# From River
***to***
# Rock Record

***The preservation of fluvial sediments and their subsequent preservation***

**12-14 January 2009**

**Department of Geology & Petroleum Geology**
**University of Aberdeen, Scotland**

# Programme and Abstracts

**Edited by Stephanie Davidson & Sophie Leleu**

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**Thanks also go to:**

**Jennie Dick**
**Barry Fulton**
**Jim Marr**
**Sheila McKay**
**Gill Reid**

# Technical Programme – Talks

## Tuesday 13th January 2009

### Venue: Geology Department, Meston 1

**8.00 – 8.10 Stephanie Davidson on behalf of convenors:** Welcome and opening remarks

| *Session 1: An examination of the problems involved in transferring modern geomorphological knowledge to the sedimentary record, or "What not to do"!* **Chaired by Gary Nichols** | |
|---|---|
| **8.10** | **KEYNOTE: Frank Ethridge**<br>Variability in modern alluvial rivers: is this variability recognized in ancient river deposits? |
| **8.50** | **Greg Sambrook Smith** et al.<br>Which present is the key to the past? : new insights from the South Saskatchewan River, Canada, concerning flood magnitude, preservation potential and the resultant sedimentary architecture. |
| **9.10** | **Stephen Tooth** et al.<br>Fluvial process-product linkages in the wetlands of the Okavango Delta, Botswana: can we recognize these in the geological record? |
| **9.30** | **Darrel Long**<br>Architecture and depositional style of fluvial systems before land plants: a comparison of Precambrian and Modern river deposits. |
| **9.50** | **Stephen Hasiotis**<br>Ichnopedologic characteristics of fluvial and floodplain deposits: A comparison of modern and ancient deposits. |

*10.10 – 10.40 Coffee/ Tea and POSTER SESSION (Room 118)*

| ***Session 2:** What is preserved in the rock record? Implications for reconstructing fluvial architecture.* ***Chaired by Phil Ashworth*** | |
|---|---|
| **10.40** | **KEYNOTE: Martin Gibling**<br>Estimating width and thickness of fluvial channel bodies: a pragmatic approach from the rock record. |
| **11.10** | **Russell Dubiel**<br>Facies Complexity in a Continental System – The Upper Triassic Chinle Formation, Colorado Plateau, U.S.A. |
| **11.30** | **Alexander Whittaker** et al.<br>Where does sediment come from? Characterising the links between catchment erosion, sediment export and deposition in tectonically perturbed landscapes. |
| **11.50** | **Pathasarathi Ghosh** & S. Sarkar<br>Pedologic and sedimentologic criteria for recognition of floodplain sub-environments in a Triassic anabranching river deposit. |
| **12.10** | **Brian Williams** et al.<br>Pedogenic and non-pedogenic calcretes in the Devonian Ridgeway Conglomerate |

| | |
|---|---|
| | Formation of SW Wales, UK: a cautionary tale. |

***12.30 – 12.40 End of morning sessions: Discussion***

12.40 – 13.40 LUNCH

| ***Session 3:*** *What lessons can we learn from modern processes? How do we work back to the rock record?* ***Chaired by Stephen Tooth*** | |
|---|---|
| **13.40** | **KEYNOTE: Gary Weissmann** et al.<br>The Distributary Fluvial System (DFS) Paradigm: Re-evaluating Fluvial Facies Models Based on Observations From Modern Continental Sedimentary Basins. |
| **14.10** | **Adrian Hartley** et al.<br>Distributary Fluvial Systems: Characteristics, Distribution and Controls on Development |
| **14.30** | **Gary Nichols** et al.<br>Sandstone body architecture in ancient distributary fluvial systems |
| **14.50** | **Phil Ashworth** et al.<br>The dynamics and deposits of a big river: the Rio Paraná, Argentina. |
| **15.10** | **Marianne Sandstrom** et al**.**<br>Developing a new classification scheme for mud-rich facies in drylands,<br>Lake Eyre, central Australia. |

*15.30 – 15.50 Coffee/ Tea*

| ***Session 4:*** *Complicated fluvial architecture with a consideration of the autogenic and allogenic controls. The influence of medium-term processes on fluvial sedimentary architecture.* ***Chaired by Gary Hampson*** | |
|---|---|
| **15.50** | **KEYNOTE: John Holbrook**<br>A persisting preference for progressive piling:  Rock vs. river biases in the medium-term processes and architectural complexity of channel-belt stacking. |
| **16.20** | **Annamária Nádor** & Á. Tóth-Makk<br>Correlation of large scale sedimentary cycles: controls on sediment supply and storage in the Pannonian Basin, Hungary |
| **16.40** | **John Fisher** & J. Hamer<br>Evaluating the sedimentary response to climatic forces; an integrated approach from the Oligo-Miocene Huesca Fluvial Distributary System, Ebro Basin, Spain. |
| **17.00** | **Esther Stouthamer** & M. Gouw<br>Avulsion and its implications for fluvio-deltaic stratigraphy |
| **17.20** | **Marinus Donselaar** & I.Overeem<br>Gradual avulsion in the rock record: Outcrop example of the Huesca Fluvial Fan |

***17.40 – 17.50 End of afternoon sessions: Discussion***

18.00 – 19.30 Wine reception and POSTER SESSION (Room 118)

19.30 – 22.00 Conference dinner (King's College)

# Technical Programme – Talks

## Wednesday 14th January 2009

### Venue: Geology Department, Meston 1

| *Session 5: Sequence stratigraphy and the interaction between fluvial and non marine sequences. The influence of long-term processes on fluvial sedimentary architecture.* ***Chaired by Adrian Hartley*** | |
|---|---|
| **8.00** | **KEYNOTE: Ron Steel** & C. Gomez<br>Cretaceous Shoreline-Attached Fluvial Systems within Source-to-Sink Transects |
| **8.30** | **Gary Hampson** et al.<br>Controls on sandbody distribution and stratigraphic architecture in coastal-plain strata, Blackhawk Formation, Wasatch Plateau, Utah |
| **8.50** | **Peter Flaig** et al.<br>Alluvial architecture and fluvial facies of tidally influenced alluvial/delta plain deposits of the Late Cretaceous Prince Creek Formation: Colville Basin, North Slope, Alaska |
| **9.10** | **Giovanni Monegato** & C. Stefani<br>Stratigraphy and evolution of the long-lived Tagliamento fluvial system in the southeastern Alps (NE Italy). |
| **9.30** | **Rafat Zaki**<br>Fluvio-marine facies characteristics of the Quaternary rift Sediments between Wadi Um Gheig and Wadi Assal, South Quseir, North Red Sea Coast, Egypt. |

*9.50 – 10.30 Coffee/ Tea*

| *Session 6: The interaction of sediment and water in affecting incision or aggradation. The influence of short-term processes on fluvial sedimentary architecture.* ***Chaired by Raymond Eilertsen*** | |
|---|---|
| **10.30** | **KEYNOTE: Suzanne Leclair**<br>Revising assumptions about short-term hydrosedimentary processes and the preservation of river dune deposits. |
| **11.00** | **Marco Mancini** et al.<br>Allogenic and autogenic controls on the upper Pleistocene-Holocene fluvial deposits of the Tevere River, Roma, Italy. |
| **11.20** | **Kim Cohen** et al.<br>Full Holocene Storage Budget of the Rhine-Delta Sediment Trap |
| **11.40** | **Peter Clift** et al.<br>Drainage Reorganization and Erosional Changes in the Holocene of the Indus River under the Influence of a Variable Monsoon. |

***12.00 – 12.10 End of morning session: discussion***

12.10 – 13.20 LUNCH (provided) and POSTER SESSION (Room 118)

| ***Session 7:** Modelling river deposits and the petrophysical implications.* ***Chaired by Isabelle Cojan*** | |
|---|---|
| **13.20** | **KEYNOTE: Penny Patterson**<br>Alluvial Hierarchy: Description of Alluvial Strata in the Rock Record |
| **13.50** | **Christopher Saville** et al.<br>The morphology of fluvial systems draining orogenic plateaux. |
| **14.10** | **Robert Duller** et al.<br>The response of the longitudinal grain-size profile to the spatial distribution of tectonic subsidence: an integrated model and field investigation. |
| **14.30** | **Faisal Alqahtani** et al.<br>Fluvial Depositional Systems in the Malay Basin: Reconstructing Pliocene-Quaternary Rivers on the Sunda Shelf Using 3D Seismic Data. |

*14.50 – 15.10 Coffee/ Tea*

| ***Session 8:** The problems involved in interpreting fluvial reservoirs* ***Chaired by John Fisher*** | |
|---|---|
| **15.10** | **KEYNOTE: Jean-Loup Rubino & Richard Labourdette**<br>The problems involved in interpreting fluvial reservoirs: bridging the gap between sedimentologists and reservoir engineers. |
| **15.40** | **Tobias Payenberg** et al.<br>Causes of lateral and vertical facies variability in fluvial successions and their implications for exploration, appraisal and development of fluvial reservoirs. |
| **16.00** | **Derald Smith**<br>Counter Point Bar Deposit Lithofacies Model and Reservoir Significance in Meandering Rivers, Alberta, Canada. |
| **16.20** | **Tom McKie**<br>Dryland terminal fluvial reservoir architecture, Triassic Skagerrak Formation, UKCS. |
| **16.40** | **Stuart Archer** et al.<br>Reservoir characterisation challenges in the Jasmine Field of the CNS, UKCS. |

***17.00 – 17.15 End of afternoon session: discussion***

**17.15 – 17.45 Open Forum discussion: end of conference summary and way forward**

# Technical Programme – Posters

### Venue: Geology Department, Room 118

**Neal Alexandrowicz** & John Holbrook
Turning Barriers into Baffles: Fluvial Migration Processes within a Belt and the Potential for Amalgamation of Fluvial Deposits.

**Kathryn J. Amos**, Stephen T. Hasiotis, Carmen B.E. Krapf, Rachel A. Nanson, Jennifer L. Morris, Marianne L. Sandstrom, Joanna Morris
New observations from the Channel Country of central Australia.

Stephen A. Cain & **Nigel P. Mountney**
Sediment supply and accommodation as controls on fluvial behaviour and style of preservation in an ephemeral fluvial succession: the Permian Organ Rock Formation, SE Utah, USA.

**Isabelle Cojan,** J. Rivoirard & D. Renard
From outcrop to process-based reservoir modelling of fluvial meandering systems
The key issue of parameter choice.

**Stephanie K. Davidson** & Colin North
Modern analogues for ancient rivers: using regional curves to identify appropriate drainage area and hydrophysiographic region

**Stephanie K. Davidson**, Adrian Hartley and Gary Weissmann
Distributary fluvial system terminations in drylands : facies characterisation in cratonic and foreland basins

**Raymond S. Eilertsen** & Geoffrey D. Corner
The role of scouring in producing thick fluvial sequences; examples from a Holocene forced regressive river system and a present-day lake delta distributary.

**Brady Z. Foreman** & Paul Heller
Fluvial response to climate change at the 100 kyr timescale: A case study during the Paleocene-Eocene Thermal Maximum in the Clarks Fork Basin, NW Wyoming, U.S.A.

**N. (Nathanaël) Geleynse,** H.R.A.(Bert) Jagers, M.J.F.(Marcel) Stive, J.E.A.(Joep) Storms, D.J.R.(Dirk-Jan) Walstra & A.J.F.(Ad) van der Spek
Physics-based numerical modelling of a river-delta system.

**Jean-François Ghienne**, Julien Moreau, Flavia Girard & Jean-Loup Rubino
Upper Ordovician fluvio-glacial architectures and facies suites, from outbursts to estuaries.

