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BSRG Sedimentary Research

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Contents

Keynote Talks

Vanished Ocean: How Tethys Re-Shaped the World

Dorrik Stow

Heriot Watt University, Edinburgh EH14 4AS, UK

The Tethys Ocean once dominated the Earth. Between 260 and 6 Ma (million years ago) its vast waters bore witness to some of the most significant and dramatic episodes in the history of our planet. Two mass extinctions – the end Permian and end Cretaceous – rocked the world during this long period of time. Global environmental stress and changes in ocean chemistry are more correctly implicated in the cause of these events, rather than bolide impact. The warm shallow waters of Tethys then nurtured the ensuing rebirth of new organisms: exuberant Jurassic marine life; the development of sponge reefs, coral reefs, rudistid bioherms, nummulitic shell banks and the myriad fishes that adapted to each new ecosystem; the evolution of feathered birds from Tethys lagoons and cetaceans from the strandline to the deep sea. Repeated black-shale episodes (180-80 Ma) when the ocean was close to its maximum extent have given the world the majority of its oil resources. Progressive closure of the Tethys led to uplift of the Alpine-Himalayan mountain ranges, and their dramatic erosion fed the world's largest deepwater fans. Many of these play host to important oil and gas reservoirs. Ocean circulation patterns also changed and so impacted global climate, the resultant changes causing the world to plunge into its current icehouse climatic phase. Opening of the Gibraltar gateway after final closure of the Tethys reign (5.2 Ma) resulted in the outpouring of warm salty water into the North Atlantic Ocean. This is likely to help keep the Atlantic Overturn in operation and so, at least initially, stem the worst effects of global warming.

From this remarkable history of environmental change through the geological past we can learn much about our global environment today. What is robust and what precarious? How does life respond to changing stress? How does the ocean-climate nexus affect climate? Where are the tipping points towards irreversible change?

Meteoric alteration of carbonate-evaporite sequences – insights from the Tertiary Aquifer System in Qatar.

Fiona Whitaker, Rattana Thirathititham and Elizabeth Stanmore
School of Earth Sciences, University of Bristol, Bristol, United Kingdom
Fiona.Whitaker@bristol.ac.uk

Shallow marine sequences formed under arid conditions commonly comprise limestones and dolomites interbedded at a range of scales with evaporite minerals. Across the Arabian Gulf such deposits of Tertiary age comprise a thick and laterally extensive reservoir that in some areas hosts oil and gas reserves, and in others represents an important aquifer for groundwater supply. These rocks formed from waters at, or considerably in excess of, seawater salinity, and experience significant diagenetic alteration when exposed to meteoric fluids. The resulting dissolution of evaporites poses an important hazard for construction, but also drives alteration of associated carbonates. Here we use observations of fluid chemistry to inform and understanding of these diagenetic processes.

Our study focusses on the Tertiary sequence of Qatar, which records shallow marine to sabkha deposition from the Paleocene to the late Eocene, after which an extended (c.30 Ma) period of exposure has allowed for extensive karstification. The modern climate is very arid, with high rates of evaporation and a mean annual rainfall ranging from <50 mm in the south of the country, to >100 mm in the north. Rare intense rainfall events recharge the shallow aquifer via overland flow to numerous low-relief terminal depressions. Recharge is facilitated by fractures and karst features developed over the extended period of subaerial exposure. Ground waters are hosted in largely dolomitic aquifers, which include the Paleocene to Lower Eocene Umm er Radhuma and overlying Lower Eocene Rus Formation, with the Middle Eocene Abarug limestone forming a locally important aquifer in the south west the country. In southern Qatar the Rus is subdivided by a unit of gypsum and clays which is up to 50 m thick. This confines the underlying Lower Rus and Umm er Radhuma aquifers, which are fed by recharge from outcrop areas to the south and west within Saudi Arabia. In the north gypsum was either not deposited, or has since been largely dissolved from the Rus, and the two aquifers are in hydraulic continuity.

Major ion chemistry data for ground waters from wells distributed across Qatar, has been used to characterize water-rock interaction in the Eocene. Chloride concentrations show clear evidence of salinisation adjacent to the coast due to mixing with adjacent seawater from the Arabian Gulf. Fresher waters are present in the interior of the peninsula in the north compared to those in the south. Using chloride as a conservative tracer for mixing with seawater, we calculate concentrations of Ca^{2+}, Mg^{2+} and SO_4^{2-} that are derived from water rock interaction. All waters are significantly enriched in sulfate, but this is most marked in the southern province, likely reflecting the abundance of gypsum in the subsurface. Sulfate enrichment is accompanied by elevated levels of calcium. In the Abarug limestone the molar ratio of rock-derived SO_4^{2}:Ca^{2+}, is 1:1 as expected from gypsum dissolution, but across much of the country the molar ratio is significantly higher, often reaching 2:1 and suggesting a sink for Ca^{2+}. In combination with an enrichment in Mg^{2+} in waters within the dolomite aquifers, this provides clear evidence for replacement of dolomite by calcite (dedolomitization), driven by the release of Ca^{2+} from gypsum dissolution. Whilst current rates of gypsum dissolution and dedolomitisation are limited by the arid climate, this process is likely to have been more active during past pluvial periods and likely played a role in karst development.

The organic geochemical exploration of degraded metabolites during the early evolution of early land plants

Geoffrey Abbott

Geosciences, Drummond Building, School of Natural and Environmental Sciences Newcastle University, Newcastle upon Tyne, NE1 7RU UK, geoff.abbott@ncl.ac.uk

The appearance of land plants on the earth's surface is termed phytoterrestrialisation which resulted in critical anatomical developments such as wood (xylem) and leaves (cuticles). These anatomical developments were accompanied by the evolution of biosynthetic pathways for secondary metabolites such as lignin which are concentrated in specific tissues, layers or organs such as the xylem, cuticle and roots and are visible at the submillimetre scale. Metabolites such as lignin can then be degraded following death and deposition of the plants (Robertson et al., 2008; Schellekens et al., 2015).

Microanalytical techniques, including pyrolysis/gas chromatography-mass spectrometry (Py-GC/MS), have been used to characterise the degraded metabolites from a range of Devonian land plants (Ewbank et al., 1996) as well as the xylem and stereome in *Psilophyton dawsonii* (Edwards et al., 1997). Py-GC/MS has also been used in combination with FTIR and ^{13}C NMR to explore the composition of coeval enigmatic organisms including *Prototaxites dawsonii* (Abbott et al., 1998).

The question is whether or not the high resolution spatial distribution of the diagenetic products of such metabolites and cell wall materials can be correlated with microscopic structures. This is often difficult or even impossible to do because normally the fossils have to be milled prior to analysis. The Rhynie Chert in Aberdeenshire (Scotland) has some exquisite examples of early land plants and fungi which are than 400 million years old when its environment was very similar to that of the Yellowstone hot-springs system today. We have studied these plants using X-ray photoelectron spectroscopy (XPS) and time-of- flight mass spectrometry (ToF-SIMS) where milling is not necessary (Abbott et al., 2017). An argon gas cluster ion beam source was rastered over analysis areas to remove any post-depositional ingress from the top 3 nm of the specimen surface. The resolution of the HIM is 0.3 nm. The bonding environments of the organic carbon were identified using XPS on *Rhynia gwynne-vaughanii* and then ToF-SIMS was used to map the distribution of positively charged fragment ions for both aromatic and aliphatic hydrocarbons as well as silicon across the diameter of a Rhynia stem from the Rhynie Chert. This presentation will also give an overview of these high resolution surface analytical techniques that may help us gain a deeper understanding of the distribution of metabolites within the organs and tissues of fossilised early land plants.

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Predictive fluvial models: Applications, limitations and Examples

Amanda Owen[1], Adrian Hartley[2], Gary Nichols[3], Gary Weissmann[4], Alena Ebinghaus[2], Mauricio G.M. Santos[5]

[1] *School of Geographical and Earth Science, University of Glasgow, Glasgow, UK.*
[2] *Geology and Petroleum Geology, School of Geosciences, University of Aberdeen, Aberdeen, UK.*
[3]*School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ*
[4]*Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, USA.*
[5] *CECS, UFABC, Santo André, Brazil.*

Fluvial systems are inherently heterogeneous and as a result a wide array of deposit characteristics can be present in the geologic record. The need for predictive models is crucial in such instances as they enable common predictive facies and architectures to be identified, as well as help better understand how changes in major processes can affect the characteristic of deposits. A recent surge in distributive fluvial system (DFS) literature has shown the DFS model is applicable across multiple sedimentary basins of varying tectonic and climatic regimes. However, to date there is a lack of quantified examples of such systems that allows the predictive model to move forward. At a basin scale, distributive fluvial systems have been shown in modern studies to dominate continental sedimentary basins, yet their role in ancient basin fills has yet to be quantitatively documented. This talk highlights the quantified trends observed on the Salt Wash DFS and assesses how applicable the cited trends are at a basin scale while testing whether DFS do form the majority of the basin fill. The applicability of fluvial models in understanding smaller scale channel dynamins, such as planform and avulsion style identification are also discussed with cited examples of their merits and pitfalls. This talk highlights at a variety of scales that while predictive models are crucial in allowing the interpretation of what can often be spatially limited datasets, they must be used with caution, and when the models do not 'fit' the data important insights and steps forward in science can be made.

Oral Presentations

Deepwater clastic sedimentary systems

Clinothem architecture and sediment distribution in a bypass- to accretion-dominated basin margin succession (Karoo Basin, South Africa)

Miquel Poyatos-Moré [1,2], George D. Jones[3], Rufus L. Brunt[2], Daniel Tek[4], David M. Hodgson[4] and Stephen S. Flint[2]

[1] *Department of Geosciences, University of Oslo, Norway (miquel.poyatos-more@geo.uio.no)*
[2] *Stratigraphy Group, School of Earth and Environmental Sciences, University of Manchester, UK*
[3] *VNG Norge, Oslo, Norway*
[4] *Stratigraphy Group, School of Earth and Environment, University of Leeds, UK*

A stratigraphic section through a progradational basin margin succession will intersect a range of depositional environments and transition zones, such as the base-of-slope (BOSZ) and the shelf-edge rollover (SERZ). However, palaeogeographic reconstructions from vertical successions are problematic, as they do not account for the changing basin margin physiography through time and space. Accurate reconstructions require sub-seismic scale analysis of transition zones from coeval topset, foreset and bottomset segments in successive basin margin clinothems, although datasets are often limted.

In the Laingsburg depocentre, Unit G is a rare example of a preserved >60 km dip section along a single clinothem, which exposes a three-dimensional shelf-slope-basin floor transition. This unit has a well-constrained stratigraphic context, overlying extensively worked basin floor-to-slope deposits and capped by shelf-to-fluvial stratigraphy. Sand-prone wave-influenced lower shoreface/distal mouth-bar facies, deposited close to the SERZ, can be physically traced down dip for ca. 10 km as they thicken and transition into heterolithic, bypass-dominated slope/foreset deposits with incisional features interpreted as minor slope conduits/gullies. These deposits progressively fine and thin over 10's km farther down dip into a sand-starved basin floor/bottomset. Only a few km across-strike, the foreset segment is steeper, more channelized, and records a stepped geometry with local sand-filled intra-slope topography. Channel-lobe transition zone deposits lie downslope at the true BOSZ, in the most distal exposures.

Unit G separates an underlying bypass-dominated, sand-detached incisional slope system from a younger, accretion-dominated shelf. This stratigraphic context demonstrates that mechanisms of basinward sediment transfer and the nature of sedimentary systems and transition zones are modified through time and space during basin margin evolution. This shift in system behaviour is interpreted to be driven by changes in seabed topography, basin depth and slope angle, which fundamentally dictate the bypass or storage of sediment, and the spatial and temporal variability of resulting sedimentary bodies.

Strain distribution within mass-transport complexes: seismic characterisation and structural restoration, offshore Uruguay

Michael J. Steventon[1], Christopher A-L. Jackson[1], David M. Hodgson[2] & Howard D. Johnson[1]

[1] Basins Research Group, Department of Earth Science and Engineering, Imperial College London
[2] School of Earth and Environment, University of Leeds

Estimation of strain distribution within mass-transport complexes (MTCs) is important for the understanding the evolution of flows on continental margins, and their runout distances. MTCs also have the potential to form sealing units in deep-water depositional systems, albeit with highly variable seal properties. Hence, understanding the internal structural and stratigraphic variability within MTCs, particularly how this might compromise seal integrity (i.e. faults, fractures and strain characteristics), is a critical part of seal prediction.

The aims of this study are as follows: (1) provide a seismic reflection-based approach to assess intra-MTCs strain, (2) quantify the impact of post-depositional burial and decompaction on MTC strain, and (3) test the hypothesis that MTC strain is best defined by a broadly tripartite strain distribution. We interpret and structurally restore a shallowly buried (c. 1500 mbsf) and wellimaged MTC, offshore Uruguay using a high-resolution (15m vertical and 12.5x12.5m horizontal resolution) 3D seismic-reflection survey. This allows us to characterise and quantify vertical and lateral strain distributions within the MTC.

Through detailed seismic mapping and attribute analysis, we show the MTC is characterised by a complex array of kinematic indicators that spatially vary in style and concentration. We find the MTC is characterised by a broadly tripartite strain distribution, with extensional (e.g. normal faults) and compressional (e.g. folds and thrusts) structures in the proximal and distal domains, respectively. However, there is a strain deficit between these two domains (c. 2.9-14.2%), which we attribute to a combination of distributed (i.e. sub-seismic) strain and volume loss due to phenomena such as co-genetic turbidites. Our results reveal how strain is preferentially concentrated around major structures (e.g. megaclasts), and quantifies the strain expressed on a seismic-scale within the extensional and compressional domains. Our work has implications for assessing MTCs seal integrity and provides a practical approach for evaluating structural interpretations.

Is the Continental Shelf a Sediment Filter or Conveyor? An Integrated Study of Grain Character and Clinoform Trajectory across Clinothem Sequences.

Grace I. E. Cosgrove[1], David M. Hodgson[2], Miquel Poyatos-Moré[3], Nigel P. Mountney[4], William D. McCaffrey[5]

[1]*School of Earth and Environment, University of Leeds, LS2 9JT, eegiec@leeds.ac.uk*
[2]*School of Earth and Environment, University of Leeds, LS2 9JT, d.hodgson@leeds.ac.uk*
[3]*Department of Geosciences, University of Oslo, 0371 Oslo, Norway, m.p.more@geo.uio.no*
[4] *School of Earth and Environment, University of Leeds, LS2 9JT, n.mountney@see.leeds.ac.uk*
[5] *School of Earth and Environment, University of Leeds, LS2 9JT, w.d.mccaffrey@leeds.ac.uk*

Clinoform trajectories and geometries have been widely used to predict the spatial and temporal evolution of sand distribution. However, these methodologies underplay the significance of topset process-regime in determining *how* and *when* sediment is stored and reworked, or conveyed downdip. In order to address this problem, we present an integrated study of high-resolution grain character analysis, clinoform rollover trajectory analysis and mapping of sediment distribution to assess the role of topset process-regime in predicting downdip sand distribution and sediment character across clinothems. This study targets the topset, foreset, and bottomset deposits of four Miocene intrashelf clinothem sequences (offshore New Jersey, USA), which represent deposition under either river- or wave-dominated conditions. Seismic stratigraphy is combined with grain character data, derived from 624 samples collected from 3 cored research boreholes. Within river-dominated clinothems the transfer of coarse-grained sediment occurs under both rising and falling clinoform rollover trajectories, suggesting that process-regime is more important in determining sediment delivery than clinoform trajectory, making river-dominated systems effective sediment conveyors. Wave-dominated clinothems, deposited exclusively under rising clinoform rollover trajectories, largely retain sand within topset and foreset deposits, making these systems effective sediment filters. In addition, sediments in river-dominated systems are coarser, less well-rounded and more poorly sorted relative to wave-dominated systems and show greater inter- and intra-sequence variability, making the prediction of sediment character more challenging in river-dominated systems. This study highlights the need for caution when attempting to predict downdip sand distribution from clinoform trajectory alone, and provides a novel approach to predict downdip grain character profiles under end-member topset/shelf process-regime conditions. The results of this study will have widespread applications in both frontier and mature hydrocarbon basins alike, and can be used to better-constrain sediment grain-size and shape distributions in process-based forward models.

Submarine landslides in the South Atlantic: a stratigraphic record of slope stability and tsunamigenesis at an oblique-convergent plate boundary.

Uisdean Nicholson[1], Simon Libby[2], Dave Tappin[3], Dave McCarthy[4]

[1] *Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, u.nicholson@hw.ac.uk*
[2] *Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, sal34@hw.ac.uk*
[3] *British Geological Survey, Keyworth, NG12 5GG, Nottingham, drta@bgs.ac.uk*
[4] *British Geological Survey, Lyell Centre, Edinburgh, EH14 4AP, davmcc@bgs.ac.uk*

The southern margin of the Falkland Plateau is defined by the North Scotia Ridge (NSR), part of a seismically active (up to M_w 7.0) transform margin that separates the South American Plate from the Scotia Plate. Because of tectonic deformation, and possibly the erosional activity of strong bottom currents, the seabed appears to be gravitationally unstable, with the slope locally exceeding 15°. The instability of the slope is evidenced by the presence of multiple, large (100km^3) Mass Transport Deposits (MTDs), both within the adjacent basin and entrained within the thrust belt. Although the magnitude of historic earthquakes suggests that they are unlikely to have caused tsunamis directly, mass failure events triggered by these earthquakes may have been responsible for prehistoric tsunamis.

We use seismic stratigraphic and geomorphic observations of MTDs in the South Falkland Basin, adjacent to the NSR, to model the effects of large submarine landslides on such a steep continental margin. Pliocene-Recent landslides all appear to have originated at a single location, where transpressional strike-slip faults intersect the slope. Numerical simulations of the landslides demonstrate that they are capable of generating large tsunamis with wave heights exceeding 40m, and causing significant run-up and inundation of the nearby Falkland Islands. The largest Mass Transport Complex observed (the Burdwood Slide; ~1000 km^3) may even have been large enough to have generated wave heights exceeding 100m, and an ocean-wide tsunami similar in magnitude to the Holocene Storegga Slide offshore Norway.

We suggest that there are a number of mechanisms interacting at this margin to make it particularly prone to large failures. These including the locally steepened strike-slip component of the slope, erosion of the base of the prism by bottom currents, changes in the Gas Hydrate Stability Zone with glacio-eustatic sea-level changes, and moderate-large earthquakes capable of providing a triggering mechanism.

Mass transport deposit relief as a control on turbidite systems: An example from Taranaki Basin

Jefferson Nwoko[1], Ian Kane[2] Mads Huuse[3]

[1] *University of Manchester, United Kingdom, Jefferson.nwoko@postgrad.manchester.ac.uk*
[2] *University of Manchester, United Kingdom, Ian.kane@manchester.ac.uk*
[3] *University of Manchester, United Kingdom, Mads.Huuse@manchester.ac.uk*

Mass transport deposits affect the routing of turbidite systems and their resultant sedimentary architecture. Seven Large scale mass transport deposits have been identified in the Taranaki area with the aid of high quality 2D and 3D seismic Dataset. The interpretation reveals that the internal characteristics of the MTDs allows for the development of two main types of topography - Type I and type II. Type I: Stress-induced, is observed prominently in the headwall and toe regions of MTDs, resulting in loosely-connected and isolated ponds of sediment. Type II: Depositional topography is observed in the translational domain, where the effects of sediment loading are clearly recorded. The development of this topography type suggests that a continuous post differential compaction and lateral syn depositional remobilisation affected MTDs in this domain. Four main seismic facies within the MTDs have been identified as channel-levee complexes, extensional blocky facies, homogenised low amplitude amorphous facies and folded facies types. The relationship between 'ponding' of sediment and the accommodation style on top of the MTD facies is investigated, from the excavation point to the buckling stage. In proximal and distal areas with significant relief, accommodation is dominated by small 'minibasins' and tortuous corridors, whilst in the translational domain a larger basin with low amplitude topography may form. Turbidite sandstones deposited in these settings may be strongly affected by this topography, and in proximal and distal domains may have long rugose pinch-outs which present a significant risk for stratigraphic trapping, and they are also prone to syn-depositional remobilisation which may introduce significant heterogeneity at reservoir margins.

New data for high latitude channel systems: morphology and architecture

Charlotte Allen[1], Jeff Peakall[1], David Hodgson[1]

[1] *School of Earth and Environment, University of Leeds, Leeds, LS2 9JT., C.Allen1@leeds.ac.uk*

There is a major deficit in the number of high latitude submarine channel systems studied; previously thought to be analogous in many respects to fluvial systems, it has recently been shown that there is latitudinal variation in channel sinuosity. It is hypothesised that high latitude channel system morphology and internal architecture vary significantly from low latitude systems, through a combination of physical forcing and climatic-driven processes.

New, high-resolution bathymetric and seismic datasets are used to quantitatively study morphology and architecture of two high-latitude systems; the Weather Channel in the Arctic Ocean, and two unnamed channels off Northeast Greenland. Geometric profiles are taken at regular intervals along each channel, with width, margin height, thalweg depth and gradient extracted. Where possible, sinuosity and Rossby numbers are calculated to determine the role of Coriolis forcing upon channel evolution.

The Weather Channel is an ultra-high latitude (79°N), very low sinuosity, low gradient distal channel fed through tributaries connecting it to grounded ice on the Chukchi Rise. Significant intrachannel and overbank asymmetry is evident, with a Rossby number calculated at 1.16 (assuming flow rate of 1 m/s) and peak sinuosity of 1.14. The proximal, fjord-sourced Greenland channels (74°N) show significant margin asymmetry, with a peak sinuosity of 1.38. Atypically, seismic data shows wholly vertical aggradation, with no apparent lateral migration during channel development.

The comparison of these two systems show variation in planform channel morphology and architecture at high latitudes, in terms of intrachannel deposition and sinuosity, but both exhibit consistent margin asymmetry. Both systems are subject to the effects of Coriolis forcing, differentiating them from their low latitude counterparts, with subsequent variation potentially resulting from climatic factors, such as sediment flux and calibre, and flow type.

Quantifying the depositional architecture of updip basin-floor fan pinchouts

L.A.S. Hansen[1], D.M. Hodgson [1], A. Pontén [2], and S.S. Flint [3]

[1] *Stratigraphy Group, School of Earth and Environment, University of Leeds, U.K., L.A.Hansen@leeds.ac.uk, D.Hodgson@leeds.ac.uk*
[2] *Statoil ASA, Trondheim, Norway, anpon@statoil.com*
[3] *Stratigraphy Group, School of Earth and Environmental Sciences, University of Manchester, U.K., Stephen.Flint@manchester.ac.uk*

The character of submarine fan pinchouts can be used to constrain seabed topography and basin configurations, as well as form stratigraphic traps. The topography of the seabed and the flow rheology of the currents depositing the sediments greatly influences the character of these submarine fan pinchouts. The detailed sub-seismic scale analysis of the sedimentology and depositional architecture of updip lobe pinchouts has been studied in many basins, however the rate at which these characteristics change in different basin configurations is less well constrained. The Tanqua depocentre in the Karoo basin, South Africa, offers great exposures of the oblique updip pinchout of Fan 3 and 4. The fan thickness, percentage sandstone and facies were quantified from fan axis to fringe transects using detailed sedimentary logs and research boreholes.

The oblique updip pinchouts are characterized by an abundance of thick, climbing ripple dominated sandstones in the axial area, which abruptly transition to thin-bedded heterolithic deposits over a distance of <5 km. This is equivalent to a thinning rate of 12m/km with percentage sandstone decreasing exponentially in both fans. In planform, the pinchout geometry is not a sharp termination, rather there is localized thickening and reappearance of structured sandstone with localized remobilization along the pinchout margin, suggesting a complicated seafloor topography at the time of deposition. Injectites are abundant in the area of maximum thinning and they continue to appear for 2 km away from the maximum thickness of the fans in the updip location.

This abrupt change in sediment character and fan thickness towards the updip pinchout together with the irregular pinchout edge has improved our understanding of the seabed topography and local basin configurations. Quantifying the rates of change in fan thickness, facies and percentage sandstone is also crucial to define reservoir input parameters for stratigraphic traps in submarine fan systems.

The evolution of a stepped slope evolution over multiple sea-level cycles

Hannah L. Brooks[1], David M. Hodgson[1], Rufus L. Brunt[2], Jeff Peakall[1], Miquel Poyatos-Moré[2,3], Stephen S. Flint[2]

[1]Stratigraphy Group, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK., eehlb@leeds.ac.uk
[2] Stratigraphy Group, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK.
[3] Department of Geosciences, University of Oslo, 0371 Oslo, Norway

The effects of abrupt changes in slope gradient and orientation on turbidity current behaviour have been investigated in many physical and numerical experiments and examined in outcrop, subsurface, and modern systems. However, the long-term impact of subtle and evolving seabed topography on the stratigraphic architecture of deep-water systems requires fine-scale observations and extensive 3D constraints. This study focuses on the Permian Laingsburg and Fort Brown formations, where multiple large sand-rich systems (Units A-F) have been mapped from entrenched slope valleys, through channel-levee systems, to basin-floor lobe complexes over a 2500 km^2 area.

Thickness and sedimentary facies patterns throughout the deep-water stratigraphy including three thinner (typically <5 m), less extensive units (A/B, B/C and D/E) suggest seabed topography was present early during deep-water sedimentation, and was maintained in a similar area that ultimately developed to form a stepped slope profile. The stepped slope profile evolved through 3 key stages of development: Phase 1, where sediment supply exceeded deformation rate, causing thickness changes within basin floor lobe complexes; Phase 2, where sediment supply was on average equal to deformation rate, resulting in channel complex entrenchment and basin floor lobe thickness; and Phase 3, where deformation rate outpaced sediment supply, to form intraslope lobes and sediment bypass-dominated zones. Detailed outcrop studies of slope evolution at this scale are rare, and therefore this investigation provides key sedimentological and stratigraphic information lacking from seismic reflection datasets. This study demonstrates that stepped slope profiles can form progressively in passive margin settings without influence of mobile substrate, and that thin sandstone units are more sensitive records of seabed topography.

The significance of hierarchy in deep-marine architectural organisation – a database approach.

Sophie Cullis[1] , Marco Patacci[1], Luca Colombera[1] and William D. McCaffrey[1]

[1] Turbidites Research Group, University of Leeds, Leeds, LS2 9JT, UK, eesle@leeds.ac.uk

It is common practice for deep-marine clastic sedimentary units to be classified hierarchically. Although many classification schemes have been defined in the literature, it remains unclear whether apparent hierarchical organisation is real, over what spatial scales it might exist and what might control its development. The significance of deep-marine hierarchical ordering is here tested using a database approach, whereby modern and ancient deep-marine datasets are digitised to a common standard within a relational database, allowing patterns of organisation and associations with possible controls to be evaluated.

Through analysis of multiple seismic and outcrop datasets, it is possible to investigate geometrical trends displayed by lobate and channel-shaped architectures – units whose hierarchy is commonly classified in the literature. However, when relating geometrical trends to hierarchical terminology it becomes evident that no clear scalar ordering exists, contrary to what might be expected. A universal deep-marine hierarchy based upon scale is thus not possible. However, preliminary results show that geological controls, such as system size and basin confinement, produce different lobe dimension populations. Interestingly, both channel and lobe architectural units show strong relationships between morphometric parameters of respective child and parent units. This child-parent scale-dependent relationship is not affected by the same geological controls that influence the overall lobe dimensions. This implies that the external controls (system size and basin confinement) play a key role in producing the scale-dependent, hierarchical, geometric trends that are observed in lobate architectures. Such scale dependencies can be used to build statistical estimates of likely hierarchical organisation, helping to inform reservoir modelling.

Overall, database-assisted analyses help to assess the significance of organisational trends found in deep-marine environments. The influence of system controls are considered and suggest a more complex manner of organisation to exist within deep-marine systems than what the current scientific literature commends under its many 'hierarchical' classifications.

Tying Lithology to the Seismic Character of Mass Transport Complexes (MTCs), Gulf of Mexico

Nan WU [1], Christopher A-L Jackson [1], Howard Johnson [1], David Hodgson [2].

[1] *Basins Research Group(BRG), Department of Earth Science & Engineering, Imperial College London, Prince Consort Road, London, SW7 2BP, England*
[2] *School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, England*

Previous seismic reflection- and outcrop- based studies on mass transport complexes (MTCs) have focused primarily on their large-scale external form and internal structure. However, due to a limited number of well penetrations, very few studies document the characteristics of deeply buried MTCs, where they may form a key part of petroleum systems. Here we use high-quality 3D seismic reflection, well log (e.g. gamma ray, resistivity, and sonic) and biostratigraphy data from the Atwater Valley, Gulf of Mexico, to interpret the lithology, geometry and spatial distribution of MTCs in salt controlled mini-basins. Seismic facies analysis of three different MTCs is used to define (1) external and internal geometries of the seismic packages, (2) the reflectivity and continuity of seismic reflections, and (3) their corresponding log responses. Results suggest that intervals with contorted, discontinuous, high-amplitude seismic reflections correspond to low gamma ray well log response, which represent sandy debrites that may act as reservoirs. Chaotic to transparent, medium- to low-amplitude reflections, which correlate to high gamma ray intervals, are interpreted as muddy debris that may act as seals. These seismic and well log characteristics may aid further petroleum systems analyses, including prediction of MTC source areas and the reservoir and seal potential of MTCs within mini-basins.

Depositional architecture of a slope apron system

R. Healy[1], D. Hodgson[1], L. Hansen[1], R. Wild[2], A. Pontén[2], S.S. Flint[3], I.A., Kane [3]

[1] *Stratigraphy Group, School of Earth and Environment, University of Leeds, Leeds , LS2 9JT, UK,* eershe@leeds.ac.uk.
[2] *Statoil ASA, Trondheim, Norway*
[3] *Stratigraphy Group, School of Earth, Atmospheric and Environmental Sciences, University of Manchester, M13 9PL, UK.*

Submarine slope successions provide an important palaeoenvironmental archive to investigate controls on the transfer of sediment between continents and the deep ocean. An underexplored factor on the depositional architecture of submarine slope systems is sediment supply by multiple point sources, despite this being a common configuration observed in many seismic reflection and seabed datasets. A rare example of an exhumed multiple point source system is Unit 5 of the Skoorsteenberg Formation, Tanqua depocentre, Karoo Basin, South Africa, which is exposed over 1000 km^2, and is intersected by eight research boreholes. Unit 5 is underlain by point sourced basin floor systems (Fans 1-4), and overlain by a largely unchannelised shelf-margin clinothem succession.

Unit 5 is characterised by various thin-bed turbidite facies associations, including: thickening upwards units, which can comprise sigmoidal bedsets; climbing ripple laminated units with symmetrical ripples on bed tops; units with intense in-situ soft-sediment deformation; and units rich in hybrid beds. Intercalated sand-rich deposits range from channel-fills characterised by multiple incisional surfaces and draped by mudclast conglomerates to lobe complexes. A clear proximal to distal distribution of channel complexes to lobe complexes is documented. In several areas, proximal lobe deposits are incised by sand-rich channel elements, recording base-of-slope settings. There is also an overall trend of increasing incision from south to north through time. Palaeocurrent data, the distribution of thin-beds, and rates of thinning, point to the presences of subtle seabed topography on the depositional architecture of Unit 5. The mapping of Unit 5 from a channelized slope to distal basin-floor setting over a 40 km long dip transect provides an important record of basin margin evolution from bypass- to accretion-dominated processes.

Channelisation 'caught in the act': Insights into deep-marine channel evolution from the Gull Island Formation, County Clare, Ireland

Ross Ferguson[1], Ian Kane[1], Rufus Brunt[1], and Ole Martinsen[2]

[1]*School of Earth and Environmental Sciences, University of Manchester, Oxford Road, Manchester M13 9PL, U.K.* ross.ferguson@manchester.ac.uk

[2]*Statoil ASA, Sandsliveien 90, Sandsli, 5254 Bergen, Norway*

Channelisation in deep-marine environments is an inherently enigmatic process. Occurring sporadically within inhospitable environments, direct measurement of modern examples over significant timescales typically proves challenging. To combat this, outcrop proxies are often used. Whilst the ancient rock record can only record the terminal architecture of the system and cannot provide direct real-time measurement of flow processes, it does provide an invaluable resource for assessing the stratigraphic evolution of sedimentary systems. One such example is a previously under-investigated outcrop within the Carboniferous Gull Island Formation from County Clare, Ireland. Drone photography, sedimentary logging, and facies analysis have been used to characterise laterally continuous sandstones which extend at least 2.6 km, 'sandwiched' between mass transport deposits. Steeply dipping strata reveal a 30m thick strike-section through sandstone beds that pinch laterally and exhibit evidence for scouring and bed amalgamation. These observations are suggestive of a 'high amalgamation zone', marking the axial pathway of the system into a more lobe-like unit i.e. the channel-lobe transition zone. An alternative model is that these deposits capture very early-stage channelisation that has been terminated prematurely by later extensive mass transport deposit.

A combination of satellite and drone imagery has revealed a 200m wide channel form which truncates some of these sandstone beds. A 90m wide slide block from the channel margin contributes towards the channel fill, indicating these margins were relatively steep. The channel was subsequently filled by 10m of mass transport deposit, resulting in diversion of sediment gravity flows and probable avulsion of the channel elsewhere on the slope. This offers a unique insight into channel evolution, capturing the development of the channel form at a relatively immature stage of its development. Through incision of lateral, presumed genetically related lobe deposits, this channel demonstrates progressive basinward propagation and presumably, consequent contemporaneous progradation on the basin floor.

Sedimentary architecture of a detached deep-marine canyon head: Examples from the East Coast Basin of New Zealand

A.D. McArthur [1], W.D, McCaffrey [1]

1. School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK

Submarine canyons are key conduits for the distribution of sediment across continental margins. Although many connect directly to hinterland supply, others form downstream, in deeper-water. Such "detached" canyons are increasingly recognised, e.g. offshore East Africa. The nature of detached canyons remains enigmatic, as their setting restricts analysis of their formation, evolution and architecture. Here we examine Miocene outcrop analogues from the trench-slope East Coast Basin, New Zealand and compare their morphology and architecture with active detached canyon systems offshore.

The outcropping system preserves the downstream margin of a sub-basin at palaeo-water depths >700 m (based on foraminifera). A 6 km wide by 430 m deep incision is filled by heterogeneous siliciclastic sediments, 50% of which comprises graded thin-beds with traction structures, interpreted to result from oscillatory flows. These are intercalated with fourteen concave-up lenses, up to 15 m thick, of sigmoidally-bedded, amalgamated sandstones, which preserve ripple and flute-like casts on bed-bases, interpreted as mouth-bar deposits at the head of a submarine canyon. Palaeoflow was eastwards, towards the sub-basin margin. On the margin of the down-dip sub-basin, stacked and amalgamated lenticular sandstones and conglomerates are preserved. These are interpreted as the fill of a submarine channel, at least 3 km wide by 50 m deep. The channel can be tied to the up-dip canyon, which must therefore traverse the intervening structural high. This interpretation is supported by bathymetry data, which demonstrate the presence of detached canyons cross-cutting ridges. Seismic studies demonstrate multiple phases of canyon cut and fill, with a down-stream architectural evolution comparable to the outcrops.

These results demonstrate that detached canyons can cut actively developing sea-floor structures, distributing sediment away from intra-slope corridors and feeding otherwise-starved areas of the slope. Although the downstream channelised portion demonstrates better reservoir properties, detached canyon heads may form up-dip stratigraphic traps.

Spatial variability of initial reservoir potential within deep-water channel and lobe elements: examples from the Hecho Group, South-central Pyrenees, Spain.

Daniel Bell[1], Ian A. Kane[1], Anna Pontén[2], Stephen S. Flint[1] and David M. Hodgson[3]

[1] Stratigraphy Group, School of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL, U.K.
[2] Statoil ASA, Research Centre Rotvoll, NO-7005 Trondheim, Norway
[3] Stratigraphy Group, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, U.K

The porosity and permeability of unconsolidated sediments are controlled by primary sedimentary texture and mineralogy; this then has a strong control on the final reservoir quality of a sedimentary succession in the subsurface. Deep-water depositional systems are built up from deposits of discrete sediment gravity flows, which may be more common in specific sub-environments within the systems. The depositional reservoir quality, from grain-scale to larger hierarchical levels, is controlled by the spatial and temporal distribution of these gravity flow types. Therefore, understanding the sedimentary processes controlling changes in texture is critical for improved prediction of reservoir quality at different scales. One well-constrained, exhumed deep-water lobe in the Jaca Basin, and one channel element in the Aínsa Basin, located in the South-central Pyrenees, Spain, were studied and sampled to characterise the depositional reservoir quality of facies in axial to marginal settings. Construction of architectural panels and strategic sampling at multiple locations enables analysis of spatial changes in architectural and textural properties. A quantitative method for collecting hand-samples was developed to determine the grain-scale character of lobe and channel elements in different parts of the system. Samples were analysed in thin-section to establish how different depositional processes affect textural properties. Results show that high-density turbidites are concentrated in lobe- and channel-axis positions and exhibit the best primary textural properties for reservoir quality. Conversely, low-density turbidites dominate distal lobe-fringe and channel-margin positions and have poorer primary textural properties for reservoir quality. The variable properties of discrete architectural elements provides input to useful predictive concepts applicable to both exploration and development phases.

Architecture and reservoir quality of low-permeability Eocene lacustrine turbidite sandstone from Dongying Depression, East China.

