile was systematically altered so the velocity maximum was lowered toward the bed through the addition of roughness elements at the water surface, whilst maintaining flow depth and depth-averaged velocities. This produced downstream velocity profile that more closely resembles to those found in density currents (and open-channel flows with strong curvature). The initial lowering of the position of velocity maximum position increased dune heights and lengths by a factor 2.5, whilst the condition with the lowest velocity maximum position produced a stable upper-stage plane bed. Notably, predictions based on flow depth and mean velocity used in these experiments remained within the dune regime phase-space. The results therefore demonstrate that the vertical position of the downstream velocity maximum can be a better predictor of equilibrium bedform geometries than flow depth or depth-averaged velocity and also highlights that paleo-hydraulic reconstructions need to account for the possible variation in profile shape between different types of geophysical flows.

This research improves our fundamental understanding of bedform stability, which improves our ability to interpret the flow-form scaling laws of subaqueous dunes for a broader variety of depositional environments.

TALK

ORIGIN OF VARIATIONS IN MUD-CONTENT IN TIDE-INFLUENCED DELTAS: DELTA LOBE ABANDONMENT OR MAXIMUM TURBIDITY ZONE?

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Tide-influenced deposits contain muddy facies due to the deposition of mud during slack water. Patterns of mud deposition are well-known in transgressive deposits in both modern estuaries and ancient estuarine sediments deposited in incised valleys. However, the vertical and lateral distribution of muddy facies in ancient deltaic deposits is less well-constrained. In this study, this question is addressed using outcrop data from the Cretaceous lower Sego Sandstone (Book Cliffs, Utah, USA), a regressive deltaic deposit of mixed, wave and tide influence. Excellent exposure and lateral control in large (25 km) cliff-face exposures make the Sego Sandstone a good natural laboratory to study distributions and stratigraphic architecture.

The Sego Sandstone forms a net-regressive succession overlying marine mudstones and overlain by lower delta plain deposits. At the base of the Sego Sandstone, offshore mudstones are present which pass gradually upwards into storm-wave dominated, very fine-grained hummocky cross-stratified sandstone beds. These sandstones were deposited during storms between storm- and fair-weather wave-base. They are erosionally overlain by fine-grained, cross-bedded sandstones. The foresets of the cross-beds are draped by mudstone, which amalgamate to form rippled, heterolithic mudstone toesets. Upwards, these cross-bedded sandstones are interbedded with relatively mud-rich lenticular, wavy and flaser bedded, very fine- to fine grained heterolithic sandstones. The relief at the channelized, erosional bases of bodies of cross-bedded sandstones increases up-section. Also, the paleocurrent directions indicated by cross-stratification are dominantly flood-directed in the lower sandstones, but become increasingly bidirectional and ebb-dominated upwards. These tide-dominated deposits were deposited above fair-weather wave base, where tidal currents rework the sediment on a daily base.

It is interpreted that the upward shift from flood-directed currents to ebb-directed currents represents the regression of a deltaic coastline containing multiple distributary channels. The distribution of cross-bedded sandstones and heterolithic sandstones can be explained by two contrasting depositional models for tide-dominated deltas. In the first model, muddy heterolithic sandstones were deposited in the turbidity maximum zone, implying an along-axis change in mud content in distributary channels. Alternatively, the cross-bedded sandstones were deposited in active distributary channels, and the heterolithic sandstones were deposited largely in abandoned distributary channels, which results in a lateral change between more sandier and muddier channels fills.

MORPHODYNAMICS OF CYCLIC STEPS: A DEPTH-RESOLVED NUMERICAL MODEL

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Although the majority of sediment transport is associated to high-discharge events, and such events are prone to Froude-supercritical flow, there are only limited outcrop examples of supercritical-flow deposits. These low numbers of outcrop examples are often explained as being the result of poor preservation potential of upper-stage flow-regime deposits, due to reworking by subcritical flows in the waning stages of these high-discharge events. However, an alternative explanation for this might be that there is not enough knowledge on supercritical-flow deposits to recognise these deposits. This last argument is supported by the fact that numerical and physical experiments in recent years have strongly increased the number of recognised supercritical-flow deposits. Although large progress has been made in the study of the architecture of supercritical-flow deposits, using experimental data and depth-averaged models, scaling issues and measurement difficulties in experiments, and the limitations of depth-averaged models, are limiting understanding of the interaction between the flow and the bed development.