**Massimiliano Ghinassi**
Chute channels and meander cutoff in the Holocene deposits of the Florence alluvial plain (Italy).

**Martin R. Gibling**, R. Sinha, S.K. Tandon & M. Jain
Monsoon-generated fluvial sequences: Climatic control on alluvial architecture in the Himalayan Foreland Basin of India during the late Quaternary.

**Flavia Girard,** Jean-François Ghienne, Julien Moreau & Jean-Loup Rubino
Anatomy of Late Ordovician channels into a fluvio-glacial outburst-related delta plain.

**Marc J.P. Gouw**
Alluvial architecture of two Holocene fluvio-deltaic sequences: the Rhine-Meuse delta (The Netherlands) and the lower Mississippi valley (USA).

**Margaret J. Guccione**
Variability of abandoned channel fills and the effect on sandstone connectivity.

**Stephen T. Hasiotis,** R. Bruce Ainsworth, Kathryn J. Amos, Boyan K. Vakerelov, Carmen B.E. Krapf, Marianne L. Sandstrom & Simon Lang
Continental traces in tidal deposits in an intracratonic playa lake: An example of how sedimentary facies might sway ichnologic interpretations.

**Anne-Edwige Held** & Isabelle Cojan
Paleohydrology: A tool for restitution of catchment area and climatic fluctuations. Case study from the Oligocene of South-eastern France.

**Jens Hornung** & Lutz Reinhardt
From Outcrop to Subsurface: An Analogue Study of a Terminal Alluvial Plain (Upper Triassic, Keuper, SW-Germany).

**Jens Hornung**, Rahman Ashraf , Li Jie , Miao Yuyan, Matthias Hinderer, Sun Ge & Volker Mosbrugger
Coal seams, coarse grained channels and lacustrine river mouths: A lesson in alluvial depositional dynamics (Junggar-Basin, NW-China, Upper Triassic).

**Daniel P. Le Heron**, M.M. Buslov, C. Davies, K. Richards & I. Safonova
Jurassic and Cretaceous continental sedimentation in the West Siberian Basin, Russia: evolving fluvial systems and their preservation in the rock record.

**Sophie Leleu**, Adrian J. Hartley & Brian P.J. Williams
Large-scale alluvial architecture and correlation within a Triassic pebbly braided river system (Fundy Basin, Canada).

**Robert G. Macdonald** & Jan Alexander
*Hydraulic-jump unit bars*: experimental architectures.

**Middleton, Larry T.** & Long, Joshua
Climatic controls on the fluvial sedimentology, architecture, and cyclicity of the Jurassic Kayenta Formation, northern Arizona, U.S.A.

**Jennifer L. Morris**, Kathryn J. Amos, V. Paul Wright & Stephen T. Hasiotis
Are the Channel Country rivers of central Australia a suitable modern analogue for the lower Old Red Sandstone, U.K.?

**Joanna Morris**, Stuart Jones, Ken McCaffrey, Neil Meadows, Stuart Archer, Jamie Middleton, Ricki Charles & Henrik Waage
Permo-Triassic low net to gross fluvial systems: An analogue for subsurface reservoirs.

**Nigel P. Mountney**, Stephen A. Cain, Oliver D. Jordan & Oliver J. Wakefield

Architecture of ephemeral fluvial successions and their interaction with distal aeolian dune fields: implications for reservoir characterisation.

**Rachel Nanson**, Bruce Ainsworth & Boyan Vakarelov
Genesis of the submarine Malita Valley: A closed-contour, tidally enhanced fluvial incision, Joseph Bonaparte Gulf, Australia.

**Uisdean Nicholson,** Orji Akaa & David Macdonald
Reconstructing the palaeo-Colorado River.

**Laurent Petitpierre** & Jonathan Redfern
Distributary channels and/or incised valley fills: Interpretations for the fluvial facies of the Marar formation.

**Ann Rowan**, Merren Jones, Simon H. Brocklehurst & Stephen Covey-Crump
The influence of glacial-interglacial climatic variations on coarse-grained braided river deposits.

**Susumu Tanabe** & Yoshiro Ishihara
Fluvial response to stepwise sea-level rise: a case study from the latest Pleistocene to Holocene incised-valley fills under the Tokyo Lowland, central Japan.

**András Uhrin**, Gábor Csillag, Zoltán Hámori, Ildikó Selmeczi & Orsolya Sztanó
Pliocene rivers in the Pannonian Basin, Hungary.

**S. van Asselen** & E. Stouthamer
Peat compaction and formation, key processes controlling fluvial-deltaic architecture.

**Xavier van Lanen**, David Hodgetts, Jonathan Redfern, Brian Williams & Sophie Leleu
A Quantitative 3D Outcrop Model of a Late Triassic Gravel Dominated Braided Fluvial System (Minas Basin, Nova Scotia, Canada).

**Dario Ventra**
Hyperconcentrated alluvial facies of the Miocene Teruel Basin (Spain):
Controls and implications for basin analysis.

**G.S. Weissmann**, A.J. Hartley, G.J. Nichols, L.A. Scuderi, M. Olson, H. Buehler, & R. Banteah
Where Do Meanderbelts Form in Modern Continental Sedimentary Basins?

# ABSTRACTS

# Turning Barriers into Baffles: Fluvial Migration Processes within a Belt and the Potential for Amalgamation of Fluvial Deposits.

**Neal Alexandrowicz** & John Holbrook

*University of Texas at Arlington, Arlington Texas 96019*

Given an understanding of the internal architecture, facies relationships, and processes at work within modern river belts, what would it take for fluvial sandstones to appear as amalgamated sheets in the rock record? With advancement in the knowledge of how the interior of belts really look, it is possible to address the issue of understanding how those belt deposits might be preserved in the rock record. Studies of the Mississippi and Missouri Rivers have shown that abandoned channels are the most likely places for the accumulation of fine-grained material within the channel belt proper. While the Mississippi River represents a model for muddy fluvial systems, the abandoned channel fill seen in our study area contains a significant amount of rather gritty active channel fill. On average, only the upper 10 meters of an abandoned channel are composed of the very fine-grained muds representing truly passive fill. The abandoned channel facies, whether active or passive, constitute less than 25% of the total belt deposits, the remainder being point bar and channel bottom sands. If belt deposits are discretely preserved, fines within the belt can act as barriers to communication between porous units. If, however, the belt deposits are allowed to amalgamate during more gradual aggradation, younger belt systems could incise into the older deposits. This incision can erode away the muddy tops of older fluvial deposits and replace them with sands laid down by younger channels, thus creating amalgamated sandstone units.

Recent work on the Mississippi River has allowed us to relate dimensional characteristics of the modern river to the scour profile at the base of the belt. This scour profile is a key to determining how much of the fine grained material in the upper part of an abandoned channel might be preserved. Using this data, it is possible to determine the vertical shifts that would lead to either the preservation or the erosion of fine grained facies from fluvial deposits. Once connected by the scour surface, communication between stacked channel-belts depends on the reservoir quality. Our study shows that, even in muddy systems, the material into which a fluvial surface scours is likely to have sufficient quality to permit reservoir communication.

# Fluvial Depositional Systems in the Malay Basin: Reconstructing Pliocene-Quaternary Rivers on the Sunda Shelf Using 3D Seismic Data

**Faisal A. Alqahtani[1],** Chris A-L. Jackson[1], Howard D. Johnson [1] & M. Rapi B. Som[2]

[1]*Department of Earth Science & Engineering, Imperial College, London, SW7 2BP, UK*
[2] *Petronas Research Snd. Bhd., Bangi, 43000 Kajang, Selangor, Malaysia*

The Malay Basin is a large Oligo-Miocene to Pliocene-Quaternary sedimentary basin that is composed of rift to post-rift, shallow water clastic sediments. The youngest (Miocene to Pliocene-Quaternary), post-rift succession is dominated by thick (>7 km), intercalated coastal plain and coastal deposits, which form multiple, vertically-stacked hydrocarbon reservoirs. Coastal plain successions contain a wide variety of fluvial channel sandstones, which form highly productive, but stratigraphically-complex, reservoirs throughout the Miocene succession. This study investigates the wide variety of channel types based on a high-quality, near-surface and regionally-merged 3D seismic dataset (down to 500 m below see-bed) covering the Pliocene-Quaternary succession. A wide range of channel patterns are exquisitely imaged, including low-sinuosity/anastomosing, meandering and braided systems which provide key data on sand body geometries, dimensions and stacking patterns that can be expected in the analogous deeper (Miocene) productive reservoirs.

Detailed interpretation of seismic sections and seismic time, stratal and proportional slices through flattened and un-flattened 3D volumes, along with seismic facies analysis, horizon mapping, and attribute extractions, allow detailed analysis of the Pliocene-Quaternary fluvial systems. Examples of well-imaged fluvial channels from the near-seabed (100 msec) will be discussed. For example, the youngest channel complex comprises a major, high-sinuosity meandering channel system that trends NW-SE and occupied the axial zone of the Malay Basin. This 550 m-wide, 80 m-deep meandering channel has a meander radius of about 4 km. It contains well-developed point bars with meander scrolls and abandoned channels and displays clear accretion surfaces in cross-section. This channel complex is confined within a broad valley system that is characterized by a gently-sloping margin, which confines meander-belt width to around 13 km. This major incised valley was developed during a period of negative accommodation caused by a fall in the sea-level when the shelf was fully exposed and fluvial drainage extended into the South China Sea to the east.

These and other observation from the Pliocene-Quaternary fluvial systems will be used to determine reservoir body dimensions and geometries that will aid the construction of 3D reservoir geological models of fluvial reservoirs in the deeper prospective Miocene successions.

# New observations from the Channel Country of central Australia

**Kathryn J. Amos**[1], Stephen T. Hasiotis[2], Carmen B.E. Krapf[1], Rachel A. Nanson[1], Jennifer L. Morris[3], Marianne L. Sandstrom[1] & Joanna Morris[4]

[1]*Australian School of Petroleum, University of Adelaide.*
[2]*Department of Geology, University of Kansas.* [3]*School of Earth and Ocean Sciences, Cardiff University.*
[4]*Department of Earth Sciences, Durham University.*

The Channel Country rivers of central Australia are large mud-dominated, dryland, anabranching rivers with complex channel pattern and floodplain geomorphology. These river systems have been cited as a modern analogue for a number of ancient deposits, and may provide a useful analogue for regional seals from ancient drylands. This paper presents detailed observations from the Diamantina River, one of the principal rivers of the Channel Country and the main contributor of discharge to Lake Eyre. Fieldwork was conducted at two sites, 50 km and 500 km from the headwaters (floodplain widths of 2 km and 15 km). Observations were recorded from shallow trenches and surficial sediments, from anabranching channels including within accretionary bench and bar forms, waterhole-splay features, on levees and floodplain bar-form highs including locations of headward erosion. One larger channel-bank trench was excavated enabling a 3.75 m vertical section to be logged in stepped sections of up to 0.85m below the sloped surface. Sedimentologic logs depicting sedimentary structures, grain size and composition are presented.

Observations indicate that the modern system at both sites is dominantly erosional. Exposed tree roots, undermined and fallen trees were prevalent, on both left and right banks of channels and waterholes. Channels are eroding into both clay-rich floodplain soils and fluvial deposits consisting of interbedded mud-aggregate and sandy-mud, with low-angle planar and cross-bedding. Areas of relatively low-lying floodplain are eroding. Some accretionary benches within channels were observed, as well as mud-rich sediment drapes on banks, and some modern deposition downstream of vegetation in 'composite shadow bars'; erosional features with a depositional cover of sediment. On one of the higher floodplain features, the bar-form surface, wind-deflation of one centimetre was inferred. These observations are compared with those previously published from other Channel Country locations, which have described widespread sediment aggradation and a scarcity of toppled trees along concave banks. Present understanding of Channel Country fluvial sedimentology is reviewed and summarised.