Muhammad Jawad Munawar[1], Chengyan Lin[1], Dong Chunmei[1], Xianguo Zhang[1], Muhammad Aleem Zahid[2]

[1]*School of Geosciences, China University of Petroleum (Qingdao), P.R China, 266580,*
jawad_munawar@s.upc.edu.cn; lincy@upc.edu.cn; lcydcm@upc.edu.cn; zhangxianguo@upc.edu.cn
[5]*Faculty of Marine Sciences, Lasbela University, Uthal, Balochistan, Pakistan, 90250,*
z_aleem@live.com

Reservoir architecture and multiscale heterogeneity in turbidites represent serious challenges to production performance. In this paper, we report on the turbidites of the third member of the Eocene Shahejie Formation (Es3), which was deposited during extensive Middle to Late Eocene rifting in the Dongying Depression. Deep-water, marine turbidite sandstones are known to form moderate to excellent petroleum reservoirs. The architecture and quality of lacustrine turbidites that act as petroleum reservoirs are less well documented. The Es3m interval is interpreted as a sequence set that is composed of four composite sequences: CS1, CS2, CS3 and CS4. A total of forty-five sequences were identified within these four composite sequences. Sand bodies were mainly deposited as channels, levees, overbank splays, lobes and lobe fringes. The combination of fining up and coarsening up patterns of lithofacies in architectural elements produces highly composite flow units. Large-scale heterogeneity is a function of third- and higher-order bounding surfaces. Microscopic heterogeneity is produced by diagenetic alteration processes (i.e., the dissolution of feldspar, the formation of authigenic clay and quartz cementation). The dominant kaolinization of feldspar and mobilization of materials enhanced the quality of the reservoir by producing secondary enlarged pores. In contrast, the formation of pore-filling authigenic illite and illite/smectite clays reduced their permeability. Recovery rates are higher in the axial areas and lower in the marginal areas of architectural elements. This study represents a significant insight into the reservoir architecture and heterogeneity of lacustrine turbidites; these understandings can be applied to exploit primary and secondary production from these fields.

Drift influence on deep-marine systems - Block 2, offshore Tanzania

A. Fuhrmann[1], I. A. Kane [1], R. A. Ferguson [1], S. Barker[2], C. Siversen[3], R. L. Brunt[1]

[1] School of Earth and Environmental Sciences, University of Manchester, UK
[2] Statoil Research Centre, Sandsliveien 90, Sandsli, 5020 Bergen, Norway
[3] Statoil ASA, Martin Linges vei 33, 1364 Fornebu, Norway.

The influence of bottom currents on deep-marine turbidite systems is being increasingly recognised from many areas of the world. The coastal basins offshore East Africa provide an excellent location to study drift influence on these systems and to improve our understanding of facies distribution within them. We present an integrated study that combines 3D seismic, well-log and core data, to investigate the influence of bottom currents on Cretaceous deep-marine turbidite systems of the Block 2 area, offshore Tanzania. Seismic data reveal slope channel complexes, which are strongly confined and diverted by drift deposits and tectonic induced relief. Several channel complexes show an interaction with associated drift deposits and strongly asymmetrical levees. Combining these large-scale observations with well log and lithological information, we present a model of how bottom currents influence the facies distribution within these complexes. Sandstone-dominated turbidites and muddy debrites are interpreted to be deposited by submarine gravity flows. Reworked facies, such as coarsening upward trends, starved ripples and laminated to bioturbated mudstones are interpreted as the record of reworking by bottom currents; sharp based laminated mudstones occurring within channel fill facies are interpreted as the toes of drift deposits inter-fingering with channel-fills. These observations have a number of implications for the reservoir quality and performance of drift-influenced deep-marine systems: (i) Flow-stripping of the main channel-fill can improve the reservoir quality by reducing the detrital mud content; (ii) depending on the angle of the channel towards the bottom currents and the frequency of the subaqueous sediment gravity flows, the mud and silt proportion may increase within the channel complex; (iii) mud drapes associated with the toes of drift deposits may present fluid flow baffles and barriers within the slope channel complexes; (iv) onlap of drift deposits by channel deposits may generate viable stratigraphic traps.

Can direct measurements produce a step change in understanding of submarine flows?

Peter J. Talling[1], Matthieu J. Cartigny[1], Michael A. Clare[2], Dan Parsons[3], Ed Pope[1], Sophie Hage[1], Natasha Chapplow[1], Kate Heerema[1], James Hunt[2], Maria Azpiroz[2,4], Jamie Hizzett[2,4], Stephen M. Simmons[3], Jenny Gales[2,5], Esther Sumner[4], Daniella Vendettuoli[2,4], Charlie K. Paull[6], Gwyn Lintern[7], Roberto Gwiazda[6], John Hughes Clarke[8], Katherine L Maier[9], Jingping Xu[10], Mary McGann[9], Eve Lundsten[6], Kurt J. Rosenberger[9], and Monterey Coordinated Canyon Experiment Team and Bute Inlet Team.

[1] *University of Durham, Departments of Earth Sciences and Geography, Durham DH1 3LE, UK.*
[2] *National Oceanography Centre, European Way, Southampton, SO14 3LE, UK.*
[3] *University of Hull, School of Environmental Sciences, Hull HU6 7RX, UK.*
[4] *University of Southampton, European Way, Southampton, SO14 3LE, UK.*
[5] *now at University of Plymouth, School of Biological and Marine Sciences, Plymouth PL4 8AA, UK.*
[6] *Monterey Bay Aquarium Research Institute, Moss Landing, California, USA*
[7] *Canadian Geological Survey, Sidney, British Columbia, Canada.*
[8] *Centre for Coastal and Ocean Mapping, Durham, New Hampshire, USA.*
[9] *United States Geological Survey, Menlo Park, California, USA.*
[10] *Ocean Science & Engineering, Southern University of Science & Technology, Guangdong, China.*

Submarine flows of sediment (turbidity currents) flush globally significant volumes of sediment and organic carbon into deep-sea basins. These flows create the largest sediment accumulations on Earth, which hold valuable oil and gas reserves. These flows affect global carbon burial, how deep- sea ecosystems function, and pose a hazard to offshore infrastructure. Only river systems transport such large amounts of sediment across such long distances. However, there are remarkably few direct measurements from active submarine flows, which is a stark contrast to >1 million direct observations from rivers. Here we present an overview of major recent field experiments that have monitored submarine flows in action. They provide novel information on the internal structure, evolution, frequency, triggers, and runout distance of multiple submarine events at two contrasting locations. The first data set comes from Monterey Canyon, offshore California, which is fed by littoral cells. The second site is a river-fed delta in Bute Inlet, British Columbia. In both cases, the timing and runout distance of submarine flows was documented using novel instruments on multiple moorings placed along the 50-km long flow pathway. These new results include a striking observation that flow behaviour and runout is strongly bimodal in both locations. Flows tend to either dissipate rapidly, or runout through the entire mooring arrays. We thus test whether; the character of short or long runout flows can be distinguished at the first mooring, and whether long and short runout flows have different triggers. Do submarine flows either die out, or go big?

The dynamics of partially-confined gravity currents

Robert Kelly[1], Robert Dorrell[2], Alan Burns[3], William McCaffrey[4]

[1] EPSRC Centre for Doctoral Training in Fluid Dynamics, University of Leeds, scrk@leeds.ac.uk
[2] Energy and Environment Institute, University of Hull, r.dorrell@hull.ac.uk
[3] School of Chemical and Process Engineering, University of Leeds, a.d.burns@leeds.ac.uk
[4] School of Earth and Environment, University of Leeds, w.d.mccaffrey@leeds.ac.uk

Seafloor channels are the main conduit for turbidity currents transporting sediment to the deep ocean and they can extend for thousands of kilometres along the ocean floor. Although it is common for channel-traversing turbidity currents to spill onto levees and other out-of-channel areas, the associated flow development and channel-current interaction remain poorly understood; much of our knowledge of turbidity current dynamics comes from fully-confined scenarios. Here we investigate the role that partial confinement may play in affecting current dynamics. We present data from laboratory experiments of partially-confined, dilute saline flows of variable flux rate traversing fixed, straight channels with cross-sectional profiles representative of morphologies found in the field. Complementary numerical experiments, validated against high-resolution laboratory velocity data, extend the scope of the analysis. The experiments show that partial confinement exerts a first order control on flow structure. Overbank and downstream discharges rapidly adjust over short length-scales, providing a mechanism via which currents of varying sizes can be tuned by a channel and conform to a given channel geometry. Across a wide range of flow magnitudes and states of flow equilibration to the channel, a high-velocity core remains confined within the channel with a constant maximum velocity height. Ongoing overbank flow prevents any flow thickening due to ambient entrainment, allowing stable downstream flow evolution. Despite dynamical differences, the entrainment rates of partially-confined and fully-confined flows remain comparable for a given Richardson number.

Internal waves as the dominant mechanism for sediment support in stratified turbidity currents

Mike Tilston[1], R.W.C. Arnott[2], C. Rennie[3] and Joris Eggenhuisen[1]

[1]*Department of Earth Sciences, Utrecht University, Utrecht, Netherlands*
[2]*Department of Earth Sciences, University of Ottawa, Ottawa ON*
[3]*Department of Civil Engineering, University of Ottawa, Ottawa ON*

Turbidity currents rely on turbulence to maintain sediment suspension yet, paradoxically, suspended particles tend to supress turbulence. Unravelling the complex fluid-particle interactions of sediment suspension in supressed turbulence is therefore essential to explaining the propagation of these flows. Three mechanisms have been discussed extensively in literature: 1) dampening through increased effective viscosity; 2) inhibited diffusion through stable stratification development; 3) conversion of turbulence energy to work for maintaining suspension. Yet the basic question for suspension mechanics is how much turbulence really matters. Not all vertical motions are turbulence, and if particle suspension results from the balance between gravitational settling versus bed-normal velocity fluctuations that keep them aloft, there might be an alternative mechanism responsible for generating velocity fluctuations.

The present study attempts to address this issue by linking three-dimensional velocity profiles to density measurements obtained from a medical grade CT scanner from three experimental turbidity currents (~17.5% by mass) of well sorted sand that differ only in terms of their particle composition (d_{50}: 150μm, 330μm, and 330μm). The Richardson gradient number characteristics of each flow indicate the presence of a highly stabilized layer within the current, suggesting turbulence suppression. This prediction is confirmed by measurements of the intensity of the vertical velocity fluctuations in the current, which are muted with respect to clear-water turbulent flows. The theory behind the Richardson gradient number suggests that the observed vertical motions are internal waves. These vertically coherent motions are capable of penetrating the stably stratified layer, and traverse the area of the velocity maximum, which is typically viewed as a barrier to sediment exchange by turbulence. They are therefore effective in vertical mixing of sediment through the flow in stably stratified flows with suppressed turbulence.

We conclude that when sediment supresses turbulence, internal waves take over as the dominant mechanism for particle suspension.

The stratigraphic incompleteness of submarine channel deposits

Vendettuoli, D[1]., Clare, M.[2], Cartigny, M.[3], Vellinga[1], A., Hage[1], S., Hizzett[1], J., Talling, P.[3], Hughes Clarke[4], J., Waltham, D.[5], Hubbard, S.[6]

[1] *University of Southampton, School of Ocean and Earth Science, UK, D.Vendettuoli@soton.ac.uk*
[2] *National Oceanography Centre, Marine Geoscience, UK*
[3] *Durham University, Department of Geography, UK*
[4] *Center for Coastal and Ocean Mapping, University of New Hampshire, USA*
[5] *Royal Holloway University of London, UK*
[6] *University of Calgary (Canada)*

Turbidity currents transport prodigious quantities of sediment across the world's oceans through submarine channels. These flows damage strategically important seafloor infrastructure and their deposits host major oil and gas reservoirs. We therefore need to understand these flows, but their very powerful nature makes direct monitoring challenging. Most studies to date thus focus on the deposits that turbidity currents leave behind in the sedimentological record. However, deposits of individual flow are likely to be reworked. This leaves us with the questions: How complete is the stratigraphy of these deposits? Are some events better preserved than others?

We address these questions by re-analysing the most detailed time-lapse mapping yet of a turbidity current system. This field dataset comes from the fjord-head Squamish Delta in British Columbia, Canada where Hughes Clarke (2016) collected 93 near-daily repeat surveys in 2011. These surveys revealed the seafloor response to more than 100 turbidity currents. Here we use temporal changes in seabed elevation to understand patterns of deposition and erosion. We calculate the total thickness of sediment deposited at each location, and the percentage of this sediment that is preserved (the stratigraphic completeness).

Our study shows that the average stratigraphic completeness near to submarine channels is <1. This low value is largely due to upstream migrating bedforms that constantly rework previously emplaced sediments. Surprisingly, even at the terminal lobes, stratigraphic completeness is typically <5%. These results provide new insights into the evolution of submarine channels and why their deposits produce a highly incomplete record of submarine flows.

Biological mediation of turbidity currents, mudflows, and slides

Jaco H. Baas[1], Melissa Craig[2], Kathryn Amos[2], Lorna Strachan[3], Andrew Manning[4,5], David Paterson[6], Julie Hope[7], Scott Nodder[8], Megan Baker[1]

[1] School of Ocean Sciences, Bangor University, Menai Bridge, Isle of Anglesey, LL59 5AB, UK, j.baas@bangor.ac.uk
[2] Australian School of Petroleum, The University of Adelaide, Adelaide, South Australia, Australia, melissa.craig@adelaide.edu.au
[3] School of Environment, University of Auckland, Private Bag 92019, Auckland, New Zealand
[4] School of Marine Science and Engineering, Plymouth University, Drake Circus, PL4 8AA, UK
[5] HR Wallingford, Howbery Park, Wallingford, OX10 8BA, UK
[6] Scottish Oceans Institute, School of Biology, University of St Andrews, St Andrews, KY16 8LB, UK
[7] Institute of Marine Science, University of Auckland, Private Bag 92019, Auckland, New Zealand
[8] National Institute of Water & Atmospheric Research (NIWA), Private Bag 14901, Kilbirnie, Wellington 6241, New Zealand

Marine benthic and pelagic micro-organisms produce cohesive extracellular polymeric substances (EPS) that represent 40% of the total marine organic carbon pool. EPS research to date has focussed on the coastal environments, where EPS contribute to seabed stability by forming a cohesive matrix with bonds between sediment particles. The effects of this cohesive material on sediment gravity flows (SGFs) in the deep ocean have not been investigated, despite many decades of outcrop, subsurface, modern real-time observational, numerical, and experimental research. Here we present laboratory data that offer the first insights into the potential of biological cohesion for modulating muddy, physically cohesive, SGF dynamics. These data indicate that turbulence-modulated, high-density turbidity currents, mudflows and slides, are more susceptible to changes in flow properties than fully turbulent, low-density turbidity currents at concentrations of EPS typically present in the deep ocean. Even relatively low concentrations of EPS, i.e. without the need to invoke the erosion of EPS contained in biofilms, markedly decrease the head velocity and run-out distance of these high-density SGFs. These outcomes greatly improve our understanding of the natural distribution of sediments in the deep ocean, where SGFs are the primary process by which sediment and organic carbon are transported from the continental margin and where SGF deposits form the world's largest hydrocarbon reservoirs.

A Predictive Model for Submarine Canyon Type Based on River Influence and Proximity to Land.

Sumner, E.J.[1], Paull, C.K.[2]

[1] *Ocean and Earth Sciences, University of Southampton, UK. E.J.Sumner@soton.ac.uk*
[2] *Monterey Bay Aquarium Research Institute, USA. paull@mbari.org*

In recent years progress has been achieved in directly measuring turbidity currents in submarine canyons and channels. It is useful to consider how representative these observations are of the diversity that potentially exists in the dynamics of turbidity currents among different canyons and channels. Firstly, we integrate sediment core, bathymetric and (in a limited number of cases) direct observations of turbidity current dynamics from 20 submarine canyons on the northern California Margin. We use this dataset to construct a diagram that explains canyon type, and thus turbidity current characteristics (grain-size carried, flow power, relative frequency of flows), based on the relative influence of rivers and proximity to land. This diagram enables prediction of canyon type and thus processes using two easily measurable characteristics: (i) the sediment flux of the nearest river; and (ii) the distance of the canyon head from the shoreline. Secondly, we test and refine the model using published data on submarine canyons from around the world. We also discuss the influence of outsized events such as earthquakes on submarine canyons. Finally, we use this diagram to suggest where it might be fruitful to focus future monitoring efforts.

Origin and significance of cross-stratification and related scour surfaces in amalgamated deep-water sandstones

Peter D.W. Haughton[1], Andrew J. Pulham[2]

[1] UCD School of Earth Sciences, University College of Dublin, Belfield, Dublin 4, Ireland peter.haughton@ucd.ie
[2] Consultant Geologist, Cobalt International Energy, 920 Memorial City Way, Suite 100, Houston, Texas 77024 USA pulham.andy@gmail.com

Amalgamated sandstones filling deep-water channels or in proximal lobe deposits tend to lack obvious current-generated sedimentary structures presenting an interpretation challenge in cores which can severely impact reservoir characterisation. However, structures can be present but just poorly expressed. They can be revealed by differential weathering in outcrop or via the use of computed tomography (CT) imaging in the case of cores. Where structures have been identified, these do not conform to those formed by migrating bedforms in open-channel flows. Here we focus on cross-stratification filling fields of small, decimetre-scale scour features in the Pennsylvanian Ross Sandstone Formation, western Ireland, and enigmatic cross-bedding and associated scours revealed by CT scans of cores from the Paleogene Wilcox Formation, offshore Gulf of Mexico.

'Scour-and-fill' structures in the Ross Sandstone Formation (e.g. Elliott, 2000) superficially resemble trough cross-bedding but were not produced by dune migration. Significantly they are only found within channel-fill sandstones where typically they occur within axial fills, commonly centrally within amalgamated sandstone packages. Inclined sandstone laminations downlap onto and fill elliptical scours which are well exposed in plan view and cut one into another. The scours are lined with consistently finer grained sand and abundant heavy minerals suggesting flow separation. Scouring may have been associated with the passage of knick points that fashioned scours in consolidated sand that were then infilled or healed by down-current advance of a slip-face.

CT scans from Wilcox cores reveal an array of cross-bedded structures. Scours are commonly lined by highest density, finest grained sand and are comparable to the Ross scours. Sets of dipping laminae between scours can steepen-up, flatten-up and also show systematic upward rotation of dip. Palaeocurrent trends within 'cosets' can range up to 360º. Combined these features suggest Wilcox cores are intersecting highly 3D bedforms with both down-stream and up-stream migration.

Tb or not Tb (Act II): Banding in turbidite Sandstones

Chris Stevenson[1], Jeff Peakall[2], Dave Hodgson[2], [3]Dan Bell, [2]Aurelia Privat, and [2]Menno Hofstra

[1]*Earth, Ocean and Ecological Sciences, University of Liverpool, L69 3BX, Christopher.stevenson@liverpool.ac.uk*
[2]*School of Earth and Environment, University of Leeds, LS2 9JT*
[3]*School of Earth and Environmental Sciences, University of Manchester, Manchester, M13 9PL, U.K.*

Submarine gravity flows include a range of flow types from turbidity current to debris flow, and hybrid flows that are transitional between the two. Their associated deposits range from clean sandstones to mud-rich sandstones, and composite deposits of both mud-rich and clean sandstone. This contribution examines banding, an enigmatic hybrid facies comprising mud-rich bands intercalated within otherwise clean turbidite sandstones. Here we present a suite of onshore and offshore examples of banding in three deep-water systems. Banding typically occurs towards the tops of beds, overlying structureless and planar-laminated sandstones. It can have a variety of morphologies including sub-parallel mud-rich bands, low-angle lenticular bands, and complex heterolithic bedforms that transition from steeply dipping muddy foresets into low-amplitude bedwaves. Banding is strongly associated with erosion of flows into muddy substrates such as mud-rich MTD's and hemipelagic seafloor mud. Banding requires cohesive mud to form. The origin of this mud likely comes from local entrainment of unconsolidated mud into the base of the flow. Sustained traction breaks up the entrained mud, resulting in the cyclic development of cohesive plugs near to the bed. The balance of cohesive versus turbulent forces in the flow dictate the mud content and morphology of banding. Recognizing banding as a product of deposition from mud-charged flows with sustained traction allows this facies to be more effectively used to interpret flow processes and palaeo-environments in the geological record.

Novel Sand-Mud Sedimentary Structures in the Aberystwyth Grits Group and the Borth Mudstone Formation

Baker, Megan L.[1], Baas, Jaco H.[2], Metcalfe, Aaron[3], Seal, Rebecca[3]

[1] *School of Ocean Sciences, Bangor University, Menai Bridge, Isle of Anglesey, United Kingdom, m.baker@bangor.ac.uk*
[2] *School of Ocean Sciences, Bangor University, Menai Bridge, Isle of Anglesey, United Kingdom, j.baas@bangor.ac.uk*
[3] *School of Ocean Sciences, Bangor University, Menai Bridge, Isle of Anglesey, United Kingdom*

The interpretation of sedimentary structures formed in sand-mud sediment beds is complicated by the presence of cohesive clay, because adding even minor amounts of clay to a non-cohesive flow or bed can lead to the development of a diverse range of sedimentary structures unlike those found in pure sand. Fieldwork conducted in the distal, mud-rich part of the Aberystwyth Grits Group and the Borth Mudstone Formation (west Wales), found many novel mud-sand bedforms. The occurrence of these bedforms in the field matched those produced by decelerated flows composed of sand, silt and mud particles in the laboratory (Baas et al., 2016, J. Geol. Soc.). In the laboratory, these bedforms were stable at different flow velocities and rheologies. As the cohesive forces in the flow (and the proportion of clay) increased relative to the turbulence forces (and the flow velocity), the flows changed from turbulent via transitional to laminar and the sedimentary structures changed accordingly.

The sedimentary structures identified in the field and in the laboratory included classic current ripples, large ripples and low-amplitude bed-waves (LABW; bedforms a few millimetres high and up to several meters long), which are interpreted to be produced under flows increasingly dominated by cohesive forces. Dimensional analysis of the field data shows that these bedform types have distinct height and length ranges. In addition, the different bedform types have a spatial distribution, with large ripples more common in the proximal region of the study area and LABW more common in the distal sections. Thus, bedforms formed under mixed sand-mud flows may help to infer location within the distal parts of mud-rich deep-marine systems. A better recognition of fan-fringe facies and the sedimentary structures present, based on understanding the cohesive control on flow behaviour, may improve reservoir models.

Spatial and temporal evolution of submarine lobe deposits

Spychala, Y.T[1], Eggenhuisen, J.T.[1], Tilston, M.[1]

[1]EuroSEDS, Department of Earth Sciences, Utrecht University, 3584 CS Utrecht, NL

Submarine lobes are a major component of submarine fans and represent the main depocentre for sediment in deep-water distributive settings. As such they are of palaeo-environmentaland economic interest. While outcrops and seismic datasets allow the in-depth study of lobe facies, internal architecture and plan-view geometries, they do not allow for the study of the influence of flow conditions and basin set-up that led to these deposits.

Ten flume experiments were conducted in the 6x11 m Eurotank flume to study the depositional characteristics of lobate deposits associated with 1) different basin floor dipping angles (0-4°), 2) different sediment concentration of the parent turbidity current (11-19 % Vol), and 3) varying discharge (25 - 40 m3/h). Data analyses focused on lobe dimensions, the location of the depocentre and temporal deposit evolution.

The experimental turbidity currents formed distinctive lobate-shaped deposits with a strong dependency on the basin set-up and initial flow conditions. Generally, five relationships can be observed: 1) with increasing basin-floor dip lobe length and aspect ratio (L/W) increases;2) lobe length is proportional to the sediment concentration of the flow; 3) higher sediment discharges lead to more elongated lobe bodies; 4) as the aspect-ratio increases the main depocentre of the lobe shifts to more distal areas; 5) lobe width remains similar over all runs and is therefore proposed to be primarily dependent on grain size. In most runs deposition started away from the break-of-slope and subsequently backstepped until the lobe onlapped onto the slope.

The results of the conducted experiments enable a deeper understanding of the parameters that govern lobe dimensions and their spatial evolution. This will eventually allow to make more solid conclusions about the flow properties of studied outcrop deposits.

Turbidity Currents in Channel-Lobe Transition Zones (CLTZs): Loss of Lateral Flow-Confinement Controls Patterns of Erosion and Deposition.

Pohl F.[1], Tilston M. C.[1], Eggenhuisen J. T.[1], Cartigny M. J. B.[2], Spychala Y.[1]

[1] *Faculty of Geosciences, Utrecht University, The Netherlands, (F.Pohl@UU.nl)*
[2] *Departments of Earth Science and Geography, Durham University, UK*

On the source-to-sink flow-trajectory, turbidity currents are initially laterally confined by canyon- walls or channel-levees. At some point they lose their confinement and begin to spread laterally, which reduces their capacity to keep sediment in suspension and promotes formation of sediment lobes. However, in some turbidite systems the channels are separated from lobes by a CLTZs, characterized by large fields (10s km) of erosive features such as scours and erosional lineations. Bed morphology suggests that the structure of the unconfined flow in the CLTZ is similar to that of the channel system, rather than the unconfined flow that developed further downstream. As such, there appears to be a lag between the loss of lateral confinement and reorganisation of the current's flow structure of which the latter is hypothesised to play a significant role in creating large-scale scours in the CLTZ.

Here we present the flow structure, along with the erosional/depositional patterns, from experimental turbidity currents in a three-dimensional flume that is divided into a confined and an unconfined section. Sediment suspensions used to generate the currents were held constant, composed of sand (d50: 140μm) with a concentration of 17%(vol.). Downstream variations in the flow field is mapped with an array of ultrasonic-Doppler-profilers and erosional/depositional patterns are mapped using a laser scanner. Results suggest that turbidity currents exhibit a rapid flow collapse upon loss of lateral confinement, and that this flow collapse is associated with a dynamic mechanism that enhances sediment scour and suspension.

The results are the first measurements of a flow mechanism that credibly explains the erosional features often observed in CLTZs. Improved understanding of the formation of CLTZs will improve the reconstructions and interpretations of CLTZs from the rock record as well as the verification of reservoir characterisations of turbiditic deposits close to areas of lateral confinement change.

Contourite material properties and the association with initiating long run-out submarine debris flows

Neal Gunn[1], Jared West[1], Bill Murphy[1] and Bill McCaffrey[1]

[1] *Institute of Applied Geosciences, School of Earth and Environment, University of Leeds, LS2 9JT, UK, ear0njg@leeds.ac.uk*

Contourites are deposits of rapidly accumulated sediment that have been transported or worked by persistent ocean currents. This results in a variety of bedforms characterized by low density, high porosity and high moisture content often with an associated low strength. Large scale Mass Transport Complexes (MTCs) that pose a risk to submarine infrastructure have been identified hosted within contourite drifts. It is proposed that the observed slope failures are a result of the inherent instability of the contourite drifts based on their material properties.

Engineering Geomorphological mapping has been undertaken on a 3D seismic volume for an area of 170 x 90km offshore Uruguay in area of known contourite bedforms and slope failures to identify landforms and link these to submarine processes. This work has been supplemented by geophysical logging of eight selected pistons cores from across the continental rise at depths of between 1,200 and 3,100m. Six of the cores were split and imaged, and four were further sampled for sediment particle size analysis, index tests and fall cone penetrometer testing.

Mapping identified a 300m thick contourite plastered drift between ~1,200m and the lower slope rise transition at about 2,600m; within this feature are hosted two large MTCs. This is the only location where such features are present. Sediment cores within this material identified homogeneous, very loose, olive-grey, silts and rare fine sands.

Mapping confirms the close association between contourite processes and large scale slope failures. The results of the logging, geophysical and geotechnical testing of the sediments identifies them as being inherently 'weak' due to their nature of deposition. However, large areas of the plastered drift are not subject to failure suggesting that additional factors may be required to trigger failure.

Obtaining material properties for deep sea sediments is difficult and expensive and therefore assumption and interpretations are made primarily from seismic surveys and proxies. The ability to classify these materials and undertake detailed geotechnical testing provides a more robust understanding their behavior that results in improved modelling of their stability and potential to generate the long run-out debris flows that pose a risk to submarine infrastructure.

Sedimentology of tidal point bars in a microtidal regime: inferences from the Northern Venice Lagoon (Italy)

Massimiliano Ghinassi[1], Andrea D'Alpaos[1], Lara Brivio[1], Alvise Finotello[1], Luca Carniello[2], Marco Marani[2,3] and Alessandro Cantelli[4]

[1] Department of Geosciences, University of Padova, Padova, Italy (massimiliano.ghinassi@unipd.it).
[2] Department of Civil, Environmental and Architectural Engineering, University of Padova, Padova, Italy.
[3] Department of Civil and Environmental Engineering and Nicholas School of the Environment, Duke University, Durham, USA
[4] Shell Technology Center Houston, 3333 Highway 6, South Houston, TX 77082-3101, USA

Meandering channel network exert a fundamental control on hydrodynamic and morphodynamic processes within tidal landscapes. However, the planform evolution of tidal meanders is currently inferred via assumption that erosion and deposition occur along the outer and inner bank of the bend, respectively. The present study addresses the internal architecture and morphodynamic evolution of a tidal meander bend in the Venice Lagoon (Italy), through an approach integrating aerial photographs, bathymetric field surveys, three-dimensional high-resolution geophysical investigations and facies analysis on sedimentary cores.

The Venice Lagoon, a brackish water body about 50 km long and 10 km wide, is located in the northern sector of the Adriatic Sea and is characterized by an average water depth of about 1.0-1.5 m. The lagoon is connected to the Adriatic Sea through three inlets and is affected by a tidal range of about 1.0 m. The present study focuses on the Gaggian Channel, located in the Northern, and best naturally preserved, part of the Venice Lagoon. The Gaggian Channel is about 100 m wide, up to 7.5-8 m deep and forms two adjacent bends, which receive tributaries, on both the inner and the outer banks.

We find that the evolution of the Gaggian Channel was punctuated by abrupt changes in channel dynamics, that contrast with the predictable and monotonous rise and fall of the tides. We highlight here that changes in tidal asymmetry and increase in water and sediment discharge from lateral tributaries influence sedimentation patterns within the study meander bend in such a way that challenges classical models of tidal meander morphodynamics. Our result suggest that dynamics at a certain meander can be dependent on events that happen elsewhere in the system, and meandering patterns in the tidal landscape can retain the signatures of processes acting at larger spatial scales.

Terrestrial to deep marine Mesozoic meta-sedimentary successions in Singapore

TJH Dodd[1], MR Gillespie[1], **AG Leslie[1]**, T Kearsey[1], RS Kendall[2], T Bide[3], MR Dobbs[3], KW Lee[4], SL Chiam[5], and KH Goay[5]

[1]*British Geological Survey, Lyell Centre, Research Avenue South, Edinburgh, EH14 4AP, UK.* tdodd@bgs.ac.uk

[2]*British Geological Survey, Cardiff University, Main Building, Park Place, Cardiff, CF10 3AT.*

[3]*British Geological Survey, Environmental Science Centre, Keyworth, Nottingham, NG12 5GG*

[4]*Tritech Group Ltd., 2 Kaki Bukit Pl, Singapore 416180*

[5]*Building and Construction Authority, Singapore 579700*

A comprehensive understanding of Singapore's geology is critical to both future development and ongoing management of the subsurface. The British Geological Survey (BGS) is working with the Singapore Building and Construction Authority (BCA) to deliver a modern geological knowledge-base to benefit the widest possible stakeholder community. BCA have implemented a new and comprehensive ground investigation programme, recovering drillcores from approximately 100 deep boreholes (~200 m long) and acquiring conventional 2D seismic reflection data from across some 350 km^2 of ground. The new data set provides an unprecedented opportunity to unravel the complex geological relationships that exist in the Jurong and Sentosa groups; a complex fore-arc succession cropping out in southwest Singapore and a correlative of the Raub Group in Malaysia.

In general, the geology of Singapore is an extremely challenging geological setting to model and conceptualise. This paper presents an initial suite of conceptual models that illustrate the range of stratigraphical intervals encountered in Singapore. These models have been developed through detailed sedimentological and litho-facies analysis, making use of the newly acquired borehole and outcrop data. Deposition occurred in sedimentary environments that range from the deep marine realm to terrestrial settings. We propose that the Mesozoic to Cenozoic-aged meta-sedimentary succession can be separated into three broad subdivisions: the Jurong Group, the Sentosa Group and a suite of overlying, younger formations. Internally, across all groups, ten distinct formations are recognised.

This analysis was conducted, and integrated with other studies that examine the igneous petrology and structural geology in Singapore. This integrated approach has dramatically improved the understanding of Singapore Geology, and will eventually form the basis for a revised and robust stratigraphic framework for Singapore.

High-resolution study of a preserved fluvial-to-marine succession for refinement of regional palaeogeography: example from the Neslen Formation, Utah, USA

Shiers, M.N.[1], Colombera, L.[2], Mountney, N.P. [3], Hodgson, D.M.[4]

[1] University of Leeds, now: CASP, West Bldg, Madingley Rise, Madingley Road, Cambridge CB3 0DH michelle.shiers@casp.cam.ac.uk
[2] FRG, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, l.colombera@leeds.ac.uk
[3] FRG, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, n.p.mountney@leeds.ac.uk
[4] Stratigraphy Group, University of Leeds, Woodhouse Lane, Leeds, LS2 9JT, d.hodgson@leeds.ac.uk

Reconstructing palaeo-shoreline position in ancient successions is important for improved understanding of the dynamic sedimentology of the fluvial-to-marine transition zone (FMTZ); this has implications for reconstructing regional palaeogeography, and also applied value in predicting characteristics of down-dip reservoir units. The FTMZ can extend 10s to 100s of kilometres up-dip from the shoreline, though the full extent – from shallow-marine to fully fluvial strata – cannot necessarily be traced uninterrupted through the rock record. Here, we analyse an up-dip portion of an ancient preserved FMTZ in the Campanian Neslen Formation (Floy to Sagers Canyons, Book Cliffs, Utah) to estimate the approximate distance to the contemporaneous shoreline for different parts of the stratigraphy.

One-hundred-and-six vertical sedimentary logs, totalling 3000 m, and 194 stratigraphic panels collectively detailing a 20 km-wide stratigraphic window have been used to undertake detailed facies and ichnological analyses in a part of the succession oriented perpendicular to the trend of the palaeoshoreline. The relative position of the shoreline through time has been tentatively established by assessing changes in marine influences, and sand-body geometry and type. Inferences of channel slope and bank-full depth have enabled estimation of backwater lengths (part of the river where the streambed drops below sea level) of 20 and 40 km for different intervals of the stratigraphy. Mapping the position of the shoreline onto the stratigraphy reveals additional coastline complexity not revealed by analysis of facies belts alone. This approach has identified a large marine-influenced embayment present in the late Campanian, previously thought to have been infilled by the time of deposition of the Neslen Formation. The novel multi-faceted approach employed to constrain the distance to the shoreline is important for provision of a refined regional palaeogeographic reconstruction.

Schizophrenia in sedimentology: The J-3 Unconformity and the Curtis Formation, Central-Eastern Utah, USA

Valentin Zuchuat[1], Sigrid Da Costa[1], Anja Sundal[1], Alvar Braathen[1], Ivar Midtkandal[1]

[1]*University of Oslo, Sem Sælands Vei 1, 0371 Oslo, Norway; valentin.zuchuat@geo.uio.no*

The tide-dominated, Upper Jurassic Curtis Formation crops out in Eastern-Central Utah, overlying the continental to marginal marine Entrada Sandstone. The contact between the two sedimentary formations is formally identified as the J-3 Unconformity, which can be traced over significant distances. It has since been regarded as a "simple" subaerial unconformity, followed by a third order transgression within an enclosed basin and the resulting deposition of the tide-influenced Curtis Formation. However, careful inspection of the different facies and their sub-regional correlation clearly shows that the essence of the J-3 Unconformity is not merely characterised by a long-lasting phase of subaerial exposure. It instead displays evidence of an intricate poly-erosional history, happening during short-lived syn-depositional transgressive and regressive periods. The initial bounding surface was locally altered by processes associated with development of the Curtis Formation, and the nature of their impact is strongly process-dependent. Pre-Curtis erosional processes mainly involved aeolian deflation and fluvial incision, creating a basinwide gentle relief. Syn-Curtis erosional mechanisms were controlled by the distribution and magnitude of tidal forces within the basin, resulting in a steeper and more localised relief in comparison with pre-Curtis widespread denudation. Furthermore, sedimentary processes alone can't explain the present-day relief observed with the J-3 Unconformity. Indeed, tectonic played, at various scale, a key role in the funnelling of the various erosional forces and the distribution of the depocentres, with (i) m-scale grabens and horsts structures, and (ii) hydroplastic sand remobilisation, both observed within the uppermost strata of the Entrada Sandstone, as well as (iii) syn-Curtis sub-regional tectonic uplift. This study shows that reducing an unconformity to a single process is insufficient. Instead, careful mapping and understanding of such a schizophrenic surface can provide a non-negligible amount of information regarding the dynamic of a basin and its subsequent infill.

Shelf edge and slope along-strike architecture and sediment distribution: Karoo Basin, South Africa.

Luz Elena Gomis Cartesio[1], Miquel Poyatos-Moré[1,2], Rhodri Jerrett[1], David Hodgson[3], Stephen Flint[1]

1. Stratigraphy Group, University of Manchester, Manchester, United Kingdom.
2. Department of Geosciences, University of Oslo, Norway.
3. Stratigraphy Group, University of Leeds, Leeds, United Kingdom.

Although some basin margin successions may appear consistently progradational along depositional-dip sections, interaction of mixed-coastal processes and differential spatial configuration results in complex along-strike sedimentary architectures, generally less well understood, and with major implications in sediment distribution.

The 70 km-long, NW-SE-oriented exposure in the northern Tanqua depocentre was characterized with 53 logs and helicopter/drone-based photo-panels. >2500 palaeocurrent measurements show N-NE sediment transport and E-W/NE-SW bidirectional components, consistent with an outcrop orientation along-strike to the progradation direction.

Regionally, southern upper-slope and shelf-edge parasequences (50-75 m-thick) are interpreted as river-dominated deposits with abundant bypass features (distributary channels, minor gullies and shelf-incised canyons) and sand delivery to the upper-slope. Along-strike to the north, parasequences show abundant wave-reworking indicators and no evidence of gullying/incision.

This differential distribution is interpreted as allogenically controlled by higher subsidence in the southern part, with a relatively fixed sediment entry point. However, autocyclic compensation of deltaic lobes, migration of channels and oversteepening near the shelf edge led to further erosion and bypass. In the long term, this evolved into an erosive, steeper slope and narrower shelf in the south. Longshore currents redistributed sediment towards a northern less steep depozone, resulting in higher sand amalgamation in a shallower and wider accretionary shelf, without major bypass or sand supply to the upper slope.