Froude-supercritical flows can lead to the formation of bedforms such as antidunes, chutes-and-pools and cyclic steps, the last of which will be focussed on herein. Cyclic steps are described as a series of upstream migrating steps, each step is characterized by a lee-side of the bedform which is eroded by a Froude-supercritical flow and depositional stoss-side of the bedform associated with subcritical flow. The transition between the two flow-regimes is characterized by a hydraulic jump which is located roughly in the trough of a cyclic step bedform. The deposits of cyclic steps can be characterised by backset laminations terminating upstream against the erosional or transportational lee-side of the cyclic step, the backsets can also be eroded by the lee-side of the next upstream-migrating bedform on the downstream end.

The study presented provides a quantification of physical parameters, such as shear stresses and sediment concentrations, which have proven to be difficult to obtain via depth-averaged numerical modelling or experiments. A novel approach is taken by using a fully depth-resolved computational fluid dynamics model, capable of rendering complex 3D geometries, allowing for a more detailed picture on morphodynamic interaction between flows and cyclic steps bedforms than ever before.

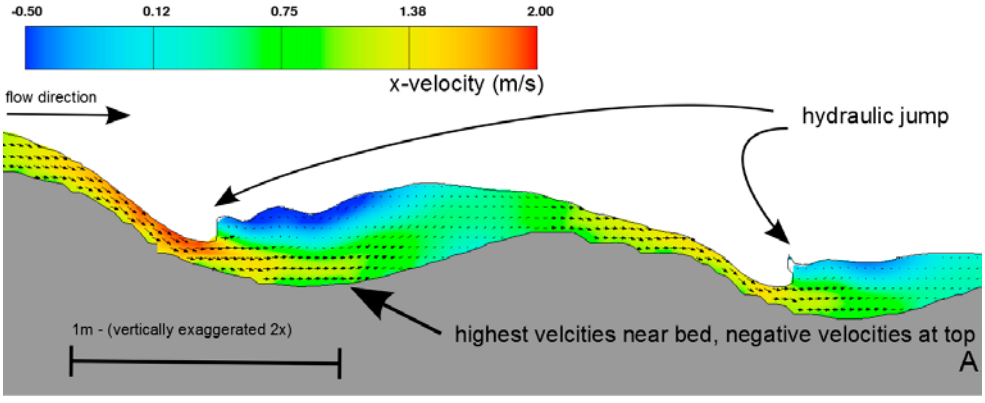

Figure 1 A snapshot of the computational fluid dynamics model. A unidirectional flow over a sediment bed. The x-velocity shown here is the downstream-directed component of the velocity field.

TALK

THE PALAEOPROTEROZOIC TONGWANE FORMATION (SOUTH AFRICA): TRANSITIONING FROM IRON FORMATION DEPOSITION TO CARBONATE DEPOSITION ON THE KAAPVAAL CRATON PRIOR TO THE GREAT OXIDATION EVENT