## Reservoir characterisation challenges in the Jasmine Field of the CNS, UKCS.

**Stuart Archer**, Alison Ferguson, Simon Ward, Andy Cole, Iain Mearns.

*ConocoPhillips (UK) Ltd. & University of Aberdeen*

The Jasmine Field was discovered in 2006 in block 30/06 of the Central North Sea. Jasmine represents a significant new resource in this mature area, building on the success of the Jade and Judy fields in the J-Block area. Recent appraisal drilling and field development planning on Jasmine is being supported by an active reservoir characterisation programme including coring, LWD and wireline logging (including the acquisition of image logs), geomodelling activities, state-of-the-art seismic reprocessing and multiple in-house and contractor / university studies.

The main Jasmine structure is a turtle-back faulted anticline located west of the Joanne salt pillow on the J-Ridge, where a thick succession of Triassic continental clastics is preserved in a salt withdrawal mini-basin. The primary reservoir is the Joanne Member of the Skagerrak Formation, which is a moderate-high net/gross fluvial succession. At a regional scale, tectonics and climate are the principal allogenic controls on Skagerrak stratigraphic development, but salt tectonics is the primary control on net/gross at local mini-basin scale. The rate of salt withdrawal and the development of "halokinetic accommodation space" varies temporally and spatially within and between mini-basins. The main challenge is to develop a 4D stratigraphic model that links net/gross, facies types and their architecture to geographic position and stage of mini-basin development. There is a clear requirement for more refined models since stratigraphic predictions from seismic alone have proved problematic. Preserved thicknesses of the Joanne Member can be mapped seismically as a rough proxy for net/gross, but this simple method suffers from numerous limitations: challenged seismic image from which to map mini-basin extent; truncation of top reservoir by post-depositional erosion and lack of consistent top reservoir reflector; low angle post-depositional domino faulting means fault reconstruction is required before original thicknesses can be mapped.

In addition to these geophysical challenges, sedimentological uncertainties include paleoflow, where there are conflicting interpretations of proximality trends and degree of lateral input. The range of facies, including degree of lacustrine influence is also still hotly debated. The depositional origin and preserved architecture of the fine grained facies is of crucial importance in dynamic modelling since the dimensions of floodplain remnants will have very different dimensions to lacustrine facies.

Jasmine is close to two currently producing Triassic fields, Jade and Judy, which act as powerful local analogues and provide dynamic reservoir performance knowledge to optimise the Jasmine Field development plan.

# The dynamics and deposits of a big river: the Rio Paraná, Argentina

**Ashworth, P.J**.[1], Amsler, M.L.[2], Best, J.L.[3], Hardy, R.J.[4], Lane, S.N.[4], Nicholas, A.P.[5], Orfeo, O.[6], Parsons, D.R.[7], Reesink, A.J.H.[1,8], Sandbach, S.[4,5], Sambrook Smith, G.H.[8] & Szupiany, R.N.[2]

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[7]*School of Earth and Environment, University of Leeds, Leeds, UK*
[8]*School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK*

Little is known about the morphology, dynamics and sedimentology of the world's largest multi-thread rivers. There are good theoretical reasons to suggest that observations and data obtained for small rivers (less than 1 km wide) may not be transferable directly to the world's largest rivers. For example, force-balance considerations suggest a dependence on width-depth ratio that does not scale linearly with flow discharge and this may then affect the depositional sedimentology. This paper reports on a combined 'process' and 'depositional form' study in one of the world's largest multi-thread rivers - the sandy Rio Paraná, Argentina.

Bathymetric and 3D flow data were taken in a 38 km long, 4 km wide reach from boat surveys using single and multi-beam echo sounders, acoustic Doppler current profilers (ADCP) and dGPS. Initial results demonstrate that the main channels of the Paraná at low flow are dominated by dunes up to 3.5 m high that scale with flow depth. Unit bars in the Paraná are less common than observed in smaller rivers. The deposits of recent km-scale mid-channel bars were characterised using Ground Penetrating Radar (GPR), resistivity surveys and shallow (5 m) and deep (30 m) cores. The internal structure of mid-channel bars is dominated by decimetre to sub-m high, stacked dune sets and up to 7 m thick, high-angle, bar margin accretionary sets. Re-activation surfaces on bar margins are common, whereas cross-bar channels are less prevalent as compared to smaller braided rivers.

These preliminary field observations suggest that whilst there may be some differences in the basic flow processes in small and large rivers, the deposits of large rivers have the same characteristics as smaller rivers. Thus, with appropriate scaling, it may be possible to use geostatistical databases derived from a mix of different sized rivers in reservoir models.

# Sediment supply and accommodation as controls on fluvial behaviour and style of preservation in an ephemeral fluvial succession: the Permian Organ Rock Formation, SE Utah, USA

Stephen A. Cain[1,2] & **Nigel P. Mountney**[2]

*1 – Earth Sciences, Keele University, Keele, Staffordshire, ST5 5BG, UK*
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The fluvial Organ Rock Formation, which forms part of the Pennsylvanian-Permian Cutler Group of the Paradox foreland basin, is exposed across much of SE Utah and adjoining parts of northern Arizona and represents a wedge of coarse-grained fluvial strata that progressively fines south-westwards (distally) away from its source area, the Uncompahgre Uplift. By the time of onset of Organ Rock deposition (Leonardian/Artinskian), the Paradox basin was in an overfilled state, resulting in the progradation of a 100 m-thick wedge of fluvial strata across a wide part of the basin floor. These deposits record a downstream transition from a proximal fluvial system that was dominated by in-channel sedimentation in which evidence for both repeated nodal avulsions and entrenchment is evident, through a medial zone in which channels lay within belts that were subject to a variety of lateral accretion, avulsion and anabranching processes, to a distal zone where evidence for in-channel sedimentation is less abundant and in which sheet flood and aeolian dune elements are dominant.

The progradational nature of the lower part of the Organ Rock Formation, together with the vertical stacking and repeated overprinting of multi-storey gritstone channel complexes, is indicative of a fluvial system that was initially characterised by high rates of sediment supply that outpaced the slow rate of load-induced, post-orogenic accommodation creation. By contrast the upper part of the succession, which is characterised by a retrogradation of coarse-grained clastic facies back towards the hinterland and the vertical stacking of multiple sheets of fine- to very fine-grained sandstone, is representative of a distal fluvial sheet flood environment. By late Organ Rock times, the calibre of sediment delivered to the basin had decreased, probably in response to the retreat of the fluvial source area as the Uncompahgre Uplift became progressively denuded. The ubiquitous presence of rhizoliths, a restricted non-marine fossil assemblage and calcrete palaeosols throughout the succession suggests that the role of climate change in dictating the nature of the preserved succession was secondary to the roles of a limited rate of accommodation space creation and the switch from an initially high rate of sediment delivery to a lower rate of supply, as the basin-bounding uplift diminished.

# Drainage Reorganization and Erosional Changes in the Holocene of the Indus River under the Influence of a Variable Monsoon

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The Indus River is one of the oldest in Asia, dating from the time of India-Asia collision ~50 Ma. Although the upper reaches of the Indus appear to have been trapped in the suture zone since this time its path to the ocean has changed greatly. In the Eocene the delta lay in the Katawaz Basin of western Pakistan and has been progressively displaced eastwards through time. Provenance data from sediments in the Indus submarine fan indicates that the basin geometry draining the Transhimalaya and Karakoram remained fairly stable until the Late Miocene. After this time however, the river gained large amounts of Lesser and Greater Himalayan catchment, presumably at the expense of the Ganges, although the trigger for this drainage capture is not clear. When viewed over shorter timescales, the varying intensity of the summer monsoon rains drastically affects the evolution of the Indus. After a very arid phase at the Last Glacial Maximum (LGM) 20 ka, the Indus shows a strong shift in its eroded drainage area towards a more Himalayan provenance. This is clearly shown in zircon U-Pb ages, biotite and muscovite Ar-Ar ages and bulk sediment Sr and Nd isotopes. Sediment flux to the delta, especially at 12–8 ka accelerated rapidly as the intensifying monsoon stripped material from the Greater and especially the Lesser Himalayan ranges. This was a time of major landsliding and mass wasting that allowed the delta to prograde seaward despite the rising sea level. Coring shows that the coast has not been displaced far inland (<50 km) since the Last Glacial Maximum. Erosion continued to be strong in the heavily glaciated Karakoram as well, fed by moisture from the Westerly Jet, but declined in relative terms as the Holocene began. The Indus has further reorganized as the monsoon weakened from 8 ka to the present. New trenching in NE Pakistan now suggests that the Indus may have flowed much further to the east as recently as 5 ka, around 170 km east of the present trunk river. At the same time the presence of abandoned channels on the eastern edge of the basin (around the present-day Pakistan-India border) suggests that some of the drainage in this area may have dried up as a result of the weaker monsoon or was captured into the adjacent Sutlej or Yamuna Rivers. Either way, these observations hint that a much larger river may have once flowed here. Harappan archaeological sites are clustered along this larger, dried up river and suggests that the loss of flow in these eastern channels may be have caused the abandonement of the Harappan sites, which occurred ~4 ka. Whether these channels were part of the Indus or an independent system remains unclear. However, trenching in southern Pakistan shows that after ca. 3 ka all the river channels were part of a greater Indus River that migrated across the full width of the flood plain between the Kithar Ranges in the west (around the present-day Pakistan-Afghanistan border) and the Thar Desert in the East. The present Indus River is strongly aggradational even in its upper reaches and over the entire length of its lower alluvial plain where it has building built a large scale alluvial fan. In contrast, the large Himalayan tributaries have experienced incision after the early Holocene monsoon maximum. Cannibalization of Punjabi plain sediments through incision later in the Holocene has supported a continuously high Indus sediment load. This feedback mechanism thus provided a buffer at millennial time scales during periods of diminished river discharge of individual tributaries.

# Full Holocene Storage Budget of the Rhine-Delta Sediment Trap

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We present the complete budget of Holocene-delivered Rhine sediments in the Netherlands and adjacent parts of Germany. A stratified approach allowed to quantify the amount of deposits stored in the Rhine delta, slicing the total volume based on:

- Genesis, using an architectural element approach
- Spatial extent, using alluvial architectural and sequence stratigraphical zonations: 'estuary', 'lagoon'; 'lower', 'central' and 'upper' delta, 'delta apex'; total 150 km inland
- Age: using $^{14}$C-dates in cross-sections. Slicing spans last 9 k BP in 500-yr intervals (!).

The input data for our budget inventory is derived from earlier Rhine-Meuse delta studies (See http://www.geo.uu.nl/fg/palaeogeography). Valley-wide cross-sections (yielding width-averaged thickness and lithofacies proportions, per segment, per time slice) and GIS maps (area of channel belts *vs.* floodbasin, per time slice, per segment) summarize this data. Our analysis yields a complex set of spreadsheet data, allowing detailed accountancy of sediment import and export, broken down by class, segment and time-slice. This set of numbers documents architectural build up and embedded spatial and temporal trends in a truly quantitative fashion. This opens exciting new ways to explore Holocene deltas (especially 3D rate of deposition, preservation-by-facies; trapping efficiency and sediment residence time) as analogues to ancient fluvio-deltaic reservoirs.