Across-strike variability is also seen at smaller scale, as each parasequence can be subdivided in bedsets and cycles. Delta lobe off axes and fringes show more wave reworking and are thinner than axial deposits, which are thicker, coarser and more amalgamated, with channels and soft-sediment deformation. Variations in parasequence scale are influenced by allocyclic controls as climate, relative sea level, tectonic subsidence and sediment supply. Bedset-scale variability represent delta lobe switching as internal autocyclic changes, whereas cycle-scale variability represents minor autocyclic changes within the same environment of deposition.

Facies architecture and stratigraphic development of a thin, low-gradient delta along a sandy coast – the Cretaceous Mesa Rica Sandstone in New Mexico (USA)

Anna van Yperen[1], Ivar Midtkandal[1], John Holbrook[2], Miquel Poyatos-Moré[1]

[1] Oslo University, Department of Geosciences, P.O. Box 1047 Blindern, NO-0316 Oslo geosciencesnces@geo.uio.no
[2] Texas Christian University, School of Geology, Energy and the Environment, 2950 West Bowie Street, Fort Worth, Texas 76129 sgee@tcu.edu

A rare case of thin, low-gradient delta architecture is documented along Albian-Cenomanian sections in New Mexico, where analysis of facies distribution, depositional architecture and the spatial extent of stratigraphic surfaces reveal a characteristic pattern of laterally varying shallowing-upward facies successions. Its upstream equivalent, the dominantly fluvial Mesa Rica Sandstone is characterized by a ~350 km NNW-SSE depositional profile from southeast Colorado to northeast New Mexico. Here, it feeds a 15-20 m thick contemporaneous delta that has received limited attention besides micropaleontology, palynology and organic geochemistry. This study focuses on its facies architecture and the spatial distribution of architectural elements and key stratigraphic surfaces in order to unravel controlling factors, locally and regionally.

Seven facies associations form the basis for constructed cross-sections along a 20km+ escarpment, which has an oblique orientation relative to sedimentary transport direction. The number of vertically stacked parasequences varies locally, but an inverse relationship between thickness and parasequence count results in a generally constant thickness for the whole succession. Within-parasequence variation in dominant processes occurs over less than 2 km. Key stratal surfaces show remarkable similarities with the previously established framework for the updip fluvial part of the system, allowing long-distance correlation.

Sub-regional flooding surfaces and a laterally varying number of paraseqeuences are interpreted to reflect lobe abandonment followed by local subsidence and later re-activation. This suggests that autogenic lobe switching accounts for flooding surfaces of limited lateral reach, whereas allogenic forcing explains widespread flooding and their associated surfaces. Accurate identification and temporal constraints on flooding events may be applied as a framework to improve facies mapping and consideration for compartmentalization in delta successions. Unraveling the interplay of paleo-bathymetry, dominant processes (fluvial, wave, tidal) and slope gradients for the Mesa Rica Sandstone delta will contribute to the understanding of delta development in low-accommodation basins in general.

Allocyclic vs autocyclic controls on shallow-water delta architecture evolution and sandbody stacking patterns

Grant Cole[1], Matthew Watkinson[1], Rhodri Jerrett[2], Mark Anderson[1]

[1] *School of Geography, Earth and Environmental Sciences, Plymouth University, Devon, UK; grant.cole@plymouth.ac.uk*
[2] *School of Atmospheric, Earth and Environmental Sciences, University of Manchester, 2.44 Williamson Building, Oxford Road, Manchester, M13 9PL, U.K.*

Architectural element analysis was initially developed for and applied to the understanding of autocyclic (internal) and allocyclic (external) controls on stacking patterns in fluvial successions. More recently, architectural element analysis has also been applied to deltaic successions (e.g. Cretaceous, Western Interior Seaway & Carboniferous, Appalachian Basin), and these studies have highlighted the importance and predictability of autocyclic processes on the evolution and architecture of mouth bars and mouth bar complexes. However, few studies have highlighted how both allocyclic and autocyclic processes can influence the stacking pattern of mouth bars into mouth bar complexes, and mouth bar complexes into major delta front successions. The Jorcas outcrop, in the southwest of the Galve sub-basin, Spain has superbly exposed, near continuous (1.7km in length), 12-14m thick amalgamated delta front sandstones that highlight the role of allocyclic and autocyclic controls on the evolution of this shallow-water delta front succession.

This study focuses on syn-extensional Lower Cretaceous coeval deltaic clastics and shelf carbonates of the Xert Formation. The deltaic succession is composed of up to 5 parasequences deposited during a longer term transgressive phase. The Jorcas outcrop consists of a set of 3 parasequences that exhibit both delta lobe switching (autocyclic) and accommodation space creation (allocyclic) controls on their spatial and vertical evolution. Individual parasequences show a progressive spatial change in mouth bar clinoform architecture from low angle ($\sim 10^{o}$) clinoforms, with bedforms migrating down their foresets, to higher angle ($\sim 25^{o}$) gilbert type clinoforms. This spatial evolution is related to a deepening of the receiving basin and a reduction in the influence of frictional forces, in response to a reduction in sediment supply during gradual delta lobe shifting and/or changes in the rates of relative sea-level rise. This differs from published models which suggest shallow-water deltas should show evidence for increased frictional force influence with progradation.

Environmental change during relative sea-level rise and marine transgression at Dogger Bank

Andy Emery[1], David Hodgson[1], Natasha L. M. Barlow[1], Jonathan Carrivick[2], Carol Cotterill[3]

[1] Stratigraphy Group, School of Earth and Environment, University of Leeds, LS2 9JT. ee06ae@leeds.ac.uk
[2] School of Geography, University of Leeds, LS2 9JT
[3] Marine Geosciences, British Geological Survey, Lyell Centre, Edinburgh

Dogger Bank, in the Southern North Sea, experienced marine transgression during rapid postglacial relative sea-level rise in the Holocene. The rate of sea-level rise and corresponding marine flooding provides an excellent analogue to study the effects of future sea-level rise on coastal realignment and inundation processes. A dense grid of 2D seismic reflection data and vibrocores acquired for the Forewind windfarm project provide a unique dataset to study these process interactions.

Investigation of vibrocores from the south-east of Dogger Bank reveals a significant amount of palaeoenvironmental change within six metres sediment. A transgressive sequence, from salt marsh, through intertidal flat to shallow marine sands, overlies glacial sediments. This generally low-energy assemblage is punctuated by high-energy events, denoted by sandier, poorly-sorted units with pebble-grade clasts.

Calibration of the core stratigraphy to seismic reflection data allows the identification and correlation of seismic facies. Key transgressive surfaces have been mapped to understand the distribution and evolution of coastal geomorphology and sedimentary environment during relative sea-level rise. Diatom analysis helps to constrain sedimentary environments preserved in the cores. A sea-level index point from the salt marsh peat constrains the ages of sediments. However, the rate of relative sea-level rise during this time is still poorly constrained, therefore the roles of accommodation and supply in ravinement processes or in-place drowning during transgression is still poorly understood. Further seismic mapping and core logging will constrain the interplay of processes and landform preservation during transgression, which can be applied to ancient systems, and for future coastal protection strategies.

The Effects of Pleistocene Climate Change on Nearshore Sandstone Facies, Stratigraphy and Diagenesis

Matthew Watkinson[1]

[1] *SoGEES, University of Plymouth, PL4 8AA, UK.*

Sedimentary successions interpreted as having been deposited in shoreline environments ('raised beaches') are widely recognised as evidence for global climate driven sea-level change during the Pleistocene. A challenge has been to date these successions but, despite the increasing range of dating techniques, results have been problematic and contradictory.

This study presents analysis of an exceptionally exposed Mid-Late Pleistocene shoreline succession whose sequence stratigraphic, sedimentological and diagenetic evolution is poorly constrained. Addressing these shortcomings can resolve dating uncertainties and generate a deeper understanding of Pleistocene palaeogeography, oceanography and relative sea-level change.

The case study presented here is of interglacial nearshore sandstones from Saunton Sands, north Devon. The 6-8m succession is here interpreted to represent the deposits of two transgressive-regressive cycles, which correlate to interglacial MIS's 7 and 5e. The lower unit contains a basal transgressive succession, which deepened from dissipative foreshore, across a ravinement surface to upper shoreface environments. Shallowing through lower and upper foreshore/ backshore (aeolian dune) settings can be demonstrated, and suggests that the tidal range was microtidal (significantly less than today). This regressive sequence is capped by a palaeosol, with rhizocretions and calcite cements containing evidence for meteoric paleo-groundwater flow. The secession is consistent with deposition during initially rapid and then decelerating rate of rise of relative sea level, followed by climate driven forced regression evidence by the meteoric diagenesis. The subsequent transgression stacked upper foreshore or backshore facies, indicating renewed generation of accommodation space as sea-level rose during the last interglacial.

This case study highlights the importance of careful interpretation of facies in terms of depositional setting, and of a robust sequence stratigraphic framework. It also provides constraints on the rates at which diagenetic reactions can occur in shallow marine sandstones, and a case study for understanding heterogeneity distribution in wave-dominated shoreline petroleum reservoirs.

Exploring the drivers of modern carbonate hardground formation in Abu Dhabi

Hazel Vallack[1], Fiona Whitaker[2], Sarah E. Greene[3], Stephen W. Lokier[4]

1: School of Geographical science, University of Bristol
2: School of Earth Sciences, University of Bristol
3: School of Geography, Earth and Environmental Sciences, University of Birmingham
4: Department of Geoscience, Khalifa University of Science and Technology, Abu Dhabi, UAE

Authigenic carbonates, in the form of concretions and hardgrounds, are common early diagenetic features of sedimentary rocks and have been linked directly to the global carbon, sulphur, and iron cycles. Authigenic minerals have been identified as important indicators of palaeoenvironmental conditions, but a direct interpretation of these palaeo-proxies is challenging as a comprehensive understanding of the direct drivers of authigenic carbonate precipitation is limited.

The sea floor of the modern Arabian Gulf is characterised by extensive areas of recently-lithified carbonate sediments. Previous work has characterised a laterally-extensive, marine hardground comprising bioclastic grains cemented by calcium carbonate. This diachronous surface occurs at shallow depths within the supratidal sabkha (late Holocene). In the marine realm, active lithification via the precipitation of acicular aragonite and high Mg-calcite cements, forms a range of firm grounds and hardgrounds.

This study focusses on evaluating the physical and biogeochemical processes that control hardground formation, through the analysis of pore-water chemical profiles and shallow sediment cores from above and below hardgrounds at two contrasting sites on the Abu Dhabi coast. Both sites lie within the inter-tidal zone, with Site A located downdip of a well-developed sabkha, and Site B in an open lagoon. Hardgrounds at both sites are cementing within a few 10s of cm of the sediment-water interface associated with narrow intervals of elevated porewater pH. Sediments above and below the hardgrounds show sharp contrasts in redox state, indicating that the hardgrounds may form a barrier to fluid exchange, possibly promoting the development of anaerobic conditions beneath it, which may further promote hardground cementation. Further analyses of porewater chemistry (dissolved ions, nutrients, isotopes, DOC and CH_4 content), microbiology (16*S* and 18S rRNA), as well as more complete sediment and hardground characterisation will allow development of a process-based model for the formation of these marine hardgrounds.

Source-to-Sink analysis of the Moroccan Atlantic Margin: tracing source areas for Lower Cretaceous reservoirs of the Essaouira-Agadir Basin (EAB)

Emmanuel Roquette[1], Stefan Schröder[1], Tim Luber[1], Jonathan Redfern[1]

[1] *North Africa Research Group, University of Manchester*
emmanuel.roquette@postgrad.manchester.ac.uk

Recent studies by the North Africa Research Group have proven that the Moroccan Atlantic Margin has experienced km-scale vertical movements during its post-rift evolution. This uplift has controlled the distribution of the basins and the nature and origin of the sediments brought to the margin. Deciphering the provenance of sediment in the shallow-marine to fluvial transition zone along continental margins is key in unlocking the potential formation and distribution of reservoir sandstones.

The Early Cretaceous shallow-marine to fluvial coarse clastic successions of the Agadir Essaouira Basin are an exploration target offshore, but limited successful drillings reflect the poor understanding of the depositional systems and its links to the eroding hinterland. This highlights the need of a more holistic approach, tracing sediment routing and the main input points through time.

The integrated study being carried out aims to develop the first regional palaeogeography and tectonostratigraphic Source-to-Sink model of North-West Africa by deciphering the controls, timing and volume of the sediment supply to the margin and by constraining the importance of sediment recycling, mixing and storage.

Preliminary research has selected three main source candidates: the Hercynian massifs of the Western-Meseta in the North, the Western High Atlas (WHA) where both Hercynian magmatism and Panafrican series are exposed, and the mixed Proterozoic series of the Anti-Atlas. Low temperature geochronology has shown evidence of subsidence in the Anti-Atlas during the Late Jurassic/Early Cretaceous which may have allowed sediments from the Tindouf Basin/Reguibat shield to access the basin. To assess the likely multiple origins of the sediments, detailed petrography has been conducted along with SEM and QEMSCAN imagery and has demonstrated the presence of ignembrite clasts (abundant in the WHA and Anti Atlas) and hydrothermal metamorphism (described in the Meseta). The study will continue with heavy mineral analysis and the dating of detrital zircons.

Abrupt grain size transitions drive rapid changes in channel dynamics

Elizabeth Dingle[1], Hugh Sinclair[2], Mikael Attal[2], Maggie Creed[2,3], Laura Quick[2], Tim Kinnaird[4]

[1] School of GeoSciences, University of Edinburgh, Edinburgh EH8 9XP UK (elizabeth.dingle@ed.ac.uk)
[2]School of GeoSciences, University of Edinburgh, Edinburgh EH8 9XP UK
[3]School of Engineering, University of Edinburgh, Edinburgh EH9 3FB UK
[4]School of Earth & Environmental Sciences, University of St Andrews, St Andrews KY16 9AL UK

Rivers draining the largest mountain ranges on the planet carry huge quantities of sediment, most of which is ultimately delivered to the sea hundreds to thousands of kilometres downstream. As sediment is transported downstream by rivers it undergoes a series of transformations, but in virtually all rivers an unusually abrupt transition in river bed grain size from gravel to sand occurs, also known as the gravel-sand transition. All of the gravel-sized (and larger) sediments delivered out of mountain ranges are trapped upstream of this transition. Whilst migration of the gravel-sand transition is commonly thought to reflect environmental forcing, such as changes in basin subsidence rate or water and sediment discharges, little is known about whether the transition may also act as a driver of environmental or morphological change. Here we present new point-depth suspended sediment concentration and grain size data across five transects between the Himalayan mountain front and immediately downstream of the gravel-sand transition on the Karnali River (west Nepal) in the Himalayan foreland basin. Our initial results suggest that near-bed sediment concentration rapidly increases across the gravel-sand transition from ~4 g/l to >110 g/l between sampling locations only a couple of kilometres apart. We compare our observations against proposed hypothesis on how gravel-sand transitions develop. Combining this with optical satellite imagery and new OSL ages of palaeochannels in the Karnali River floodplain (between the Himalayan mountain front and gravel-sand transition) we also demonstrate a stark contrast in the rate and style of channel migration upstream and downstream of the gravel-sand transition, which we discuss in terms of sediment dynamics. Understanding how the gravel-sand transition develops and its influence on wider river morphology has direct implications not only on the modern river system, but also on the development and interpretation of foreland basin stratigraphy and ancient fluvial processes.

The impact of sediment recycling on the gravel sand transition in the Himalayan foreland basin

Quick, L.A.[1], Sinclair, H.D.[1], Attal, M.[1] and Dingle, E.H.[1]

[1] School of GeoSciences, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, United Kingdom

Since the Miocene the Himalayan mountains have been drained, incised and eroded by large trans-Himalayan rivers which transport sediment from the mountains and onto the plains. A notable feature of these rivers is the gravel sand transition (GST), which is characterised by an abrupt grain size change from gravel to sand and is often associated with a break in channel gradient. Gravel trapped upstream of the GST are dominated by quartzite pebbles compared to other Himalayan lithologies, and it has been proposed that differential pebble abrasion during fluvial transport has led to this over-representation. However, the recycling of Siwalik Formation has not been investigated as a potential cause of quartzite dominance in the gravel bars at the mountain front or for the abrupt grain size change at the GST.

The Siwalik deposits comprise Neogene fluvial sediments originated from Himalayan erosion, which were deposited in the Indo-Gangetic foreland basin and later exhumed by thin-skin tectonics. The Upper Siwalik conglomerates comprise predominately quartzite pebbles which are analogous to the pebbles trapped upstream of the GST in present day river systems. Due to the resistant nature of the quartzite conglomerate pebbles they are re-incorporated back into the fluvial network and 'recycled' by the mountain and foothill-fed rivers which cut through the Siwalik range. The recycling of the pebbles may enhance the quartzite content and alter the grainsize distribution of the gravel bars at the present-day mountain outlet, which potentially contributes to the abrupt nature of the GST and therefore the break in channel gradient.

Through a comparison of pebble abrasion data and field observations we can test to what extent Siwalik conglomerate recycling impacts the lithological proportions and sediment grainsize distributions at the mountain outlet of the Karnali river in Western Nepal, and the influence his may have on the GST.

Using floodplain ecosystem dynamics to recognize avulsion patterns: A case study from the Bighorn Basin, Wyoming

Alena Ebinghaus[1], Amanda Owen[2], David W. Jolley[1], and Adrian J. Hartley[1]

[1]University of Aberdeen, Department of Geology and Petroleum Geology, Meston Building, Aberdeen, AB24 3UE, UK
[2]University of Glasgow, School of Geographical and Earth Sciences, East Quadrangle, Glasgow, G12 8QQ, UK

River avulsion plays a key part in our understanding of sediment distribution, architecture and stratigraphy in continental sedimentary basins. In the sedimentological record, commonly two types of avulsion deposits are recognized: progradational and abrupt. However, due to floodplain erosion during channel migration, sedimentary features that are important in the identification of avulsion may be missing, leading to potential misinterpretation of avulsion patterns. To recognize avulsion independently from sedimentological observations, we characterized the floodplain plant ecosystem and its response patterns to channel migration, using a combination of floodplain palynology and geochemistry combined with sedimentary data from two Eocene fluvial successions in the Bighorn Basin, Wyoming. This integrative and multi-disciplinary study aims to provide a more refined approach to assessing avulsion patterns and basin fill stratigraphy.

Our data indicate a close relationship between floodplain plant ecosystem properties, pedogenesis and proximity to the main channel. Sediment geochemical analysis combined with palynological examination suggests that splays were common throughout floodplain deposition, and gradually increased in frequency and proximity prior to emplacement of the main channel. This implies that progradational avulsion is more common in the studied sections than preserved sediment lithofacies suggest, contrasting with the sedimentological interpretation of previous studies of similar sections in the basin.

The integration of floodplain plant ecosystem analyses with sedimentological data provides a strong tool to study floodplain dynamics, and allows to develop a more refined assessment of avulsion patterns than studies solely based on sedimentological observations. The findings of this study support the importance of floodplain dynamics in influencing channel migration. Integrating floodplain ecosystem data with sedimentary data therefore forms a key part in modelling avulsion and sediment distribution in continental basins.

Role of fluvial abandonment mechanisms in governing the preserved form of point-bar deposits in the stratigraphic record

Catherine E. Russell [1], Nigel P. Mountney [1], David M. Hodgson [1], Luca Colombera [1]

[1] Fluvial & Eolian Research Group School of Earth and Environment, University of Leeds, UK eecer@leeds.ac.uk

Abandoned reaches of modern rivers are routinely considered as analogues for deposits of interpreted ancient abandoned fluvial systems. The evolutionary behaviour of an active fluvial channel reach markedly influences the mechanism of meander-loop abandonment, which in turn, influences the resultant dimensions of the point-bar deposit. However, the dimensions and facies distributions of active fluvial meanders and their associated point bars will only preserve their morphological form in the rock record where avulsion has occurred. Three main types of river-reach abandonment are recognised: (i) neck cut-off, where the up- and down-stream limbs of a meander bend intersect in response to bend tightening; (ii) chute cut-off, where a cut-through channel links up- and downstream limbs of a meander; and (iii) avulsion, where a channel reach change orientation, thereby abandoning its previous reach. Each cut-off mechanism results in the development of an abandoned channel with particular facies and geometric characteristics.

In this study, observations were made from 110 abandoned point-bar deposits from 11 active rivers to assess styles of meander loop abandonment. Six types of individual loop cut-off, and 8 cut-off groups (i.e. repeating pattern) are identified. The most common individual cut-off type is neck cut-off (52%), and the most common group stacking type is “nodal, unidirectional” (i.e. overlapping unidirectionally at apex; 18%). Analysis of the preserved planform shapes of abandoned point-bar meander bodies reveals that equant (1:1) and elongate (1:<1) shapes are almost equally prevalent. Elongate point-bar sandbody shapes are currently underrepresented in 3D geological models of ancient fluvial point-bar deposits. Moreover, the shape of a meander bend arising from abandonment via chute cut-off encourages cannibalisation of the previously deposited and genetically linked point-bar deposit. Therefore, the preserved fluvial stratigraphic record is likely biased towards point-bar deposits that were abandoned via neck cut-off, rather than chute cut-off.

Classification and quantification of crevasse splay deposit

M. Mostafizur Rahman[1, 2], John A. Howell[1] and David I. M. Macdonald[1]

[1]Department of Geology and Petroleum Geology, University of Aberdeen, AB24 3UE, UK
Email: mrahman@abdn.ac.uk, john.howell@abdn.ac.uk, d.macdonald@abdn.ac.uk
[2]Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh

Crevasse splays are a common architectural element in fluvial and fluvio-deltaic settings where the dominate hydrocarbon reservoirs are comprised of channel deposits. Crevasse splays are often ignored as a potential reservoir and as such are less well understood. The present study aims to improve understanding of crevasse splay deposits from a reservoir perspective providing a new classification scheme and facies models.

Data were collected from modern and ancient systems. For the modern, data came from Google Earth imagery of seven river-delta systems from diverse climatic and geomorphic settings. For the ancient, ten outcrops from a 40 km-long section of the Middle Jurassic Ravenscar Group on the Yorkshire Coast were studied. Outcrop data were derived from field observations, and LiDAR and UAV (drone) based virtual outcrops (VO). Crevasse splay geometry, distribution, lithofacies and stacking pattern were studied in planform Google Earth imagery and cross-section on the VO.

We studied 750 crevasse splays; they show significant variation in size and shape. Genetically, three types of crevasse splays are observed: 1) single crevasse splays—0.5-2.5 m thick body formed from a single outlet; 2) laterally amalgamated crevasse splays—0.5-2.5 m thick contemporaneous laterally connected bodies formed from multiple outlets, and 3) crevasse splay complexes—2.5-6.5 m thick larger lobate delta-like features, fed by a channel that splays from the parent channel. Based on shape splays are classified as: lobate (L/W ratio <1.5), tongue-shaped (L/W >1.5) or crenulated (L/W ratio <1.5 and irregular). In most of the cases the splays occur at the convex bend of meanders, though these are also common in the straight part of the channel, especially in the delta top. Climatic condition i.e., rainfall, river bed slope, river type, sediment load and the depth of the feeder channel are the most important factors controlling the formation of crevasses splays.

The overlooked overbank: quantitative prediction of stratigraphic architecture in fluvial overbank successions

Catherine E. Burns[1], Nigel P. Mountney[1], David M. Hodgson[1] and Luca Colombera[1].

[1] *Fluvial Research Group, School of Earth and Environment, University of Leeds, LS2 9JT, UK and ee09ceb@leeds.ac.uk*

Outcrop-based studies of fluvial successions predominantly focus on sand-prone channel complexes; less attention has been directed towards finer-grained fluvial overbank successions. Commonly, overbank successions comprise a volumetrically significant part of many fluvial successions, and many contain thin but extensive sand bodies, notably crevasse-splay deposits. From an applied standpoint, overbank elements can form important connectors and baffles between major channel bodies that can enhance or disrupt overall reservoir connectivity, respectively.

Quantitative facies and architectural-element analysis of outcrop successions from the Morrison Formation (Upper Jurassic) and the Castlegate and Nelsen formations, Mesaverde Group (Upper Cretaceous), Utah and Colorado, USA, supported by analysis of 10 modern fluvial systems, has been undertaken to better constrain the range of sedimentary architectures present in fluvial overbank areas. A nested, hierarchical stacking of the deposits of fluvial overbank successions are recognized and record accumulation of the following components: (i) lithofacies; (ii) individual beds; (iii) splay elements comprising genetically related beds that stack vertically and laterally and represent the deposits of individual flood events; and (iv) splay complexes comprising one or more genetically related elements that have a common breakout point and represent the deposits of multiple flood events.

Lithofacies arrangements are used to establish: (i) recognition criteria for overbank elements; (ii) criteria for the differentiation between distal parts of splay elements and floodplain fines; and (iii) empirical relationships with which to establish the extent (ca. 280-500 m long by 180-1000 m wide) and planform shape of splay elements in the Morrison Formation (teardrop) and Castlegate and Neslen formations (semi-elliptical). Splay deposits occur as parts of thicker floodplain-dominated successions that are preserved in response to longer-term autogenic controls, such as channel-migration patterns, flooding, and avulsion frequency of parent channels, and allogenic controls, such as changes in subsidence, climate, base-level and sediment supply.

Delayed sedimentary response to the PETM, Northern Spain

Robert Duller[1], John Armitage[2], Tom Dunkley-Jones[3], Hayley Manners[4], Stephen Grimes[4]

[1] University of Liverpool (United Kingdom)
[2] Institut de Physique du Globe de Paris, Université Sorbonne (France)
[3] University of Birmingham (United Kingdom)
[4] Plymouth University (United Kingdom)

The Palaeocene-Eocene thermal maximum (PETM) represents a globally abrupt episode of global warming. This event is marked in the terrestrial and marine sedimentary record as a negative $\delta^{13}C$ excursion, which is concomitant with an increase in the amount and size of detrital material. However, the precise temporal relationship between the $\delta 1^{3}C$ marker horizon and the onset of increased detrital material is unknown. Detailed analysis of a terrestrial and marine section within the same sediment routing system suggests that the production and transport of detrital material from mountain catchments to these sites lags behind the negative $\delta^{13}C$ marker horizon by ca. 10-15 ka. A number of mechanisms could be responsible for this lag and these shall be discussed. Numerical modelling demonstrates that timescales of landscape response to a step change in precipitation can account for the observed lag. Crucially, the identification of a time lag between the carbon release event and the onset of increased sediment calibre tells us something fundamental about timescale of coupling between the climate and landscape system. If the anthropocene is indeed analogous to the rates of increase of global warming experienced during the PETM, our results indicate that we may have to wait 10 ka before its full effects are transmitted to the sedimentary record.

Sedimentary architecture and depositional controls of a Pliocene river-dominated delta in the semi-isolated Dacian basin

Elisabeth L. Jorissen[1], Arjan de Leeuw[2,3], Christiaan G.C. van Baak[3,2], Oleg Mandic[4], Marius Stoica[5], Hemmo A. Abels[6], Wout Krijgsman[1]

1 Palaeomagnetic Laboratory 'Fort Hoofddijk', Faculty of Geosciences, Utrecht University, Budapestlaan 17, 3584 CD, Utrecht, The Netherlands; e.l.jorissen@uu.nl & W.Krijgsman@uu.nl
2 Université Grenoble Alpes, Institut des Sciences de la Terre, 38000 Grenoble, France; arjan.de-leeuw@univ-grenoble-alpes.fr
3 CASP, West Building, Madingley Rise, Madingley Road, Cambridge, CB3 0UD, United Kingdom; C.G.C.vanBaak@uu.nl
4 Geological-palaeontological Department, Natural History Museum Vienna, Burgring 7, 1010 Vienna, Austria; oleg.mandic@NHM-WIEN.AC.AT
5 Department of Palaeontology, Faculty of Geology and Geophysics, Bucharest University, Bălcescu Bd. 1, 010041, Romania; marius.stoica@g.unibuc.ro
6 Department of Geosciences and Engineering, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, The Netherlands; H.A.Abels@tudelft.nl

Sedimentological facies models for (semi-)isolated basins are less well developed than those for marine environments. Their interpretation is nevertheless vital to understand sedimentary processes and depositional controls responsible for the sedimentary architecture of deltas flowing into restricted depositional environments.

Along an 835m-thick Pliocene section, we investigate the processes governing a delta flowing into the Dacian Basin, an ancient embayment of the Black Sea. This prograding delta shaped a sedimentary succession reflecting a transition from distal shelf to proximal fluvial conditions. This upward shallowing has resulted in a rhythmic succession of 64 regressive parasequences of on average 13,5m. These high frequency parasequences combine into nine low-order regressive sequences of around 100m and into three high-order regressive sequences of around 300m.

The deltaic progradation into a semi-isolated basin resulted in a river-dominated delta, marked by a strong river domination and the near-absence of indications of sediment redistribution by wave- or tide processes. Deltaic sediments were however deposited in an unusual depositional environment. The semi-isolated basin was filled with brackish-water, facilitating frequent sediment transport by hyperpycnal plumes and enhancing the preservation of *in situ* brackish- and fresh-water faunas, burrows and organic material. The delta prograded into a shallow basin on a low-gradient slope, creating thin sharp based sand bodies in numerous thin parasequences, due to a multiplication of the terminal distributary channels, covering a wide depositional area. The frequent delta-lobe switching led to sediment starvation on the top of the abandoned delta lobe, marked by reddish oxidized shell-rich indurated flooding surfaces.

A robust magnetostratigraphic time frame is used to compare the observed sedimentary cyclicity with the amplitude and the frequency of various climatic cycles. Parasequences and sequences are not in phase with any Milankovitch climatic cycle, suggesting that astronomical climate forcing didn't influence the autogenic delta-lobe switching.

The peculiar sedimentary architecture of this delta illustrate that the restricted depositional environment affected the deltaic progradation, which resulted in an unusual sedimentary succession. Deltas evolving in (semi-)isolated should therefore be analyzed and interpreted differently from open marine deltas.

Controls on morphological change within wandering gravel-bed rivers over decadal time scales: River Coquet, Northumberland, UK

Safaa Al Zerouni[1], Andy Russell[1], Andy Large[1] and Neil Ross[1]

Newcastle University, School of Geography, Politics and Sociology, Daysh Building, Claremont Road, Newcastle-upon-Tyne, NE1 7RU, UK.
(s.alzerouni@newcastle.ac.uk)

There is need for new approaches to understanding wandering gravel-bed rivers which take into account fluvial dynamics through time and resultant 3-D sedimentary architecture. While previous studies have focused either on short time periods (e.g. individual floods) or over relatively small spatial scales (e.g. the reach scale), far fewer studies have quantified the subsurface sedimentary architecture of contemporary UK wandering gravel bed rivers over significant spatial scales. This research addresses this gap by examining the relationship between historical planform change and subsurface sedimentary architecture for the River Coquet, Northumberland UK. In its mid-reaches, the Coquet represents one of the most dynamic gravel bed rivers in the UK, displaying a characteristic 'wandering' behaviour with considerable historic (~150 years) channel change and morphological instability.

Here, we identify and quantify changes in channel morphology over decadal and centennial time-scales. In addition, we characterise fluvial deposits by building up a 3-D sediment architectural model. This illustrates the importance of sediment architecture as evidence of palaeo-fluvial change and dynamism.

River channel behaviour over time was determined through combining high quality data (topographic survey, historical maps, aerial images and LiDAR) with Ground Penetrating Radar (GPR) survey and analysis of sedimentary sections. To provide context on planform dynamics, channel adjustment between 1860 and 2016 was quantified for: channel width, migration rate and channel avulsion processes, palaeochannel re-occupation and/or instigation of new channels. Long-term instability of the river channel is attributed to flood events impacting on the low gradient system primarily via avulsion. Woody debris in the modern system is observed to encourage sediment deposition and lateral bar development leading in turn to significant channel instability. Collection of GPR data to depths of 10 m allows reconstruction of longer-term evolution of wandering river system and provides insights into how the modern floodplain surface relates to previous system-scale geomorphology.

Controls on rapid post eruption fluvial system response, Calbuco, Chile

Andrew J. Russell [1], Alejandro Dussaillant[2], Claudio Meier[3,4], Andrés Rivera[5], Mauricio Mella[6], Natalia Garrido[6], Jorge Hernandez[5], Felipe Napoleoni[5], Cristian Gonzalez[2] & Devin Harrison[1]

[1]School of Geography, Politics & Sociology, Newcastle University, Newcastle upon Tyne, UK andy.russell@ncl.ac.uk

[2]Universidad de Aysén, Coyhaique, Aysén, Patagonia, Chile

[3]Centro de Investigaciones en Ecosistemas de la Patagonia, Coyhaique, Chile

[4]University of Memphis, USA

[5]Center for Scientific Studies, Valdivia, Chile

[6]SERNAGEOMIN, Puerto Varas, Chile

Calbuco, a 2015m high, glacier capped, stratovolcano in the heavily populated Los Lagos district of southern Chile, has a history of numerous volcanic eruptions. Calbuco experienced a powerful eruption on 22 April, 2015 followed by additional major eruptions on 23 & 30 April. The eruption deposited ~0.5 km^3 of tephra and generated Pyroclastic Density Currents (PDCs) which interacted with snow and glacier ice to form lahars which descended into river catchments radiating from the volcano for distances of up to 14 km. PDCs overprinted proximal lahar deposits in the Rio Blanco Este and Rio Blanco Sur on the northern and southern flanks of Calbuco respectively. Satellite imagery acquired following the first two eruptions on 24 April, 2015 shows largely undisturbed PDC deposits in the upper reaches of the Rio Blanco Este with no fluvial system adjustment in the medial and distal reaches downstream of the furthest lahar extent. Field (TLS and dGPS) and airborne (LiDAR) surveys of the Rio Blanco Este in July 2015, January 2016 and April 2016 show major (~20 m) proximal erosion of PDC and lahar deposits generating simultaneous medial and distal aggradation of up to 5 m burying a two story hydropower plant. Erosion of proximal PDC deposits in the Rio Blanco Este generated a 'stair case' of erosional terraces, each capped by <2m thick flood deposits. Aggrading medial and distal reaches of the Rio Blanco Este are characterised by channel avulsion and widening. Despite the presence of large volumes of tephra our study highlights the importance of reworked PDC deposits as a driver of major rapid fluvial system response within 1 year of the eruption. Continued erosion of PDC deposits and tephra at high elevations on Calbuco has the potential to generate further fluvial system response over decadal timescales.

The sedimentology, architecture and depositional setting of the fluvial Spireslack Sandstone of the Midland Valley, Scotland: insights from Spireslack surface coal mine.

Ellen, R.[1], Browne, M. [1], Mitten, A. [2], **Clarke, S. M[2]***., Leslie, A.G. [1] & Callaghan, E.[1]….

[1] British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh, EH144AP, UK, s.m.clarke@keele.ac.uk
[2] Basin Dynamics Research Group, School of Geography, Geology & the Environment, Keele University, Keele, Staffordshire, ST5 5BG, UK

The characterisation of subsurface fluvial hydrocarbon reservoirs commonly relies on models derived from well-exposed analogues that allow observations and description of lateral and 3D variability, in addition to sediment character.

Spireslack surface coal mine, Scotland, exposes a section from the Carboniferous Lawmuir Formation (Brigantian) through into the Upper Limestone Formation (Arnsbergian). As the most continuous Mississippian section exposed at outcrop in Scotland, the exposures provide excellent opportunities to study lateral continuity and variability within this part of the Carboniferous strata.

In this work, we describe and name for the first time the 'Spireslack Sandstone'; an erosively based, sandstone-dominated unit in the Upper Limestone Formation. The Spireslack Sandstone comprises two fluvial sandstone bodies (that are the focus of this work), and an upper, possibly fluvio-estuarine, succession.

From a facies analysis of log data, augmented with interpretations of element geometry and bounding surface relationships in 2D sections, we interpret the fluvial part of the Spireslack Sandstone as a low sinuosity, sand-dominated, mixed load fluvial system deposited in a palaeovalley of significant localised relief.

We tentatively suggest that the Spireslack Sandstone may represent a fluvial system responding to base level changes during deposition of the Upper Limestone Formation. Consequently, we provide a fluvial facies model for the Spireslack Sandstone that differs somewhat from the classical delta-top fluvial model that can be attributed to other fluvial sandstones within the Carboniferous section.

The regional significance of the Spireslack Sandstone to the evolutionary story of the Carboniferous section remains untested and equivocal, but our model, and the exposures at Spireslack, may provide an analogue for similar highly incised Carboniferous fluvial sandstones and their associated stratigraphical traps suggested by other workers from subsurface data of the North Sea.

GPR architecture and post-depositional evolution of jökulhlaup sediments, Gígjökull, Iceland

D. Harrison, N. Ross, and A.J. Russell

School of Geography, Politics and Sociology, Newcastle University, Daysh Building, Newcastle Upon Tyne NE1 7RU, UK (email: d.harrison3@newcastle.ac.uk)

High magnitude volcanically-induced jökulhlaups (glacial outburst floods) can deposit significant volumes of sediment and ice, causing major landscape change and generating a range of environmental management issues. The 2010 Eyjafjallajökull eruption and its associated jökulhlaups provide a perfect opportunity to reconstruct jökulhlaup hydrological processes, to test conceptual models of jökulhlaup sediment deposition and post-depositional landscape change. Combining new low-frequency (40 MHz) ground penetrating radar (GPR) and differential GPS surveys of the Gígjökull basin with existing datasets, we have: (1) geophysically characterised the deposits associated with the 2010 Eyjafjallajökull eruption; and (2) quantified post-depositional (2010-2016) elevation change, to evaluate the role of buried ice on post-jökulhlaup landscape response and recovery.

The Gígjökull basin jökulhlaup deposits are up to 80 m thick and characterised by numerous sedimentary units, which have distinctive radar facies, and are delimited by strong continuous reflectors. Structures within these units provide process-insight into the multiple high-magnitude flood events of 2010. Our geodetic observations demonstrate significant lowering of the surface of the jökulhlaup sediments over the six years since deposition (i.e. 0.46 m a^{-1} between 2010 and 2015; increasing to 1.93 m a^{-1} between 2015 and 2016). We interpret this lowering to be the result of the meltout of buried ice within these sediments.