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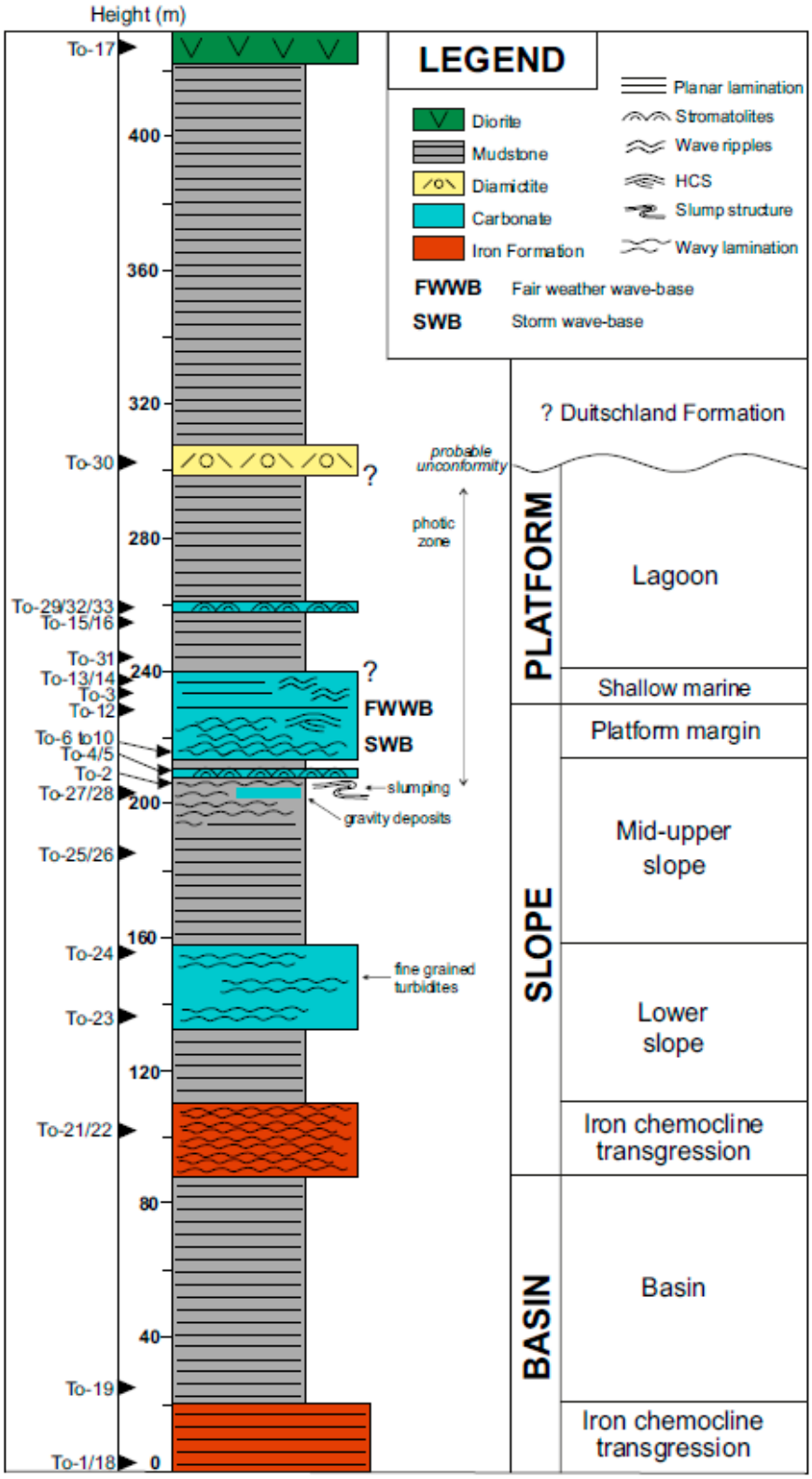
The Tongwane Formation (Chuniespoort Group, Transvaal Supergroup, South Africa) is a Palaeoproterozoic sedimentary succession that rests conformably on the Penge Iron Formation. Although undated, the Tongwane Formation is thought to predate the Great Oxidation Event (GOE), and possibly 'snowball Earth' periods. It can thus shed light on environmental conditions on the eve of these important events. However, the sedimentology and petrology of the Tongwane Formation has not been previously discussed in the published literature. Logging and sampling was conducted along the Tongwane type section. Thin sections were prepared from samples and analyses of bulk rock XRF, XRD, as well as C and O isotopes, were carried out.

A depositional and diagenetic model of the Tongwane is proposed. Sedimentary structures and facies relationships are consistent with a prograding carbonate ramp environment. Distal, basinal facies are ferruginous mudstones and iron formations which are overlain sequentially by: (i) slope interlaminated ferruginious, siliceous and carbonate mudstones including fine-grained turbidites and slump deposits, (ii) shallower water carbonates displaying HCS and wave ripples, and (iii) low energy mudstones with stromatolitic horizons. This is one of the rare documented cases of shallow-water carbonate deposition coeval with deeper water deposition of iron formations.

We propose a four stage diagenetic/metamorphic model: (1) carbonate recrystallization, stylolite formation, and dolomitization occurred during early diagenesis and the first km of burial, (2) primary iron oxyhydroxide deposits underwent diagenetic alteration to iron oxide (magnetite, hematite) and iron carbonate (siderite) phases by maximum burial depth of approximately 4 km, (3) interaction of alkaline, metasomatic fluids added significant sodium to the system causing alteration of iron oxides, but mainly siderite, to riebeckite, and (4) medium-grade contact metamorphism which elevated temperatures above 420°C leading to the total replacement of siderite with grunerite, and the growth of biotite and andalusite in mudstones. It is likely that iron oxides weathered to form goethite during late stage (near surface) exhumation and exposure.

We present C and O isotopes, and major and trace bulk rock XRF data that suggest that the Tongwane was deposited in a dysoxic to oxic environment in which free oxygen could have been accumulating prior to the GOE (as preserved on the Kaapvaal Craton). However, we acknowledge that the metamorphic overprint of the section is such that preserved geochemical data may be misrepresentative of Palaeoproterozoic water column chemistry and that further study is needed to better assess the role of devolatilisation and metasomatic fluids.