The data shows strong increased amounts of fine grained sediment delivery in the last 3000 years, owing to Bronze Age agricultural revolutions in the hinterland. Compared to the Middle Holocene 'natural forested hinterland', suspended load delivery has tripled. This has important bearings when scaling the Holocene Rhine-Meuse delta 'recent example' to ancient deltas in hydro-carbon reservoirs, whether through applying sequence stratigraphic concepts or through forward model simulations: The last 3000 years, Rhine deltaic deposition and areal growth ran at trice the rate it would have done in a situation without humans (as many other Eurasian deltas with increasingly dense populated hinterlands). This means that the high-stand deltaic system tract is disproportionally large for the Holocene 4$^{th}$-order half cycle. It suggests uniformly scaled Holocene delta geometries to be better analogues for ancient 3$^{th}$ order cycles, than for Neogene-Quaternary 4$^{th}$ order cycles.

# From outcrop to process-based reservoir modelling of fluvial meandering systems The key issue of parameter choice

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The need of models for heterogeneous reservoirs has stimulated the development of new models both process-based and stochastics. Such a model of fluvial meandering systems, developed at the school of Mines, is a comprehensive one. It comprises a realistic migration pattern of the channel centerline, (based on hydraulic studies) and reproduces event processes such as overbank floods, levee breaches, crevasse splays and avulsions. Various architectures are to be produced by changing frequency and intensity of overbank floods or avulsions, or by constraining the aggradation rate by an equilibrium profile. The number of parameters which rule the model has been kept limited: channel parameters, floodplain slope, frequency and intensity of other elements such as overbank floods and avulsions.

In order to address the potential of such a modelling to field data, a study has been conducted on the Miocene Loranca formation (central Spain). This meandering succession is around 100m thick. Channel depth is based on measurement of point-bar and channel-fill thicknesses, giving a mean value of 3.5 m. The complex pattern of a meandering system makes difficult the estimation of the channel width from the outcrop. The channel width is thus estimated by using a classic hydraulic formula, ($d=24.6h^{1.45}$). The aggradation rate is controlled by overbank floods and avulsions. Evaluation of overbank intensity is based on the levee thicknesses (0.43 m), characteristics of sheet flood deposits that show little decrease in thickness and grain size away from the channel. Levee breaches are attested by regular crevasse-splays. The rate of successful avulsions is taken at 2000 years, based on paleosol maturity stage and lateral extent of the point bars. Amongst the needed parameters, erodibility coefficient, floodplain slope and overbank flood frequency could not be directly inferred from the field. Erodibility coefficient and slope value are taken by default at $2\ 10^{-8}$ and 0.001, respectively. Overbank frequency is adjusted to reproduce the N to G that varies between 16 and 37% along the studied interval. These ratios could easily be obtained by changing the frequency of the overbank floods (from 190 to 600 iterations), while keeping the other parameters constant. Thus, the simulated 3D block and the outcrop display similar sand bodies and facies distribution.

A further step in the potential of the model is demonstrated through a conditional simulation, run with the on conditional parameters and using measured sections as wells. The number of iterations is very similar to that of the non conditional simulations, indicating that processes were respected during the conditional simulation, despite a 10% relative increase in the N to G. Matching of simulated sandbodies with data is close to 90%.

# Modern analogues for ancient rivers: using regional curves to identify appropriate drainage area and hydrophysiographic region

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A new approach is recommended for estimating the catchment size and paleohydrology for ancient rivers from analysis of their sedimentary record. Previous sedimentological studies have relied on discharge-area relationships created by amalgamating data from a wide range of hydro-physiographic catchment characteristics. Geomorphologists and civil engineers have been developing an extensive database of relationships that account for the catchment response to specific climates, lithologies and hydrological processes. These regional hydraulic geometry relationships (regional curves) plot as logarithmic curves, are independent of channel planform and are based on bankfull discharge, which is the effective channel-forming discharge and is more relevant to the construction of the rock record than the mean or peak discharge values used previously. The Kayenta Formation in Utah and South West Colorado is used as an example to demonstrate the value of these region-specifc relationships to assess the range of uncertainty in catchment interpretation, for illustrating the range of possible modern climatic analogs with associated modern river examples, and for suggesting where revisions are required to publish paleogeographic reconstructions.

# Distributary fluvial system terminations in drylands: facies characterisation in cratonic and foreland basins

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A series of scenarios are presented summarising an analysis of 170 distributary fluvial system (DFS) terminations in cratonic and foreland tectonic basin settings in arid climatic regimes. Various terminations were mapped remotely for individual systems in different arid basins World-wide and then amalgamated to derive facies characterizations in each setting. It was found that in dryland steppe and desert climates the style of DFS termination is driven primarily by the type of drainage system in the basin; endhoreic basin DFSs terminate in perennial lakes or playas or dissipate in dune fields, whereas exhoreic basin DFSs terminate as tributary fans to an axial drainage system. Furthermore, this differentiation of termination according to drainage system is independent of tectonic setting. Existing facies models derived for "terminal fans" inadequately describe the range of facies in dryland terminations, nor do they account for the tendency for DFSs to dominate basin-fill in certain regimes. It is proposed that distributary fluvial systems form an important and frequently largely overlooked component of arid climatic regimes; previous research focus has been on their development in temperate climates.

# Gradual avulsion in the rock record: Outcrop example of the Huesca Fluvial Fan

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The Huesca Fluvial Fan (Miocene, Ebro Basin, Spain) shows a gradual downstream change from vertically-stacked and laterally-amalgamated meandering-river sandstone deposits organized in channel belts in the mid-fan area, to small, isolated sandstone and siltstone bodies produced by narrow and shallow meandering channels at the fluvial fan fringe. River channel dimensions of the latter are estimated from sandstone body thickness and measured from clay plugs and range from 20-40 m width and 1-4 m depth. The fan fringe fluvial sediment bodies have a ribbon to sheet shape, depending on the amount of lateral accretion of the meandering channel prior to avulsion and abandonment. The sediment bodies have an undulating erosional lower surface and show a continuous fining-upward grain-size succession from medium-to-coarse sandstone and mudstone pebbles at the base, to very-fine sandstone and siltstone at the top. Sigmoidal-shaped, siltstone-draped lateral accretion surfaces occur in the upper third part of the sediment bodies. In cross-sections in the lateral accretion direction the sediment bodies are wedge-shaped and end in a clay plug whose thickness is much smaller than that of the attached lateral accretion sediment body. Towards the clay plug the erosional base of the sediment body gradually steps up. Sediment grain size at the channel base laterally decreases along this step-up. Well-exposed fully 3D outcrops show a strong increase in channel sinuosity towards the last phase of fluvial channel activity, to the point that the remnant channel erodes part of its previously-deposited point bar. 3D geometries and lithofacies characteristics are interpreted to reflect a gradual upstream river avulsion, whereby decreasing water discharge resulted in reduced transport capacity of the river, and hence in the step-up of the erosional lower surface and in finer-grained sediment load. Simultaneous increase of sinuosity results of the now underfit streams occupying the originally wider fluvial valley. Further downstream at the fluvial fan termination, the measured widths of the individual fluvial sediment bodies are strongly reduced. Narrow sandstone ribbons with few lateral accretion surfaces testify to more frequent avulsions in this realm. Thin (10-50 cm thick), very-fine sandstone and siltstone sheets with low-angle climbing ripples extend as wings from the ribbons. The sheets appear to have formed as crevasse-splay and terminal sheets during peak run-off unconfined flow.

The fluvial architecture at the fringe of the Huesca Fluvial Fan shows that the area was occupied by small rivers that frequently changed course following upstream avulsion, and there was no stable pattern of distributary channels.

# Facies Complexity in a Continental System – The Upper Triassic Chinle Formation, Colorado Plateau, U.S.A.

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The Upper Triassic Chinle Formation of the Colorado Plateau and coeval rocks throughout the Western Interior of the United States were deposited over about 20 – 25 million years as a continental-scale fluvial-lacustrine-eolian depositional system near the west coast of Pangea. The deposystem evolved over time as the result of interactive tectonic and climatic controls. Subtle tectonic movements due to arc magmatism and marked paleoclimate change from primarily arid to a dominantly megamonsoon regime resulted in complex facies associations. The Chinle comprises, in ascending order, the Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Rock Point Members. Shinarump fluvial systems at the base of the Chinle occupy paleovalleys eroded into the underlying marine and deltaic Lower to Middle Triassic Moenkopi Formation. Shinarump fluvial systems include continental-scale trunk drainage systems sourced from both the continental interior and tributary streams from local highlands, all of which flowed generally to the northwest. Lacustrine and marsh complexes of the Monitor Butte Member developed as the trunk rivers meandered and avulsed to cut off or restrict tributary streams and form dendritic lakes. Lacustrine deltas and subaqueous levees filled the lakes during alternating wet and dry seasons. Moss Back Member fluvial trunk streams aggraded over the Monitor Butte lake and marsh sediments. Petrified Forest Member fluvial systems are the most varied in the Chinle, containing a myriad of channel forms, as well as levees, crevasse splays, and abundant paleosols that modified floodplain sediments. Owl Rock fluvial, paleosol, and lacustrine strata and Rock Point eolian and playa deposits complete the upper Chinle section.

Chinle fluvial systems have been interpreted in previous studies as primarily meandering or braided streams. However, single fluvial models, even more recent sophisticated and detailed meandering and braided models, do not adequately characterize the complexity observed in Chinle systems. Comparison to modern alluvial systems, now readily available from satellite images and other research, indicates that alternative depositional models need to be developed from specific modern fluvial analogues and alluvial megafans around the world. It is especially important to capture the climatic setting and characteristics of high-stage versus low-stage regimes to more accurately explain the complexity and architecture expressed in facies associations of the Chinle continental-scale depositional system.

# The response of the longitudinal grain-size profile to the spatial distribution of tectonic subsidence: an integrated model and field investigation

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Regional grain-size trends preserved in sedimentary rocks, together with the migration of specific grain-size discontinuities, contain important information on the overall dynamics of sediment routing systems and their sensitivity to external forcing mechanisms. The simplest way of viewing downstream grain-size changes is that the coarsest grains are preferentially deposited in upstream locations, therefore setting the overall fining. However, in detail, the rate of downstream fining in a fluvial system is governed by: (1) the physical characteristics of the input sediment supply; (2) the spatial distribution of subsidence rate; and (3) the detailed mechanics of sediment transport and deposition, making temporal and spatial predictions of grain-size non-trivial. A key challenge is to explore how these first two factors control the calibre and spatial distribution of deposit grain-size over timescales of $10^4$-$10^6$ years without incorporating the details of hydraulics and sediment transport, which have been developed for modern fluvial systems over short time scales, and which are largely immeasurable for time-averaged stratigraphy in the geological past. In order to accomplish this we assume self similarity between the long-term, longitudinal grain-size distribution of the substrate and the dimensionless relative mobility function for gravel, which utilises only local mean and standard deviation of sizes in transport as scaling parameters (*c.f.* Fedele and Paola, 2007). This approach has been successfully applied to a small number of field and laboratory experiments, raising the prospect of its application to a wide variety of sedimentary basins, but has not yet been robustly field-tested with respect to documented temporal and spatial variations in grain-size in preserved fluvial deposits. We address this challenge by testing model predictions of downstream sediment calibre, developed for self similarity, as a function of subsidence and initial grain-size distribution, and comparing them to grain-size data collected in the Spanish Pyrenees from both a small length-scale depositional system (<10 km), the Ermita-Pallaresa Groups of the wedge-top Pobla Basin, and a large length-scale depositional system (30 to 40 km), the Senterada-Antist Groups, where we have independent constraints on the timing of thrust motion, and hence the spatial generation of accommodation. Our results show that the assumption of self-similarity can be applied to documented trends in the spatio-temporal variation of regional grain-size to infer subsidence history, and show the generic utility of this approach to the predictive modelling of grain-size within sedimentary systems at a range of physical length scales.