Our geophysical data adds to the limited inventory of GPR-characterised jökulhlaup sediments in Iceland and around the world. The use of the GPR data in conjunction with the jökulhlaup observations will allow for a convincing depositional model of the Gígjökull deposits to be created, incorporating primary and post-depositional processes. Our findings quantify the hazard potential of ice-rich jökulhlaup flows, by constraining sub-surface properties, and the relationship between buried ice and zones of rapid land surface elevation change. Evaluating the geomorphological processes that are characteristic of the Eyjafjallajökull jökulhlaups, and comparing these to hydrograph shape, will provide useful information to constrain jökulhlaup propagation modelling, and hence inform future mitigation strategies.

Deglacial history of the Anvers-Hugo Trough, western Antarctic Peninsula

Zoë Roseby[1,2], James Smith[2], Matthieu Cartigny[3], Claus-Dieter Hillenbrand[2], Kelly Hogan[2], Robert Larter[2], Peter Talling[3], Claire Allen[2], Brad Rosenheim[4], Werner Ehrmann[5] and Gerhard Kuhn[6].

1University of Southampton, Southampton, SO14 3ZH; Z.Roseby@noc.soton.ac.uk
2British Antarctic Survey, Cambridge, CB3 0ET
3Department of Geography, Durham University, Durham, DH1 3LE
4University of South Florida, College of Marine Science, 140 7th Avenue South, St. Petersburg, FL 33701
5Institute for Geophysics and Geology, University of Leipzig, Talstrasse 35, D-04103 Leipzig, Germany
6Alfred Wegener Institute for Polar and Marine Research (AWI), D-27568 Bremerhaven, Germany

We are currently seeing the retreat and thinning of the majority of Antarctic Peninsula ice streams and marine terminating glaciers. Although our understanding of the factors driving the current changes is increasingly improving, the future response of ice streams to climate change remains uncertain. This is because the mechanisms driving ice stream retreat can occur over larger spatial and temporal scales than those captured since the beginning of observational and satellite monitoring. Sedimentary sequences, deposited on polar continental shelves during past episodes of ice sheet advance and retreat, provide an important archive of past changes over longer timescales. A crucial component of glacial reconstructions is dating the timing of grounded ice retreat. This is achieved through dating the transition between sub-glacial and open marine sediments. A detailed retreat chronology allows us to understand the rate of deglaciation and the ability to relate this to regional and global forcing mechanisms. We can additionally use dating to interpret subglacial sediment transport and deposition rates, which aids our understanding of the timescales and processes that form depositional features such as grounding zone wedges. This year a grant from the Steve Farrell Memorial Fund allowed me to visit the University of South Florida, where I carried out Ramped PyrOx ^{14}C dating on sediment samples recovered from the Anvers-Hugo Trough, western Antarctic Peninsula Shelf. This novel method allows viable chronologies to be obtained from Antarctic sediments and overcomes the major problem encountered when attempting to date Antarctic sediments; the scarcity of preserved biogenic calcium carbonate. The results of this study indicate that grounded ice within the trough rapidly retreated in just 3 kyr, whilst glaciogenic sediments continued to be delivered to the trough ~3 kyr later.

Evidence for the long-term sedimentary environment in an Antarctic subglacial lake

Smith, A.M. [1], Woodward, J. [2], **Ross, N.,[3],** Bentley, M.J.[4], Hodgson, D.A.[1], Siegert, M.J.[5], King, E.C.[1],

[1] British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK amsm@bas.ac.uk; daho@bas.ac.uk; ecki@bas.ac.uk

[2] Department of Geography, Northumbria University, Ellison Place, Newcastle Upon Tyne NE1 8ST, UK john.woodward@northumbria.ac.uk

[3] School of Geography, Politics and Sociology, Newcastle University, Claremont Road, Newcastle Upon Tyne NE1 7RU, UK neil.ross@ncl.ac.uk

[4] Department of Geography, Durham University, Lower Mountjoy, South Road, Durham DH1 3LE, UK m.j.bentley@durham.ac.uk

[5] Grantham Institute and Department of Earth Science and Engineering, Imperial College London, South Kensington SW7 2AZ, UK m.siegert@imperial.ac.uk

Lakes beneath the Antarctic Ice Sheet are of fundamental scientific interest for their ability to contain unique records of ice sheet history and microbial life in their sediments. However, no records of subglacial lake sedimentation have yet been acquired from beneath the interior of the ice sheet, and understanding of sediment pathways, processes and structure in subglacial lake environments remains uncertain. Here we present seismic reflection data from Subglacial Lake Ellsworth, showing that the lake bed comprises very fine-grained sediments deposited in a long- term, low energy environment, with low water- and sediment-fluxes. We interpret prolonged low sedimentation rates over a minimum of 150 ka, and possibly >1 Ma. We present a new conceptual model of subglacial lake sedimentation, allowing a framework for evaluating processes in subglacial lake environments, and for determining future lake access locations and interpreting subglacial lake samples.

The origins and fill histories of buried palaeo valley systems and overdeepened bedrock troughs in the Midland Valley of Scotland

Timothy I. Kearsey[1*], Jonathan R. Lee[2], Andrew Finlayson[1], Kathryn A. Lee[2], Russell S. Lawely[2]

[1] British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP, UK, : *timk1@bgs.ac.uk*

[2] British Geological Survey, Nicker Hill, Keyworth, NG12 5GG, UK

'Buried' palaeo valley systems have been identified widely beneath lowland parts of the UK and the North Sea. Their concealed occurrence can have significant implications for groundwater, hydrocarbon and geothermal resources. Equally the links between geometry and the sediments that infill them are poorly understood but provide important clues to their genesis and applied properties.

In the Midland Valley of Scotland 'buried valleys' of over 100 m depth have been recorded yet have typically only been studied in isolation. Utilising a digital dataset of over 100,000 boreholes which penetrates the full thickness of Quaternary deposits in the Midland Valley of Scotland, 18 buried palaeo valleys where identified, ranging from 5-36 km in length and 24-162 m in depth.

Geometric analysis has revealed four distinct valley morphologies, some of which appear to cross cut each other with the deepest features aligning east-west. These east-west features align with the ice flow during the Late Devensian glaciation (c. 30-17 ka). The shallower features, appear more aligned to ice flow direction during ice sheet retreat, and were therefore probably incised under more restricted ice-sheet configurations.

Analysis of the fills shows they also vary greatly. The shallower restricted ice sheet features are filled with between 52-82% diamicton. However, the large, east-west features have more heterogeneous fills, which are either dominated by clay (29-44%) or sand (6-22%). The presence of localised sand and gravels that pre-date the advance of the Main Late Devensian ice sheet confirms that the east-west features have been active over several glaciations, and that the fill may not be linked to the processes that cut the valley. All the features that sit below the Holocene marine incursion limits have more heterolithic fills than those above it suggesting that they existed as valleys after ice retreat with remaining accommodation space infilled during a final stage of marine inundation.

GoForth: Preliminary interpretations from new borehole data on the glacial controls of the Quaternary sedimentary evolution of the Forth Estuary, Scotland

Romesh Palamakumbura, Maarten Krabbendam, Katie Whitbread, Tim Kearsey, Andrew Finlayson and Sarah Arkley

British Geological Survey, the Lyell Centre, Research Avenue South, Edinburgh, EH14 4AP, romesh@bgs.ac.uk

The Forth Estuary in southern Scotland is an example of a glacially-controlled estuarine system that developed during the Last Glacial Maximum (LGM). The Late Devensian evolution of the Forth Estuary provides a unique opportunity to study a marine terminating glacial system, with well-preserved uplifted sediments related to deglaciation in a marine and estuarine setting. We present new data from borehole records on the spatial distribution of subglacial till and glaciomarine deposits from proximal to distal parts of the Forth Estuary.

The glaciomarine deposits include interbedded clays, silts, sands and gravels with occasional shells and a deposit thickness of approximately 3-5 m, at around 30 to 40 m aOD (above present day Ordnance Datum). These are interpreted as glacial-marine sediments deposited during a sea-level incursion immediately after LGM ice sheet melting or collapse that also resulted in regional-scale isostatic uplift. Overall, the post-glacial estuarine infill of the Forth Estuary comprises silts, clays, sands and occasional gravels of variable thicknesses from less the 10 m to nearly 70 m. These sediments predominantly overlie glacial till deposits of less than 1 m to nearly 60 m thickness. The estuarine sediments are likely to represent multiple phases of deposition from the Windermere interglacial to the Holocene. The highly variable thickness of estuarine and glacial till sediments suggests glaciomarine and estuarine deposition was onto a pronounced pre-existing topography on top of the glacial till deposits. This indicates major erosion of the glacial till deposits prior to the estuarine infill. “Buried gravel” deposits from Grangemouth to Stirling were previously described and interpreted as ice raft deposits of Younger Dryas age (Peacock, 1998). Borehole records however, only suggest a discontinuous 1 m-thick gravel deposit at 2-5 m depth in the distal parts of the estuary that may have been deposited from trapped ice-bergs along the edges of the mouth of the estuary. Finally, in the distal parts of the Forth Estuary the entire sequence is overlain by sands and clays with shell-rich horizons from -5 to 20 m OD. These sediments are interpreted as having been deposited during a short-lived sea-level transgression during the Holocene.

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An exhumed Paleozoic glacial landscape in Chad

Daniel Paul Le Heron[1, 2]

[1] Department of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK
[2] Department of Geodynamics and Sedimentology, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria

In northern Chad, an outcrop belt of Paleozoic rocks occurs in the Ennedi-Bourkou range. There, satellite image interpretation reveals a series of clearly expressed palaeo ice-stream pathways, which are encased in sandstone plateaux. At least 5 palaeo-ice stream pathways are recognised, measuring 5-12 km wide. Each contains well expressed belts of mega-scale glacial lineations (MSGLs) with occasional drumlins. The palaeo-ice stream tracks are confined to present-day low lying areas, representing ancient valley networks, and have sinuous geometries. The features occur on multiple plateaux / stratigraphic levels. Their dissection by late Neogene rivers discounts a modern-day origin as aeolian features, and offset suites of MSGLs by E-W striking faults confirms their geologic antiquity. The palaeo-ice stream pathways appear to have drained a newly discovered Late Paleozoic palaeo-ice sheet of probable Visean age that flowed northward toward present day Libya, with an estimated <250 m thick tidewater ice margin. This discovery has wide-ranging implications, from increasing the known extent of Late Paleozoic ice sheets, and potentially their effects on sea level changes.

The problems of modern estuary facies models: are they suitable analogues for transgressive, fluvially-influenced shoreline successions in the stratigraphic record?

Gary Nichols[1]

[1] RPS Energy Training, Goldvale House, Church Street West, Woking, UK, garyjnichols@live.co.uk

[2] School of Environment and Technology, University of Brighton, Lewes Road, Brighton, UK

Modern estuaries are confined areas of mixing of freshwater and the sea formed as a consequence of sea level rise flooding the mouth of a river. Facies models of estuaries are valley-confined with tidal and/or wave influence and in sequence stratigraphic terms they mark the transgressive flooding over a valley formed by incision during a preceding sea level fall.

Successions of strata which show a retrogradational facies pattern from fluvial, through tidally-influenced coastal plain to shallow marine can be documented from a variety of locations of different ages. These include the Carboniferous of NW Ireland, Lower Cretaceous Wealden facies in southern England, Aptian-Albian strata on Alexander Island on the Antarctic Peninsula, Palaeocene coal-bearing successions on the island of Spitsbergen in the Arctic and the Eocene strata of the Barito Basin in southern Borneo. In each case there is a transition from fluvial to tidally-influenced facies, but none show any evidence of the lateral confinement that characterises a modern estuary. In the case of the Barito Basin, the transgressive succession can be traced laterally, perpendicular to palaeoflow for over 60 km: this is interpreted as a setting where a distributive fluvial system was undergoing transgression to form a wide, unconfined 'estuary'.

Modern analogues do not provide a basis for facies models for laterally-extensive transgressive successions as there are few modern examples of distributive river systems meeting a shoreline. However, coastal valley incision driven by high-magnitude sea level falls is a feature of the current icehouse conditions and consequently modern transgressive settings at the mouths of rivers take the form of valley-confined estuaries. During greenhouse periods, lower amplitude sea level fluctuations provided settings where valley incision was a less common feature along coastlines and 'estuarine' conditions would have taken the form of laterally-extensive, during periods of relative sea level rise.

When the past isn't present: Investigating palaeobathymetry, palaeotides and sedimentary preservation in the mid-Campanian Western Interior Seaway

Christopher D. Dean[1], **Daniel S. Collins[1],** Alexandros Avdis[1], Peter A. Allison[1], Gary J. Hampson[1], Marijn van Cappelle[2]

[1] Department of Earth Science and Engineering, Imperial College, London, UK, christopher.dean09@imperial.ac.uk
[2] PDS Group, Lange Kleiweg 10, 2288 GK Rijswijk, The Netherlands

A lack of suitable modern analogues prevents the application of uniformitarianism for reconstructing palaeobathymetry and sedimentary processes in ancient epicontinental seaways. Furthermore, interpreting ancient sedimentary processes and environments is limited by stratigraphic resolution and completeness, preservational bias towards lower frequency-higher magnitude processes, and uncertainty in the process and bathymetric interpretations of sedimentary structures. However, in basins with well-constrained palaeo-shorelines and preserved tidal deposits, numerical tidal modelling provides a quantitative means of understanding the physiographic controls on tidal sedimentary processes, and thereby constrain palaeobathymetric estimates. The mid-Campanian Sego Sandstone (USA) provides an ideal test case that comprises high quality, mixed tide and wave-influenced, coastal–deltaic deposits within the 'Utah Bight', a structural embayment of the Cretaceous Western Interior Seaway (WIS) of North America. Integrated palaeogeographic sensitivity tests and palaeotidal modelling, using an astronomically-forced and global tidal model (Fluidity) at a maximum 10 km resolution, suggest that tides were unable to transport silt or sand in the Utah Bight unless the seaway had a deep basin centre (c. 400 m) and deep southern entrance (c. 100 m).

Maximum tidal velocity vectors suggest a south-easterly directionality and ebb tide dominance, consistent with palaeocurrent measurements from the Sego Sandstone. However, tidal cross stratification in very fine to fine-grained sandstones suggests local-scale tidal amplification below the maximum resolution of palaeogeographic reconstructions and model meshes. Our results strongly suggest that palaeobathymetry in the seaway and southern entrance were deeper than recent previous estimates, which increased inflow of tidal energy into the basin and enhanced local-scale resonance effects. In the absence of analogical reasoning, tidal modelling is shown to be a useful tool for investigating palaeobathymetry in ancient epicontinental seas.

Diving into Hot Water: Geothermal Prospecting in Carboniferous Limestone Karst (A UK Study)

Nadia Narayan[1], Prof Jon Gluyas[1], Dr Charlotte Adams[2], Dr Jonathan Imber[1]

[1] Durham University, Department of Earth Sciences, Arthur Holmes Building, Science Site, South Road, Durham, DH1 3LE (UK)
[2] Durham University, Department of Geography, Lower Mountjoy, Science Site, South Road, Durham, DH1 3LE (UK)

Resource assessments in the 1970s-80s, conducted by the UK government, founded the only deep geothermal producing well in the UK at Southampton. Here, water emanates from 1.8km at 76°C in Triassic Sandstones. Whilst resources were determined in radiothermal granites and Mesozoic sedimentary basins across the UK, the study failed to further explore potential resources in Pre-Permo-Triassic strata. Karstified Carboniferous Limestone (CL) is one potential resource that has been disregarded despite the unit hosting many of the tepid spring waters in Britain (the famous Bath Spa springs host waters reaching ~45°C) and having the ability to form connected porosity and permeability networks (the Three Counties Cave System – the longest national cave network spanning 89km across three counties – is hosted in the Great Scar Limestone of the CL Group).

In response to the lack of attention directed towards a prospective low enthalpy geothermal resource, this study aims to carry out an evaluation of the geothermal potential of karstified CL in Britain. Methods applied include geothermometry analysis on spring waters, drillcore analysis, bottom-hole temperature and fluid flow rate data analysis and 2D seismic reflection interpretation of potential karstified surfaces (represented by unconformities in the geological record). Unconformities are larger in Southern England compared to Northern England. Despite this, there is evidence for karstification in wells drilled in the Midlands as displayed at Welton A14 (Lincolnshire) which experienced lost circulation in the limestone, indicating significant permeability. Fluid flow rates of ~455m^3/d have been detected further west in the Ridgeway borehole in Sheffield at temperatures of 48.9°C from limestone at an 883m depth and in the Cheshire Basin, core samples from Milton Green indicate the presence of vuggy limestone. Geothermometry analysis of spring water across the UK indicate tepid waters are also present in strata older than the CL, with several geothermometry indicators for Builth Wells spring waters suggesting high temperatures in excess of 100°C.

With 48% of the energy consumption in the UK attributed to heating and a rise in energy consumption in 2016 by 1.6% due to increased demand for heat, the application of geothermal energy is of significant interest to tackle this demand, in addition to associated energy security issues.

Composite architecture from a low-accommodation aeolian system stack – lateral translation versus bedform climb?

Colm Pierce[1,2], John Howell[1], Holger Rieke[3]

[1] Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom.
[2] CASP, Madingley Rise, Cambridge, United Kingdom. colm.pierce@casp.cam.ac.uk
[3] DEA, Hamburg, Germany.

Aeolian strata are commonly reported as products of unimodal migrating and climbing parent bedforms deposited during the migration of a single co-genetic erg system. Depositional models frequently depict aeolian architecture as homogenous, with set or coset bounded compartments related to largely uniform climbing bedform morphologies.

In contrast, the Page Sandstone Formation shows considerable internal heterogeneity from set to system scale. A minimum of six thin (4–33m) but well defined cycles of deflation to the water-table and growth to a dry coastal erg system occur. Extensive bluff exposures were surveyed over an area >1km^2 near Page, Arizona where the formation is 55m+ thick. We focused upon the mesoscale/semi-regional architecture of the system stack. Integration of detailed logs and Lidar-generated digital outcrop models resulted in multiscale dimensional data. Stratification types, architectural element geometry, facies distributions/proportions and palaeoflow measurements were mapped to reveal parent dune character.

Distinct stratification styles and set-scales were observed both across super surface bounded system resets and within super surface bounded co-genetic phases of erg migration, recording the passage of variable parent dune morphologies. Bedform climb is frequently not demonstrable at the scale of the studied outcrops with erosional trough geometries dominating. Our data suggests that accumulation of the Page Sandstone Formation was strongly influenced by scour and fill reworking of the sediment pile. We believe this was produced by dry erg migration during lowstands where crescentic duneforms with scour pits of various depth eroded into a mobile sandy substrate. Preservation was controlled by the relatively rapid stabilization and partial preservation of the individual ergs due to episodic tectono-eustatic water table rise.

This study demonstrates that in dry systems where accommodation space is limited conventional climbing aeolian architecture is juxtaposed with and overprinted by architecture linked to translation without obvious climb and downclimbing dunes, where erosional re-working by bedforms of various scales accounts for much of the depositional architecture.

Improving Reservoir Characterization and Modelling of Aeolian Systems using Process-based Geometrical Models and Multiple Point Statistics

J. R. Mullins[1], C. S. Pierce[2], J. A. Howell[1], S. J. Buckley[3]

[1] University of Aberdeen, Department of Geology and Petroleum Geology, King's College, Aberdeen, Ab243UE, james.mullins@abdn.ac.uk
[2] CASP, Madingley Rise, Madingley Road, Cambridge, CB3 0UD
[3] DEA AG, Überseering 40, 22297 Hamburg, Germany

Aeolian reservoirs are commonly considered to be homogeneous "tanks of sand". However, under certain conditions (e.g. viscous oil, deep burial, low permeability) they will typically contain significant spatial anisotropy that is commonly not captured during conventional subsurface reservoir modelling. Significant permeability contrasts and spatial heterogeneity controlled by bedform arrangements are present.

Current geostatistical algorithms enable the reproduction of spatial statistics, but are unable to integrate sedimentological rules that govern the spatial arrangement of deposition and stratification of principle facies and therefore fluid flow.

Process-based geometry models produce detailed and geologically realistic models that honour depositional rules, but are difficult to condition to observed well data. To address this issue a new workflow in which the results of process based models are used as "Training images" for Multi-Point Statistics This methodology has been tested on the high-quality outcrops of the Page Sandstone Formation, Arizona, which provide a unique opportunity to study bedform geometry and dune architecture on multiple scales.

The work flow involved characterising the aeolian succession from vertical sections (analogous to wells), then creating process based models of the dunes bodies. These were then used to condition the MPS models and finally compared back to drone derived, photogrammetric Virtual Outcrops of the Page. Reservoir models were created at reservoir (km) scale that accurately captures the individual bedform geometries and heterogeneities observed at the outcrop. These models are sufficiently generic to be applicable at an inter-well scale while remaining sufficiently specific to depict the expected architectural complexity contained within aeolian depositional environments.

This methodology can be applied to differing aeolian systems, with different parent dunes, as well as other depositional environments including deepwater reservoirs, where similar architectural elements can be modelled accurately using only a few simple geobodies.

The World's Weirdest Sedimentary Structures

Jon Noad[1,2]

[1] *Sedimental Services, Calgary, Alberta, Canada; jonnoad@hotmail.com*
[2] *Adjunct Professor, University of Alberta, Edmonton, Alberta, Canada*

Sedimentary structures form during deposition of sediment, and represent products of physical, chemical and biological processes. Certain processes are common in many modern environments, and it is usually fairly straightforward to be able to identify those responsible for creating particular structures. However, every sedimentologist, at some time in their career, has been confronted with baffling bedforms and teasing traces.

Sedimentary structures can be formed as primary structures, by sediment deposition, or as secondary structures created as traces left by organisms, through dewatering and diagenesis, or through modification of pre-existing structures through mass movement, erosion or reworking. They can form on bedding planes or within bedding structures. Stratification and cross-stratification are well understood, but secondary structures are far more diverse.

Trace fossils cover a huge range of architectural forms, and the palaeontological portion of this presentation will concentrate on some recently discovered, enigmatic structures, including interpreted dinosaur rutting scrapes. A variety of dewatering structures will be featured, as well as contorted beds that possibly underwent tectonically related, synsedimentary deformation. Diagenetic cementation can create strikingly odd concretions and patterns such as liesegang rings, and an extraordinary set of markings from the Summerville Formation will be on display.

Structures that occur at the most unexpected scales will be contrasted with more typically sized examples, and several structures that resist rational explanation will be presented along with hypotheses as to their origin. It is hoped that enough interest might be generated to provide material for a potential paper on this general theme.

Using volcanogenic sediments in W and N Cyprus to document Late Cretaceous subduction of the Southern Neotethys

Guohui Chen[1]*, Alastair Robertson[1] & Timur Ustaömer[2]

*[1] School of GeoSciences, University of Edinburgh, Edinburgh EH9 3FE, UK (*Guohui.Chen@ed.ac.uk)*
[2] Istanbul University, Faculty of Engineering, Department of Geology, Istanbul, Turkey

Late Cretaceous subduction-related magmatism in the E Mediterranean records progressive closure of the S Neotethys. In W Cyprus, the sedimentary cover of the Troodos ophiolite (c. 90 Ma) includes c. 750m of Late Cretaceous volcaniclastic sediments (Kannaviou Fm.). Deep-marine volcaniclastic sandstones include redeposited fallout tuff. Petrographic evidence suggests a volcanic arc source (e.g. colourless, vesicular volcanic glass shards, pyroxenes and hornblende), together with a subordinate continental contribution (e.g. muscovite, polycrystalline quartz). Most samples plot in the oceanic arc fields on Bhatia-type, multi-element discrimination diagrams (e.g. La-Th-Sc, Th-Sc-Zr), although a few are in continental island arc fields. Spider diagrams (PAAS-normalised) show similarities with some fore-arc basin turbidites. Electron microprobe analysis of non-recrystallised volcanic glass (K_2O, SiO_2, CaO) indicates a non-specific volcanic arc source. Ion probe analysis of glass (e.g. U/Th, Th/Nb, Th/La and Sm/La) is indicative of continental crust or subducted terrigenous sediment involvement in melting. SIMS U-Pb analysis of euhedral to sub-euhedral magmatic zircons yield an age of c. 80 Ma. Taking account of regional comparisons, the Campanian Kannaviou Formation was sourced from an incipient continental margin arc. The relatively depleted nature of the arc magmatism (oceanic arc field in some discrimination diagrams) may reflect melting of previously thinned crust, or derivation from previously depleted upper mantle. Late Cretaceous felsic volcanogenic rocks (up to 400m thick) are also exposed in the Kyrenia Range, N Cyprus (Selvilitepe (Fourkovouno) Formation). Discrimination diagrams (e.g. Th vs. Co) and normalised spider plots indicate compositions similar to central-Andean evolved high-K felsic and shoshonitic lavas. SIMS U-Pb zircon dating gives a Campanian age (c. 73 Ma). We infer that the W Cyprus and N Cyprus Campanian (c. 80 vs. c. 73 Ma) arc-related volcanogenic rocks represent early versus more advanced stages of northward subduction beneath a Tauride microcontinent, prior to Cenozoic closure of the Southern Neotethys.

Buffering of tectonic signals in conglomerates using detrital cosmogenic ^{21}Ne to quantify channel recycling in the Great Plains of Nebraska

H.D. Sinclair[1], F.M. Stuart[2], S.M. Mudd[1], L. McCann[1,2] & Z. Tao[1,2]

[1] *School of GeoSciences, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, UK.*
[2] *Isotope Geosciences Unit, Scottish Universities Environmental Research Centre, East Kilbride G75 0QF, UK*

The accumulation of conglomerates far from mountainous sources are commonly interpreted in terms of tectonic and/or climatic forcing. In the Great Plains of Nebraska, fluvial channel conglomerates have been used to imply regional tectonic tilting and surface uplift of the central US in late Miocene times, and the modern incision has been interpreted in terms of Quaternary climatic forcing. In order to relate depositional signals to source area changes, the process and response timescales need quantifying. For the first time, we use detrital comogenic nuclides (^{21}Ne and ^{10}Be) to quantify transport durations from quartzite pebbles in the modern and ancient North Platte River of the Great Plains of Nebraska. We demonstrate that at ~400 km from the mountain front, the majority of pebbles in modern river gravels and ancient conglomerates have a long history of transport, storage and recycling from older paleo-channel systems, with the majority of pebbles recording millions of years of burial and storage prior to deposition. These results indicate significant buffering between source area forcings and depositional records in this system. Interestingly, we see no evidence of a change in the degree of storage and recycling from pebbles of Miocene, Pliocene or modern river channels as may be expected from the proposed history of tectonic and climatic impact on these systems.

Three main controls, two preserved outcrops and a basin in a Cretaceous sea

Oliver Jordan[1], Robert Duller[2] & Peter Burgess[2]

[1] *Statoil UK, Paddington, London, olijo@statoil.com*

[2]*University of Liverpool, School of Environmental Sciences, 4 Brownlow Street, Liverpool*
Robert.Duller@liverpool.ac.uk, Peter.Burgess@liverpool.ac.uk

It is generally accepted that basin-scale stratigraphic architecture is governed by the interaction between the rate of tectonic subsidence, the rate and sign of sea level change and the rate of sediment supply. However, because the rate of sediment supply is difficult to determine from geological datasets it assumed to be a constant, unless a dataset requires the explanation by a 'normal regression'. Given this, there is a tendency for stratigraphers to conceptualize changes in stratigraphic architecture and parasequence stacking as a result of changing sea level. Here we aim to isolate the control that sediment supply might have on the development of basin scale stratigraphic sequences.

The San Juan Basin, (New Mexico, USA) and the Uinta Basin, (Utah, USA) preserve time-equivalent stratigraphy from the Cretaceous Western Interior Seaway foreland basin. However, even though both regions experienced the same sea level variations and exhibit broadly similar depositional environments, the stratigraphic architecture preserved in each basin is surprisingly different. The natural assumption would be to assume local fluctuations in sediment supply or accommodation. However, the preserved stratigraphy in both basins display thick sedimentary packages indicating abundant accommodation and supply from the thrust belt. Interestingly, the San Juan sections are thicker compared to the Uinta despite the assumption that the San Juan location was believed to be further away from the thrust belt. Conversely the San Juan exhibits a retrogradtational architecture and stacking pattern, whilst the Uinta exhibits a progradational architecture and stacking pattern. It is anticipated that a semi-quantitative approach to solving the cause of these contrasting stacking patterns will highlight the need to incorporate sediment supply into stratigraphic models in a more formal way.

What causes spikes in detrital zircon frequency? The case of Neoproterozoic South China

Steven Robinson

steven.robinson.11@ucl.ac.uk

The Yangtze Block constitutes the north-western half of the South China Craton, and the Nanhua Rift Basin – a trough comprising several sub-basins – occupies most of the south-eastern half of the block. Although exposures are limited, most crystalline basement beyond the rifted area appears to be Palaeoproterozoic or older, punctuated on the margins by mid-Neoproterozoic granites (*s.l.*). The rift began to open c. 860 Ma and, taken as a whole, preserves a continuous sedimentary record down to the Cambrian and beyond. It also contains mid-Neoproterozoic granites, most if not all intruding the supracrustals.

The detrital zircon record of the basin in the period 860–660 Ma has been more intensively sampled than that of any other comparable region, and probably more than that of any comparable time interval. Sifted for discordance, youngest U-Pb ages can be used to date the approximate depositional age of each sedimentary unit, and all ages analysed into the intervals 660–1000 Ma, 1000–2000 Ma and > 2000 Ma (Groups N, MP and AP). Group AP captures Archaean-Early Palaeoproterozoic crustal growth plus remelting when zircon ages were reset. Group N captures the period of greatest zircon frequency.

The relative proportions of the three groups vary markedly and systematically with time, but nearly all formations show a high proportion of Group N. They also vary by region. In the south-western part of the rift basin, N zircons rose in the period 860–820 Ma from ~25% to 60–95% of the total and remained at that level down to a sedimentary hiatus c. 750 Ma. Further north the pattern is more oscillatory. The initial rise in N frequency is interpreted to reflect increasing granite magmatism, the ascent of magma to higher levels in the crust and rapid downcutting into the plutons. Depositional ages were very close to youngest zircon ages because plutons were being exhumed by faulting soon after emplacement. Granite magmatism peaked 820–780 Ma, declining sharply to minimal levels by the start of the Cryogenian. Early-to-mid Cryogenian sedimentation is best understood as reflecting a continuation of tectonic erosion, accentuated by thermal subsidence as the granites cooled.

Evidence for marine conditions in East Greenland during the Late Triassic: Implications for North Atlantic palaeogeographies

Steven D. Andrews[1] & Audrey Decou

[1] *Camborne School of Mines, University of Exeter, Penryn Campus, Cornwall, UK, TR10 9FE ; s.andrews@exeter.ac.uk*

The continental Triassic succession north of 72° in East Greenland has seen little investigation but is key in understanding how facies belts vary towards the East Greenland Shelf, and more widely in the North Atlantic region, through this period. This study presents sedimentological analysis of exposures in northern Traill Ø (the Mols Bjerge) and further north in northern Geographical Society Ø (Laplace Bjerg). These sections are correlated with the more widely studied succession which lies to the south, in Jameson Land and broad scale palaeogeographic reconstructions of the North Atlantic are presented.

A largely continental Triassic succession of over 650 m thickness was recorded from the Mols Bjerge. However, a 125 m thick clean sand unit (the Vega Sund Member), which includes in its upper part the Gråklint Beds, is re-interpreted as of shallow marine origin. This is consistent with evidence for marine incursions within the Gråklint Beds, where observed to the south. Nearly 1100 m of Triassic strata were recognised on Laplace Bjerg. Within this succession 300 m of clean, cross bedded sandstones are recorded and are correlated with the clean sandstones of the Vega Sund Member recorded in the Mols Bjerge. The increased thickness of marine strata developed at this time provides further evidence for a more extensive marine influence in the north. Furthermore, this correlation places much of the bitumen staining previously reported from Laplace Bjerg within Triassic strata.

This work has important implications for regional palaeogeographies and the character of the Triassic succession in adjacent basins. Furthermore, this work has significantly advanced our understanding of the Laplace Bjerg exhumed hydrocarbon trap and provides evidence for a previously unrecognised play in the north Atlantic region.

Can we reconstruct sediment supply signals from clastic sedimentary successions?

Stephan Toby[1], Isabella Masiero[1], Robert Duller[1], Peter Burgess[1]

[1] *University of Liverpool, 4 Brownlow Street, Liverpool L69 3GP, stephan.toby@liverpool.ac.uk*

In an attempt to reconstruct past forcing from the sedimentary record, for example by climate or sea-level variations, stratigraphers typically analyse a vertical column of strata using physical measure such as grain size, sedimentary facies, or bed thickness. However, preservation of a signal in a single vertical succession is likely complicated when deposition continuously generates topography that then influences subsequent deposition, leading to a complex spatial distribution of strata over the basin, and potentially a shredded input signal. Given that siliciclastic sedimentary systems exhibit this kind of autogenic complexity, can we reconstruct allogenic signals from vertical successions of siliciclastic strata? To explore this question, we have developed a reduced complexity model: Lobyte3D. Lobyte3D represents various gravity-driven, sediment transport mechanisms in a very simple, but logically consistent way. The model can represent a simplified approximation of channelized and sheet flow bedload and suspended transport, as well as debris flow and turbidity flow transport. Here we have set up Lobyte3D to generate a submarine fan system from which we can extract vertical sections and cross-sections comparable to stratigraphic data obtained from outcrop studies. We show that when using spatially limited data such as stratigraphic logs, the strata often show no or very limited evidence of order despite strong forcing with an allocyclic sediment supply signal. We show that even a simple topographic-deposition feedback is enough to make a supply signal unrecognizable with limited data typically available from outcrop studies.

The Halibut Slide - a giant submarine landslide triggered by Paleocene mantle plume activity in the North Atlantic

Euan L. Soutter[1], Ian A. Kane[1] & Mads Huuse[1]

[1] School of Earth and Environmental Sciences, University of Manchester, Oxford Road, Manchester M13 9PL, UK [2] Affiliation, Address and Email Address

The 310 km long, mid-Paleocene 'Halibut Slide', is one of the largest submarine landslides on Earth, and the largest known in an epicontintental setting. Approximately 62 million years ago, plume-related uplift in the North Atlantic caused instability of Cretaceous chalk slopes across the North Sea Basin. Instability was enhanced by over-steepening of the western basin margin and increased seismicity along reactivated Mesozoic faults. The Danian-aged Halibut Slide (HS) is suggested to be a consequence of this major tectonic event. Basal megascours, up to 1 km wide, 150 m deep and 70 km long, indicate a Grampian High (NE Scotland) initiation zone for the slide, with tributary slides from intra-shelf Mesozoic highs also evident. The megascours were formed by up to 1 km wide and 160 m tall chalk megaclasts that are shown to out-run the main slide body by up to 10 km. The ~1.1˚ basal shear surface of the slide significantly modified the shelf to slope profile. The HS is confined down-dip by remnant Mesozoic rift topography on the basin floor. A splay from the HS forms the Montrose Slide (MS), with both of the slide surfaces having extending over ~7000 km^2 and having a decompacted volume of 1280 km^3. This major mass-wasting event heralded the termination of 40 Ma of chalk deposition in the basin. Throughout the rest of the Paleocene, sediment transfer from the shelf to the basin was dominated by siliciclastic turbidity currents. Turbidite system routing was strongly affected by the topography created by both of these slides. This is manifested by both onlap and thickening against the slide body and differential compaction and subsequent thinning over the slide crest. The discovery of this major submarine landslide provides new insights into the response of sedimentary systems to regional and deeply rooted tectonic events.

Depositional history of the Late Cretaceous to Recent carbonate-dominated successions in the Exmouth Plateau, offshore NW Australia

Harya D. Nugraha[1*], Christopher A-L. Jackson[1], Howard D. Johnson[1], David M. Hodgson[2]

[1]*Department of Earth Science and Engineering, Imperial College, London*
[2]*School of Earth and Environment, University of Leeds, Leeds*
**email: harya.nugraha14@imperial.ac.uk*

In oceanic settings, deep-marine stratigraphy is a valuable archive of process interactions of sediment gravity flows, pelagic sedimentation, and thermo-haline bottom-currents. One such setting is the Exmouth Plateau, NW Australia, which was a sediment-starved, carbonate-dominated continental margin throughout the Late Cretaceous to Recent. We combine 2D and 3D seismic interpretation with lithologic and biostratigraphic information from wells to reconstruct tectonic and oceanographic history. Three seismic units (SUs) have been identified. (1) SU-1 (Turonian – Maastrichtian) is c. 500 m-thick and characterised by five broad mounded features (c. 300 m-thick, 100 km-long, 30 km-wide), and channels (c. 100 m-thick, 250 km-long, 4 km- wide). These features are interpreted as the result of contour-parallel bottom-currents, which might have been related to the onset of the opening of the Southern Ocean. (2) SU-2 (Base Cenozoic – Late Miocene) is c. 800 m-thick and characterised by three main features: (i) an accretion of sediments (i.e. foresets) that are parallel with the present-day margin, (ii) an intensely channelized zone around the toesets of the accretion, and (iii) thinning of sediments (c. 200 m) onto the Exmouth Plateau Arch. The first two features might be formed by stronger bottom-currents, which coincided with the establishment of circum-polar ocean circulation. The third feature could reflect the initial influence of the collision of Australia and Eurasia. (3) SU-3 (Late Miocene – Recent) is c. 800 m-thick and comprises mass-transport complexes (MTCs). These MTCs were emplaced away from the margin and the arch, and the thickest accumulation is located in the Kangaroo Trough, where they occupy at least 50% of the SU-3 total thickness. At this stage, there is no evidence of bottom-current activity, and thus tectonic processes were more dominant, perhaps linked to ongoing collision. This study shows relative contributions of both tectonic and oceanographic processes, and their interactions through time.