Measured sedimentary profile of the Tongwane Formation with interpretation of the depositional environment.

TALK

RARE EARTH ELEMENTS AS PROVENANCE DISCRIMINATORS OF SUBMARINE MEGA-LANDSLIDES IN THE NORTHERN NORTH ATLANTIC

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The North Atlantic margin provides evidence of several very large (>100 km3) submarine landslides. Motion of some of these slides has been shown to generate damaging tsunamis which travelled long distances across the ocean, such as that generated by the Storegga slide at 8.15 ka BP. If such a tsunami occurred again, it would pose a major hazard to northern European coastlines. Therefore identifying the source and age of past slide deposits is important to quantifying the risk to UK and the rest of coastal Europe. In this study we analyse the distal deposits of slides (turbidites) to assess their provenance. We present initial results from a new core dataset from the Storegga slide, Trænadjupet slide, Lofoten Drift mud pond and basin, and the outer edge of the Voring plateau. Our preliminary results reveal the source of a previously unsampled mega-bed below the Storegga slide.

Turbidite mudcaps were analysed using ICP-MS for Rare Earth Element (REE) abundances to establish relationships between distal deposits. REEs are a good source discriminator due to the stability of lanthanide group elements, and the preservation of elemental ratios during transport. Only mud was analysed to avoid the bias associated with heavy mineral concentrations due to hydraulic fractionation. Clusters of distinct elemental ratios indicate different provenances for the distal turbidites, including Eu/Eu* anomaly, $\sum$REE, (Gd/Yb)N and (Sm/Nd)N. The clusters provide insight into the history of past large slides in the region and the influence of contour current-reworking of deep-water deposits.

A mega-bed deposit below Storegga on the Aegir Ridge was previously identified from geophysical data and we interpret this as the Tampen Slide turbidite, originating from the same sector of the Norwegian margin as the Storegga Slide. The Norwegian basin has both a long record of large scale landslides, commonly linked to glacial-interglacial transitions, but is also an important location of deep-water formation, with strong currents capable of transporting turbidite muds over significant distances.

The interaction between submarine landslides and ocean currents is not well understood. Future work will involve tracking out turbidite mud caps in deep water to understand the influence of contour currents at different water depths, as well as understanding the extent of landslide run-out. This has important implications for ocean circulation models as well as future hazard assessments.

PROBING THE SEDIMENTARY RECORD OF PAST CLIMATE CHANGE USING ALLUVIAL FAN STRATIGRAPHY

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Climate profoundly influences the erosional-depositional processes that shape the Earth's surface. However, the extent to which sediment routing systems are either sensitive, or are buffered, to rapid climate change remains extremely contentious. A good way to address this fundamental question empirically is to examine the sedimentary record, because this constitutes the only physical archive we have of mass transport across Earth's surface as a function of past climate. Terrestrial sediments have the potential to preserve the erosional record of upland landscape response to high-frequency climate forcing, while advances in exposure-age dating now enable detailed time-series of sediment characteristics, such as grain size, to be compared quantitatively with known palaeo-climate archives. Here, we use exceptionally well-constrained data from the Sierra Nevada, California, to demonstrate that the sediment characteristics and channel widths of alluvial fan deposits capture orbitally-induced climate fluctuations with high fidelity over a complete glacial-interglacial cycle. We demonstrate that the grain sizes of these sediments scale with Pacific sea surface temperature reconstructions for the last 140 ka, increasing systematically with ocean surface warming. We propose this signal is driven by changes in surface runoff, controlled by the magnitude and intensities of flow-triggering storms. Our results (i) provide new constraints on the sensitivity of sediment routing systems to climate changes of known magnitude; (ii) show that the response time of these systems to climate change can be rapid ($\leq 10^4$ years); and (iii) demonstrate that stratigraphy can be successfully inverted for past environmental changes where transport and deposition rates are high.

USING HYDROCARBON RESERVOIRS AS ANALOGUES TO ASSESS SHALE SEALS FOR CARBON CAPTURE AND STORAGE

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Carbon capture and storage (CCS) will probably occur initially in hydrocarbon fields, which have tried and tested seals. However so-called 'saline aquifers' have much larger storage potential, but the seals are untested. Hence, the capillary entry pressure of the seals is unknown, and the safe column height of CO_2 cannot be assessed unless core samples are available — which they may not be, especially in the early stages of investigation. Generic sealing capacity can be assessed using natural hydrocarbon reservoirs. For the UK North Sea, both oil and gas fields are filtered by eliminating those in which the hydrocarbon column height is known to be limited by a spill point or by the limited thickness of the reservoir; in the remaining reservoirs the column height is at least potentially limited by capillary leakage through the seal. The assumption is then made that, in these fields, the buoyancy pressure of the hydrocarbons equals the capillary entry pressure of the seals at the field crest.