# The role of scouring in producing thick fluvial sequences; examples from a Holocene forced regressive river system and a present-day lake delta distributary

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Anomalously thick, fluvial successions comprising stacked fining-upward units, are often related to aggradational phases controlled by changes in base level. However, another mechanism capable of promoting thick fluvial deposits of high preservation potential is scouring and subsequent infilling. Scouring within a channel or during channel migration may lead to reworking of a large proportion of the sandbody base, causing local thickening. Correct interpretation of erosion surfaces is crucial for establishing robust sequence stratigraphic models, and it is therefore important to distinguish between the level of autocyclic scour within alluvial channels, and incisions made by allocyclic processes like base-level lowering.

A more than 20-m-high and 600-m-long section at the bank of the Tana River at Masjok, northern Norway, consists of 3 stacked units of sandy fluvial sediments that. They are part of an early-to-mid Holocene, forced regression sequence deposited close to sea-level. GPR profiling shows that the fluvial unit is more than 30 m thick and has a basal relief of more than 17 m. We suggest that the succession formed by infilling of a large scour, with each individual unit representing a separate infilling stage. Simultaneously, it is possible that a stillstand or slight rise in relative sea level at the time of the regional mid-Holocene Tapes transgression caused the river bed to aggrade, which would account for some vertical thickening of the succession in its upper part. However, this does not explain the large vertical relief at the base of the fluvial sediments, the anomalous >30 m thickness compared with a norm of 5-10 m elsewhere in the valley, nor the fact that the lowermost sediments must have been deposited 10s of meters below contemporaneous sea level.

A modern analogue to the Masjok section is a series of scours occurring within the distributaries of the Lake Øyeren delta, southern Norway, identified by multibeam survey. The scours occur at confluences, bends, and confinements along soft-bed channels, as well as in bedrock. Their base is up to 22 m below local base level (i.e. lake level), and they are up to 4.6 times deeper than mean channel depth. The deepest scour was 23 m deep in 2004 and is located at a channel confinement. It probably formed due to flow convergence during one flood cycle and, once formed, has kept its overall shape and migrated more than 50 m downstream during the last 4 years, producing scour-fill deposits more than 10 m thick at its upstream end.

# Variability in modern alluvial rivers: is this variability recognized in ancient river deposits?

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Most classifications of Holocene alluvial rivers are based on channel planform and/or sediment load. Researchers generally agree that these classifications are flawed because classes are not mutually exclusive, and different criteria are used to define the different classes. Holocene rivers show a high degree of morphological variability with end member channel types recognized as anabranching (anastomosing), braided, straight, meandering and wandering. Individual rivers also show a high degree of longitudinal and vertical (through time) variability that is related to changes in climate, tectonics, base level, valley slope, tributary contributions and accidents. If a single Holocene river can display such variability, then limited exposures of ancient river deposits could easily lead to erroneous interpretation of the paleo-river type.

The high degree of variability in plan-view morphology of Holocene rivers is not reflected to date in interpretations of ancient fluvial deposits. In most cases these deposits continue to be classified as meandering or braided channels in spite of general agreement that many of the measured characteristics have little relationship to channel patterns (Bridge, 1985, 1993 and 2006, Miall, 1995, and Brierley, 1996). The situation is particularly troublesome for subsurface deposits, where traditional data sources, such as continuous cores, wireline logs, and pressure data do not permit unambiguous correlation of units between adjacent wells, let alone interpretations of paleo-channel patterns. Some ancient fluvial channels are interpreted as straight in spite of the fact that straight channels rarely persist for any distance in modern alluvial rivers and little is known about their sedimentology and stratigraphy. Also, recognizing the important distinction between channels and valleys in alluvial strata is difficult in part because of the overlap in dimensions.

Reconstructions of ancient channel plan forms are possible from exceptional 3D outcrop exposures and with detail evaluation of large-scale, inclined strata. Moreover, with the advent of quantitative seismic geomorphology the ability to infer channel morphologies, to estimate their size and dimensions, and to differentiate channels and valleys in the subsurface has increased significantly. Time-slice images permit enhanced assessment of lateral variability and temporal evolution of fluvial systems. Even though these techniques will provide valuable information regarding paleochannels and paleovalleys, the great variability of modern rivers suggest that extrapolation from limited exposures and subsurface data will continue to be problematic.

# Evaluating the sedimentary response to climatic forces; an integrated approach from the Oligo-Miocene Huesca Fluvial Distributary System, Ebro Basin, Spain.

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The stratigraphic architecture of fluvial deposits is determined by a number of allogenic and autogenic controls operating at a range of different timescales. Although the controls are numerous, most can be linked back to tectonics, climatic change or variations in sediment supply. In practice it is often difficult to determine which, if any of these factors played a dominant role, thus interpretations of sedimentary response to specific controls over geological timescales are usually limited.

The distal zone of the Oligo-Miocene Huesca Fluvial Distributary System provides a unique opportunity to evaluate the link between stratigraphic architecture and climate change on a geological timescale. A high resolution geochemical dataset has been used to calculate "climofunctions" for mean annual temperature (MAT) and mean annual precipitation (MAP) through time. Sedimentary logging, photo panel interpretation and quantitative grain size analysis have been used to accurately capture the sedimentology.

By combing the use of fluvial sedimentology, palaeopedology and geochemistry this study directly compares a quantitative record of climate change recorded in the palaeosols of the fluvial system to vertical and lateral changes in its stratigraphic architecture.

# Alluvial architecture and fluvial facies of tidally influenced alluvial/delta plain deposits of the Late Cretaceous Prince Creek Formation: Colville Basin, North Slope, Alaska

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The Colville Basin is an early Cretaceous foreland basin that was filled by east/northeastward prograding clastic wedges sourced from the evolving Brooks Range orogenic belt of northern Alaska. The non-marine Prince Creek Formation is part of a genetically related, predominantly progradational couplet of coastal-plain facies (Prince Creek Fm.) and shallow-to marginal-marine facies (Schrader Bluff Fm.) that make up the second of these major basin-filling clastic wedges. The early Maastrichtian Prince Creek Fm. is a dinosaur-bearing, alluvial/delta plain succession exposed for approximately 90 km in 30-50 m high bluffs along the Colville, Kogosukruk, and Kikiakrorak rivers of northern Alaska.

An architectural/facies analysis of the northernmost 50 km of bluffs indicates that the bulk of the Prince Creek Fm. is composed of three fluvial facies associations and their associated floodplain deposits. In order of decreasing percentage of exposed basin fill these are: (1) 2-6 m thick erosionally based, heterolithic, laterally accreting, ubiquitously rooted sheet sandbodies containing fine-grained sand/mud or silt/mud couplets and numerous mud-filled abandoned channels, (2) 1-3 m thick erosionally based, rooted, fine-grained ribbon sandbodies containing primary vertical and secondary lateral accretion that are incised into either the heterolithic sands or floodplain fines, and (3) 13-20 m thick, medium-grained, multi-storey fining-upward successions that include basal conglomerate lags but lack abundant roots.

Heterolithic sheet sandbodies are interpreted as tidally-influenced, highly sinuous meandering, ephemeral distributary channels on the lower delta plain. Ribbon sandbodies are often found in tiers, sometimes stratigraphically at the same level as the heterolithic sheet sands and are interpreted as anastomosed channels. Multi-storey, fining-upward successions are interpreted as meandering trunk channels. The ephemeral nature of smaller channels in the overall fluvial system is suggested by ubiquitous root traces in the bulk of the channel fill. The non-channelized, finer-grained facies are interpreted as overbank deposits including crevasse splays, levees, lakes, swamps/mires, and paleosols.

The predominance of heterolithic channel-fill in the Prince Creek Fm., the appearance of pelecypods and dinoflagellate cysts near the top of the formation, and the interfingering of the Prince Creek Fm. with shallow marine facies of the Schrader Bluff Fm. are all consistent with tidal influence in alluvial/deltaic deposits of the Prince Creek Fm.

# Fluvial response to climate change at the 100 kyr timescale: A case study during the Paleocene-Eocene Thermal Maximum in the Clarks Fork Basin, NW Wyoming, U.S.A.

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Within ancient fluvial successions it is often difficult to separate a uniquely climatic effect from autogenic and other allogenic controls due to problems of convergence/equifinality in preserved fluvial structure. However, if a climate change event is known a priori these problems may be largely circumvented. This study represents a preliminary assessment of the fluvial response to an abrupt (100-200 kyr) instance of global warming at the Paleocene-Eocene boundary (~55 Ma) within the Clarks Fork Basin of northwestern Wyoming (U.S.A.). The carbon flux into Earth's oceans and atmosphere associated with the Paleocene-Eocene Thermal Maximum (PETM) significantly impacted the global carbon budget and climate, shallowed latitudinal thermal gradients, and drastically altered ocean circulation patterns. The consequences for the hydrologic cycle were an increase in tropospheric humidity and a shift to a 'wet' climate state at mid-latitudes. However, evidence for both transient aridity (paleosol data) and increased seasonal precipitation (megafan deposition, computer simulations, and paleofloral data) exists at these latitudes during the PETM.

Based on data from this study and others, sand-body thicknesses increase by an order of magnitude during the PETM in the Clarks Fork Basin. However, bar clinoform heights decrease by ~0.2 m. Paleocurrents shift from a north-northwest direction to north-northeast and back to north-northwest directions across the event. The mean maximum grain size within channel lags doubles and caliche nodules make up nearly 100% of lag clast compositions during the PETM. These results suggest decreases in flow-depths for PETM rivers, but an increase in reworking and removal of floodplain fines. Because sedimentation rates remain constant across the PETM, these patterns imply a greater meandering and/or avulsion rate during the PETM. We tentatively suggest this data is more consistent with increased precipitation and seasonality of precipitation scenarios.

# Physics-based numerical modelling of a river-delta system

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Recent computer model studies on hypothetic river-delta systems may shed light on the functioning of both present-day and ancient real-world river-delta systems. Model boundary and initial conditions reflect the state of a river-delta system at an imaginary point in time and direct its future behaviour. Within the Delft3D software package, models have been set up, aiming at the simulation of alluvial deltas under progradational conditions. A stratigraphic module registers valuable information on the dynamic coupling of morphologic and sedimentologic process variables. Here, we highlight the role of the terrestrial feeder system, as signalled by Nemec (1990) and Davis (1899), so as to understand shoreline protuberances in their transgressive mode or bifurcate generation at some locus in the terrestric-oceanic system. Starting the simulations with a single-stream channel, fed by a constant upstream water discharge, and partially confined by its floodplain, sediment pulses are released towards a linear sloping reservoir, being devoid of any type of wave action, ambient currents or relict landforms. Divergent transport patterns, leading to bar formation at the river mouth, are followed by trunk channel bifurcation and subsequent spatial shift of channelized-unchannelized flow transition zones, to result in the establishment of a (partly subaerial) dendritic drainage network, known to be typical for a river-dominated delta. Meanwhile, simulations reveal distinct developments of planform and cross-sectional profile of the feeder channel(s), as well as sediment sorting patterns, therein. For instance, the initial straight channel, characterized by a relative high width-to-depth ratio, gives way to an anabranching planform that gradually transforms into a dominant meandering mode. Herewith associated, lateral, longitudinal and vertical grading patterns are established, including active bed coarsening and lateral fining in migrating bend axes. Changing delta morphology and stratigraphy are closely linked to parent channel dynamics; time-varying magnitude and rate of dispersal of sediments, derived from, or bypassing the lower river system, shape basinal levels (mouth-bar, levee and distibutary formation, closure and infill of distributaries). Notwithstanding several uncertainties related to the numerical modelling of mixed-load river systems, the present approach provides a new way to carefully disentangle the riverine rock record, in addition to physical modelling, real-world investigations and alternative model studies.