Deepwater salt-related controls on sediment dispersal and architecture: Santos Basin, offshore Brazil

Clara Rodriguez[1], Christopher L-A Jackson[2], Rebecca Bell[3], Atle Rotevatn[4], Malcolm Francis[5]

[1] Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College London, SW7 2BP, United Kingdom, c.rodriguez11@imperial.ac.uk
[2] Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College London, SW7 2BP, United Kingdom, c.jackson@imperial.ac.uk
[3]Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College London, SW7 2BP, United Kingdom, rebecca.bell@imperial.ac.uk
[4]Centre for Integrated Petroleum Research and Department of Earth Science, University of Bergen, Allegaten 41, 5007 Bergen, Norway, atle.rotevatn@uib.no
[5]Schlumberger, WesternGeco. Schlumberger House, Gatwick, West Sussex, United Kingdom, mfrancis@slb.com

Salt and sediment interactions are constrained in the spatial extent and the geological time scales that are documented. Seismic-scale studies of deeply-buried, ancient depositional systems that interact with salt are challenging due to the low seismic resolution and poorly imaging of dipping minibasin flanks. Thus, most of the current understanding of salt-sediment interactions comes from shallow, relatively young deep-water systems, which are used as analogues to understand similar salt-sediment interactions in deeply buried systems.

We integrate 3D seismic and borehole data to document the controls on sediment dispersal and architecture in deep-water Santos Basin, offshore Brazil. Our results highlight the influence of gravity-driven downdip salt flow on slope morphology and on sediment dispersal and architecture. During the first phase of sedimentation (Turonian-middle Campanian), sand-rich channels and lobes were confined within proximal minibasins and to the hangingwalls of landward-dipping, salt-detached listric faults. During the middle Campanian-to-Paleocene phase, sand-rich channels and lobes eventually filled and bypassed proximal minibasins, with coarse clastic deposition then occurring further downslope. Syn-depositional seabed deformation, driven by passive and active diapirism, and salt-detached thrusting and folding directly controlled sediment distribution and architecture within distal minibasins downslope: (i) channel deflection and diversion around salt-cored highs; (ii) channel and levee uplift and rotation on the flanks of rising salt-cored highs; (iii) progressive lateral channel migration, expressed in the form of lateral accretion packages (LAPs); (iv) local ponding and long-distance lateral and frontal confinement of channels and lobes. During the Paleocene-to-middle Oligocene, continued rise of proximal salt walls dissected previously deposited deep-water systems, with deposition from mass transport complexes (MTCs) becoming increasingly important.

This work represents a significant advance on the understanding of a long-time scale (> 60 Myrs) and regionally extensive (20,122 km^2) salt and sediment interactions and provide important insights into the tectonostratigraphic evolution of the Santos Basin.

Depositional setting, provenance and tectonic-volcanic setting of Eocene-Recent deep-sea sediments of the oceanic Izu-Bonin forearc, NW Pacific (IODP Expedition 352)

Alastair Robertson [1], Steffen Kutterolf [2], Aaron Avery[3], Alan Baxter[4], Katerina Petronotis[5], Gary Acton[6], Claire Carvallo[7], Julie Schindlbeck[8]

[1] *University of Edinburgh, James Hutton Rd., Edinburgh, EH93FE, Alastair.Robertson@ed.ac.uk*
[2] *GEOMAR, Wischofstrasse, 24148 Kiel, Germany, skutterolf@geomar.*
[3] *Florida State University, Tallahassee, USA, ajal2b@my.fsu.edu*
[4] *University of New England, Armidale NSW 2351, Australia, alan.baxter@une.edu.au*
[5] *IODP, Texas A&M University, College Station, USA, petronitis@iodp.tamu.edu*
[6] *Sam Houston State University, Huntsville, TX 77341-2148, USA, gdacton@shsu.edu*
[7] *Université Pierre et Marie Curie, Paris, France, Claire.Carvallo@impmc.upmc.fr*
[8] *Universität Heidelberg, 69120 Heidelberg, Germany, Julie.Schindlbeck@geow.uni-heidelberg.de*

Especially when combined with biostratigraphy and magnetic properties, deep-sea hemipelagic muds that contain volcanic ash (fallout tephra) provide a remarkable tape recorder of magmatic and tectonic processes. An example is the Eocene-Recent sedimentary development of the Izu-Bonin outer forearc. Whole-rock chemical analysis of hemipelagic mud, combined with analysis of tephra shards, indicate: 1. Oligocene-Early Miocene sediments were mainly derived from fractionated oceanic arc volcanic products, correlated with the Izu-Bonin arc; 2. Late Miocene-Pleistocene sediments received an important contribution from a continental island arc, correlated with Japan; 3. Tephra input during the later Miocene and Plio-Pleistocene, as indicated by tephra analysis, was masked by a dominant input of Western Pacific-like hemipelagic sediment and, or Chinese loess, especially for the lower slope sites during the early Miocene. The basin development is restored as follows: Supra-subduction zone seafloor spreading during early Eocene (c. 52 Ma) created an irregular topography on which talus accumulated. Oxide-rich sediments accumulated on the igneous basement by mixing of hydrothermal and pelagic sediment. Basement volcanism was followed by a hiatus of up to 15 m.y. as a result of topographic isolation or sediment bypassing. Variably tuffaceous deep-sea sediments accumulated during Oligocene to Early Miocene and from mid-Miocene to Pleistocene. Sediments ponded into extensional fault-controlled basins, whereas condensed sediments accumulated on a local basement high. Oligocene nannofossil ooze accumulated together with felsic tuff, mainly derived from the adjacent Izu-Bonin arc. Accumulation of radiolarian-bearing mud, silty clay and hydrogenous metal oxides beneath the CCD characterized the Early Miocene, followed by Middle Miocene-Pleistocene increased carbonate preservation, deepened CCD and tephra input from both the oceanic Izu-Bonin arc and the continental margin Honshu arc. After genesis in a near-equatorial setting the Izu-Bonin forearc basement migrated northward and clockwise to collide with Honshu (S Japan) by early Miocene, strongly influencing regional sedimentation.

Active normal faults and coupled landscape response: bedrock variability in the southern Gulf of Corinth, central Greece

Jesse R. Zondervan[1,2], Alexander C. Whittaker[1], Rebecca E. Bell[1], Stephen E. Watkins[1], Sam A.S. Brooke[1]

[1] Department of Earth Science & Engineering, Imperial College, South Kensington, London SW7 2AZ, UK
[2] now at: School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA

*corresponding author: jesse.zondervan@plymouth.ac.uk

Fluvial erosion processes control landscape response to climatic and tectonic signals and its propagation into sedimentary basins. Considerable effort has gone into quantifying and modelling the effect of changes in uplift rates on fluvial erosion in bedrock rivers. However, current landscape models, based on stream power, tend to ignore the effects bedrock variability.

The lack of available data relating rock strength to bedrock erodibility in fluvial settings has limited our ability to explore this question. Recent attempts at modelling to resolve this issue rely on indirect or theoretical rock strength properties. An alternative approach requires field measurements of rock strength together with geomorphological and tectonic constraints to quantify the effect of rock strength on river evolution.

The Gulf of Corinth, central Greece, is one of the fastest extending rifts in the world and tectonic boundary conditions are well constrained. We (1) review published constraints on uplift along the active normal faults on the southern coast of the Gulf, and project uplift away from the faults into three catchments using a viscoelastic dislocation model; (2) test how channel width and slope vary in these rivers upstream of the active faults, and we use this data to estimate the distribution of stream power down-system; (3) systematically measure rock strength, using a Schmidt hammer, to constrain its effect on river response to uplift.

All the rivers have knickpoints upstream of the active faults and we show they are responding transiently to active faulting. By assuming that our derived uplift rate equals stream power-driven erosion rate we calculate the erodibility, k, of bedrock. We demonstrate that stream powers in rivers crossing faults in the southern Gulf of Corinth correlate with rock strength and derive a non-linear power relationship between bedrock erodibility k and Schmidt hammer rebound. These findings highlight the need to incorporate bedrock variability into stream power erosion models.

Pliocene-Pleistocene Polis graben, W Cyprus; using sedimentary facies, biostratigraphy and Sr isotopic dating as a tectonic tape recorder

Elizabeth M. Balmer[1], Alastair H. F. Robertson[1], Isabella Raffi[2] and Dick Kroon[1]

[1] *University of Edinburgh, School of GeoSciences, Grant Institute, James Hutton Road, Edinburgh EH9 3FE, UK. b7elizabeth@gmail.com; Alastair.Robertson@ed.ac.uk; Dick.Kroon@ed.ac.uk.*
[2] *Universitario G. D'Annunzio, Dipartimento di Geotechnologie Ambiente e Territorio, Universita' "G.d'Annunzio" Chieti-Pescara. isabella.raffi@unich.it*

The Pliocene and Pleistocene sedimentary infill of the Neogene-Recent Polis graben provides an excellent opportunity to understand extensional basin development in an evolving deep-marine to shallow-marine setting. Exceptionally, a young, still-active marine extensional basin has been exposed subaerially owing to collision-related uplift. A combination of facies analysis, nannofossil biochronology and strontium isotopic dating allows a composite succession to be determined for the first time and illustrates how the basin evolved from Late Miocene to Pleistocene. Six lithofacies are recognised in the northern outcrop of the Polis graben which allow evolving palaeoenvironments to be inferred. By the end of the Miocene (Messinian), a major c. N-S-tending graben was established, while major faulting continued until recent time. Deposition after the Messinian salinity crisis began with relatively deep-water hemipelagic calcareous mud (c. 5.08 – 2.76 Ma). This was followed by incoming of repeated normal-graded bioclastic carbonate interbeds (couplets) (c. 2.76 - 1.6 Ma). The upward facies change is explained by tectonically controlled shallowing that enabled neritic carbonate production on the basin margins. The appearance of abundant basement-derived material (e.g. ophiolitic extrusive detritus) in the highest stratigraphic levels of the basin fill (central-north and northwest areas) (c. 1.7 - 1.6 Ma) reflects the onset of rapid surface uplift. The basin fill therefore documents a two-stage, pulsed uplift process. The first caused shallowing of the marine basin (c. 2.7 Ma), and the second (c. 1.6 Ma) terminated marine sedimentation. The uplift of the basin relates to the early stages of Africa-Eurasian plate collision in the Eastern Mediterranean region. Eustatic sea level change is interpreted as a significant but less critical depositional control compared to tectonics in this case. The Polis graben can serve as an overall reference for the development of comparable extensional grabens where such high-resolution dating may not be obtainable.

Fluvial depositional architectures and facies variations in an early syn-rift setting: the Rodini conglomerates, Gulf of Corinth, Greece

David J. P. Somerville[1*], Nigel P. Mountney[1], Richard E. L. Collier[2], Luca Colombera[1]

[1] *Fluvial & Eolian Research Group, University of Leeds, School of Earth and Environment*
[2] *Basin Structure Group, University of Leeds, School of Earth and Environment*
** Corresponding author: David Somerville, eeds@leeds.ac.uk*

Understanding the responses of depositional architectures and facies variations to tectonic forcing at outcrop allows us to better recognise similar interactions in the subsurface. Models may be constrained with quantitative data collected on scalar and spatial facies relationships and architecture geometries.

The western Gulf of Corinth, Greece, is an extensional province in which earliest syn-rift conglomerate deposits transition vertically and laterally into sandstones. This study uses quantitative methods to analyse conglomerate facies distributions and thereby reconstruct fluvial system response to rift-basin evolution. Research objectives are as follows: (i) to develop a tectonostratigraphy for the area to account for variations in sedimentary architecture, both spatially and temporally; (ii) to determine the palaeoenvironmental evolution of the area, by measuring geometries and distributions of fluvial architectural elements; (iii) to determine sediment input points into the basin and reconstruct sediment distribution mechanisms via quantitative clast-fabric and facies analysis.

Composite graphic sedimentary logs (600 m cumulative length) record lithological variations; in combination with tectonic dip and regional structural data, this has enabled generation of a tectonostratigraphy. Detailed sedimentary logs (200 m), recorded at the decimetre scale from 20 localities, reveal the organisation and arrangement of 15 distinct lithofacies. Recognition of subtle facies variations was enabled by analysis of clast size, shape, and orientation (itself an indicator of palaeocurrent), for sets of 50 clasts from each conglomerate facies at each locality.

Key results are as follows: (i) the dominant sediment source into the basin came from the north over the hanging-wall dip slope, where drainage was then diverted to the east by newly formed faults; (ii) small fluvial fans formed around the tips of basin-bounding faults, and were restricted in size by footwall-uplift drainage diversion; and (iii) a novel method of interpreting conglomeratic facies has been developed, using systematic analyses of clast fabric and textures.

Modelling Facies Architecture and Heterogeneity of Meandering River Successions in Evolving Rift Basins

Na Yan[1], Nigel P. Mountney[1], Luca Colombera[1]

[1] *Fluvial & Eolian Research Group, School of Earth and Environment, University of Leeds*

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

A numerical forward stratigraphic model – the Point-Bar Sedimentary Architecture Numerical Deduction (PB-SAND) – is used to explore the relationships between differential rates of subsidence and resultant fluvial channel-belt migration, reach avulsion and stacking in active, fault-bounded half grabens. The model is used to reconstruct and predict the complex morphodynamics of fluvial meanders, their generated bar forms, and the associated lithofacies distributions that accumulate as heterogeneous fluvial successions in rift settings. Point-bar sandbody connectivity and stacking patterns are predicted in response to variations in rates of fault-driven subsidence, resulting accommodation generation, rates of river migration, and avulsion frequency. Results show how the connectivity of point-bar sandbodies can be quantified as a function of subsidence rate, which itself decreases away from the locus of fault displacement, both along faults toward their points of tip-out, and up hanging-wall slopes.
Spatial variations in the connectivity of point-bar sandbodies are controlled by the relative significance assigned to input parameters that mimic allogenic and autogenic processes.

PB-SAND facilitates understanding of facies heterogeneity and connectivity variations of fluvial successions in rift basins, allowing examination of the influence of geologic boundary conditions on sedimentary architecture at different scales. Model outputs incorporate sedimentary architecture and stratigraphic heterogeneities of fluvial system elements realistically, and in a format that can be integrated into conventional reservoir-modelling practice, particularly to aid in the assessment of sandbody connectivity.

Slip or supply? Contrasting architectures of contemporaneous and adjacent Early Pleistocene, syn-rift fan deltas (Gulf of Corinth)

Barrett, B.J.[1], Hodgson, D.M.[1], Collier, R.E.Ll.[2] & Dorrell, R.M.[3]

[1] *The Stratigraphy Group, School of Earth and Environment, University of Leeds, LS2 9JT – eebbca@leeds.ac.uk; d.hodgson@leeds.ac.uk*

[2] *Basin Structure Group, School of Earth and Environment, University of Leeds, LS2 9JT – r.e.l.collier@leeds.ac.uk*

[3] *Energy and Environment Institute, University of Hull, HU6 7RX – r.dorrell@hull.ac.uk*

Syn-rift delta deposits form significant petroleum reservoirs in the North Sea and beyond, and are important exploration targets. To build accurate reservoir models and critically appraise their potential reserves a robust understanding of their heterogeneities, stacking styles and nature of the key stratigraphic surfaces used for correlations is important. Outcrop analogues provide a high resolution framework to develop such understanding. Syn-rift deltaic stratigraphic architectures are built from the combined influence of eustatic sea level changes, sedimentation and tectonic subsidence, which all vary in time and space. Here, we use sedimentary logging, UAV-based photogrammetry and 3D digital outcrop modelling to undertake a sequence stratigraphic analysis and comparison of two exhumed, Early Pleistocene syn-rift fan deltas, the Selinous and Kerinitis, in the Gulf of Corinth, Greece. They are located at two different positions in the hangingwall of the Pyrgaki-Mamoussia fault – one at the fault tip (the Selinous) and one near the fault centre (the Kerinitis). Their excellent exposure provides a rare opportunity to compare the stratal geometries and controls of shallow marine strata at different relative positions along the same fault. The field data demonstrate contrasts in key features, such as the thickness, number of units, unit cyclicity, rollover trajectory, and nature of flooding surfaces and sequence boundaries. The fan deltas were subject to the same climatic and eustatic signals, but different subsidence regimes and catchments. Our 3D sequence stratigraphic forward model, 'Syn-Strat', is utilised to constrain these controls on development, and to demonstrate the ability to predict stacking patterns and the nature of key stratigraphic surfaces using the model. Recently published work considers the contrasting sequence stratigraphic evolution of deltas in the hangingwall and footwall of faults in this region, but this is the first work to demonstrate the along-strike influence of a single fault on the stratigraphic architecture.

Deep-water processes, architecture and facies distributions around an intra-basinal horst-tip in coarse grained delta bottomsets in a syn-rift setting

Tim Cullen[1], Richard E.L Collier[1], Rob L. Gawthorpe[2], David M. Hodgson[1], Katerina Kouli[3]

[1] Institute of Applied Geoscience, School of Earth & Environment, University of Leeds, Leeds LS2 9JT t.m.cullen1@leeds.ac.uk
[2]Department of Earth Sciences, University of Bergen, Allégaten 41, N-5007, Bergen, Norway
[3]National and Kapodistrian University of Athens, Athens, Greece

Deep-water sediment dispersal patterns in rift settings is controlled by the interplay of topography, sediment supply and relative base-level changes, which are all highly variable spatially and temporally. Syn-rift deep-water sands represent a significant hydrocarbon play-type worldwide, with recent exploration successes in the North Sea highlighting a need to further the understanding of sub-seismic stratigraphic architecture in these settings. Extensive outcrops surrounding the Xylokastro Horst in the Gulf of Corinth, Greece present an exceptional opportunity to investigate syn-rift deltas and a coeval deep-water clastic system deposited in the hanging wall of a rift margin border fault. The Early-to-Middle Pleistocene syn-rift stratigraphy comprises >400m thick Evrostini/Ilias Gilbert-type deltas located mainly at fault segment boundaries along the northern flank of the Xylokastro Horst. The northern hanging wall to the horst includes axially deflected gravity current deposits that are connected to the bottomsets of the deltas. A new stratigraphic scheme for the West Xylokastro Fault block from integrated fieldwork and digital outcrop modelling allows investigation of architectural changes in relation to key basin-evolution events such as fault activity and sea level fluctuations. Outcrops of the Evrostini/Ilias deltas and associated coarse-grained gravity current deposits permit investigation of down-dip flow transformation in relation to seabed topography at bed-scale through to seismic-scale stacking patterns. Depositional architecture is complicated by the influence of multiple sediment sources, including laterally emplaced mass transport deposits, and shows a variety of architectural elements in the bottomsets that differs from classic pro-delta models for Gilbert-type deltas. Interaction with both large and small-scale rift structures, and the resultant basin-floor topography has influenced the character of coarse-grained sandbody pinchouts. As such, an understanding of the depositional architecture of syn-rift sandstones within a deforming basin-floor setting is highly relevant to current on-going hydrocarbon field developments and exploration targets worldwide

Microfacies Variability of the Lower Carboniferous (Arundian) Hodder Shale, Bowland Basin

Timothy Ohiara, Kevin Taylor, Patrick Dowey

School of Earth and Environmental Sciences, The University of Manchester, Manchester, M13 9PL. timothy.ohiara@manchester.ac.uk

The Hodder Mudstone forms the lower section of the Bowland-Hodder Shale, a potential shale-gas play in the UK. The microtextural and mineralogical heterogeneity within the Hodder Mudstone is poorly understood. To better understand stratigraphic and process controls on the deposition of the Hodder Mudstone, the textural and compositional variability of eleven cores along the northern margin of Bowland Basin were studied. Analyses included visual core description and logging combined with X-ray diffraction mineralogy, optical and electron microscope petrography. From this data a microfacies analysis was applied to succession.

Nine microfacies (MF-1 to MF-9) were distinguished based on relative genetic variations in structure and composition. These were then grouped into two microfacies association: Laminated mudstones (MA1) are comprised of ripple- and planar-laminated silt- and clay-rich mudstones; unlaminated mudstones (MA2) include unlaminated, bioclastic, silt- and sand-rich mudstones. Detrital mineral compositions within microfacies ranged from silt-sized tectosilicates (quartz and albite) to silt- and clay-sized phyllosilicates (muscovite, kaolinite and chlorite). Authigenic mineral cements included, sulphides (pyrite and marcasite) and minor phosphate.

The Hodder mudstone was deposited along a mid-ramp to basin floor setting. Microfacies variability indicates the combined actions of storm-generated turbidity flows, slope failures, sediment resuspension and hemipelagic fall-out in a relatively shallow water (~150-200 m) environment. Soft sediment deformation resulted from translational flow of mass transport deposits. This study identifies the sedimentary processes which control microfacies variation within the Hodder Mudstone providing a basis for further petrophysical characterization. More widely, the study has implications for understanding of comparable carbonate-rich in epicontinental carbonate ramp mudstone facies.

UK Shale Gas: Using Geochemistry and Biostratigraphy to Correlate Wells in the Upper Bowland Shale Formation

Walker, J.[1], van der Land, C.[1], Jones, M.[1], Vane, C.[2], Hough, E.[2], Hennissen, J.[2] and Wagner, T.[3]

[1] Newcastle University, School of Natural and Environmental Sciences, Department of Geosciences.
[2] British Geological Survey, Keyworth, Nottingham, NG12 5GG.
[3] Heriot-Watt University, School of Energy, Geoscience, Infrastructure and Society, Institute for Life and Earth Sciences.

The Pendleian Upper Bowland Shale Formation (UBSF) is a target for UK shale gas extraction. Reliable well correlation is limited due to grain size homogeneity, but needed as folds and extensional faults increase uncertainty. Currently, maximum flooding surfaces - so called 'marine bands' - are used as stratigraphic marker beds. Marine bands are mudstones enriched in specific goniatite index fossils, formed during periods of enhanced fossil preservation. As UBSF goniatite fossils are poorly preserved and challenging to identify, organic and inorganic geochemical analyses are used alongside biostratigraphy. However, the exact relationship between marine band geochemistry and basin palaeoceanography is poorly understood.

Here we present a lateral comparison of sedimentological, palynological, biomarker and elemental data across two cores (from north west UK) and at outcrop (Clitheroe), transecting the Bowland sub-basin of the Penine Basin. Marine bands across this transect are rarely bioturbated. Rock-Eval and reflected light microscopy suggest that the total organic carbon (TOC) is mostly comprised of amorphous organic matter (AOM) most likely consisting primarily of Type II/III kerogen. Marine bands are not always connected to high TOC values, however solvent extractable organic matter (EOM) is typically most abundant within a marine band. Gas chromatography mass spectrometry (GC/MS) molecular marker analyses indicate that the marine bands were deposited during the periodic occurrence of photic zone anoxia. This indication is supported by the associated abundance of redox sensitive trace metals (e.g. U, V and Mo).

We show that processes controlling marine band formation are 1. not fully represented by the goniatite fossils 2. occur over a longer period of time than is represented by the goniatite fossils. It is only by using high-resolution geochemistry that we can improve the reliability of biostratigraphy and increase the accuracy of UBSF well correlation.

Depositional processes and palaeoenvironmental evolution recorded in mudstones during the Permian icehouse-to-greenhouse transition, Karoo Basin, South Africa

Kévin Boulesteix[1], Miquel Poyatos-Moré[1,2], Stephen Flint[1], Kevin Taylor[1], Stephen Hasiotis[3], David M Hodgson[4]

[1] *School of Earth and Environmental Sciences, University of Manchester, Manchester, U.K.*
[2] *Department of Geosciences, University of Oslo, Oslo, Norway*
[3] *Department of Geology, University of Kansas, USA*
[4] *Stratigraphy Group, School of Earth and Environment, University of Leeds, Leeds, U.K.*

The Permian Ecca Group of the Tanqua depocentre (SW Karoo Basin, South Africa) represents an exhumed basin-floor to shelf succession. The sand-dominated upper part has been extensively documented, however the underlying 850 m-thick mudstone-dominated succession remains understudied. The Early Permian period is characterized by the transition from glacial to post-glacial climatic conditions, and the presence of ice across different parts of southern Gondwana during the Middle Permian is still a matter of debate. This study aims to characterize the range of depositional processes in the Lower Ecca Group mudstones.

A 950m long core from a research borehole in the Tanqua depocentre is described for the first time. Macro- and microfacies descriptions indicate that the basal part of the succession is characterized by 5-15m thick packages of 0.5-5mm thick inverse-to-normal graded mudstone beds interpreted as hyperpycnites separated by 5-20m thick packages of bioturbated coarser mudstone that include extrabasinal and intrabasinal grains. These cyclical and organized packages are overlain by a less organized, 200m thick finer-grained mudstone package with an upward increase in thin-bedded (1-20cm thick) turbidites. The succession also includes two distinct intervals of ash turbidites. The ichnofacies association indicates an open marine environment with punctuated stressed conditions.

The highly cyclic arrangement of the basal hyperpycnites and bioturbated mudstones are tentatively interpreted to indicate deposition during glacial/interglacial cycles in a river-influenced offshore marine setting. The vertical transition into less organized, finer-grained mudstones may indicate a basin deepening and the progressive end of glacially-influenced sedimentation in the SW Karoo Basin, coincident with increased volcanic activity, as recorded by the ash beds. The stratigraphic increase in sandstone turbidites points towards a progressive change in sediment provenance, and ultimately development of sand-rich basin-floor fan systems. Therefore, the succession represents a rare expanded fine-grained record of the transition from icehouse to greenhouse conditions.

An integrated approach to a well-established problem: hyper organic enrichment and heterogeneity in the Kimmeridge Clay Formation

Elizabeth Atar[1], Andrew Aplin[1], Christian März[2], Thomas Wagner[3] and Jonny Imber[1].

[1]Dept. Earth Sciences, Durham University, DH1 3LE, UK, elizabeth.atar@durham.ac.uk, a.c.aplin@durham.ac.uk
[2] School of Earth and Environment (SEE), The University of Leeds, LS2 9JT, Leeds, UK, c.maerz@leeds.ac.uk
[3]Lyell Centre, Heriot-Watt University, Edinburgh, EH14 4AS, United Kingdom t.wagner@hw.ac.uk

The Kimmeridge Clay Formation is a laterally extensive mudstone formation that was deposited throughout north-west Europe in the Late Jurassic. Mudstones capture the most 'complete' sedimentary record and therefore make excellent datasets for investigating the climatic, tectonic and geographic controls on sediment deposition, oceanic and atmospheric processes, environmental perturbations, and the evolution of flora and fauna. In addition to this, the Kimmeridge Clay formation was deposited at a time of elevated atmospheric CO_2 so understanding the formation of such deposits may provide an insight in to how the atmosphere and oceans respond to anthropogenic global warming. A section of the Kimmeridge Clay Formation from the Cleveland Basin, Yorkshire, spanning the *wheatleyensis* to *pectinatus* ammonite zones, was chosen to investigate fluctuations in total organic concentrations and depositional controls on the timescale of kiloyears.

Organic enrichment within mudstones is controlled by a number of key parameters which can be summarised in the productivity versus preservation debate. However, the two end member scenarios of this debate, namely oceanic restriction (preservation) and oceanic upwelling/runoff (productivity), are strongly influenced by tectonic configuration. Results, including petrography, pyrite framboid size distributions, mineralogical, elemental, RockEval, carbon and lithium isotope data, show that marine algal blooms were the key driver behind hyper organic carbon enrichment in the Kimmeridge Clay Formation in the Cleveland Basin. Oxidative decomposition of organic material and bacterial reduction of sulphate led to the generation and maintenance of anoxic-euxinic waters, which facilitated the preservation of organic carbon. However, weathering and detrital supply proxies remain constant indicating weathering and detrital supply to the basin were not responsible for the fluctuations in organic enrichment observed. The integration of geochemical data, petrographic observations and atmospheric—ocean modelling is necessary to investigate and re-evaluate the processes at play in settings where there are no modern-day analogues.

Distinguishing turbiditic from hemipelagic mud in Cretaceous deepwater black shale successions: implications for oceanic anoxia.

João P. Trabucho Alexandre[1], Darren R. Gröcke[2]

[1] Department of Earth Sciences, Universiteit Utrecht, P.O. Box 80115, 3508 TC UTRECHT, the Netherlands. J.Trabucho@uu.nl.
[2] Department of Earth Sciences, Durham University, South Road, Durham DH1 3LE, UK. D.R.Grocke@durham.ac.uk.

In Bouma's (1962) turbidite facies model, all mud was classed as an "e" division. Kuenen (1964) proposed a distinction be made between turbiditic mud (et or e) and hemipelagic mud (ep or f division). However, the distinction between the two is not always obvious to the naked eye, particularly when the mud contains enough organic matter to be considered a black shale (i.e., ≥0.5 wt%).

In geochemical studies of deepwater black shales, it is particularly important to distinguish turbiditic mud from hemipelagic mud. Black shales are often used as sedimentary evidence for deepwater oceanic anoxia, but it is seldom considered whether the evidence is in situ. Organic matter and proxies for anoxia in turbiditic mud represent materials that were reworked from shallower water, rather than local biogeochemical signals.

We studied partly lithified middle Cretaceous deepwater black shales from ODP Site 1276, Newfoundland Basin, Canada. Our data show that it is possible to distinguish black mud turbidites from black hemipelagites using grain size and geochemical data. From bottom to top, turbiditic mud (et) can be subdivided into three parts (Piper 1978): laminated mud (e1), graded mud (e2), and ungraded mud (e3). Textural grading is observed as a progressive decrease in mean grain size. Compositional grading includes an upward decrease in calcium carbonate and in hydrogen index (i.e., an upward decrease in the quality of organic matter). Hemipelagic mud is texturally ungraded and contains extremely degraded organic matter and no carbonate.

The middle Cretaceous deepwater black shale succession in the Newfoundland Basin results from variations in the rate of supply of organic matter. The materials were reworked from shallower water and should not be interpreted as evidence for deepwater oceanic anoxia. Detailed facies analyses of other Cretaceous deepwater black shales may reveal that more units are graded and of possible turbiditic origin than currently presumed.

The Afterlife of Sediments – Diagenesis and Fluid-Rock Interactions

Clastic/Evaporitic Interactions in Arid Continental Settings: Implications for Reservoir Quality, Characterisation and Fluid Flow

R.Pettigrew [1*], S.M.Clarke[1], P. C.Richards[1]

[1] Basin Dynamics Research Group, Keele University, Staffordshire, ST5 5BG
**r.p.pettigrew@keele.ac.uk*

In arid continental settings, the interactions between competing aeolian, fluvial, lacustrine and evaporitic environments exert strong controls on the sediments deposited, their preservation, and lithofacies connectivity in the subsurface. They strongly influence basin-wide fluid migration, along with reservoir-scale character, petrophysical properties and production behaviour. While the distribution and preservation of different facies associations within any one of these environments are reasonably well constrained, the relationships between deposits of coeval environments and their temporal evolution have received comparatively little attention despite their potential to affect both basin-scale fluid migration and reservoir quality.

We present results of sedimentary interactions between evaporitic deposits and those of other arid environments from the Paradox Basin, USA, along with the influence of physical versus chemical processes and analysis of the allocyclic-controls upon them. Studies are based upon extensive regional fieldwork examining the sedimentology, geometries, and interactions.

The margin of the Cedar Mesa erg of the Paradox Basin preserves complex interactions of clastic and evaporitic sediments. The highly variable sedimentary fill shows large variations spatially and temporally which grade through aeolian, sabkha and lacustrine settings with complex interactions occurring where these environments transition. Where present, the sabkha facies dominate, reworking aeolian dune sediment into poor reservoir quality evaporite rich sands and blocking fluid pathways.

This work details the facies present in a continental sabkha allowing for identification and interpretation of these complex interbedded relationships over a regional scale. The results have been developed into idealised models and recognisable log signatures which characterise and assess their impact on reservoir quality. Wetting or drying climatic cyclic trends, on various orders of magnitude, have also been identified, which govern distinct spatial facies changes. Identification of these allows for basin wide correlation and prediction of where facies will occur in space and time.

The impact of depositional facies on diagenesis, fracturing and reservoir properties within a carbonate-dominated slope: Widmerpool Gulf, Lower Carboniferous, UK

C.Breislin[1], C.Hollis[1], V.Banks[2], A.Juerges[3], J.Marshall[4], J.Riding[2]

[1] *The University of Manchester, Williamson Building, catherine.breislin@manchester.ac.uk*
[2] *British Geological Survey, Keyworth*
[3] *Shell International Exploration and Production, Amsterdam*
[4] *University of Liverpool, Herdman Building*

Within carbonate reservoirs, diagenesis and fracturing can significantly impact reservoir properties. Depositional facies can act as a template for diagenesis, since primary rock texture controls porosity and permeability at deposition, and both depositional facies and diagenesis influence the degree to which a rock will fracture. This study investigates the impact of mixed carbonate-siliciclastic depositional facies on subsequent diagenesis, mechanical stratigraphy, and reservoir properties. Detailed core logging of 5 boreholes of Visean limestone from the Derbyshire Platform and Widmerpool Basin was undertaken (lithology, grain size, diagenetic features, dolomitisation, paragenesis, fracture intensity, mechanical layer thickness), supported by petrography (PL, CL, and UV) and geochemistry (stable carbon and oxygen isotopes).

Within the Widmerpool Basin, a carbonate-dominated slope developed on the Southern margin of the Derbyshire platform from the Arundian to the Namurian, with the thickness and frequency of siliciclastic facies increasing through time. Paragenesis revealed that silicification formed during early burial, with multiple phases of pervasive fault-controlled dolomitisation occurring during subsequent burial. Oil charge occurred after the first phase of dolomitisation, with later bitumen being confined to fractures. MVT-style and haematite mineralisation were found in the last stage of fracturing.

Results show the depositional facies controlled subsequent diagenesis, with silicification preferentially within silica-rich facies, and dolomitisation preferentially within silica-poor facies. Dolomitisation was most intense within clean, fine grained packstones-grainstones, improving reservoir quality through the development of a well-connected intercrystalline pore network. Fracture intensity is controlled by mineralogy, with dolomitised silica-poor wackestone and grainstone facies having the greatest intensity of fracturing. Mechanical layer thickness controlled the length of the fractures, however the overall intensity is more greatly affected by the lithology.

In conclusion, the original depositional facies controlled the subsequent diagenesis; which, in the case of dolomitisation, increased the fracture intensity of this layer, as well as the reservoir quality.

Lithofacies control on deformation bands

Oliver J.W. Wakefield[1], Ed Hough[1], Jan Hennissen[1], Daniel Parkes[1]

[1] *British Geological Survey, Keyworth, Nottingham oliverw@bgs.ac.uk*

Deformation bands are strain localisation features common in highly porous clastic sedimentary bodies. They form as predominately planar features with lateral extents commonly of a few metres and thicknesses frequently less than a centimetre. Deformation bands affect reservoir quality as they can have significantly reduced permeability compared to that of the host rock (typically 3-5 orders of magnitude lower). As such, the frequency and arrangement of multiple deformation bands within a reservoir sandbody can have implications for recovery rates. Despite the potential negative implications, our current ability to predict the presence of deformation bands is largely limited to their proximity to larger-scale (seismically resolvable) fault structures. However, using outcrop examples from the Triassic, aeolian-fluvial Sherwood Sandstone Group in the Cheshire Basin, this study is able to demonstrate a link between host lithofacies types and the frequency of deformation bands.

Specifically, this study has shown that deformation bands are most likely to occur within the highly permeable aeolian facies types, notably grainflow and grainfall facies (constituent aeolian sand dune facies types). Deformation bands observed in aeolian facies types also have significantly larger lateral extents and are more likely to occur in complex morphologies compared to those identified in non-aeolian facies types. A new working classification scheme based on deformation band geometry is proposed that aims to provide information on the anisotropy resulting from multiple variable arrangements of deformation bands. This new scheme is complimentary to the kinematic and dominate mechanism of deformation schemes currently adopted.

Vertical effective stress as a control on quartz cementation in sandstones

Olakunle J. Oye[1*], Andrew C. Aplin[1], Stuart J. Jones[1], Jon G. Gluyas[1], Leon Bowen[2], Ian J. Orland[3], and John W. Valley[3]

[1]Department of Earth Sciences, Durham University, DH1 3LE, UK
[2]Department of Physics, Durham University, DH1 3LE, UK
[3]WiscSIMS Lab, Department of Geoscience, University of Wisconsin, Madison, WI, 53706-1692, USA
[*] o.j.oye@durham.ac.uk

Temperature-controlled precipitation kinetics has become the overwhelmingly dominant hypothesis for the control of quartz cementation in sandstones; the supply of silica is not generally deemed to be important. Here, we integrate quantitative petrographic data, high spatial resolution oxygen isotope analyses, basin modeling and a kinetic model for quartz precipitation to suggest that the supply of silica from stress-sensitive intergranular pressure dissolution at grain contacts is in fact a key control on quartz cementation in sandstones. We present data from the deeply-buried Upper Jurassic Fulmar Formation sandstones from the high-pressure, high-temperature (HPHT) Elgin field in the UK sector of the Central North Sea where, despite the current burial temperature of 190 ˚C, quartz cement occurs in low amounts (4.6 ± 1.2% of bulk volume). Oxygen isotope data identifies that cementation occurred over 100 Ma and a temperature range of 80-150 ˚C, during which time high fluid overpressures resulted in consistently low vertical effective stress. We argue that the very low amounts of quartz cement can only be explained by the low vertical effective stress which restricted silica supply as a result of inhibited intergranular pressure dissolution at grain contacts.

Controls of Reservoir Quality in Namurian Tight Gas Sandstones, Southern North Sea

Natalia Wasielka[1*], Jon Gluyas[1], Andrew Aplin [1], Stuart Jones[1]

[1] *Department of Earth Sciences, Durham University, South Road, Durham, DH1 3LE, UK*
[*] *Corresponding author email address: natalia.wasielka@durham.ac.uk*

The Namurian (Upper Carboniferous) Millstone Grit sandstones, offshore UK, although locally producing hydrocarbons, are still poorly understood tight gas prospects. Reservoir effectiveness remains the key exploration risk. This is caused by large variations in reservoir quality between depositional facies and by small variations in diagenetic style within the facies, which can result in permeability differences of several orders of magnitude over small volumes of reservoir. It is therefore important to be able to identify sandstones with sufficient reservoir quality to optimize the drilling and gas recovery process and minimize exploration failures and appraisal costs. This study focuses on both primary (i.e. sedimentological) and secondary (diagenetic) controls on porosity and permeability distribution, in order to develop predictive reservoir quality distribution models and to understand in quantitative terms the diagenetic processes which have contributed to loss of porosity and permeability.