Using published hydrocarbon column heights of the filtered fields, along with hydrocarbon properties (density; interfacial tension with water; contact angle), the limiting porethroat radius of the seal lithology is calculated. This is the smallest porethroat radius found on potential leakage pathways – through which the hydrocarbon (or CO_2) must pass, or else be effectively contained. The radius may correspond to either a pore within the rock matrix, or a fracture.

The distribution of limiting porethroat radii thus calculated (International Journal Greenhouse Gas Control, 28, 126–133) is approximately log-normal, and the range corresponds with the range of literature values worldwide measured on shale samples. This suggests that the assumption that capillary leakage is the limiting factor in the retention of hydrocarbons is acceptable, and hence that capillary leakage is at least potentially the factor limiting the capacity of storage sites in CO_2 storage. The statistical distribution of porethroat radii could be used to assess an untested seal in a saline aquifer, in a Monte-Carlo approach to assessing the storage capacity which is similar to that used for assessing the reserves of a hydrocarbon field. The method presented here has the advantage of effectively sampling an entire field for the seal effectiveness, removing the issues of upscaling and representativeness inherent in measurements on core-sized samples of shale seals. Application to a saline aquifer clearly depends upon the judgement that the data set presented is plausibly applicable to the untested seal.

THE DATING OF LATE QUATERNARY FLUVIAL AND MARINE TERRACE SEDIMENTS IN SOUTH-WEST IRAN AND THEIR USE IN DETERMINING EARTH SURFACE MOVEMENTS

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Within the Mesopotamian-Persian Gulf Foreland Basin the subdued relief of the Dezful Embayment acts as a drainage node for the River Karun, River Dez and other major rivers which flow from the Zagros Mountains across the Khuzestan Plains, generally transverse to a succession of NW-SE trending folds and thrust faults. The NW-SE oriented Zagros Deformation Front (ZDF) demarcates the meeting of the NW-SE Zagros structural trend of the Dezful Embayment and the N-S Arabian structural trend of the Mesopotamian Foredeep. Evidence for rates of tectonic uplift within the region has been compiled using radiocarbon dating of sediments of two marine terraces of the north-east Persian Gulf coast (with a correction for $^{+}$0.7 m of hydro-isostasy), archaeological dating of ancient hydraulic structures and canals in Khuzestan, OSL dating and archaeological dating of sediments of six Karun river terraces in the Upper Khuzestan Plains (Woodbridge, 2013), and interpolation of rates of GPS-detected horizontal surface motion of the Zagros relative to Arabia (Hatzfeld et al., 2010). This indicates that Earth surface movements in lowland south-west Iran can be considered in four NW-SE trending zones parallel to the ZDF:

SW of the ZDF: Subsidence

Vicinity of the ZDF (approximately 0–20 km to the SW and NE of the ZDF): Minimal vertical Earth surface movements

Approximately 20–60 km to the NE of the ZDF: Uplift at rates of c. 0.1–0.8 mm yr^{-1}

Approximately 60–130 km to the NE of the ZDF: Uplift at rates of c. 0.2–2.3 mm yr^{-1}

These approximate, slightly overlapping zones are broadly in accordance with what is known of the structural geology of the region, particularly a propagation of the deformation of the sedimentary cover towards the south-west since about 5 Ma (Allen et al., 2004). The general differences in Earth surface movements between these zones accounts for the slight influences of tectonics on major rivers in the Lower Khuzestan Plains in the vicinity of the ZDF and to the SW of the ZDF, and the prominent influences of tectonics on major rivers in the Upper Khuzestan Plains to the NE of the ZDF.

TALK

THE WEIRD WORLD OF THE BRAZILIAN PRE-SALT: GELS, CLAY DISSOLUTION AND A MANTLE SOURCE?

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The discovery of giant fields in Cretaceous lacustrine carbonates from offshore Brazil and now West Africa, created a feeding frenzy in searching for analogues. However, what has emerged is an appreciation that the reservoirs are the products of extreme conditions in alkaline lakes where the precipitation of Mg-silicates controlled both carbonate formation and porosity development as the clays later dissolved. A non-actualistic depositional and diagenetic model has had to be devised but there are many unresolved issues including the source of the lake chemistry, with the finger currently pointed at serpentinisation of the mantle.