# Upper Ordovician fluvio-glacial architectures and facies suites, from outbursts to estuaries

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In North Africa, Upper Ordovician glacial sequences comprise fluvial successions deposited under sand-dominated conditions and high aggradation rates. They represent short-term depositional events ($10^3$-$10^4$ years) in relation with deglaciation to interglacial stages. Relationships with the subglacial drainage network (abundant *vs.* limited meltwater and sediment input, upstream connection with tunnel valleys) essentially controlled facies associations. Five types are illustrated.

1- **Braided channels and bars**. Channel deposits are composed of trough cross-beds, > 2 m in height. Bar deposits are made of small-scale trough and tabular cross-beds. Their assemblage compose several kilometres wide lenticular sand-bodies, 5-15 m in thickness, interfingered with diamictite units. They reflect proximal proglacial outwash fan environments (Mauritania, Algeria).

2- **Sand bars and sandy floodplains**. Channel belts comprise large-scale cross-stratified macroforms, > 3 m in height. Floodplain succession include sinuous channels, 10-50 m wide, with lateral accretion structures and are dominated by climbing ripple assemblages. They fill in glacially-cut depressions and reflect confined, proximal, flood-dominated outwash fan (Libya).

3- **Channel-levées systems, sandy floodplains**. Channels are 100-200 m in width, with 3-5 m high sandy levées. They are laterally equivalent to erosion-based (gutter cast), dm-to m-thick sand sheets. These tabular beds represent sand-dominated floodplain deposits within which waxing- to waning flow conditions are recorded. They fill in tunnel channels or palaeodepression up to 200 m in depth and reflect a type of confined, distal, flood-dominated outwash fan (Morocco, Algeria, Libya).

4- **Sinuous channel deposits with no lateral accretion.** They are characterized by several metres thick climbing dune assemblages and thin-bedded floodplain sandstones. The floodplain is marked by sandy Bouma-like facies sequences, rare silty channel plugs, and small-scale secondary channels. This facies association constitutes topsets of 50 km long delta systems, with thicknesses ranging from 5 (downstream) to 50 m (upstream). They reflect outburst-dominated outwash fans (Algeria, Libya).

5- **Meandering channels with large-scale lateral accretion structures**. These channels, up to 10 m in height, are associated with km-wide point bars. Channels are plugged by coarse-grained cross-bedded sandstones (flood-related plug) or by finer-grained facies (abandonment). Waning-flow sequences are preserved in the upper part of point bars. These deposits form sheet-like units reflecting early post-glacial sea-level rise. Estuarine conditions may locally arise (Morocco, Libya).

# Chute channels and meander cutoff in the Holocene deposits of the Florence alluvial plain (Italy).

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The meander cutoff process is mostly known for the neck cutoff, whereas minor attention has been dedicated to the chute cutoff, where chute channels form in the meander neck and tend to rip it up during the main floods (McGowen and Garner, 1970 ; Gay et al., 1998).

This work deals with the sedimentary features of chute channels formed in the down-river edges of the meander neck. The study deposits are located along the northern margin of the Firenze-Prato-Pistoia Basin and belong to the Holocene succession of the Florence alluvial plain.

In this succession, two main types of chute channels have been recognised at the top of point bar deposits. Type1 is represented by 3-6 m wide and 0.5-1 m deep straight channels filled with mud aggregates and overlaying a basal gravel lag made of reworked caliches. These channels drained the point bar top, and are thought to be have been initiated as runoff channels and successively widened during floods, when a shallow flow encompassed the point bar (Johnson and Paynter, 1967). Type 2 channels, 3-6 m wide and 1-1.5 m deep, are moderately to high sinuous and filled with well-stratified gravels sourced from the nearby rocky relieves. According to their infill, the type2 channels were connected with the main channel, and experienced the fluctuations due to alternating flood and low-flow stages.

Although both type1 and type2 channels occur as isolated, the transition from type1 to type2 is clearly documented. Such a transition is considered to be the result of the meander cutoff dynamics described by Gay et al. (1998). In such frame, the type1 chute channels represent the early stage of cutoff phase, when an headcut is incised on the down-river edges of the meander neck. This channel is active during the floods and drains only the point bar top, as confirmed by the caliche channel lag and transport of mud aggregates. The nickpoint of the headcut migrates upriver across the meander neck during the floods, when fast currents shape it into a straight route. The turning of type1 into type2 channel represents the connection of the upriver migrating headcut with the main channel and the finishing of the cutoff process. At this stage the cutoff channel is permanently drained and receives bedload from the main channel. The progressive shaping of the newly formed channel will lead it to turn into the main channel and formation of an oxbow lake in the abandoned meander branch.

# Pedologic and sedimentologic criteria for recognition of floodplain sub-environments in a Triassic anabranching river deposit.

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The stratigraphic architecture of deposits generated by anabranching fluvial systems is characterized by dominance of fine-grained extra-channel deposits over channel-fill deposits. In addition to channel-fill bodies, sandy and heterolithic deposits produced by non-channelized flows constitute a major part of such succession. As a result, the total spectrum of sandy and heterolithic bodies of such successions show wide variations in geometry, scale and internal organization. We present here contrasting internal organization and geometry of the sandy and heterolithic bodies and characters of associated paleosol profiles preserved in a Triassic mud-dominated fluvial succession and demonstrate how it can be used to identify different sub-environments within a wide floodplain.

The Middle Triassic Denwa Formation (~300 m) to the Satpura Gondwana basin of central India has been interpreted to be deposits of supply constrained, low energy, ephemeral, anabranching fluvial system under a semiarid climatic setting. A fluvial system having a very wide floodplain that is traversed by channels of varying scale including a few narrow, stable trunk channels was envisaged. It is an overwhelmingly mud-dominated succession. Mudstones are pedogenically modified and massive. They enclose dispersed sandy and heterolithic bodies of varied dimensions and sedimentary characteristics. Channel sandbodies are sparse, lenticular to short tabular in morphology and seldom show amalgamation. There are also numerous sheet to tabular bodies, that are comparable in dimension with the channel bodies, but having sub-horizontal or complexly organized sand-mud heterolithic fills. These bodies were interpreted as deposits of weakly -/non -channelized flows related to splay/avulsion processes.

The paleosol profiles developed on the mudstones and splay/avulsion bodies are similar to modern calcic vertisols. They are of 3 basic associations: A) Simple immature profiles developed in vertically juxtaposed mudstone - splay sandstone complexes. This association developed in proximal floodplain areas that received high but episodic sedimentation. B) Thick sub-mature cumulative profiles developed in very thick mudstone intervals associated with thin and fine-grained splay deposits. It was developed in distal floodplain areas bordering ephemeral floodplain lakes-ponds that received low but rather continuous supply of fines from a number of splays. C) Mature profiles showing evidences of multi-phase pedogenesis developed in mudstones underlying channel-fill bodies. These represent abandoned floodplain reaches denied of sediment input for a period long enough for the development of mature profiles.

# Estimating width and thickness of fluvial channel bodies: a pragmatic approach from the rock record

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We frequently need to know the width and thickness (W and T) of river channel deposits in the geological record because of their importance as hydrocarbon reservoirs and aquifers. To date, there has been no adequate compilation of these properties, nor a classification that represents the types of channel body that geologists can actually identify in the rock record. A commonly used approach draws on W and T of modern, freely migrating channels and channel belts and equations derived from them. However, surface dimensions may be a poor guide to those of preserved channel bodies, which are frequently amalgamated vertically and laterally, and available equations fail to represent the diversity of fluvial style and the fact that many channels and valleys are cut into resistant substrates. According to a widely used paradigm in sequence stratigraphy, channel-body geometry largely reflects the rate of accommodation creation in basins, but this assumption has not been thoroughly tested.

Based on published literature from the ancient record, I have plotted on W/T diagrams the dimensions of more than 1500 channel bodies and valley fills for which reliable information are available, using a classification based largely on their geomorphic setting. The literature information ranges from precise measurements of individual bodies, to size ranges for hundreds of bodies, to minimum values for very large bodies. Because the width of sub-surface channel bodies is particularly difficult to estimate from drilling data, the dataset can assist by providing a maximum or common width range for a chosen thickness. The dataset shows that real channel bodies exhibit a disturbingly large width range; for example, documented meandering-channel bodies 10 m thick vary in width from <100 m to 10 km – a variation of more than two orders of magnitude that is not represented by simple equations. Key points of the compilation include:

1) Braided and low-sinuosity river deposits are overwhelmingly dominant in terms of scale, with examples more than 1200 m thick, 1300 km wide, and with W/T >15,000. They formed during periods of active tectonism and slow exhumation, and have probably been the dominant style throughout Earth history. In contrast, the familiar meandering river deposits with laterally accreted point bars are restricted in scale (less than 50 m thick) and appear to be minor components of the fluvial record. They seem never to have built basin-scale deposits, as some computer models have implied.

2) Fixed channel deposits include those of anastomosing rivers, delta distributaries, distal alluvial fans, crevasse channels, and channels in eolian dunefields. Most have W/T ratios less than 100 and commonly less than 15. Although some narrow channel bodies reflect rapid accommodation creation, many show evidence for tough banks and rapid filling, suggesting that most owe their narrow form to local geomorphic factors. The convergence in form across this diverse group represents the *initial aspect ratio* of newly formed channels (width / depth mainly <25), with subsequent modest widening. Some exceptionally narrow channel bodies (W/T <1 in some cases) represent the effects of thickening due to channel reoccupation, compaction, and faulting.

3) Valleys cut into bedrock tend to be relatively narrower than those cut into slightly older sediments. In the latter group, Carboniferous valley fills appear to be larger than Jurassic and Cretaceous valley fills, perhaps due to the effects of Late Paleozoic glacioeustasy. Glacial tunnel valleys are relatively narrow, reflecting catastrophic flow events that incised bedrock and frozen ground.

# Monsoon-generated fluvial sequences: Climatic control on alluvial architecture in the Himalayan Foreland Basin of India during the late Quaternary

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In the Himalayan Foreland Basin of northern India, cliff exposures of alluvium extend along the Ganga and other big rivers in the western and southern plains, some 1200 km inland. These dryland river successions date back to ~130 ka, spanning the last glacial cycle. A remarkable aspect of the cliffs is the presence of discontinuity-bounded sequences a few meters to tens of meters thick, the bounding surfaces of which can be traced for tens of kilometers. Some surfaces are gullied erosional surfaces with local groundwater cements and a mantle of reworked gravel. Others represent large badland gully systems, and include former gullies up to 10 m deep filled with colluvium and reworked carbonate gravel. Still others represent an abrupt change from floodplain to lacustrine and eolian deposits, implying major changes of paleoenvironment.

Fluctuations in monsoonal precipitation – driven by changes in sun's energy and glacial boundary conditions -- have affected large parts of Asia, as documented from computer-based modeling and regional facies evidence. These fluctuations should have exerted a strong driving force on the alluvial stratigraphy of the Himalayan Foreland Basin. We set out to test this hypothesis.