Detailed core logging, petrographic analysis, SEM, SEM-CL, and burial history modelling have been applied to study the diagenetic history of the reservoir and the relationship between sedimentary facies and diagenetic alterations. Initial results from three wells from Copernicus discovery (Quad 44) show that fluvial facies association displays the best porosity values, owing to the lowest amount of detrital clay amongst all facies. Permeability appears to be largely controlled by diagenetic processes, with the highest permeabilities recorded within quartz cemented sandstones. Carbonate cements have a more detrimental effect on permeability preservation. There is, however, a link between diagenetic alterations and depositional facies. Petrographic and cathodoluminescence analyses have proven the presence of multiple generations of quartz cement, which is consistent with the complicated burial history of the reservoir that experienced several phases of burial and uplift. Residual oil was found between two quartz generations. It is thought to have formed relatively early in the burial history and remigrated during later uplift and seal breaching.

Does the thickening of illite crystals control the formation of secondary porosity in oilfield sandstones?

Mark Wilkinson[1]

[1] *School of Geosciences, University of Edinburgh, James Hutton Road, King's Buildings*

Secondary porosity is a common feature in sandstones, with controversy over whether the porosity is effective, i.e. a genuine increase, or balanced by the precipitation of clay or other minerals. In the Jurassic Fulmar sandstone of the UK North Sea, secondary porosity is abundant, but authigenic clay is rare – leading to the proposal that the products of feldspar dissolution (including aluminium) must have been exported from the sands. Yet whole-rock chemical data fail to show export – so where has the Al gone?

It has previously been reported that, in authigenic illite separated from oilfield sandstones, both the potassium content and the crystal thickness increase with increasing burial depths. Although there is little or no analytical data about how aluminium changes with depth, the structural formula for illite shows that, as potassium increases, so does aluminium (at the expense of silicon, to retain charge balance). Hence, the aluminium content of authigenic illite must increase with depth. This means that, either the illite continuously recrystallizes during burial, or that the amount of illite must increase (and the new illite is more K and Al-rich than the older). The former idea, continuous recrystallization, would be expected to reset K-Ar ages, which are generally thought to be reliable indicators of the formation of illite, and this explanation can be rejected. Hence, new illite is forming during burial, which is consistent with the thickening of individual illite crystals.

It is hence proposed that aluminium from the dissolution of feldspar is taken up by the thickening of fundamental particles within grain-coating clays. As the products of feldspar dissolution are absorbed largely within clay coats, so the micro-porosity of these coats decreases, but the porosity of the pore network outside of the clay coats is enhanced by the addition of secondary porosity.

Mineral cement development and element mobility within the Haynesville-Bossier Shale

Patrick J. Dowey, Kevin G. Taylor

University of Manchester, School of Earth and Environmental Sciences, Manchester, M13 9WJ, UK, patrick.dowey@manchester.ac.uk

Despite recent advances, diagenetic processes in fine-grained sediments are still relatively poorly understood. Key questions still to be resolved include the extent of element mobility during the diagenesis and how mineral cements develop in low porosity and permeability systems. This study utilises data from the Haynesville-Bossier Shale to outline authigenic phases, identify mobile elements, and characterise mineral cement development during diagenetic evolution. Datasets include transmitted light and SEM microscopy techniques complimented by bulk mineralogical datasets.

Early diagenetic mineral cements are interpreted to have developed in proximity to the sediment surface. Calcite cement resulted from anaerobic/dysaerobic oxidation of organic matter; and bacterial sulphate reduction produced pyrite. Microbial activity in soft and unconsolidated sediments generated non-ferroan dolomite cement. The dissolution of reactive silicate and oxhydroxide phases may have enabled kaolinite to precipitate in uncompacted bioclasts. The illitisation of smectite and the maturation of organic matter are the most likely sources of elements for late diagenetic mineral cements. Illitisation provided a source of Fe and Mg for chlorite and ferroan dolomite precipitation. Illitisation, along with pressure solution, may have supplied Si for quartz and replacive albite cements. Organic matter conversion to kerogen may have provided $CaCO_3$ for late diagenetic calcite-filled fractures and ferroan dolomite precipitation. During late diagenesis, elements appear not to have been mobile on the reservoir scale, but would have required local element sources.

Replacive mineral cements occur during both early and late diagenesis. Early diagenetic euhedral pyrite replaces calcite within bioclasts. During late diagenesis, calcite is replaced by albite and quartz cement replaces primary detrital matrix material. Petrographic observations indicate that the cements formed through force of crystallization replacement, rather than through dissolution-precipitation reactions. Identification of three distinct replacive mineral cements in the Haynesville-Bossier Shale may indicate that this is a more common replacement mechanism than is currently recognised.

The durability of detrital clay coatings at shallow burial depths

Verhagen, I. T. E.[1], Noel, M. E.[1] and Den Hartog, S. A. M.[1]

[1] University of Liverpool, Earth Ocean and Ecological Sciences, Jane Herdman Building, 4 Brownlow Street, Liverpool, L69 3GP, United Kingdom

Detrital clay coatings are often interpreted to act as pre-cursors for authigenic grain-coating clays, which in turn are linked to anomalously high porosity and permeability in deeply buried clastic reservoirs, especially grain-coating chlorite. However, the durability of the detrital coatings during burial - and therefore their ability to transition from detrital coatings into authigenic coatings - is still poorly understood. Burial or compaction could affect the amount of clay coverage on the grains and the location of the clay within the sediment. This could control the extent of the authigenic coatings at depths over 2 km and thus play an important role in the porosity- preserving potential of these grain-coating clays. To better understand the effects of shallow burial on detrital grain-coating clays, uniaxial compression experiments were carried out in the Rock Deformation Laboratory at the University of Liverpool. The specific aims of this study were to: 1) study how shallow burial affects the structure and distribution of the grain-coating clays; and 2) investigate the effect of initial clay content of the samples on compaction. Surface samples from three locations located in the Ravenglass Estuary (Lake District, UK) were subjected to 12.5 MPa and 37.5 MPa, which corresponded to a simulated burial depth of 500 m and 1500 m, respectively. Subsequent analysis of the samples consisted of SEM and SEM-EDS analyses to study the microstructure and textural characteristics of the samples. The initial results of this study show that the detrital clay-coatings can be preserved at shallow burial depths and that samples containing greater amounts of clay, both grain-coating and matrix, undergo more compaction compared to 'cleaner' samples. The results of these experiments will increase the understanding of the formation of authigenic grain-coating clays and their overall impact on reservoir quality.

Diagenesis on the edge - Clay mineral coats and quartz overgrowth

Stephan Stricker, Stuart J. Jones, Shanvas Sathar
stephan.stricker@durham.ac.uk

As the exploration of hydrocarbons moves into more complex and deeper basinal settings the need to understand the effect of high pressure and high temperatures (HPHT) on diagenetic processes, reservoir quality, and rock properties becomes even more important. Understanding the role played by clay mineral grain coatings in inhibiting quartz cementation in HPHT geological settings is of immense importance. This study utilises the examples from complex fluvial channel sandstones of the HPHT sandstone reservoirs of the Triassic Skagerrak Formation in the Central Graben, North Sea. Despite complex depositional setting, diagenetic history, high overpressures (>40 MPa) and high temperatures (up to 185 °C) encountered, hydrocarbons are currently being produced from the HPHT reservoir sandstones of the Skagerrak Formation. To identify the role played by clay-grain coatings in maintaining exceptional reservoir quality in the HPHT reservoir sandstones to depth, a multidisciplinary approach involving petrographic analysis (optical, SEM, SEM-EDS, CL, fluid inclusions), as well as burial history, temperature and pressure modelling has been adopted across the Skagerrak Formation of the Central Graben, North Sea. Furthermore, results from hydrothermal reactor experiments highlight the morphological evolution and interaction of authigenic clay-grain coatings and quartz cement overgrowths under high pressures and high temperatures. The regional comparison of the clay-grain coatings, the type and quantity of quartz cement overgrowth, as well as the implications of temperature and pore fluid pressure in combination with the hydrothermal reactor experiments demonstrate the importance of understanding the pressure and temperature evolution for the diagenetic phases in the Skagerrak Formation sandstones. The results indicate that grain coats tend to develop thinner under lower-pressure conditions (<15 MPa) with higher amounts of macro-quartz cement. Conversely, higher-pressure conditions (>15 MPa) tend to develop thicker and more regular clay-grain coats resulting in effective inhabitation of macro-quartz overgrowths even at high temperatures (130-170°C). Hydrothermal reactor experiments provide experimental evidence that increased chlorite grain coating growth rates correspond with increased pore fluid pressures. However, under higher-pressure (>70 MPa) and high-temperature (>115 °C) conditions quartz tend to nucleate and precipitate as micro-quartz in-between and beneath the chlorite grain coatings. This study has demonstrated for the first time the effects of pore fluid pressure on the development of authigenic clay-grain coatings and quartz cement overgrowths and highlights the significance of understanding the development and the evolution of pore fluid pressures during burial.

Predictive distribution of sandstone reservoir quality by linking diagenesis to depositional facies and sequence stratigraphy: Evidence from the Middle Jurassic Ravenscar sandstone, Yorkshire Coast, UK

Sunday E. Okunuwadje, David Macdonald, Stephen Bowden

School of Geosciences, University of Aberdeen, Sunday.okunuwadje@abdn.ac.uk

The Middle Jurassic Ravenscar sandstones exposed along the Yorkshire Coast are important clastic analogues to the North Sea Brent Group reservoirs. Analysis of these sandstones by linking diagenesis to depositional facies and sequence stratigraphy provides a powerful tool for predicting the reservoir quality distribution of these sandstone reservoirs. This study focused on the Jurassic coastal successions between Cloughton Wyke and Burniston Bay, comprising the Cloughton, Scarborough and Scalby formations.

The sections consist of nine facies associations organised into eleven 4th-order sequences and two 3rd-order depositional sequences. These sequences are bounded by key stratigraphic surfaces which reflect the cyclic shift in the depositional setting from an overall wave-dominated coastal-shelf setting in the south to a tide-dominated fluvial channel-coastal environment in the northern section.

Three systems tracts were recognised consisting of lowstand (LST), transgressive (TST) and highstand (HST). The LST sandstones representing deposition in low, sinuous braided channel systems have the highest reservoir quality (Reservoir Quality Index, RQI, 0.10-0.40 μm with an average value of 0.22 μm; Flow Zone Indicator, FZI, 0.36-1.29 μm with an average value of 0.76 μm). The TST sandstones representing a wide range of depositional environments consisting of crevasse delta, back-barrier lagoon, lagoon, tidally-influenced meandering channel and crevasse channel-splay complex systems have low reservoir quality (Reservoir Quality Index, RQI, 0.00-0.16 μm with an average value of 0.06 μm; Flow Zone Indicator, FZI, 0.01-0.62 μm with an average value of 0.24 μm). The HST sandstones representing shelf transition to shoreface settings could not be sampled due to accessibility problems.

Diagenetic evaluation of these system tracts shows that the LST sandstones consist of three diagenetic facies hence the relatively wide range in both the RQI and FZI values whereas the TST sandstones comprise two diagenetic facies thus the relatively narrow range in the FZI and RQI values. These diagenetic facies show an increasing trend in both RQI and FZI values from the poorest diagenetic facies characterized by high compaction, weak dissolution and high mixed-authigenic cemented sandstones to the best diagenetic facies characterized by medium compaction, moderate dissolution, and low mixed-authigenic cemented sandstones.

Storm-induced turbidity flows in the Capbreton submarine canyon, coupling currents, fresh deposits and morphodynamics

R. Silva Jacinto[1], P. Duros[2], H. Gillet[3], B. Dennielou[1], L. Simplet[1] and A. Gaillot[1]

[1] Ifremer, Unité Géosciences Marines, 29280 Plouzané (France). Ricardo.silva.jacinto@ifremer.fr
[2] Foram Study Group, Villevêque (France). Pauline.duros@outlook.fr
[3] University of Bordeaux, EPOC-OASU, UMR 5805, 33615 Pessac (France). herve.gillet@u-bordeaux.fr

The Capbreton submarine canyon is the major canyon on the French Atlantic coast which is exposed to the westerly storms of the Bay of Biscay. The canyon remains active and hence a major sedimentary connection between the shelf and the deep sea in the all bay. Being an active canyon at the present sea level, the Capbreton canyon may also be the source and the conduit for catastrophic events such as slope failures, down-slope gravity flows or proximal tsunamis, which may impact coastal populations and both coastal and deep-water infrastructures.

A multidisciplinary study has been developed in order to quantify the present turbidity activity in the canyon. The developed methodology mixes (1) multiple bathymetric surveys at 300 m depth (2013, 2015, 2016) and 1300 m depth (2013-2016) canyon meanders providing morphological evolutions, (2) repeated location (2016-2016) sediment cores preserving the sediment-water interface (radionuclides datation, ecology of benthic foraminifera, lithofacies analysis) collected from both the thalweg and adjacent terraces along the canyon, (3) moorings deployed during two winters (2015-2016 and 2016-20217) with sediments traps and 75 kHz ADCP current meters, (4) a processes-based numerical modelling.

Results show a fairly coherent picture of the turbidity activity in the canyon popping out from different proxies and physical evidence. Major storms in the Bay of Biscay onset gravity flows of of an estimated sediment concentration up to several grammes per litre in the canyon, producing deposits whith an heterogeneous stability and major morphological changes down to 1500 m deep.

From this pluridisciplinary and pliuriannual study, the Capbreton submarine canyon stays regularly active in the present highstanding demonstrating that submarine canyons disconnected from their fluvial sedimentary sources may preserve their potential for sedimentary transfert to the deep-sea and hazards along the continental margins.

Ready… Steady… Flow? Common observations of turbidity current frequency and triggering from disparate settings

Clare, M.A.[1], Talling, P.J.[2], Rosenberger, K.[3], Pope, E. [2], Cartigny, M.J.B.[2], Azpiroz, M.[1], Hizzett, J.[1], Hughes Clarke, J.E.[4], Paull, C.[5] and Monterey CCE Team

[1] Marine Geosciences Group, National Oceanography Centre, Southampton, UK m.clare@noc.ac.uk
[2] Departments of Earth Sciences and Geography, University of Durham, UK
[3] United States Geological Survey, Santa Cruz, USA
[4] Center for Coastal and Ocean Mapping, University of New Hampshire, USA
[5]Monterey Bay Aquarium Research Institute, Moss Landing, USA

Turbidity currents pose a hazard to seafloor infrastructure, convey sediment to the deep sea, and provide nutrients to benthic communities. Despite their importance, we still know little about specifically how and when these powerful long run-out flows are triggered. New advances in direct monitoring now allow us to precisely constrain turbidity current frequency and test the efficiency of previously hypothesised triggering mechanisms.

Here we document the precise timing of sub-annual turbidity currents based on direct measurements of flows at four different sites. Two sites are located at offshore fjord-head deltas in British Columbia (Squamish delta & Bute Inlet), which are fed by melt-water in spring and summer. The third is the deep-water Congo Canyon, which is located offshore Angola, and is fed by the second largest river in the world. Fourth is the Monterey Canyon, offshore California, which does not have a direct link to a river and is instead fed by littoral drift.

Despite the differences in scale and setting, all of the sites show similar trends in turbidity current frequency. The first commonality is that flow timing is typically delayed (hours to weeks) following a period of rapid sediment discharge, rather than immediately coincident with it. The second commonality is that flows are rare (typically they do not occur at all) less than half of the year in each of the sites. Instead, flows are clustered within a specific time window. We underline the importance of preconditioning over a time window and propose that an environmental threshold must be exceeded in order to "switch on" these systems. This threshold primarily relates to magnitude of sediment delivery at the head of the channel or canyon. Once that threshold is surpassed, then systems are primed for action, quivering on the brink, where even small external perturbations can trigger flows.

Submarine Slope Failure with Hybrid Dilative-Contractional Behaviour

Joana Silva[1*], Joris Eggenhuisen[1]

[1]*Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3508 TC Utrecht*

**corresponding author: j.r.silva@uu.nl*

Submarine slope failure is an important mechanism that releases sediments stored on the continental shelf into the deep sea. Such events are associated with shear-deformation of the failing slope sediment. Granular materials are known to change volume when sheared. When the sheared material is saturated with a fluid, the change in volume is associated with fluid motion and excess pore pressure gradients. Failures can be triggered in loose sand through liquefaction. Such failures are associated with contraction and positive excess pore fluid pressures. Contrastingly, breaching failures in denser sand are characterized by slow release of sand grains during dilation of the failing sediment, and negative excess pore pressures.

A set of experiments is performed in the Eurotank Flume Laboratory (Utrecht University) to study styles of erosion, transport and deposition of sand during slope failure with different porosities. The experiments consist of a submerged column of sand with a length and height of 0,40m and width of 0,22m. The sand (median diameter, D_{50}=0,135mm) is deposited in a flume filled with water and constrained with a removable vertical plate on one side. Initial porosity is varied from 0,40 to 0,50 by different preparation protocols. The failures are triggered by removing the confining plate. For the most loose and dense packings respectively, the sand deposit contracts and suddenly collapses behaving like a fluid, or maintains a vertical failure with the generation of negative excess pore pressure characterized by dilative behaviour. A specific style of hybrid failures is presented for intermediate porosities, where a mixed dilative-contractional behaviour is observed. These hybrid dilative-contractional failures have not been described in existing literature.

The styles of submarine slope failure can only be treated by combining sedimentology of underwater deposits with geotechnical treatment of embankments, and fluid flow in porous media.

Detailed measurements of the sediment concentration structure of turbidity currents in the Congo submarine canyon

Stephen M. Simmons[1], Maria Azpiroz[2,4], Matthieu J.B. Cartigny[3], Michael A. Clare[4], Daniel R. Parsons[1], Esther J. Sumner[2], Peter J. Talling[3]

1 School of Environmental Sciences, University of Hull, U.K., 2 Ocean and Earth Science, University of Southampton, European Way, Southampton, 3 Departments of Earth Sciences and Geography, University of Durham, 4 National Oceanography Centre, Southampton

There remain very few direct measurements of oceanic turbidity currents owing to the difficulties of deploying instruments at depth that can withstand these highly energetic flows. Recent studies have successfully used acoustic Doppler current profilers (ADCPs) to measure velocity profiles of turbidity currents; however, measuring the sediment concentration of field-scale flows has remained out of reach. Here, we present a novel method to determine the sediment concentration structure of deep-sea turbidity currents, based on the integration of acoustic backscatter measurements made with multiple ADCPs. Two frequencies of ADCP were deployed at 2,000 m water depth in the Congo submarine canyon, offshore Angola, over a period of three months in 2010. We present the velocity and concentration structure of nine turbidity currents derived using this novel method. These data are the most detailed measurements (<6 second resolution) yet made of oceanic turbidity currents.

We find that flow duration is strongly bimodal; some flows are sustained for periods of 5-10 days whilst others dissipate within a single day. All flows are mainly dilute sediment suspensions, but some sustained flows contain a short-lived, faster-moving initial period of coarser-grained and higher concentration suspension within a few meters of the bed. The bodies of the sustained flows exhibit a steady maximum flow speed of 0.8-1 m/s that does not vary with flow thicknesses, which may indicate an equilibrium at which available sediment is maintained in suspension by the flow speed, creating density-driven flows that persist for several days that have not yet been observed in other canyon systems.

Stability of detrital grain-coating clays during sediment transport

Adriana Crisóstomo Figueroa[1] and Iris T. E. Verhagen[1]

[1] *University of Liverpool, Department of Earth, Ocean and Ecological Sciences, Jane Herdman Building, 4 Brownlow Street, Liverpool L69 3GP, United Kingdom, sgacriso@liverpool.ac.uk*

Detrital grain-coating clays are known to act as precursors of the diagenetic grain-coating clays that inhibit quartz cementation and increase reservoir quality in deeply buried sandstone reservoirs. However, no research has been published to date that demonstrates that detrital grain-coating clays are stable during sediment transport processes. Flume experiments were performed using sediment from the Ravenglass Estuary (Lake District, UK), where the distribution of modern detrital grain-coating clays is well known. Scanning electron microscopy and automated mineralogy analysis were undertaken with samples taken before and after the experiments to determine the stability of the detrital grain-coating clays. Experimental results show that detrital grain-coating clays originated from estuarine sediments can be stable during the sediment transport in clay-rich flows during turbulence-enhanced transitional flows and lower-phase transitional plug flows. The stability of the detrital grain-coating clays was enhanced by 1) high initial clay coat coverage of the grains, 2) detrital grain-coating clays trapped in a ripple structure, and 3) a strong detrital grain-coating clay attachment potentially due to the presence of a biofilm. The three factors combined with sediment transport within a plug flow zone can originate a higher preservation potential and lead to the formation of the diagenetic grain-coating clays at depth.

Supercritical-flow deposit distribution and facies in a channelised mid-slope, base-of-slope, and proximal basin-floor, Middle Eocene, Ainsa Basin, Spanish Pyrenees

Pauline Cornard, Kevin T. Pickering

[1] *University College London, pauline.cornard.15@ucl.ac.uk, kt.pickering@ucl.ac.uk*

Many sandy submarine fans should contain an abundance of evidence for deposition and/or erosion beneath supercritical-flow conditions, because it has been postulated that turbidity currents should be supercritical on any subaqueous slopes > 0.5°, with the formation of an hydraulic jump at the break-of-slope, e.g., the transition from submarine canyon onto the basin floor (Komar, 1971). In recent years, many researchers have focussed on supercritical- and subcritical-flow deposits using flume-tank experiments (e.g., Cartigny et al., 2011; Postma et al., 2014; Postma and Cartigny, 2014) or from direct observations on currently active deep-water systems (e.g., Hughes et al., 2012).

An extensive field study was undertaken in the Middle Eocene, Ainsa Basin, Spanish Pyrenees, where representative deposits from channelised mid-slope (Gerbe System) to break-of slope and proximal-basin floor (Banaston and Ainsa systems) environments are observed. A range of sedimentary deposits are interpreted as being deposited under supercritical conditions, and from this study, two supercritical "facies" are defined. The first, linked to an erosion phase, is related to metre-scale scour-and-fill structures. The production of these scours is likely due to an hydraulic jump with the infilling of these scours mainly due to (i) backfill caused by the upstream-migration of the hydraulic jump, and/or (ii) structureless infill linked to the stabilisation or bypass of the hydraulic jump. The second facies is typical of a depositional phase under supercritical conditions. This facies is represented by stacked concentrated density flow deposits and low-density turbidity-current deposits, which are mainly composed of breaking and stable antidunes at the bottom of the deposit, and dunes at the top the deposit.

The distribution of the supercritical-flow deposits is analysed as a function of the depositional environment. The results show an initial decrease and then increase in the proportion of supercritical-flow deposits from the mid-slope (Gerbe System) to the proximal basin-floor environment environments (Banaston and Ainsa systems). This data is consistent with previous mapping of the Ainsa Basin that suggests overall decreased confinement from the Gerbe to Banaston systems, but increased confinement between the Banaston and Ainsa systems.

Poster Presentations

Deep water clastic sedimentary systems

Progradational and Retrogradational Patterns in Turbidite Sand Sheets: Similar Allogenic Cycles to Slope Channel Systems?

JIANAN WU[1], BEN KNELLER[2]

[1] *School of Geosciences, University of Aberdeen, UK; wujianan@abdn.ac.uk*
[2] *School of Geosciences, University of Aberdeen, UK; b.kneller@abdn.ac.uk*

Although sequence stratigraphy from shallow water to deep water systems has been widely discussed in the literature, the relationship between slope channel systems and turbidite sand sheets, especially in high order sequences (e.g. 4th and 5th) have received less attention. Many authors have pointed out the repeated cut and fill processes in slope channel systems based on both seismic and outcrop data. The hierarchy of scours and fills may be related to different scale of waxing/waning cyclicity, and also correlated to different phases of progradation and retrogradation. Is it possible therefore to predict similar process on basin floors or ponded deposits, and to correlate them with the channel architecture?

In this study, we built an entire 3D 3rd order slope channel model from outcrop in Rosario Formation, Maastrichtian, Mexico, and also a detailed correlation along depositional dip in Cerro Toro Formation, Campanian, Chile. With some thickness runs tests and facies Markov chain analysis, we attempt to build a series of hierachical boundaries in these two sedimentary environments.

The results suggest that during the formation of the 3rd order channel-bounding surface sediments bypass and are deposited on the basin floor. Although intra-channel bounding surfaces (equivalent to sequence boundaries) form at all levels in the hierarchy; during fill stages, more sediments are trapped in the channel, and less transported to basin floor. The formation of bounding surfaces and subsequent fill phases in slope channels may be correlated with cycles of progradation and retrogradation in corresponding turbidite sand sheet deposits. For turbidite sand sheets, asymmetrical trends of thickness are common in more proximal parts due to erosion that corresponds to the bounding surfaces within the channels, while in distal parts of the sheet system more symmetrical or random trends of thickness are prevalent.

Syn-kinematic deep-water facies distribution against the flanks of the Bakio diapir, Basque-Cantrabrian Basin, North Spain

Zoë Cumberpatch[1*], Ian Kane[1]**,** Euan Soutter[1]**,** Ben Kilhams[2], Christopher Jackson[3], David Hodgson[4], Mads Huuse[5]

[1] SedRESQ, School of Earth and Environment, University of Manchester, Oxford Road, Manchester M13 9PL
[2] Shell Upstream International Europe, London, SE1 7NA
[3] Basins Research Group, Department of Earth Science and Engineering, Imperial College, London, SW7 2BP
[4] Strat Group, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT
[5]Basins Research Group, School of Earth and Environment, University of Manchester Oxford Road, Manchester M13 9PL
*zoe.cumberpatch@postgrad.manchester.ac.uk

Deep-water successions can form stratigraphic traps where they onlap salt diapirs. However these are commonly poorly imaged in the subsurface due to steep structural dips, fractures, sedimentological heterogeneity and salt overgrowths. Outcrop analogues provide valuable insight for constraining facies variability and geometrical configurations of these complicated onlaps. The Bakio Diapir, Basque-Cantrabrian Basin, northern Spain, provides an outstanding opportunity to study a halokinetically influenced deep-water succession. The Triassic-aged gypsum body, which grew in the Albian, is flanked and capped by unconformity-bound Albian-Cenomanian aged deep-water halokinetic sequences. The exposed section consist of lower Albian outer shelf carbonaceous marls and chaotic, slump-derived limestone breccias. The carbonaceous deposits are overlain by distinctly different siliciclastic packages (Black Flysch Group) on each flank of the salt diapir. The mid-late Albian Punta de Bakio and Jata units overlie the Bakio Breccias to the west, these are marls interbedded with fine- grained siliciclastics and marls interbedded with fine- coarse grained turbidites and slumps respectively. In the east of the study area the Bakio Breccias are overlain by the late Albian Sollube and early Cenomanian Cabo Matxitxako units characterised by thin-bedded, fine-grained siliciclastic turbidites with marls, and amalgamated, thick-bedded, coarse-grained siliciclastic turbidites respectively. The Cabo Matxixako unit is interpreted as a series of stacked deep-water lobes affected by both halokinetic growth and autocyclic flow processes. The halokinetic sequences at Bakio are multi- sourced and show interbedding of slides, slumps, debrites, hybrid beds and turbidites. Carbonates are sourced from the diapir roof and gravity flow deposits are sourced from the Landes Massif to the North suggesting episodic periods of diapir growth and collapse, which are important to understand when estimating hydrocarbon column height and considering stratigraphic trap potential.

Sedimentological characteristics of a confined deep-marine basin margin: the Grès d'Annot, SE France

Euan L. Soutter[1], Ian A. Kane[1], Mads Huuse[1] & Kristina Helland-Hansen[2]

[1] School of Earth and Environmental Sciences, University of Manchester, Oxford Road, Manchester M13 9PL, UK [2] Affiliation, Address and Email Address
[2] Statoil ASA, Sandsliveien 90, NO-5020, Bergen, Norway

Deep-water siliciclastic systems are often affected by seafloor topography. A greater understanding of these systems and their depositional processes can aid in paleogeographical reconstructions and facies predictions in exposed and subsurface basins. The Eocene-Oligocene Grès d'Annot of the western Alpine foreland basin, SE France is an example of a basin that has been structurally reconstructed using its exhumed deep-marine sequence. The sequence was deposited within a suite of well-exposed and well-studied confined basins. The eastern margin of one of these basins, the Annot basin, remains poorly understood and forms the basis of this study. The margin is shown to vary in its degree of lateral and frontal confinement, with turbidite beds in the south showing less evidence of a steep confining margin than in the north. This variation is believed to be caused by the interaction of underlying Mesozoic structures on the foreland basin geometry. The bounding slope is also shown to have a highly rugose and complex relief. The rugosity causes abrupt termination of high-density turbidites and irregular bed thickness distributions in lower-density turbidites. The rugosity is interpreted as being formed by slump scars, as further indicated by abundant slumps within the sequence. The slumping is suggested to be caused by syn-depositional deformation on the Alpine thrust front. Evidence of a steep eastern basin margin is also suggested by flow transformations over tens of metres approaching the slope, resulting in complex sequences of hybrid beds. The internal divisions of the beds are shown to respond differently to the slope, allowing a predictive model for hybrid-bed evolution at steep basin margins to be proposed. This study enables both a refined paleogeographical understanding of the Alpine foreland basin and new insights into heterogeneity distribution within confined deep-marine basins globally.

Identifying and constraining basin-floor lobe elements using well log data and electrofacies modelling: Fans 3 & 4, Skoorsteenberg Fm., Tanqua depocentre, Karoo Basin, South Africa

David R. Lee[1], David M. Hodgson[1]

[1] *Stratigraphy Group, School of Earth & Environment, University of Leeds*

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

The lobe elements and their constituent facies associations are defined by a combination of petrophysical characteristics (e.g. gamma-ray, sonic velocity, resistivity) determined through calibration of the high resolution well log dataset with the core. The resulting suite of electrofacies were used to train an artificial neural network (ANN) model to facilitate the prediction of stratigraphic architectures. Facies associations and architectural lobe elements were correctly identified in more than 80 % and 70 % of cases respectively using the trained ANN when tested against the known stratigraphic composition of nearby validation wells. Misidentification in the electrofacies modelling results can be attributed to the presence and variability of mud- and organic-rich components within hybrid beds commonly observed in the sand-rich lobe elements. It is shown that the approach adopted here can be employed to reduce uncertainty in the identification of sub-seismic elements in non-cored wells and thus help constrain the extent and architectural characterisation of submarine fan systems based on existing depositional models for basin-floor lobe deposits.

Detailed characterisation of thin-beds in Pennsylvanian slope and fan deposits, Co Clare, western Ireland

Morris, E.A.,[1] Haughton, P.D.W.,[1] Pierce, C.,[1,2] Shannon, P.M.,[1] Martinsen, O.J.[3] and Barker, S.P.[3]

[1] iCRAG, UCD School of Earth Sciences, University College Dublin, Belfield, Dublin 4, Ireland; emma.morris@ucd.ie; peter.haughton@ucd.ie; p.shannon@ucd.ie
[2] CASP, West Building, Madingley Rise, Madingley Road, Cambridge, UK; colm.pierce@casp.cam.ac.uk
[3] Statoil ASA, P.O. Box 7200, 5020, Bergen, Norway; ojma@statoil.com; sbark@statoil.com

Sand-prone intervals within deep-water depositional systems tend to attract the bulk of academic and industry research attention as they typically form either the axial parts of terminal lobes or the axial fills of submarine channels. Finer grained and thinner bedded successions are often assigned to either overbank/levees or distal lobe-fringe settings but are less commonly investigated and hence are relatively poorly understood, particularly where they occur as subordinate components within otherwise relatively sandy successions. However, understanding how these thin-bedded units arise is important, particularly as they are often used to stratigraphically subdivide lobes and to recognise hierarchical stacking arrangements in basin-floor fan settings. The thin-bedded successions also act as important baffles and barriers within many hydrocarbon reservoirs, but may contribute to production elsewhere.

Recent work has demonstrated the occurrence of significant thin-bedded and fine-grained successions within the Ross Sandstone and Gull Island Formations of the Clare Basin; a Pennsylvanian-aged basin floor and slope succession respectively. Locally, these finer-grained facies subdivide lobes or lobe complexes forming either condensed sections or distinctive alternating stacks of thin-bedded hybrid event beds (HEBs) or low-density turbidites that persist laterally for several kilometres. High-frequency switching between HEB-prone and turbidite-prone packages has been identified in other systems (e.g. Forties Field, North Sea), however, the origin and depositional control of this distinctive partitioning of bed types is still poorly understood. The Clare outcrops have recently been the target of a behind-outcrop research drilling campaign by Statoil ASA and University College Dublin whereby twelve, fully cored and logged (wireline and borehole image) boreholes were acquired. This core and log dataset, in combination with the outcrop exposures on the west coast of County Clare, form a unique dataset with which to examine the thin-bedded component of this ancient deepwater system.

Investigating tectonic versus climatic controls on mass flow deposits

Julie Harrald[1], Angela Coe[1] and Luke Mander[1]

[1]School of Environment, Earth and Ecosystem Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK. Julie.Harrald@open.ac.uk, A.L.Coe@open.ac.uk, Luke.Mander@open.ac.uk

High-volume mass flow deposits are a common feature of active submarine fault scarps. Slippage on the fault causes relatively sudden over-steepening, slope instability and rapid sediment movement. However, a similar effect can be caused or exacerbated by a relative fall in sea-level, which alters the dynamics of the sedimentary system and increases the rate of erosion and sediment supply.

In NE Scotland, around 1 km of marine sedimentary deposits accumulated on the hanging wall of the basin-bounding fault of the Inner Moray Firth. The fault was active for over 8 Ma in the Late Jurassic providing a sufficiently long time scale for the relative influence of tectonic and climatically-driven changes to be deciphered. Previous researchers have suggested that movement on the fault was the dominant control on the sedimentary succession in this area (e.g. Bailey & Weir, 1932; Pickering, 1984; Thériault & Steel, 1995; McArthur, Hartley & Jolley, 2013), whereas in other regions the sedimentary rocks of this age are predominately controlled by climate (Weedon, Coe & Gallois, 2004; Gygi, Coe and Vail, 1998).

In this research project, we are investigating the relative influence of climate and tectonics on this succession through detailed facies analysis, sequence stratigraphy and refinement of the age-resolution using palynology. Graphic logging and facies analysis of a part of the succession shows that both the fine- and coarse-grained deposits can be subdivided by the dominant grain / clast size and type. The fine-grained facies, which have previously been grouped, can be subdivided into a spectrum of five different types, ranging from very muddy to very sandy tiger stripe. The coarse-grained facies vary from sandy plant beds to clast-supported boulder beds. The more subtle variations in the fine-grained deposits and their juxtaposition with the coarse-grained beds are now being analysed for systematic changes.

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Probabilistic Geometric Modelling of Sand Distribution and Geometry in Topographically Complex Deep Marine Basins

Donald N Christie[1], Frank Peel[2 3], Esther Sumner [1], Gillian Apps[2]

[1] University of Southampton, Southampton, UK, d.n.christie@soton.ac.uk, e.j.sumner@soton.ac.uk
[2]University of Texas at Austin, Austin, Texas, frank.peel@beg.utexas.edu, gillianmargaretapps@gmail.com
[3]Imperial College London, London, UK,

Poor data quality and density poses a significant financial risk to companies exploring in topographically complex basins such as the Gulf of Mexico. It can restrict the use of traditional seismic interpretation techniques when identifying potential hydrocarbon accumulations. The inability to visualize and map key horizons increases the risk of dry wells, typically costing around $220-230 Million USD in areas such as the Gulf of Mexico.

This project will attempt to help manage risk by producing a geometric forward modelling package able to predict the probable distribution and geometry of sand rich packages in deep marine basins.

To enable quick and efficient computation, only a small number of physical inputs are considered. These are: the structural growth rate of the underlying basin, the background sedimentation rate representing hemipelagic settling, and a Clastic Limiting Surface, which is the surface above which no sand is deposited. By using simple mathematical equations, matrices, and a small number of variables, the package will be able to run numerous iterations to produce a quick and cost efficient method of predicting stratal distribution and geometry. Comparing the results against real world data will enable the modelling package to produce a best-fit model of the sediment architecture and bathymetry through time, and show the probabilistic distribution of turbidites through time and space.

The model is currently being developed in 2D and will be tested against subsurface data from the Gulf of Mexico to see if the suggested interplay between variables is able to produce geologically realistic results. Once this is complete, development will move onto 3D modelling.

This software will enable geoscientists and companies to produce a best-fit model of the geometry and distribution of sand in areas where traditional seismic interpretation techniques are insufficient to effectively manage risk.

Cross-stratification in turbidite systems

Isabel de Cala[1], Lawrence Amy[2], Robert Dorrell[3], Marco Patacci[1] and William McCaffrey[1]

1. Turbidites Research Group, School of Earth and Environment, University of Leeds, U.K eeisdc@leeds.ac.uk, M.Patacci@leeds.ac.uk, W.D.McCaffrey@leeds.ac.uk
2. School of Earth Sciences, University College Dublin, Ireland. lawrence.amy@ucd.ie
3. Institute of Energy and Environment, University of Hull, UK. R.M.Dorrell@leeds.ac.uk

Cross-stratification (~1m in height) is a common structure in many deep-water clastic systems. Cross-stratification at this scale may form due to more than one process (dune or antidune migration, or scour-fill). When cross-stratification occurs, it creates a distinct facies identifiable in ancient and modern turbidite systems and as part of subsurface hydrocarbon reservoirs and cores. A key consideration is whether we can identify patterns of cross-stratification spatial occurrence at the system scale. Potentially, such patterns could be exploited in hydrocarbon exploration and development contexts to make large-scale predictions of sand presence and architecture. In this research, a field study is used to constrain the cross-stratification types and their characteristic facies-tract associations in a confined minibasin.

Sixty cross-stratified beds analysed in the Peïra Cava basin (SE France) are mostly interpreted as the result of dune bedform migration, based on their downstream orientation and high-angle foresets. Some cross-stratified beds have lower-angled and more complex cross-stratification patterns that may be the product of antidunes. Cross-stratified beds often laterally thin and thicken over wavelengths 2-6m resembling asymmetric bedform profile shapes. Alternatively, cross-stratification occurs within larger massive beds (~5m thick) in the middle or top of the deposit surrounded by massive sands. This variety in cross-stratification characteristics and bed types suggest a range of processes were involved in its development in Peïra Cava. Log correlations demonstrate bed continuity at kilometre scale, but cross-stratification discontinuity implies bedforms in this system are not part of an extensive bedform field. Cross-stratification is confined to proximal-medial parts of this mini-basin. However, in other turbidite systems, e.g. the Marnoso-Arenacea Formation and the Ainsa (Spain), cross stratification occurs in medial-distal settings. The results show apparently systematic modes of cross-strata occurrence within individual systems. It remains to be seen whether differences in styles of cross-stratification occurrence between systems arise in a consistent fashion, due to combinations of specific sets of boundary conditions, or whether they are unpredictable.

The variability of submarine canyons on passive margins: comparative analysis and implications for the prediction of deep-water sedimentary architecture.

Daniel Tek[1], Bill McCaffrey[1], Luca Colombera[1], Marco Patacci[1]

[1] *School of Earth and Environment, University of Leeds, Leeds, LS2 9JT. ee11dt@leeds.ac.uk*

Differences between the morphology of submarine canyons developed on active and passive margins have long been recognised; however subtler variability in the characteristics of canyons on passive margins has been relatively underappreciated. Slope gradient, rates and mechanisms of sediment supply, and the size and physiography of the continental shelf are all invoked as controls on the spacing and type of canyons that develop along passive margins.

We introduce a study that makes use of global bathymetry and seismic data from the published literature to erect a general model to account for variability in the geometry, spacing and type of canyons. This model is used to classify passive margins in relation to the characteristics exhibited by the canyons. Based on this classification, the basin-floor deposits of basins with contrasting canyon morphologies can be compared to determine whether canyon spacing, geometry and type can be used predictively for inferring the nature of down-dip deep-water deposits. A relational database, the Deep-Water Architecture Knowledge Store (DMAKS), is used to compare the architecture of channel-levee and fan systems via the integration of sedimentological and geomorphological data collated from the published literature.

Margins associated with single, highly entrenched, river-connected canyons are associated with relatively organised deep-water fans fed from a point source, the canyon mouth. Margins containing numerous, smaller canyons and gullies are associated with less predictable, more variable fan architectures. The presence of large, river connected canyons is likely to affect the down-system propagation of allogenic signals from more proximal parts of the system. The proposed approach aims to quantify this variability, in view of its importance for predictions in contexts of deep-water hydrocarbon exploration.

What controls the nature and rate of submarine channel evolution? New insights from high-resolution repeat mapping of an active submarine channel

Maarten S. Heijnen[1], Michael A. Clare[1], Matthieu J.B. Cartigny[2], Peter J. Talling[2], Sophie Hage[1,2], Gwyn Lintern[3], Cooper Stacey[3], Daniel R. Parsons[4]

[1] *Marine Geosciences, National Oceanography Centre, Southampton, European Way SO14 3ZH, UK*
[2] *Departments of Geography and Earth Sciences, University of Durham, U. K.*
[3] *Natural Resources Canada, Geological Survey of Canada, BC, Canada*
[4]*School of Environmental Sciences, University of Hull, U.K.*

Subaqueous canyons and channel-levee systems are among the most important conduits for sediment transport on Earth; however, datasets that capture their ongoing evolution and directly measure the sediment transport processes within them are rare. In order to make inferences of the processes that excavate, modify and infill submarine channels we largely rely on the deposits that are left behind and results of scaled-down experimental studies. However, submarine channel morphology can be rapidly modified by successive turbidity currents, with channel bed and bank instabilities contributing to a complex morphodynamic evolution. It is therefore challenging to understand the controls on how channels evolve, which processes are most important, and what can be reliably interpreted from the resultant deposit morphology, architecture and facies.

Here, we can reconcile these issues using unusually detailed timelapse bathymetry surveys that capture morphologic evolution of an active submarine canyon and channel-levee system. Surveys capturing change over sub-annual to decennial timescales were performed in Bute Inlet, British Columbia over a ten-year period. We first present an overview of the morphological evolution of the system over a range of timescales. Second, we classify the nature and quantify the scale of erosional and depositional changes observed. Finally, we attempt to link these morphological changes to natural processes, such as turbidity current flow regime, to explain the evolution of the system. We illustrate this discussion with three main morphologic changes: 1) upstream-migrating crescentic bedforms that relate to frequent stratified turbidity currents; 2) upstream-migrating knickpoints that likely relate to non-stratified flow dynamics; and 3) meander-bend erosion and deposition that may relate to both turbidity currents and channel-margin instability. We discuss how the combination of these, and other processes, control the nature and rate of channel evolution, and we compare the findings to examine what can be reliably interpreted from deposits.

Predicting Shoreline–Shelf Processes: Insights from Numerical Modelling of Ancient Tides

Daniel S. Collins[1], Alexandros Avdis[1], Peter A. Allison[1], Howard D. Johnson[1], Martin R. Wells[2], Gary J. Hampson[1], Jon Hill[3], Matthew D. Piggott[1]

[1] *Department of Earth Science and Engineering, Imperial College, London, UK,* dscollins.geo@gmail.com
[2] *BP, Chertsey Road, Sunbury-on-Thames, TW16 7LN, UK*
[3] *Environment Department, University of York, York, UK*

Waves, tides, rivers and storms control shoreline–shelf sediment transport and sediment supply to slope–basin floor systems. Predictive decision trees and classifications for ancient shoreline–shelf processes conceptualise the importance of palaeogeography, especially the influence of shelf width on tidal resonance potential. However, multiple palaeogeographies can invariably be constructed for a given region and time, even in relatively data-rich basins. This study synthesises the geographic controls on tides by comparing modern tides with numerically modelled tides and preserved sedimentary records in three ancient case studies: 1) Oligocene–Present, South China Sea, SE Asia; 2) Early Cretaceous (Aptian–early Albian) Lower Greensand Seaway, NW Europe; and 3) Late Pennsylvanian (Carboniferous) Midcontinent Seaway, North America.

On a regional scale (100–1000s km), tidal processes within partly-enclosed basins are controlled by: 1) tidal inflow and outflow, which is determined by the number, position and physiography (shape and bathymetry) of inflow and outflow areas; 2) basin physiography, including embayments, which influences tidal resonance; and 3) partitioning of tides by flow constrictions (islands and bathymetric highs). Tidal resonance also depends on the relative strength of diurnal versus semi-diurnal tidal constituents. On a local scale (1–100s km), tides are largely controlled by the relative strength of tidal amplification, due to funnelling and shoaling effects, and frictional damping on the continental shelf and within embayments and gulfs.

Our results suggest that regional-scale palaeogeography is the primary control on tidal processes within partly-enclosed basins. Tidal resonance potential is a secondary control that is influenced by several factors, including shelf width. However, overprinting of tidal sediments by lower frequency-higher magnitude storm and fluvial processes complicates process reconstruction of ancient shallow-marine deposits. This is addressed in a series of modified decision trees and classifications that increase the confidence in predicting ancient shoreline–shelf processes based on palaeogeographic reconstructions.

Knickpoint Migration and Long-term Submarine Channel System Evolution within Bute inlet, British Columbia, Canada

Chen, Ye[1], Parsons, D.[1], Cartigny, M.[2], Hughes Clarke, J.[3], Stacey, C.[4], Hage, S.[5] , Talling, P.[2], Azpiroz, M.[5], Clare, M.[6], Hizzett, J.[5], Hunt, J.[6], Lintern, G.[4], Sumner, E.[5], Vellinga, A.[5], Vendettuoli, D.[5], Simmons, S.M.[1] and Williams, R.W.[1]

1School of Environmental Sciences, Hull University, UK
2Department of Geography, Durham University, UK (matthieu.j.cartigny@durham.ac.uk)
3Center for Coastal and Ocean Mapping, University of New Hampshire, USA
4Natural Resources, Geological Survey of Canada, Canada
5School of Ocean and Earth Science, University of Southampton, UK
6 Marine Geoscience, National Oceanography Centre, UK

Turbidity currents play a major role in the transport and delivery of substantial volumes of sediment into the deep sea. Recent work has identified that knickpoints are a dominant morphological feature in many submarine channel systems. Through repeat high-resolution seafloor mapping and the collection and analysis of sediment cores and bed samples along a submarine channel system in Bute inlet, British Columbia, Canada. We examine the evolution of knickpoints and interpret the sedimentary facies associated with knickpoint dynamics formed and maintained by turbidity currents. Combined with the ADCP data derived from a set of moorings, we analyse the detailed turbidity current structure over knickpoints and explore factors controlling knickpoint formation through to the dynamics and deposits that result from knickpoint migration. We discuss how knickpoint dynamics may connect the proximal and distal sections of submarine channel systems and thus impact on longer term channel evolution.

Halokinetic Controls on the Evolution of Shallow Marine Facies Architecture: Insights from the Upper Jurassic Fulmar Formation, United Kingdom Continental Shelf

James Foey[1], Stuart M. Clarke[1], Tom Randles[2], Steven Banham[3], Ian Stimpson[1]

[1] *Basin Dynamics Research Group, Geography, Geology and the Environment, Keele University, Keele, United Kingdom, j.a.l.foey@keele.ac.uk*

[2] *British Geological Survey, Edinburgh, United Kingdom.*

[3] *Department of Earth Science and Engineering, Imperial College London, London, United Kingdom.*

Documented outcrop examples of halokinetically-influenced siliciclastic shallow marine environments are sparse and consequently, their sedimentology remains poorly understood. Salt withdrawal and dissolution has the potential to enhance basin subsidence and create topographic barriers to sediment transport. Conventional wisdom dictates that the preserved distribution of facies temporally and spatially within salt-withdrawal minibasins is a consequence of subsidence and sedimentation rates. However, in the absence of suitable outcrop examples, only a detailed study of subsurface data can enhance the understanding of facies distribution and reservoir quality, both within and between salt-withdrawal minibasins.

The Upper Jurassic Fulmar Formation of the Central North Sea provides an ideal opportunity to study the effects of halokinesis on shallow marine sediments. The succession was deposited into salt-wall collapse basins formed by the dissolution of mobile Zechstein salts. The geographical distribution and facies of the formation were controlled by the complex interplay of basin-scale tectonics, active salt migration and dissolution. The presence of numerous closely spaced well penetrations and continuous 3D seismic data enable a detailed interpretation of the subsurface.

This multidisciplinary study has three aims: i) to determine the architecture of the shallow marine salt-withdrawal mini basin-fill, ii) to determine the spatial and temporal distribution of facies within and between salt-withdrawal basins, and iii) where possible, relate the variation in facies to active salt withdrawal and sedimentation rates.

In this work we have integrated ichnofabric, sedimentological, wireline and biostratigraphical data with 3D seismic data from the Central North Sea. Initial results indicate that the gross depositional environment of the sediments remains unaffected by the development of salt-withdrawal minibasins, minibasin development may act solely to preserve thickened packets of sediment.

Further work on the project will aim to produce predictive depositional models of facies distribution and connectivity applicable to the Fulmar Formation and similar salt-influenced, shallow-marine hydrocarbon plays.

Improving mangrove proxies for sea-level reconstructions

Juliet Sefton[1], Sarah Woodroffe[1], Erin McClymont[1]

[1] Geography Department, Durham University, South Road, DH1 3LE, Durham, United Kingdom
juliet.p.sefton@durham.ac.uk, s.a.woodroffe@durham.ac.uk, erin.mcclymont@durham.ac.uk

Studying past sea-level changes is important for many fields of Earth-system science; understanding past ice-volume fluctuations, providing empirical evidence for sea level and palaeoclimate models, and calculating the background signal upon which historical and current sea-level trends are evaluated. Mangroves accumulate sediments close to mean sea level, and therefore provide important sedimentary archives of past sea-level changes in under-sampled, low-latitude locations. However, mangrove sediments currently make poor sea-level proxies because microfossils (which are commonly used for high resolution environmental reconstructions) are not well preserved due to the warm and acidic conditions. A better understanding of mangrove environments and sedimentary processes is needed to provide sub-metre scale reconstructions of recent sea-level changes from these environments.

This study seeks to identify features (e.g. sediment texture) in the mangrove sedimentary record that can increase the precision of sea-level reconstructions. A primary objective is to further investigate mangrove sedimentological sea-level proxies, using grainsize analysis and by monitoring sediment accumulation rates a mangrove forest. These analyses will be compared with palynological sea-level proxies, and potentially with new organic geochemical sea-level proxies. Here, we present a preliminary dataset of surface sediment grainsize distributions and total carbon composition across a mangrove zone from the island of Mahé, in the Seychelles archipelago. Mahé is an ideal setting for this study as the mangroves are easily accessible, the tidal range is small (so the mangrove zone is narrow) and different mangrove species are zoned by elevation.

Ultimately, we hope the findings of this study will be applied to palaeo-mangrove sediments in other low-latitude locations, and will allow us to more accurately than ever before reconstruct sea-level changes from mangroves during the late Holocene.

Origin, evolution, and mobility of large seabed bedforms, offshore East Anglia, UK

Stephen J. Eaton[1], David M. Hodgson, Natasha L. M. Barlow[1], Estelle E. J. Mortimer[1], Carol Cotterill[2]

[1] School of Earth and Environment, University of Leeds, LS2 9JT, UK
[2] British Geological Survey, Edinburgh, UK

Marine sedimentary bedforms pose significant challenges to the installation of offshore infrastructure. Understanding the evolution and mobility of sedimentary bedforms under different hydrodynamic conditions will help mitigate risks associated with future infrastructure strategies in the marine environment. Some of the largest and most widely dispersed depositional bedforms are sediment waves, and are found on nearly all continental shelves. Despite sediment waves being a relatively common feature, the origin and evolution of these bedforms is poorly constrained.

Offshore datasets are rarely available for analysis. However, Vattenfall Wind Power have provided a new, comprehensive, high resolution integrated dataset that will enable a detailed study of the Quaternary stratigraphy and a range of sediment bedforms in the area offshore of East Anglia, UK. Using ultra high resolution (UHR) seismic reflection data, an overview of the Quaternary stratigraphy offshore East Anglia will be presented that describes and interprets the primary stratigraphic intervals and the seismic facies. The Holocene stratigraphy, and the range of modern seabed bedforms, from large to very large (height 0.75 m to >5 m) sediment waves, superimposed dunes, and erosional bedforms, will be analysed using high resolution bathymetric data and sub bottom profile (SBP) seismic. Using SBP seismic the internal architecture of these bedform and structures can be imaged to support process interpretations. In the future, additional datasets including repeat bathymetry data, backscatter data, vibrocores, grab samples and MetOcean data, will help to refine understanding of the hydrodynamics and mobility of bedforms on the seabed.

Variability of shoreline trajectory and clinoform geometry in dip and strike directions in the Eridanos Delta on the Dutch Continental Shelf

Eva Zimmer[1], John Howell[1]

[1] Department of Geology and Petroleum Geology, Meston Building, University of Aberdeen, Aberdeen AB24 3UE, United Kingdom

Shallow marine deltaic and shoreface deposits occur in regionally extensive sediment geobodies that serve as reservoirs in many regions worldwide (e.g. North Sea, Mediterranean Sea, offshore Western Australia, Alaskan North Slope). The shallow section (< 1 second) of conventional 3D seismic volumes contains a wealth of detailed geometric data which is commonly overlooked. A North Sea dataset has been used as analogues to better characterise shallow marine reservoirs. In the data 9 clinoform bound packages have been mapped and measurements such as clinoform dip and shoreline trajectory have been taken along multiple cross-sections and used to provide a unique insight into 3D clinoform geometry.

Data were taken from the Late Cenozoic Eridanos Delta in the Dutch sector of the Southern North Sea using the 3D seismic CNS/NNS MegaSurvey from PGS. The identified clinothems of the delta are laterally extensive bands of relatively uniform length. Clinoform dip, shoreline trajectory and bed taper show low variations along strike. Clinoform dip increases during outbuilding of the delta and the systems exhibits a falling shoreline trajectory.

Low variation of clinoform dip along strike as well as uniform length of the clinothems suggest that the delta is wave-dominated. This is contrary to existing literature which proposes a change from wave- to river-dominated as the delta progrades westwards. The increase in clinoform dip during outbuilding of the delta is interpreted to be due to sequential stacking of the clinothems whereas the variation in clinoform dip along strike is due to grain size distribution away from fluvial input points.

Tidally Influenced Deposits and Their Relative Importance in the Dakota Sandstone/Naturita Formation: San Rafael Swell, Utah, U.S.A.

Phillips, Stephen P.[1]; Howell, John A.[1]; Hartley, Adrian J.[1]

[1]*Department of Geology and Petroleum Geology, University of Aberdeen, AB24 3UE, United Kingdom*

The Dakota Sandstone/Naturita Formation (D/N) of the San Rafael Swell (SRS), Utah contains extensive tidal deposits that, in part, record the initial transgression of the Cretaceous Western Interior Seaway (WIS). On the San Rafael Swell, there are comparatively few studies dedicated to this formation. The focus of this poster is to introduce data acquired during our 2017 field reconnaissance, and to discuss future goals. Data has been collected at 15 sites around the SRS including: 3 drone surveys, 9 measured sections, photographs, and paleocurrent measurements. Of particular interest is the relative importance of tidally influenced deposits and their occurrence within the D/N. We believe that tidally influenced deposits represent a large portion of the total sequence. In future, we aim to build upon previous and current work, to provide a regional scale look at sand body variability using 3D drone imagery augmented by measured sections. The analysis will provide detailed information regarding sand body dimensions, distribution, facies, and architecture. This data can be used as an analogue in geologic and reservoir modelling, and will add to our current understanding of transgressive systems, local paleogeography, and the way in which the WIS was flooded.

Characterization of a low-accommodation shallow-marine succession (Lower Jurassic, SW Barents Sea, Norway)

Miquel Poyatos-Moré [1], Tore Grane Klausen[2], Snorre Olaussen[3], Reidar Müller[4], and Ivar Midtkandal[1]

[1] Department of Geosciences, University of Oslo, Norway (miquel.poyatos-more@geo.uio.no)
[2] Department of Earth Science, University of Bergen, Norway
[3] University Centre in Svalbard (UNIS), Norway
[4] Arcadia Research, Oslo, Norway

Low-accommodation shallow-marine systems are often challenging to interpret and map, even with advanced seismic interpretation tools, due to their amalgamated/condensed, low-gradient nature, which often falls within sub-seismic resolution. As a result, detailed studies of such systems are scarce, and their resulting depositional architecture is still poorly understood.

In the SW Barents Sea (Norway), the Stø Formation comprises a condensed, laterally-extensive, clastic nearshore to inner shelf succession, deposited on a shallow epicontinental platform during the Toarcian-Bajocian. Deposits have been grouped within three stratigraphic units, which reflect variations in relative sea-level during an overall transgressive regime, with regional flooding surfaces and extensive depositional hiatuses. Smooth, linear and cylinder-shaped low-reading gamma ray log patterns distinguish the Stø Fm from the underlying Nordmela Fm. Sandstones are mineralogically and texturally mature, mainly fine- to medium-grained, but recent provenance analyses reveal different sedimentary sources.

Common marine macro-fossils, chamositic and glauconitic grains and authigenic phosphate occur in distinct beds, with several horizons of extraformational pebble grade conglomerate, suggesting a balance between sediment input and basin subsidence. Marine trace fossils are common, and large-scale low/high angle and hummocky cross-stratification point towards their interpretation as dominantly wave-dominated clastic offshore transition to foreshore deposits, with local storm-generated beds and tidally-influenced deposits.

Regional correlativity of stratigraphic units suggests block faulting was never able to isolate different depozones. However, differential spatial thickness and facies distribution through time indicate an interaction between regional tectonics and dominant process regime still existed, and played a significant role in the creation of local acommodation and the resulting sediment accumulation.

This study describes the overall facies development in the Stø Formation and its development in terms of sequence stratigraphic principles, adding important information on how shallow-marine systems develop in low-accommodation settings. This information allows for more detailed paleogeographic reconstructions, with implications for reservoir sandstone distribution and characterization.

Morpho-sedimentary responses to explosive volcanism: aftermath of the 2015 Calbuco eruption, southern Chile

Dr Vern Manville[1], Dr Robbie Jones[2], Dr Eliza Calder[3]

[1] School of Earth and Environment, University of Leeds (v.r.manville@leeds.ac.uk)
[2] School of Earth and Environment, University of Leeds (now at Willis RE: robbie_j_jones@outlook.com)
[3] School of Geosciences, University of Edinburgh, UK (eliza.calder@ed.ac.uk)

Landscapes impacted by explosive volcanism exhibit some of the highest sediment yields on Earth due to the overwhelming of ambient drainage and sedimentary systems by huge volumes of particulate material. While we have a first-order understanding of morpho-sedimentary responses in terms of patterns and chronologies of erosion, resedimentation, and aggradation, more recent studies have focussed on untangling the system- and catchment-specific controls that govern the style, severity and duration of the post-eruptive impact.

An exemplar of this approach is afforded by the April 2015 eruption of Calbuco Volcano in southern Chile. This c. 0.31 km^3 event generated sub-Plinian eruption columns, multiple topographically confined pyroclastic density currents, and both hot and cold primary eruption-triggered lahars in multiple drainages. Fieldwork and remote-sensing analyses have focussed on 3 major catchments with differing physiography and hydrological regimes that each received differing proportions and volumes of tephra and pyroclastic flow material.

Overall, except for where an internal impermeable crust is developing, the majority of the coarse tephra deposited by the 2015 eruption appears to have low remobilisation potential, suggesting that Calbuco lies close to the other end of the spectrum of post-volcanic landscape sensitivity to that shown by the 2008 Chaitén eruption. In the most heavily impacted catchment, which lay under the tephra dispersal axis and received extensive pyroclastic flows, major rain-triggered lahar activity was delayed until the first significant post-eruptive rainfall event in mid-May 2015. Since then up to 12 m of aggradation has occurred as remobilised material is translated downstream as a kinematic wave. Other catchments have behaved differently as a function of basin physiography, hydrology and the volumes and spatial distributions of pyroclastic material, although whether peak remobilisation has already occurred is contingent on the stability of a large reservoir of as yet untapped material identified high on the mountain.

Quantitative lithofacies characterization of fluvial, aeolian and lacustrine response to salt-walled mini-basin evolution: comparisons between presently active systems and ancient successions

Simon D. Jackson*[1] Nigel P. Mountney[1], Luca Colombera[1], Steven G. Banham[2], Na Yan[1]
*[1] School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK * eesdj@leeds.ac.uk*
[2] Faculty of Engineering, Department of Earth Science & Engineering, Imperial College, London, SW7 2AZ, UK

Modern and ancient salt-walled mini-basins have sedimentary basin fills that record complex evolution in response to spatio-temporally varying surface topography and subsidence histories. Intraformational unconformities within the fill of these basins preserve evidence of differential tilting of the depositional surface at the time of accumulation. Patterns of subsidence and accommodation generation are recorded by thickening of accumulated successions in depocentres, and onlap and truncation onto growing salt-walls. Such basin development exerts a primary control on fluvial, aeolian and lacustrine system behaviour, accumulation and long-term preservation.

This study aims to investigate fluvial, aeolian and lacustrine system response to salt-walled mini-basin development. Specific objectives are to demonstrate system response to salt-sediment interactions whereby growing salt walls and subsiding mini-basins influence sedimentation. Case-study examples include: (i) fluvial drainage patterns in modern systems, e.g., Zagros Mountains (Iran); (ii) comparative analyses of the lithofacies of ancient successions, e.g., Paradox Basin (Utah), Sivas Basin (Turkey), Cumberland Basin (Canada), and La-Popa Basin (Mexico).

Remote-sensing analysis of the Zagros region documents modern fluvial system response to on-going surface deformation arising from salt movement. Example responses include: (i) drainage diversion; (ii) exposure and incision of salt-wall cores; (iii) river migration in response to salt-wall propagation.

A database approach has been used to compare facies and architectural-element relationships of sediment bodies that comprise the fill of ancient salt mini-basins. Data have been coded in a standardized format within a relational database – FAKTS. Output on facies proportions provides a description of vertical and lateral variations in facies architecture between and within mini-basins. Results demonstrate: (i) partitioning of fluvial sand fairways between coeval mini-basins by salt-wall surface topography; (ii) accelerating subsidence and underfilled basin development as salt evacuation beneath evolving mini-basins reaches climax; (iii) decelerating subsidence as remaining salt is evacuated from beneath mini-basins and time of grounding on basement is approached.

Facies analysis of the Castlegate Sandstone, Utah: An integrated approach

Andrew J. Mitten, Stuart M. Clarke, Jamie K. Pringle

[1] *School of Geography, Geology and the Environment, Keele University, Keele, Staffordshire, UK, ST5 5BG, a.j.mitten@keele.ac.uk, s.m.clarke@keele.ac.uk, j.k.pringle@keele.ac.uk*

Fluvial sandstones create some of the largest clastic reservoirs in the world but the quality of these reservoirs, and recovery from them, are strongly controlled by depositional style. However, the internal architecture of fluvial sandbodies is difficult to ascertain from down-hole data alone, and the rapid spatial and temporal variations in lithofacies make inter-well correlation of fluvial strata notoriously difficult. The aim of this study is to investigate the complex nature of sandbody architecture within a high net-to-gross fluvial reservoir, by using an integrated approach with photogrammetry, pseudo-well log and petrographic data from the Campanian Castlegate Sandstone at its type locality north of Helper, Utah, USA. This integrated, outcrop-based, pseudo-well-log data approach allows analysis of surface outcrop data to be directly related to down-hole data.

Terrestrial photogrammetry data collected on key outcrops were combined with traditional sedimentary logging and hand-held gamma ray spectrometry data. These data were then used to create pseudo-well datasets, combined with petrographic analysis of collected rock samples. This high-resolution data set was used to produce a detailed interpretation of the strata within the Castlegate.

Twelve facies and five facies associations were identified, with a complex variability in sedimentary architecture and changes in channel stacking patterns. Subsequent environmental reconstruction indicates that the complex architecture of the Castlegate was initially deposited in a highly avulsive, low-sinuosity, bedload-dominated fluvial system before evolving into a tidally influenced, laterally migrating, fluvial system up the succession. This change in fluvial style was induced by transgression during the Campanian Age.

Further work will focus on key stratigraphical horizons identified within collected spectral gamma ray data and the palaeosols horizons within the formation. Such surfaces represent key sequence stratigraphical markers otherwise overlooked during more traditional, less integrated, sedimentological approaches.

Fluvial-Aeolian Interactions Within Arid Continental Basins: Insights from the Kayenta Formation, Western USA.

Priddy, C.[1*], Clarke, S.M.[1], Richards, P.[1], Randles, T.[2]

[1] Basin Dynamics Research Group, Keele University, Keele, Staffordshire, ST5 5BG,
**c.priddy@keele.ac.uk*
[2] British Geological Survey, The Lyell Centre, Edinburgh, EH14 4AP

Arid continental basins commonly comprise sedimentary fill from fluvial and aeolian environments, and while the preserved facies associations within each environment have been studied in great depth, the relationships between coeval depositional environments have received little attention. The temporal and spatial distributions of these environments can greatly affect reservoir quality and basin-scale migration.

We present results from interactions of fluvial and aeolian deposits of the Kayenta Formation across the Colorado Plateau, USA, along with insights into the allocyclic controls upon them. These studies are based upon extensive regional fieldwork to examine the sedimentology, small and larger scale interactions and geometries of the proximal and medial sediments. Using 3D photogrammetry techniques and sedimentary logging, environmental models have been derived, showing the complex interactions between ephemeral fluvial and aeolian environments, through both space and time, how the sediments are preserved, and their impact on reservoir quality.

The Kayenta Formation comprises fluvial-aeolian associations of varying reservoir quality. Relationships between them are spatially predictable, governed by one system's dominance. A dominant aeolian system limits fluvial sediments to interdune corridors and controls localised sediment supply, resulting in flash-flood and debris facies of moderate reservoir quality comprising sediments of aeolian calibre and texture. Dominance of the fluvial system restricts aeolian bedforms and preserves extensive ephemeral fluvial sediments of poor reservoir quality with fluvial textures dominated by extraformational sediment. The temporal evolution between systems preserves unique facies, but a switch in dominant system takes place quickly, severely limiting the vertical extent of interactions and potentially isolating reservoir intervals of basin fill.

The study provides evolutionary sedimentary models that can be applied to subsurface data from the arid Permian basin of the Southern North Sea, and other similar settings, in order to better characterise basin-scale migration and reservoir quality in terms of the evolving basin fill.

Development of predictive fluvial facies models: Huesca Fluvial System, Spain

Ben Martin[1], Amanda Owen[2], Richard Williams[3]

[1] *University of Glasgow, Glasgow, Scotland: b.martin.1@research@gla.ac.uk*
[2] *University of Glasgow, Glasgow, Scotland: Amanda.owen@glasgow.ac.uk*
[3] *University of Glasgow, Glasgow, Scotland: Richard.williams@glasgow.ac.uk*

Recent research has looked towards distributive fluvial systems (DFS; also known as alluvial, fluvial and mega fans) which dominate (>90%) modern continental sedimentary basins. DFS deposits have proven to have a predictive nature, and therefore we must now begin to quantify this in terms of facies distributions, spatially and temporally, alongside developing current understanding of architectural elements at a system scale, something currently lacking within the literature with only one outcrop-based, fully quantified rock record example (Owen et al. 2015). This research therefore aims to improve our ability to predict fluvial facies variability at the system scale, leading into basin-scale research.

The research is centred around the Ebro Basin, N. Spain, spanning over 80,093 km^2 and focusses on the Oligocene-Miocene Huesca DFS with aims to quantify sedimentary data and expand on prior work (Hirst, 1991). Large lateral exposures (>1km) allow us to examine DFS system changes in geometry across various system positions. This will enable us to address whether predictable downstream trends can be quantitatively identified as well as non-quantitative data such as whether a braided-meandering planform can be identified. At current, the project is using 3D digital outcrop models supplied by the SAFARI consortium to collect gross-scale data such as channel body geometry, dimensions and net:gross. Initial results indicate downstream shifts in channel geometry (massive – offset stacked) alongside decreases in storey surface frequency. Quantitative data has highlighted that whilst general downstream trends exist, variability within outcrop is prevalent within the medial areas of the system due to channel avulsion dynamics. Both the digital outcrop data and fieldwork component of the project will be correlated to provide highly accurate data which can be quantified and applied to both modern and ancient systems. Findings from this project will be closely studied with modern analogues to see how well observations align.

Fluvio-deltaic sedimentology of the Lower Carboniferous, Dinantian Yoredale Formation from the Breagh gas field and onshore Northumberland.

Matthew Booth[1*], John Underhill[1] & Andrew Gardiner[1]

[1]Applied Geoscience Unit, Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh EH14 4AS.
**M.Booth@hw.ac.uk*

The discovery of, and subsequent production from, the Breagh gas field in Quadrant 42 of the Southern North Sea challenges the long-held view that the Lower Carboniferous has limited prospectivity and lends encouragement to exploration efforts in the basin. We have conducted a sedimentological appraisal of over 200 metres of cored material from the Carboniferous Yoredale Formation from 5 wells within the Breagh gas field and integrated this with fieldwork from time-equivalent onshore sections along the Northumberland coast of NE England. Correlative sedimentary logs were constructed from 4 key onshore localities utilising regionally extensive limestone horizons as biomarkers that are also recorded in the Breagh wells. Clastic sandstone packages, which form the main reservoir units in the Breagh field, are encountered both in core and at outcrop and are up to 15 metres thick and typically comprise good quality (high net to gross), medium grained, well sorted and mature quartz arenites often displaying tabular and trough cross bedding and channelised bases. The sediments were eroded from the Caledonian mountains to the North, transported south-westwards and were predominantly deposited in braided fluvial settings, although fining upwards point bars deposited in meandering settings have also been encountered. As well as the onshore and offshore fluvial deposits, the Yoredale Formation also includes mouth bars, interdistributary bay, mire, prodelta, offshore shelf, barrier island and lagoon deposits that represent deposition from fluvio-deltaic processes. The sedimentological characteristics are similar onshore and offshore and are consistent with deposition from river-dominated deltas although wave- and tide-modified features are also locally apparent. Although the studied successions belong to the Yoredale Formation, complete 'Yoredale' cycles are rare and depositional patterns were instead controlled by a complex combination of extensional tectonics (both local and regional), eustatic sea level change, climatically driven sediment flux and regular delta abandonment processes.

Depositional setting of the Namurian Spireslack Sandstone.

MAE Browne[1], R Ellen[1], E Callaghan[1], AJ Mitten[2], **AG Leslie**[1], and SM Clarke[1&2]

[1]*BGS Scotland, Lyell Centre, Research Avenue South, Edinburgh, EH14 4AP, UK.*

[2]*Basin Dynamics Research Group, School of Geography, Geology & the Environment, Keele University, Keele, Staffordshire, ST5 5BG, UK.*

Corresponding author: rellen@bgs.ac.uk

Spireslack surface coal mine, Scotland, exposes possibly the most continuous Mississippian Sub-Period (European stages: latest Viséan – Namurian) section exposed at outcrop in the Scottish Carboniferous. Lateral continuity and variability of Carboniferous strata can be studied here and we use a variety of techniques including digital photogrammetry to produce scaled, photo-realistic, virtual outcrop models derived from major engineered faces in the Spireslack site. These capture sedimentary geometries and facies associations in the Lawmuir Formation (Brigantian) through into the Upper Limestone Formation (Arnsbergian). Taken all together, the new data support a new interpretive insight into the nature of fluvial systems in this part of the Carboniferous stratigraphy of the Midland Valley of Scotland.

We identify for the first time the Spireslack Sandstone, an erosively-based sandstone-dominated unit in the Upper Limestone Formation that comprises two fluvial sandstone bodies, and an upper possibly fluvio-estuarine succession. From an analysis of their architectural elements, we interpret these fluvial sandstone bodies as a low sinuosity, sand-dominated, mixed-load fluvial system deposited in a palaeovalley of significant relief, and possibly responding to base level changes during deposition of the Upper Limestone Formation. This differs from the delta-top fluvial setting commonly attributed to Carboniferous fluvial sandstones, and may provide an analogue for other Carboniferous fluvial sandstone stratigraphical traps.

Alluvial Architecture and Facies Associations of the Price River Formation, Mesaverde Group, Book Cliffs, Utah, U.S.A

Saroni, Justina J.[1], Hartley, Adrian J.[1], Owen, Amanda[2] and Howell, John[1]

[1]*Department of Geology and Petroleum Geology, University of Aberdeen. U.K. jjsaroni@abdn.ac.uk*
[2]*School of Geography and Earth Sciences, University of Glasgow*

Price River Formation is one of a number of Campanian-aged formations within the Mesaverde Group exposed in the Book Cliffs, Utah. This study focuses on alluvial architecture to identify types of channel bodies. Understanding of channel body geometries is useful in describing formation in Distributive Fluvial System (DFS) context.

Seven study locations were visited for documentation of alluvial architectural styles and facies associations. 12 vertical sedimentary sections (total thickness of 1675 m) were completed for facies analysis. Architecture of sandstone bodies was mapped directly from outcrop observations and LiDAR dataset. More than 70 channel bodies have been studied in detail.

Channel and floodplain deposits are the main facies observed within the study area. In-channel lithofacies dominated by cross-stratified, horizontally laminated and massive sandstone. Floodplain deposits are poorly exposed, with the exception of strongly cemented fine-grained sandstone, siltstone and mudstone.

For simple data descriptions, the formation is divided into 3 portions based on channel body geometries and percentage of channel and floodplain deposits. 1) lower portion (~120 m) is dominated by strongly amalgamated channels, the average thickness of channel bodies is 13.5 m. 2) middle portion (~190 m), characterised by channel body with both lateral and vertical stacking storey surfaces, separated by significant floodplain deposit. 3) top portion (~130 m) comprises of isolated channel bodies (thickness <5 m), which reside in a floodplain dominated succession.

The higher degree of thicker amalgamated channel deposits in the lower portion is considered to represent the proximal section of a DFS. Middle and upper portions recording medial and distal DFS respectively as indicated by decreasing in channel amalgamation and connectivity and increased floodplain preservation. A number of controls are discussed as to what the possible causes of this retrograding fluvial system are, including changes in the relationship between basin accommodation space and sediment supply.

Glacigenic reservoirs characterisation using sedimentology, geomorphology and virtual outcrop mapping

Bartosz Kurjanski[1], Brice R. Rea[1], Matteo Spagnolo[1], John A. Howell[1], David G. Cornwell[1]

[1] *School of Geosciences, University of Aberdeen*

Sedimentary packages of ancient glacigenic origin are recognized in numerous locations around the world conditions are often targeted during hydrocarbon exploration efforts(e.g. in Oman, Saudi Arabia, North Africa and Australia).

Recent discoveries of hydrocarbon accumulations made in the North Sea in the Quaternary succession (Aviat and Peon fields) that are clearly of glacigenic origin are presenting new opportunities to unlock additional resources in the easily accessible, Quaternary section. Furthermore new studies show that glacial ice was present in the North Sea Basin as early as MIS 100 (2.52Ma). Direct evidence for grounded ice at MIS 64 (~1.78 Ma) can be found From Aviat field sediments, in core, implicating a thicker glacial or glacially influenced sedimentary package than previously thought, and >1 km thick in places. The repeated high-lowstands characteristic of the glacial-interglacial cycles provide sufficient organic material during lowstands that the North Sea glacigenic section is characterised by numerous small and large gas accumulations which appear to have formed from biogenic sources. As the North Sea becomes an ultra-mature province these shallow gas accumulations, previously viewed as drilling hazards are now being considered as an attractive target for relatively low cost/low risk exploration to both provide fuel for infrastructure and when large enough for full scale production.