Based on OSL, ITL, and radiocarbon dates, our age model shows a reasonable first-order correlation between precipitation changes inferred from modeling and periods of incision and accumulation observed in the field. Fluvial activity persisted through MIS (Marine Isotope Stage) 5 to 3, when models indicate a strong monsoon. Near the onset of the Last Glacial Maximum (LGM) in MIS 2, the Ganga and other rivers experienced reduced discharge, as shown by the widespread presence of lacustrine and eolian deposits in the river valleys. As precipitation intensified following the LGM (MIS 2 to 1), incision and valley formation affected rivers across northern India and Nepal, and a large sediment pulse reached the delta and Bengal Fan. Drier periods recorded locally may correspond to the Younger Dryas. Finally, rivers aggraded as precipitation declined after about 6 ka B.P. Modest eolian activity is recorded on the plains after about 30 ka B.P., but no earlier deposits are known.

The big rivers are incised through wide interfluves traversed by small "plains-fed" rivers generated from monsoonal springs. The interfluves appear to have been constructed largely by the plains-fed rivers, which built up substantial sediment accumulations reworked from Himalayan and cratonic sources. Thus, mountain- and plains-fed rivers appear to have acted as coeval, parallel systems.

# Anatomy of Late Ordovician channels into a fluvio-glacial outburst-related delta plain

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At the end of the Ordovician, a continental-scale ice sheet extended from present-day West Africa to Saudi Arabia. In the study area (Tihemboka High, SW Libya), the Late Ordovician glacial succession is mainly recording a stillstand during final ice-sheet retreat. It corresponds to the stabilisation of an ice front and the building up of a proglacial depositional system. The architecture of this proglacial system is a multilobate fluvial-dominated deltaic complex organised in topset, foreset and bottomset. A thinning-upward suite from very coarse- to medium-grained sandstones characterizes topset successions. These topsets are interpreted as a fluvial delta plain evolving to the north in prograding lobe systems (foresets). Topset succession is up to 50 m thick upstream (to the South), gets progressively thinner northward to finally pinch out 30 km away from the inferred ice-front. This proglacial fluvial system generates particular channels. In order to study the facies and architecture of these channels, outcrops logs and high-resolution satellite images (SPOT) have been used. Special attention is also given to their relationships with the adjacent floodplain deposits.

Fluvial delta plain architecture is best highlighted on satellites images. The latter reveals a number of sinuous to straight channels exposed as inverted topographies and forming sandstones ribbons (“cordons” structures). Their axis is oriented to the NW. Slope gradient of the upper structural surface is in the 0.5-2 m/km range. Channels are organised in superimposed and intersecting networks representing at least three generations. Each ribbon has a constant width in the 200 to 700 m range. They are 10 to 30 m thick and up to 10 km long. Thick-bedded infill deposits generally consist at the base of a 2 to 5 m thick massive coarse to medium-grained sandstone including mm to cm-scale rip-up clasts. Above, the remaining infill is represented by 10 to 25 m thick medium-grained sandstones. This unit is constituted by large climbing dunes assemblages. Laterally thinner-bedded succession including horizontal laminations and ripples are ascribed to lateral (or longitudinal?) channel bar and floodplain deposits. This system is interpreted as a two stages depositional dynamic: (1) "normal" inter-outburst stages setting a compartmentalized channels/floodplain system and (2) an outburst-related coarser-grained channel plugs of the ribbons. The three different generations of channel network are consequently inferred to be three major outbursts during the ice-front activity.

# Alluvial architecture of two Holocene fluvio-deltaic sequences: the Rhine-Meuse delta (The Netherlands) and the lower Mississippi valley (USA)

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Many (petroleum) geologists use numerical models to reproduce, understand, and predict (three-dimensional) fluvial stratigraphy. An issue with modelling is that there is an ongoing shortage of high-quality, natural field data to feed the models. With this in mind, the author quantified the alluvial architecture of two Holocene fluvio-deltaic sequences (Rhine-Meuse delta, The Netherlands and the Lower Mississippi Valley, USA). The alluvial-architecture parameters explored include sand-body geometry, channel-belt deposit proportion (CDP), and connectedness ratio (CR). To quantify these, several cross sections -based on high-resolution lithologic corings- were constructed covering the complete fluvio-deltaic succession.

The spatial trends in the alluvial architecture of the Holocene Rhine-Meuse and Mississippi River successions appear to be similar. For instance, CDP in both study areas decreases from 0.7 to 0.3 in a downstream direction. In other words, the amount of sand in the sequences decreases downdip. This may have important implications for hydrocarbon exploration and production, because reservoir rocks commonly consist of channel-belt sandstones. The spatial trends in alluvial architecture of the Rhine-Meuse delta and the Lower Mississippi Valley are caused by spatial variations in channel-belt geometry, aggradation rate, and floodplain geometry. These in turn are influenced by external factors (e.g., discharge and sediment supply, base-level change), but also by internal ones (e.g., lateral channel migration rate, avulsion mechanisms). Traditional sequence stratigraphic concepts emphasize external controls acting upon the river system, notably relative base level change. However, the presented alluvial-architecture studies show that the architecture is also significantly controlled by internal factors. Therefore, it is generally relevant to consider the interaction between external and internal factors in all alluvial-architecture studies, including modelling.

Besides quantitative architectural data, the author also provides constraints for relevant model input parameters, distilled from published data from the Rhine-Meuse delta. The presented high-quality field data on alluvial architecture and the figures for model parameters hopefully contribute to the improvement of alluvial-architecture models, an enhanced understanding of fluvial stratigraphy and delta formation, and to better characterizations of hydrocarbon reservoirs.

## Variability of abandoned channel fills and the effect on sandstone connectivity

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Abandoned channel fills in alluvium can disrupt lateral connectivity of permeable channel sands. The effectiveness of this reduced connectivity is dependent on the geometry of the filled channel or stream course and the type of channel fill. Three styles of channel fills are described.

The most commonly described fills are clay plugs, produced by rapid neck cutoffs of single meander loops and short channel courses of several meander loops, or by an avulsion that abandons long channel segments. Clay plugs that fill the oxbow lakes within the single meander loops have very low permeability, but are relatively local in extent. If the number of cutoffs is limited, connectivity of the blanket channel sand is not significantly impacted. In contrast, if the meandering stream has a high suspended load, high sinuosity, and a stable channel-belt position, neck cutoffs can be numerous and form bands along both sides of the channel belt that substantially affect lateral sandstone connectivity. As the length of the abandoned channel course increases, connectivity within the channel sand is reduced.

Not all fill of rapidly abandoned channels is dominantly clay. A channel can meander so rapidly that the active channel crosscuts incompletely filled abandoned channels. Channel fill can include bedded sand and silt of a natural-levee and/or crevasse deposit from the active channel into the abandoned channel depression. These coarser deposits are interbedded with normal clayey channel fill that accumulates between floods. In these highly variable abandoned channel fills, the clay is not as laterally extensive and there better connectivity in the sand body than where a uniform clay plug fills the abandoned channels.

Clay is a minor component of channel fill where channels are abandoned slowly. As the amount of bedload relative to suspended load increases, sinuosity decreases and chute cutoffs are more likely than neck cutoffs. In chute cutoffs and some abandoned channel courses, flow is split between two channels: the first channel is abandoned slowly and fills with interbedded fine sand and silt as the second channel becomes dominant. The final fill can be clayey, but this clay plug is thinner and narrower than that of a neck cutoff. Though the permeability of the sandy and silty chute-channel fill is less than that of the surrounding channel sand, it does not prevent connectivity. Any clay plug is relatively limited in size and is less effective at reducing lateral connectivity than where clay plugs fill the entire abandoned channel.

# Controls on sandbody distribution and stratigraphic architecture in coastal-plain strata, Blackhawk Formation, Wasatch Plateau, Utah

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Current models of alluvial and coastal-plain facies architecture emphasise the role of tectonic subsidence, avulsion frequency, and proximity to the coeval shoreline as the major controls on sandbody distribution and size. Here these models are tested using outcrop data from the Cretaceous Blackhawk Formation, which forms a thick (200-300 m) interval of coastal-plain deposits in a continuous, 100-km long escarpment along the eastern edge of the Wasatch Plateau, central Utah. The escarpment is oriented sub-parallel to regional depositional strike, and is contiguous with the extensively documented, large-scale (c. 250-km long), dip-oriented exposures of the Book Cliffs. The Blackhawk Formation is coincident with overall progradation and decreasing aggradation of the coeval shoreline, although this trend is punctuated by numerous smaller scale transgressions.

The Blackhawk Formation exhibits overall trends of increasing width, abundance and interconnectedness of major fluvial channel-fill sandbodies from (1) its base to its top, and (2) along depositional strike from south to north. The first pattern coincides with a change from rapidly subsiding, coal-bearing, lower coastal plain (few, narrow sandbodies) to slowly subsiding, coal-poor, upper coastal plain (abundant, wide sandbodies). The second pattern coincides with thickening of the coastal-plain section from south to north, and is interpreted to reflect the location of a long-lived sediment entry point in the more rapidly subsiding northern part of the transect. There are significant local variations from these general trends. Some stratigraphic intervals, particularly in the lower and middle part of the formation, contain anomalously thick, wide sandbodies that appear to be confined to incised valleys. In the middle and upper part of the formation, vertical and offset lateral stacking of sandbodies produces connected clusters that do not appear to occur within valleys or at distinct stratigraphic intervals; these clusters are interpreted to record variations in avulsion style. The predominance of valley fills in the lower-to middle Blackhawk Formation likely reflects a lower coastal-plain setting, with valleys formed by the headward retreat of knick-points from falling-stage and lowstand shorelines. The occurrence of "avulsion clusters" in the middle-to-upper Blackhawk Formation likely reflects autocyclic processes at a regional scale on the upper coastal plain.

# Distributary Fluvial Systems: Characteristics, Distribution and Controls on Development.

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Distributary channel networks such as deltas, distributary fluvial systems ('megafans' and fluvial fans) and alluvial fans develop where alluvial systems undergo net aggradation and are not confined within valleys. We describe the characteristics, distribution and controls on the development of distributary fluvial systems and suggest that they represent the principal form of fluvial and alluvial deposits preserved in the stratigraphic record.

In unconfined aggradational systems, the size of the distributary fluvial system is dependent on the available horizontal accommodation space which is a function of the interaction between sediment supply, discharge, base-level, subsidence, and sedimentary basin geometry. In actively subsiding basins, distributary fluvial systems range from 700 km to less than 1 km in length before they terminate at their base-level (at an axial fluvial system, lake or playa). The largest distributary channel networks are developed in foreland basins (e.g. the Andean, Himalayan and Alaskan forelands) which display a gentle basinwards dip that may extend uninterrupted for up to 700 km, permitting the development of extensive distributary channel networks. In contrast, extensional and strike-slip basins (e.g. Rio Grande rift and Basin and Range) display smaller distributary channel systems up to 50 km in length as the space available for their development is restricted by fault spacing, gradient changes between adjacent faults and base-level changes within and between adjacent fault blocks.

Despite the range of scales over which these systems develop, a series of observations common to each system permits the definition of a number of depositional zones. The most proximal zone adjacent to the distributary intersection point consists of pebbly sands and gravels deposited in rivers forming laterally amalgamated coarse deposits. These pass downdip into a zone consisting of discrete channels which may be meandering, braided, anastamosing or straight channels with intervening overbank areas. A progressive down-dip decrease in the proportion of channel to overbank deposits occurs from the apex to the termination point. The amount of overbank deposits is related to the size of the river, sediment load transported, and the length of the distributary system. Relatively short systems may only display the proximal conglomerate and pebbly sandstone deposits, in contrast larger scale systems such as the Kosi

River (Himalayan foreland) are dominated by overbank deposits in their lower reaches. Termination of the distributary system occurs at either an axial fluvial system if externally drained or at a lake or playa if internally drained.