This project aims to broaden our knowledge regarding glacigenic sediments and landform distribution in order to assess potential reservoir candidates within glacial sedimentary packages. The study is focused on ice sheet derived sediments due to them having the highest preservation potential and the largest spatial scale of depositional systems. This goal will be achieved by integration of fieldwork involving studies of modern (Pleistocene) analogues in Scotland, Poland and, potentially, ancient outcrops in Oman with satellite imagery of modern glaciated regions (Iceland/Greenland) and high resolution seabed bathymetry (MBES).

The impact of thermal regime on the characteristics of glacial sediments

Alice M. Witherick, Richard I. Waller, Peter G. Knight

School of Geography, Geology and the Environment, Keele University, Keele, Staffordshire, UK, ST5 5BG

a.m.witherick@keele.ac.uk

Knowledge and understanding of glacial sedimentology is crucial within the study of glaciology, to appreciate the intricacies and complexities of the ice-bed interface. Thermal regime plays a part in this, changing the dominant processes that occur subglacially, therefore affecting the characteristics of this sediment. The aims of this study are to produce a comprehensive methodology via the study of contemporary glacial sediment morphology and characteristics, to identify thermal regime using subglacially derived sediment only. This will ultimately be used in the research and reconstruction of palaeo-glacial environments, through the identification of past thermal regimes.

Data from three spatial scales has been collected from two locations, a temperate and non-temperate thermal regime respectively. Published studies of this kind tend to focus in on only the meso scale, so a broader approach gives more clarity and a wider view of subglacially deposited material. With gneiss being the underlying bedrock in both locations, care was taken to isolate thermal regime as the variable most likely to cause changes in subglacial material.

Samples at the micro scale were restricted to quartz and analysed using grain mounts on the SEM, along with chemical analysis and laser sizer studies. The origins of most of the samples were known. Samples at the meso scale were analysed in the field using clast shape and roundness studies, and later calculating C40 and RA values as well as angularity and roundness. The macro scale implemented UAV use, using ArcGIS software to carry out larger scale roundness studies on boulders released from the glaciers.

Using subglacial sediment to infer glacial thermal regime is not currently used in palaeo reconstructions. This study can be used, alone or in tandem with other proxies, to change that.

The impact of freshwater mussels (order Unionoida) on river bed characteristics and sediment flux: A flume-based study.

Andrea Leng[1], Sian Davies-Vollum[2], Andrew Ramsey[3].

[1] Department of Natural Sciences, University of Derby, Derby, UK. A.Leng@derby.ac.uk
[2] Department of Natural Sciences, University of Derby, Derby, UK. S.Davies-Vollum@derby.ac.uk
[3] Department of Natural Sciences, University of Derby, Derby, UK. A.Ramsey@derby.ac.uk

Unionoid mussels are considered keystone species due to their ability to modify and link pelagic, benthic and hyporheic environments in freshwater systems, yet empirical data to determine their influence on river bed dynamics and sediment flux is lacking.

A recirculating flume-based study using the unionoid species *Anodonta anatina* investigated the impact of this species on bedform development and particle flux of a polymodal substrate representative of the grain size distribution of the mussel's habitat. It was found that the presence of *A. anatina* increased the organic content of the substrate through deposition of pseudofaeces, reduced the amount of suspended solids in the water column and reduced near-bed velocities and boundary shear stress. However, despite these impacts, a greater quantity of sediment and a larger range of grainsizes entered the sediment trap compared to the control experiment when mussels were absent from the flume. The impact of mussel bioturbation appears to outweigh any sediment stabilisation effects arising from increased organic content of the substrate and reduced near bed velocities. Additionally, sediment grainsize and depth measurements indicate that the mussels increased the topographic roughness and heterogeneity of the substrate compared with when mussels were absent. Given that freshwater mussels can exist at very high densities within rivers, increased mixing and mobilisation of bedload and transferral of suspended solids from the water to the substrate by mussels implies they constitute a critical element in the sediment dynamics of fluvial systems.

Spatial Variability of Dune and Interdune Facies in the Aeolian Navajo Sandstone, USA

David Cousins[1] and Stuart M. Clarke[2]

[1]*Basin Dynamics Research Group, Geography, Geology and the Environment, Keele University, Keele, Staffordshire, ST5 5BG, d.p.cousins@keele.ac.uk*
[2]*Basin Dynamics Research Group, Geography, Geology and the Environment, Keele University, Keele, Staffordshire, ST5 5BG, s.m.clarke@keele.ac.uk*

The advancement of predictive aeolian facies models is important for hydrocarbon exploration, particularly in mature basins, where subtle stratigraphic traps require the use of sophisticated simulations. The presence and lithological character of interdune elements can produce sedimentological heterogeneities that can potentially partition reservoirs. With this in mind, a detailed, regional-scale study of the aeolian Jurassic Navajo Sandstone of south-western USA was undertaken.

Detailed sedimentary logs, palaeocurrent measurements, architectural panels combined with 3D photogrammetry have been integrated to describe lithofacies distributions and sedimentary architectures from large-scale outcrops in southern Utah, western Colorado and northern Arizona. The outcrops were selected in order to identify the relationships between dune and interdune assemblages in both the central and marginal parts of the erg.

Interdune sedimentary processes within the Navajo were determined by variations in the water table relative to the depositional surface, and we identify a range of wet, damp and dry interdune elements at various scales and throughout the formation. We consider how a series of external factors that collectively define the sediment state of the system may act to dictate spatial changes in dune and interdune morphology, geometry and importantly, their preservation. A 3D depositional model accounting for the complex interactions between wet and dry aeolian environments across the erg is developed.

Preliminary results show interactions that demonstrate spatial patterns in dune-interdune sedimentology that can be related to sediment characteristics observable in core and well-log data. This study builds the foundation on which additional data can be added, with the aim to better predict architectural complexity within reservoirs. This will aid in producing more realistic reservoir simulations than those which could be constructed from limited subsurface data alone.

Down-system partitioning of sediment within CHI-space

P. Wooldridge[1], R. Duller[1], R. Jerrett[2], P. Burgess[1]

[1]*School of Environmental Sciences, University of Liverpool, Liverpool L693GP, UK.*
P.wooldridge@liverpool.ac.uk

[2]*School of Earth and Atmospheric Sciences, University of Manchester, Manchester,* M13 NPL, UK.

Basin scale sedimentary architecture is usually interpreted through a qualitative statement about sediment supply rate versus the rate of accommodation generation, i.e. sediment mass balance. Although conceptually useful, this approach does not offer any robust predictive capability at the architectural level. To address this, a multidisciplinary approach will be used to generate a mass balance model that can be directly applied to field and subsurface fluvial datasets. In detail we will quantify: 1) the existence fields of river system types under different mass-balance scenarios; 2) the partitioning of sediment grain size and facies for each scenario; and 3) the transfer function that describes the likelihood of parts of fluvial systems to be preserved as architecture and facies. Once quantified this will be encapsulated in a simple 'CHI-space' stratigraphic model and then validated, for the first time, against outcrop and subsurface datasets in the Ebro Basin (Spain) and central Appalachian Basin (USA). The simplicity of the model framework means that it can be directly applied to field and subsurface sedimentary systems, even with a limited dataset. It is anticipated that this work will advance our understanding of sedimentary systems and make the critical link between sedimentary surface processes and sedimentary successions.

The interaction of biofilms, sand grains and clay particles in marginal marine environments

Alison Hendry, Sanem Acikalin, Sven Lahme, Cees van der Land and Ian Head

Newcastle University, School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne. NE1 7RU, a.hendry2@newcastle.ac.uk

Complex interactions exist between biological, solid and fluid components of shallow subsurface sediment. These interactions, and their by-products often shape sediment dynamics and the evolution of porosity and permeability during burial and diagenesis. Biofilms have been identified as playing a pivotal role in the development of clay-coated sand grains in intertidal sediments. Biofilm-originated clay-coats potentially represent precursors to chlorite coats identified in deeply buried sandstone reservoirs. Thin chlorite coats prevent the formation of porosity eradicating quartz cement during diagenesis, allowing a higher percentage of primary porosity to be preserved. This may alter conventional approaches to hydrocarbon exploration, as deeply buried, finer grained sandstones with a moderate clay content (in the form of clay-coatings) may have a higher percentage of primary porosity preserved compared to traditionally targeted, coarse grained, clean sandstones. However, the factors controlling the distribution of precursor clay-coats and the exact role biofilms play in the clay-coating process remains poorly constrained. This makes the process of predicting the distribution of chlorite-coated grains in the subsurface largely elusive. This project aims to use an experimental approach, combining fieldwork and laboratory work to improve the understanding of the interaction of biofilms, sand grains and clay particles in marine and marginal marine environments. Biofilm-sediment interactions will be studied at the pore scale using Atomic Force Microscopy (AFM) and Confocal Laser Scanning Microscopy (CLSM). Field data, collected from Ravenglass Estuary (North-west England) and Bute Inlet (Western Canada) will be used alongside controlled laboratory experiments to understand the main controls on the basin scale distribution of biofilms and biofilm-associated clay-coats. The results from this project may improve the understanding of the factors contributing towards the overall distribution of chlorite-coated grains in ancient deeply buried marine and marginal marine sequences.

Interactions between microbes and minerals in microbial mats from the Abu Dhabi coastal sabkha

Kirsten E. Dutton[1], Luiza Lessa Andrade[1], Angela Sherry[1], Stephen Lokier[2], Cees van der Land[1], Ian M. Head[1]

[1] School of Natural and Environmental Sciences, Newcastle University, Newcastle upon Tyne, UK
[2] Department of Geosciences, The Petroleum Institute, Khalifa University of Science & Technology, Abu Dhabi, UAE

Recent microbial mats thrive in the extreme environment of the Abu Dhabi coastal sabkha. Microbial mats develop where extreme aridity and hypersalinity inhibit predation. These biofilms are bound together and to the sediment below by the extracellular polymeric substances (EPS) they secrete. Their fossil counterparts represent the earliest signs of life on earth.

The modern microbial mat system contains steep chemical, mineralogical and microbial gradients vertically on a millimetre scale. Photosynthetic microbes dominate the surface, whilst heterotrophic bacteria, such as sulphate-reducing bacteria, become more prominent below 6mm depth where oxygen availability is substantially reduced. Detailed SEM and XRD analyses has revealed the occurrence of carbonate minerals within the mat structure. These minerals are the result of both abiotic (allogenic and authigenic) and biotic processes i.e. microbially-mediated mineralisation whereby microbes secrete EPS which is progressively replaced by calcium carbonate as it breaks down.

To constrain the boundary conditions for mineral growth (both pathway and rate) within microbial mats, an aquarium study was established under field conditions. Initially, cyanobacteria at the surface quickly recovered from cold storage forming a green layer and the layers below become increasingly anoxic. Vertical growth of the mat was approximately 1mm over 16 weeks, at this point the mat also began to colonise the sand on which it sits. Thermogravimetric analysis (TGA) has shown that mineral mass is greater in the more-established layers where sulphate-reducers reside and XRD analysis indicates minerals within the mat are predominantly calcite and dolomite.

Ancient microbialites can contain significant porosity in the subsurface. Early lithification within the mats is the first step in the pathway of converting a mat into rock. Evidence of such structures has been found in the oil-bearing Arab Formation of the Middle East.

Grain-size analysis in thin sections: Where to start?

Wróblewska, S.M.[1]*, Spychala, Y.T.[1], Eggenhuisen, J.T.[1], Pohl, F.[1] Grundvåg, S.A.[2]

[1] *Department of Earth Science, University of Utrecht, 3584 CS Utrecht, NL*
[2]*Institutt for geovitenskap, University of Tromsø,NATURF 211 Tromsø, NO*
**corresponding author: sara.m.wroblewska@gmail.com*

Grain size and sorting are main rock features controlling depositional sand quality, which govern porosity and permeability of sandstones. The interest in careful and reproducible grain size evaluation has increased over the years. That seemingly easy analysis takes effort and needs to be done sensibly to obtain meaningful and reproducible results. It is crucial to take into account all technical, sedimentary and diagenetic dimensions which are significant in this process. Here, we present the evaluation stage of grain-size analysis for Eocene turbidite sandstones from the Battfjellet Formation, Svalbard, based on thin sections. Eventually, these thin sections will be used to study grain-size partitioning along a shelf to basin floor system.

It is important to take into account sedimentary context and diagenetic factors which have created the observable grain-size distribution in the samples. Palaeoflow direction or compaction for instance can have an impact on grain's long axis orientation and cause biased results according to the cutting of the sample. The apparent grain size can differ significantly between thin sections made from cuts parallel, perpendicular or in an angle to palaeoflow. We will quantify this effect by presenting grain-size distributions from multiple thin sections obtained from single samples cut at various orientations with respect to palaeoflow.

To decide which grain-counting method fits the particular rock samples technical decision has to be made according to the general trend in mineral composition, matrix content and grain-size differences between samples. Due to high diversity in mineral composition and low matrix content in the samples we decided for the manual grid-counting method as the most sufficient technique. This technique can be biased by subjective decisions, a set of rules therefore have to be established in the early stage of this process, to estimate operator error. These factors are essential to guarantee the universality of manual measurements.

Characterisation of organic carbon from source to sink in a river-derived turbidity current system (Bute Inlet, Canada)

Hage, S. [1,2], Acikalin, S.[3], Cartigny, M.[2], Clare, M.[4], Galy, V.[5], Gröcke, D.[6], Hilton, R.[2], Hunt, J.[5], Lintern, G.[7], Parsons, D.[8], Stacey, C.[7], Sumner E.[1], Talling, P.[2], & the Bute Inlet field teams 2016 & 2017

[1] School of Ocean and Earth Sciences, University of Southampton, U.K., sophie.hage@soton.ac.uk
[2]Department of Geography, University of Durham, U. K.
[3] School of Civil Engineering and Geosciences, Newcastle University, U.K
[4]National Oceanography Centre, Southampton, U.K. [5]Woods Hole Oceanographic Institution, MA, U.S.A [6]Department of Earth Sciences, University of Durham, U.K.
[7]Natural Resources Canada, Geological Survey of Canada, BC, Canada
[8]School of Environmental Sciences, University of Hull, U.K.

The burial of terrestrial organic carbon in marine sediments affects atmospheric CO_2 over geological timescales, thereby playing a critical role in long-term climate regulation An increasing number of studies have examined the role of rivers in transporting carbon to the ocean. However, less attention has been paid to the fate of that carbon after it has reached shallow ocean depths. Turbidity currents can carry river-derived sediments further offshore, and thus transport carbon from the shallow submarine environment to the deep ocean. Only a few measurements of active turbidity currents have been made because these powerful flows are notoriously difficult to observe and sample.

This study uses a unique dataset acquired in a turbidity current system called Bute Inlet, an ~80 km long submarine fjord, in British Columbia, Canada, with fjord-head deltas connecting to the watershed. Characterisation of the organic carbon content in a fjord is particularly key since fjords have been highlighted as major 'hot spots' for particulate organic carbon accumulation in marine sediments. We collected sediment samples at multiple locations from: 1) Bute fjord's river sources; 2) along the 40 km-long incised submarine channel which extends to 600 metres of water depth; and 3) at the lobes where the submarine channel terminates.

Here we present preliminary results of geochemical properties (Total Organic Carbon content, $\delta^{13}C$ values and C:N ratios) acquired on samples taken from the turbidity current channel and the distal lobes. These results will be compared with geochemical analyses performed on the sediment collected from the river source locations. Our overall aim is to investigate how turbidity currents distribute and fractionate different types of organic carbon at a fjord site where source to sink locations are constrained in unprecedented high detail.

Examining the link between microlithofacies and organic matter in a marine carbonate mudstone to model source rock deposition in Paratethys

Michael Morton[1], Sarah Davies[1], Stephen Vincent[2], Rachel Flecker[3], Wout Krijgsman[4]

[1]*University of Leicester, UK, mtm11@le.ac.uk*
[2]*CASP, University of Cambridge, UK, stephen.vincent@casp.cam.ac.uk*
[3]*University of Bristol, UK, ggxrf@bristol.ac.uk*
[4]*Utrecht University, the Netherlands, W.Krijgsman@uu.nl*

Outcrops on the Belaya River, on the northern side of the Caucasus in south-west Russia, expose a Paleogene to early Neogene succession. This includes two organic rich units, the Kuma Formation (Eocene) and the Maykop Series (Oligocene – Early Miocene). It is the type locality for the latter. These units form potential and proven source rocks for regional hydrocarbon reserves and are excellent analogues for age-equivalent strata in the Black Sea. It is hypothesised that the preservation of organic matter in these units occurred due to the episodic restriction of the marginal sea in which they were deposited (Paratethys), as a result of the collision of Africa and Arabia with Eurasia.

Sedimentary logging, and sampling (approximately every 50 cm) through 250 m of stratigraphy has been completed along the Belaya River. RockEval pyrolysis was conducted on the Eocene portion (Kuma Formation) of these samples. The Kuma Formation is characterised by total organic carbon (TOC) values of 1-5.5% over approximately 43 m. Detailed thin section analysis reveals a range of microlithofacies with a variety of characteristics. Examples of these are abundant well-preserved foraminifera (gradually decreasing up formation), variable types of bioturbation, occasional truncated or laterally variant laminae, and evidence of currents e.g., erosive surfaces and fragmented faunal assemblages. Facies with a dark fine-grained matrix interlaminated with concentrations of organic matter have higher TOC values than samples with a lighter matrix with not as apparent organic matter. Similarly, foraminifera and bioturbation are common in facies that exhibit lower TOC.

The characterisation of these organic-rich mudstones, correlated with their foraminiferal biostratigraphy will provide new insights, specifically, into the hydrocarbon prospectivity of the Black Sea basin, as well as, more generally, into the processes and controls on source rock development in marginal marine settings in tectonically active regions.

Testing Popular Methods of Quantifying Sediment Flux in Source-to-Sink Analysis of Ancient Sediment Routing Systems

Chris J Brewer[1], Gary J. Hampson[1], Alex C Whittaker[1], Gareth G. Roberts[1]

[1] *Department of Earth Science and Engineering, Imperial College London, London, UK.*

It is generally accepted that changes in geometries of drainage networks (e.g. relief, upstream area) and climatic variables (e.g. precipitation) determine histories of sedimentary flux to depositional basins. Here, four well known methodologies are tested whilst utilising a myriad of input data: (1) the empirical BQART model uses values of drainage basin area, relief, temperature, lithology and water discharge (Syvitski & Milliman, 2007), and has been widely applied to modern systems; (2) empirical scaling relationships between characteristic geomorphological parameters of system segments have been developed for modern systems and applied to seismically imaged ancient systems (Sømme et al., 2009); (3) the "fulcrum" model uses the palaeohydrological parameters of trunk river channels to estimate downsystem sediment discharge (Holbrook & Wanas, 2014); and (4) characterisation of downsystem-fining trends in grain size, within the context of mapped stratigraphic volumes can be used to estimate sediment flux (e.g. Michael et al., 2014).

These four methods are tested using a compilation of published literature for the Eocene Escanilla sediment routing system, which was developed in the South Pyrenees wedge-top basin and is well exposed and preserved over most of its extent. Methods based on geomorphological-segment scaling relationships, downsystem-fining trends and the "fulcrum" model all give best estimates of sediment flux that lie within the same order of magnitude (1100±1400, 1100±1700 and 720±60 Mt/Myr, respectively), and there is overlap between all three flux estimates once potential errors have been incorporated. The BQART model is highly sensitive to values selected for drainage-basin relief and climate parameters, and in its original form gives estimated sediment flux values that are 2-3 orders of magnitude greater than the other methods. This comparative analysis is a useful indicator of the sensitivities of the four estimation methods and which data types are required to use them effectively in the stratigraphic record

As Clear as Mud: Removing the Irony from the Idiom

Organic matter Young's modulus variability in shale reservoirs

Thomas D. Fender[1], Cees van der Land[1], Mohamed Rouainia[2], Thomas Wagner[3]

[1] *Newcastle University, School of Natural and Environmental Sciences*

[2] *Newcastle University, School of Engineering*

[3] *Heriot-Watt University, The Lyell Centre*

The mechanical behaviour of shales is controlled by the elastic properties of both their inorganic and organic components. The application of mechanical testing techniques is challenging due to the micrometer size of individual components. Additionally, the initial composition of organic matter and different degrees of diagenesis and catagenesis change its physical and mechanical properties. Here we present the initial results of a study into the organic matter Young's modulus in shales from different depositional environments and maturities. Young's modulus is a measurement of the elastic property of a material.

The recent application of Atomic Force Microscopy (AFM) to geosciences enables in-depth analysis of features less 1 m in size. Combining AFM with quantitative imaging techniques allows the measurement of mechanical properties in a non-destructive manner at a resolution of less 100nm. A tip of known Young's modulus is oscillated onto a sample with a similar modulus, the attractive and the force required to displace the surface by 1-2nm is recorded. The gradient of force-displacement curve is used to calculate Young's modulus.

AFM quantitative imaging is to be used on five reservoir shales; the Green River Shale- (Type I kerogen) playa lake deposits, the Tarfaya Oil Shale- (Type II/IIS kerogen) carbonate rich deposits from the continental shelf during oceanic anoxic event (OAE) 2, the Eagle Ford Shale- (Type II kerogen) carbonate rich deposits from an epicontinental sea, the Barnett Shale (Type II/III kerogen) silica rich deposits in an epicontinental sea and the Bowland Shale- (Type II/III kerogen) epicontinental sea deposits with significant terrestrial deposition. The Tarfaya and Eagle Ford shales were deposited in paleo-shelf environments during OAE2, are carbonate rich and thus may exhibit mechanical similarities. Likewise, the Bowland and Barnett shales are of similar age, maturity and both contain significant proportions of type III organic matter, again suggesting similar mechanical properties.

Depositional processes and multi-scale variability within the mudstone-dominated early Jurassic mudstones, Cleveland Basin, UK

Algundor,Neveen *; Taylor,Kevin G.*

School of Earth, and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK

The effectiveness of production from shale reservoirs depends on the understanding of the variability of the characteristics in such reservoirs, including organic carbon content, mineralogy, mircro-texture, porosity and permeability. This study aims to understand the vertical and lateral variability in the early Jurassic shales of Cleveland basin and which sedimentological, depositional and diagenetic processes are responsible for this variation. This study is using data from previously undescribed core from the Cleveland basin, UK. , as well as outcrops on the Yorkshire coast. Detailed lithofacies characteristics have been defined using optical microscopy, high resolution SEM images, and characterised for composition by TOC and XRD analysis. Eight mudstone lithfacies have been identified in the examined Grey Shales and the Mulgrave shale Member in the Felxikirk and Brown Moor Boreholes: (A) Homogeneous, argillaceous-siliceous, fine to medium mudstone, (B)Ripple-Laminated, argillaceous- siliceous, fine to medium mudstone, (C) Diagenetic detritus-derived, argillaceous – calcareous, fine to medium mudstone, (D)Silt-rich, argillaceous, fine mudstone, (E)Algal-macerals bearing, normal-graded, Carbonaceous, fine mudstone, (F)Homogeneous, argillaceous-calcareous, medium to coarse mudstone, (G)Homogeneous, calcareous, fine mudstone, (H)Fracture rich, argillaceous, fine to medium mudstone. At millimetre to centimetre-scale, these facies include fine, medium, and coarse mudstones that are composed of different proportions of argillaceous, calcareous, and siliceous minerals whose depositional fabrics have been variably affected by burrowing and diagenesis. These mudstones contain significant quantities of total organic carbon (from 1.3% to 8.9%), and cements (including kaolinite, illite, calcite and dolomite). Many diagenetic features are recognized within these rocks and include clay and carbonate cement as well as the development of pyrite framboids associated with organic matter. Overall, we interpret these mudstones to have been deposited in a shallow, high energy shelfal environment, with much evidence for dynamic sediment transport. Presence of sedimentary structures such as normally-graded beds, ripples, and pelleted fabrics indicate significant variability in processes responsible for sediment dispersal and deposition.

The Afterlife of Sediments – Diagenesis and Fluid-Rock Interactions

Textural and Diagenetic Controls on Pore Systems in the Cretaceous Eagle Ford Formation

Ilaria Gaiani[1], Andrew C. Aplin[1], Chris Greenwell[1], Pablo Cubillas[1] and Ruarri J. Day-Stirrat[2]

[1]Department of Earth Sciences, Durham University, UK
[2] Shell International E&P Inc., USA, Houston, US
ilaria.gaiani@durham.ac.uk

Quantifying the pore systems of fine-grained reservoirs is hugely challenging due not only to their extensive textural and mineralogical heterogeneity but also the sub-nanometer to micrometer size of pores. Definition of the reservoir storage and flow system, which underpins effective production, thus requires a very detailed, quantitative understanding of the porosity system and its relationship with rock texture. This work focuses on the Cretaceous Eagle Ford formation, an organic-rich marl that trends across Texas and which produces around 1 million barrels of oil and 4 bcf of gas per day. In order to understand the nature and evolution of the pore system, we have analysed a set of 46 samples from outcrops and six different wells with maturities of 0.4%, 0.8% and 1.2% Ro. XRD, transmitted and reflected light optical microscopy, EDX and SEM techniques have been used to reconstruct the mineralogical and textural framework in which the porosities occur. Carbonate contents range from 37 to 84% and TOC values from 0.5 to 7.9%. Petrographic studies show that the organic matter is mainly marine type II and that microfacies vary from finely laminated marls to fossiliferous limestones. The paragenesis of the samples, in particular the diagenesis of carbonate and the generation and micromigration of organic phases, has been determined with BSEM and SEM-EDX. MicroCT of mm-size cores, calibrated with high resolution FIB-SEM, has identified the occurrence and connectivity of the main textural domains (organic matter and porosity, microfossiliferous material, fine-grained argillaceous/carbonate matrix and pyrite), and the nature of the pore system in each domain. In the low maturity samples, the main porosity types are interparticle, enclosed within the argillaceous and coccolithic matrix, whereas in most of the mature samples the pores present a more spherical shape, suggesting that they are mainly situated within the migrated and in-situ OM. Pore systems have been characterised using a combination of high resolution SEM, mercury injection porosimetry and N_2 and CO_2 sorption. Pore sizes, calculated by analysing and combining data between SEM images and gas adsorption, appear to have a bimodal distribution with modes around 10-20 nm and 50-200 nm. Current work, using ESEM, AFM and nano-IR, is focussed on understanding the chemical interaction between the fluids and pore surfaces.

The Lower Cretaceous of the North and South Celtic Seas: Reservoir quality potential

Stephan Stricker, Stuart Jones, Jack Lee and Jonathan Imber

Department of Earth Sciences, Durham University, Durham, DH1 3LE, UK

The UK's Oil & Gas Authority (OGA) is funding the NAWAB – New Appraisal of the Western Approaches Basins post-doctoral research project as part of its Frontier Basin Research programme. The aim of the project is to evaluate the tectonostratigraphic evolution of the SW Approaches and Celtic Sea regions, to better understand their hydrocarbon potential. A cross-border, "geology without frontiers" philosophy underpins NAWAB research. One aspect of NAWAB has been to evaluate the reservoir potential of the Lower Cretaceous in the Western Approaches basins and South Celtic Sea basin, by integrating borehole data from UK, Irish and French waters with a newly acquired 2D seismic data package and published geological knowledge.

The Lower Cretaceous deposits of the North Celtic Sea area are dominated by continental-clastic sediments which yielded several productive Greensand hydrocarbon fields, such as Kinsale Head, Ballycotton and Seven Heads. The Lower Cretaceous sandstones (Greensand and Wealden Formation) of the North Celtic Sea show porosities of around 20% and permeability of ~500-5000 mD (Winn, 1994; O'Sullivan, 2001). In comparison the Bristol Channel and South Celtic Sea Basins UK are less developed with only 12 commercial wells drilled to date with reported hydrocarbon shows from several of the wells. The prograding shallow marine and deltaic Lower Cretaceous sandstones are recognised to be of similar facies between the Irish and UK sectors. However, newly acquired 2D seismics indicates significantly thinner Lower Cretaceous sandstones but where it has been identified and cored excellent reservoir quality of up to 25% porosity and permeability of over 7500 mD is identified in the South Celtic Sea.

The Lower Cretaceous sediments of the South Celtic Sea Basin, UK offer the possibility of new reservoir targets for exploration in the region and provide excellent reservoir quality with high porosity and permeability.

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Depositional Controls on Clay Minerals and the Impact on Reservoir Quality

Claire McGhee[1], Sanem Acikalin, Richard Worden[2], Cees Van der Land[1]

1 School of Natural and Environmental Sciences, Newcastle University, UK
2 School of Environmental Sciences, Liverpool University, UK

The presence of clay minerals strongly influence the physical and chemical properties of a conventional sandstone reservoir thus, are important in assessing recoverable hydrocarbons. Reservoir quality is a key control on prospectivity and field development during petroleum exploration and production. Porosity and permeability are important parameters which determine the economic value and development plans for all oil and gas fields. These pore-scale attributes are initially controlled by depositional and diagenetic processes that commonly act together to determine final reservoir qualities. The presence of clay minerals in sandstone reservoirs is generally described to have a negative impact on reservoir quality by blocking pore throats and decreasing poroperm. However, grain coating chlorites are able to preserve porosity by reducing precipitation of authigenic quartz cementation and retaining much of the original depositional porosity to significant burial depths. Understanding the controls of detrital precursor clay minerals responsible for chlorite coats is fundamental for assessing and predicting reservoir quality.

This project aims to bridge the gap between pore-scale observations and wide scale sedimentary processes to form a complete picture of the early developments within a sandstone reservoir. This will be investigated by assessing the depositional controls on different clay minerals present in the modern Ravenglass Estuary in Cumbria, England, the Bute Inlet turbidity system, Canada and the intensely studied Cretaceous deltaic successions of Utah, U.S.A. Fieldwork will include core and outcrop logging, correlation, process interpretation and extensive sampling. Sandstone petrography, SEM, XRD and QEMSCAN will be used to define textural properties, grain composition and diagenetic phases to allow for better reservoir characterisation and predictability. Using these combined methods will allow for a diverse approach to understanding the relationship between depositional processes and early diagenetic pathways that dictate early reservoir qualities at various scales in order to further understand this broad area of research.

Hydrocarbon potential of the Variscan basement, SW Approaches and Celtic Sea regions, UK

Stuart Jones[1], Bob Holdsworth[1], Stephan Stricker[1], Jack Lee[1], Susie Daniels[2] and Jonathan Imber[1]

[1] *Department of Earth Sciences, Durham University, DH1 3LE, UK*

[2] *Geospatial Research Ltd., Durham, DH1 4EL, UK*

The Variscan Front and Bristol Channel-Bray Fault (BCBF) appear to be key controls on the hydrocarbon potential of the Variscan basement. The former defines the northern limit of penetrative, Variscan deformation, whilst the latter is inferred to have been a dextral strike-slip fault, which was active during and after the Silesian and separates the Culm Basin from the South Wales Coalfield. Isotopic and trace element data indicate that the Culm Basin and South Wales Coalfield had distinct source areas during the Westphalian, consistent with significant separation of the two basins across the BCBF at this time. The Culm Basin contains Namurian-Westphalian sandstones, black shales and thin coals. Vitrinite reflectance data from North Devon suggest that the shales and coals locally retain gas generation potential. Gravity data, recently compiled by Getech as part of the OGA's 21st Century Exploration Roadmap Project, suggest that the Culm Basin extends westwards towards the South Celtic Sea Basin. Here, Irish and UK wells 58/3-1 and 93/6-1 penetrate possible Westphalian strata. Both wells displayed an increase in background gas (predominantly methane) within the Carboniferous section; gas was also noted in the overlying Triassic (Mercia Mudstone?) within 93/6-1.

The main risks associated with any Carboniferous-sourced gas play in the South Celtic Sea region are: 1) the uncertain thickness and extent of Westphalian black shales and coals; 2) the challenge locating basement domains with limited Variscan metamorphic overprint; and 3) the critical timing between post-Varsican thermal maturation and regional reservoir trap and seal development. Intra- Carboniferous reservoirs may exist, but are likely to be highly deformed and structurally complex. By contrast, Westphalian strata to the north of the BCBF and Variscan Front are likely to be significantly less deformed, and may share affinities with classic "Coal Measures" facies in South Wales and northern England, and gas prone sequences encountered in the East Irish Sea. In conclusion, the hydrocarbon prospectivity of potential Carboniferous, or Carboniferous-sourced, plays is likely to be greater to the north of the Variscan Front and BCBF than in the region to the south.

Dolomitisation through geothermal convection of seawater driven by active syn-rift volcanism: Derbyshire Platform, Lower Carboniferous, UK

C.Breislin[1], C.Hollis[1], V.Banks[2], A.Juerges[3] J.Marshall[4], I.Millar[2], J.Riding[2]

[1] *The University of Manchester, Williamson Building, catherine.breislin@manchester.ac.uk*

[2] *British Geological Survey, Keyworth*

[3] *Shell International Exploration and Production, Amsterdam*

[4] *University of Liverpool, Herdman Building*

It is often difficult to unequivocally identify the source of fluids and Mg^{2+} to explain the volume of in-place dolomite. Fault-controlled dolomitisation has been well studied and described in Lower Carboniferous (Visean) platform carbonates at various localities in the Pennine Basin and North Wales. The largest of these bodies (>60km^2) occurs on the Derbyshire Platform, on the southern margin of the Pennine Basin. Current models indicate that sufficient volumes of fluid for dolomitisation could have been supplied along faults from the juxtaposed basinal sediments, but these fluids contained insufficient Mg. Reactive transport models show dolomitization could have occurred by geothermal convection of seawater along faults during platform growth.

This study aimed to determine if field and petrographical evidence supported these two separate dolomitisation events a) from seawater during platform growth and b) from evolved basinal brines during basin dewatering. This presentation focuses on the evidence for dolomitization from seawater, based on petrographical, stable isotopic and trace element proxies. Results show that dolostone formed of planar, fabric-retentive dolomite with single-phase (ie. low temperature) fluid inclusions formed along NW-SE and E-W orientated faults, occurring only within coarse-grained, platform margin facies and in proximity to the Matlock Igneous centre. Oxygen isotope data is consistent with dolomitization from seawater ($\delta^{18}O$ dolostone = -4 to -2‰), but that $\delta^{13}C$ values (-4 to -1‰) are lighter than penecontemporaneous seawater (determined by $\delta^{13}C_{\text{unaltered brachiopods}}$ =+2‰).

In conclusion, dolomitization appears to have been initiated on the Derbyshire Platform by the coincidence of fault-controlled topographic relief and syn-depositional volcanism. It is proposed that isotopic depletion relative to seawater is the result of dolomitisation from a mixture of seawater and magmatic (CO_2) geothermal fluids. This first phase of dolomitization then formed a template, controlling the geometry and positioning of subsequent phases of fault- controlled dolomitization in the burial realm.

A general model for the helical structure of geophysical flows in channel bends

Maria Azpiroz-Zabala[1-2], Matthieu J.B. Cartigny[3], Esther J. Sumner[2], Peter J. Talling[3], Daniel R. Parsons[4], Michael A. Clare[1] and Cortis Cooper[5]

1 National Oceanography Centre, Southampton, European Way, Southampton SO14 3ZH, UK
2 Ocean and Earth Science, University of Southampton, SO14 3ZH, UK.
3 Department of Geography, Durham University, Lower Mountjoy South Road, Durham, DH1 3LE, UK
4 Department of Geography, Environment and Earth Sciences, University of Hull, Cottingham Road, Hull, HU6 7RX, UK
5 (former) Chevron Energy Technology Company, 6001 Bollinger Canyon Road, San Ramon, CA 94583, USA

Meandering channels host geophysical flows that form the most extensive sediment transport systems on Earth (i.e. rivers and submarine channels). Measurements of helical flow structures in bends have been key to understanding sediment transport in rivers. Turbidity currents differ from rivers in both density and velocity profiles. These differences, and the lack of field measurements of turbidity currents, have led to multiple models for their helical flow. Here we present the first measurements of helical flows from turbidity currents in the ocean. These ten flows lasted between one and ten days, were up to ~80-metres thick, and displayed a consistent helical structure. This structure comprised two vertically-stacked cells, with the bottom cell rotating with the opposite direction to helical flow in rivers. Furthermore, we propose a general model that predicts the range of helical flow structures observed in rivers, estuaries and turbidity currents based on their density stratification.

Effect of bed roughness on the mobility of sediment gravity flows

Serena L. Teasdale[1a], Jaco H. Baas[1], Megan L. Baker[1], Jonathan Malarkey[1]

[1] School of Ocean Sciences, Bangor University, Menai Bridge, Isle of Anglesey, LL59 5AB, UK, serenateasdale@hotmail.com
[a] now at: Geography and Geology, School of Environmental Sciences, University of Hull, Cottingham Road, Kingston - Upon - Hull, HU6 7RX, UK

Novel flume experiments offer a unique insight into the importance of bed roughness for the mobility of sediment gravity flows (SGFs). Turbulence production and bed friction were found to compete in controlling flow mobility. Hyperpycnal plumes are bottom-hugging SGFs that are crucial drivers for sediment transport from rivers into lakes and oceans. Recent laboratory studies have shown the importance of clay type and concentration for the behaviour of SGFs (Baker *et al.,* in press, J. Sed. Res.). However, the importance of bed roughness, such as in the Mississippi River Delta, has rarely been considered. Lock-exchange experiments were conducted to investigate how the head velocity and runout distance (ROD) of clay-laden SGFs vary with five different grain-related roughness types: smooth, sand, fine gravel, coarse gravel, and artificial grass. The results demonstrate a complex relationship between bed roughness and flow mobility, where head velocity and ROD generally decreased from smooth bed via sand to grass, but were anomalously large for fine gravel. We infer that increasing the vertical length scale of the roughness elements initially increased SGF mobility, because higher turbulence production delayed suspension settling, thus outcompeting higher bed friction, especially for the fine gravel. The large roughness for the coarse gravel, and especially the grass, caused the bed friction to effect the flow mobility more effectively, resulting in lower head velocities and RODs. Capture of clay between the grass blades may have further promoted flow deceleration, resulting in short RODs. In summary, bed roughness influences SGF mobility through the competition between turbulent and frictional forces, where a rougher bed does not necessarily result in a slower flow. This outcome may have important implications for the areal distribution of sediment by SGFs in the marine environment, and eventually for the 3D architecture of sedimentary sequences in prodeltas and submarine fans.

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