Distributary fluvial systems frequently display downstream flow dissipation through channel bifurcation with a decrease in channel size. In perennial systems at all flow stages at least a single fluvial channel is active, and during high stage flow a number of smaller fluvial channels and the intervening floodplain area may be active across discrete areas of the distributary system (e.g. Andean foreland and Brazilian craton). Fluvial systems characterised by more intermittent flow also display similar downstream characteristics, but interchannel areas may be strongly modified by aeolian processes and channel activity is restricted (e.g. northern and southern Africa, SW USA, Australia, parts of Eurasia and South America.. Our observations indicate that distributary fluvial systems dominate present day actively subsiding aggradational settings, where they have a high preservation potential: systems of this character are therefore likely to dominate the rock record.

# Ichnopedologic characteristics of fluvial and floodplain deposits: A comparison of modern and ancient deposits

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Studies of modern-day fluvial systems under different geomorphologic and climatic settings demonstrate that a well-defined relationship exists between depositional environments, biota, soils, hydrology, and climate. These relationships are preserved in alluvial and fluvial deposits as paleosols and trace fossils, which are a record of soil formation and biota on landscapes that resulted from (1) different magnitude and frequencies of flooding events and the amount of time in between those events, (2) proximity to flooding events, (3) position and fluctuation of the groundwater profile, (4) local topography, (5) sediment texture and composition, and (6) the climatic in terms of seasonal variability in temperature and precipitation. The abundance and diversity of traces produced by microbes, plants, invertebrates, and vertebrates during subaerial conditions as part of the soil-forming factors is dependent on the frequency and magnitude of flooding events and sediment accumulation rates. For example, the most penetrative and diverse and abundant traces are those found in well-drained, aerated floodplain soils with low disturbance and low rates sediment accumulation. Traces in aquatic or in poorly drained settings with rapid sediment accumulation will be much less penetrative and much less diverse and abundant.

Ichnopedologic associations—paleosols and their trace fossils—are linkages to understanding the soil-water balance of the climate under which they formed, as well as the relative maturity and age of pedogenically modified deposits with respect to the rates of aggradation or degradation in a landscape setting. These ichnopedologic associations are as potentially variable in the geologic record as they are today, indicating a variety of simple, compound, or cumulic, poorly to well-developed paleosols in fluvial settings with seasonally to annually, poorly to imperfectly to well-drained conditions. Basic patterns in ichnodiversity and tiering and paleosol formation are evident based on empirical observations made from modern depositional systems, biota, and landscapes. Understanding these patterns will be extremely useful for reconstructing depositional histories of continental strata from the rock record and distinguishing fluvial from lacustrine and marginal-marine deposits.

# Continental traces in tidal deposits in an intracratonic playa lake: An example of how sedimentary facies might sway ichnologic interpretations

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A study of the Kalaweerina Creek (KC) terminal splay complex (TSC) in the dryland setting of Lake Eyre in central Australia illustrates that sedimentary and biogenic structures previously considered indicative of marine tidal depositional environments are also generated in an intracratonic playa lake environment. Traces produced by a variety of terrestrial organisms cross cut such sedimentary structures as cross-beds with paired mud drapes, cross-bedding reactivation surfaces, herringbone cross-bedding, flaser, wavy, and lenticular bedding, and desiccation cracks. The architectural and surficial morphology and fill characteristics of the traces observed in trenches excavated in the TSC were characterized. Tracemakers were identified from the trenches, as well as from traces studied on the playa surface and from along the KC floodplain.

Three morphotypes dominated the TSC sediments, all of which were constructed during subaerial conditions. Vertical to subvertical tubes 0.3–1.0 cm in diameter and 5–30 cm deep, sometimes with a bulbous termination 1.3–1.5 times the tube diameter, are common in tabular and trough cross-stratified beds with mud drapes, and are less common in massive to laminated mud. Tubes are filled with sand, mud, or a combination of interlayered fill. Those tubes that open to the surface are unfilled. Tube walls are smooth but sometimes contain thin, transverse scratches. Many tubes are constructed and occupied by wolf spiders. Subvertical to subhorizontal, slightly sinuous tubes ~0.05–0.2 cm in diameter that often branch laterally and downward are common in massive to laminated mud and less common in sandier beds. Groups of tubes are 5–20 cm deep. Tubes do not appear to decrease in diameter even after they branch. Some tubes have a thin mud lining, including some found in sand beds. Most tubes are filled with mud or sand. Some tubes contain the plant roots, which is unequivocal evidence that they produced them. Several tubes contain pellets that resulted from some unknown organism that fed on the plant roots. Mostly elliptical, but some circular, elongate tubes typically with a flattened but sloped base and domal roof are found in both sand- and mud-rich layers and form an interconnected system. Tube diameters range from ~0.5–2 cm with width-to-height ratios of 1–2:1. Tubes form a simple system of subvertical to subhorizontal interconnected tubes up to 40 cm deep. In some systems, the central tube forms a downward spiral with several lateral tubes 5–20 cm long branching from it. In others, particularly in the upper part of a system, smaller diameter tubes interconnect larger diameter tubes. Tubes in mud are often lined or filled with sand sourced from the surface or a lower sand bed. Ants construct these tube systems, identified by their presence in the tubes along with their larvae and pupation cocoons.

Cross sections through spider burrows, ant nests, and plant roots in tidal sedimentary structures are easily mistaken for such trace fossils as *Skolithos*, *Gyrolithes*, *Rhizocorallium*, *and Chondrites*. These ichnogenera—considered as morphotypes or form genera—are found mostly in shallow marine environments and are used to distinguish such ichnofacies as the *Skolithos*, *Glossifungites*, and *Cruziana* ichnofacies. Co-occurrence of these traces with sedimentary structures indicative of tidal processes, however, could easily persuade an observer to interpret them as evidence for shallow marine intertidal settings based on the superficial resemblance of these traces to those found in intertidal to subtidal marine environments. Our observations suggest that interpretations of similar ancient deposits may require re-evaluation and alternative depositional environments should be considered when interpreting strata containing these classic marine tidal indicators, particularly where outcrops or core are limited.

# Paleohydrology: A tool for restitution of catchment area and climatic fluctuations. Case study from the Oligocene of South-eastern France.

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In fluvial successions, channel-fill geometry and internal structures are commonly used to define the fluvial style. On modern systems, the hydrological parameters are most often defined from the channel bankfull width and depth in association to sediment distribution. Paleohydrological parameters such as discharge, catchment area are also reconstructed from fluvial bar geometry and grain-size. Such results are mostly used to characterize paleoclimatic conditions during sedimentation.

We present here the results from the Oligocene fluvial meandering succession located in the western alpine foreland basin (south-eastern France): Barrême and Digne area. We investigate on a regional scale the drainage pattern and the climatic fluctuations over a 2Ma period. The height of the point bars is considered as the bankfull depth. The channel bankfull width is then calculated using classic equations linking channel bankfull width and depth in fluvial meandering systems.

Paleohydrological reconstruction is based on channel-point bar thicknesses that range from 4 to 9m. Estimated channel bankfull widths vary at most of 30%, depending on the equation. These results will greatly influence the other parameters such as discharge, drainage area, stream length. Data from the Barrême basin enable us to define the best set of equations as the source area is precisely known based on sandstone mineralogy. The set is then being used for the other basins, thus reducing the uncertainties on the hydrological parameters. Drainage area of the Barrême and Digne paleomeandering systems are estimated around 1200 $km^2$ and 2600 $km^2$, respectively. Stream length was in the range of 100 km for Barrême with a source in the Embrun Ubaye area and in the range of 200 km for the Digne system with a source in the internal alps to be precised.

Paleoclimatic study is conducted based on the assumption that there was no major paleogeographic rearrangement during the upper Oligocene-lower Miocene. Considering a given catchment area, changes in the discharge are then related to climatic fluctuations, pointing to humid and semi-arid periods. The Digne system (late Chattian) deposited during a relatively humid period and did not record major climatic fluctuations, whereas the Barrême system (Late Chattian to early Aquitanian) recorded significant climatic fluctuations from humid to semi-arid conditions. These results are in agreement with those from other western European continental climatic reconstruction.

These first results, show the large potential of paleohydrology on paleogeographical and paleoclimatic reconstitutions when few outcrops of former fluvial systems are available.

# A persisting preference for progressive piling: Rock vs. river biases in the medium-term processes and architectural complexity of channel-belt stacking

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From the fluid prospective, fluvial sediments constitute permeable (net) conduits wrapped within an impermeable casing (gross minus net). Most simplistically, this translates to net channel belts encased within gross backswamp units. Understanding the dimensions and stacking arrangements of channel belts thus becomes a priority and a key research driver. This priority derives primarily from the rock perspective, with sediment of modern rivers used more as a source for inference. Expectedly, both river and rock data sources have inherent biases that color interpretations. In the case of recent river strata, the surficial view is the most easily attained, leading to a preference for mapping channel plain form, channel-belt width, and surficial down-stepping terraces. These data are commonly augmented though cheap and easily targeted shallow-subsurface techniques. Though bearing excellent 2-D and good 3-D resolution, studies of extant river strata are limited by a short temporal scale (typically $\leq 10^4$ yr) and the inherent uniqueness of the very recent time period sampled. Rock studies alternatively sample longer and more diverse times because abundant outcrop, log, and core data provide a better vertical view. Outcrop and geophysical data from rock, however, typically offer less cross-sectional and/or map-view control than data from river studies. Study of medium-term ($10^4$-$10^5$ yrs) autogenic and allogenic processes and their rock expression are thus hampered temporally in river and spatially in rock data.

Architectural complexity introduced by medium-term processes is well addressed where revealed directly by the available data set, but is rarely addressed where only implicit from other data sources. A specific example can be found in the consideration of channel-belt stacking. Vertical views of fluvial strata grant an impression of channel belts that have stacked progressively upon each other with no major reversals. Observations from the recent, however, reveal that aggradation commonly reverses then reinitiates on medium-term scales. The architectural expression of this seesaw nature of aggradation is high-order incisional surfaces. These surfaces are rarely considered in rock data where they are cryptic compared to the more apparent progressive stacking. Medium-term allogenic processes are usually interpreted here only from obvious vertical changes (e.g., belt amalgamation shifts, etc.). High-order surfaces are often detected in surficial sediments where lateral exposure is emphasized, but durations here are usually too short to reveal the high complexity these surfaces may eventually preserve. Progressive stacking likely occurs only in systems that are very close the base-level buttress and/or rapidly subsiding or incising. Though rarely reported from rock studies, high-order surfaces are probably fairly common.

# From Outcrop to Subsurface: An Analogue Study of a Terminal Alluvial Plain (Upper Triassic, Keuper, SW-Germany).

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Outcrop analogue studies combined with a process-based genetic model continue to represent an adequate tool to understand subsurface successions better. At continuously exposed rock faces preservation potential, depositional cycle stacking patterns and sedimentary environment can be investigated quantitatively and often three-dimensional. These architectural rules are applied then to comparable subsurface data attached with any rock properties gained also in the outcrops.

We investigated outcrops of the SW-German Arnstadt-Formation (Norian, Middle Keuper, Upper Triassic) which act as hydrocarbon reservoirs in S-Germany and the North Sea. With large-scale outcrop panels the spatial distribution and geometry of fluvial genetic units, permeability barriers and lithofacies was determined. In total 1360 Porosity, 1860 Permeability and 4500 gamma-ray measurements were taken and interpolated with the gOcad software in order to generate local 3-D subsurface models and to characterize reservoir and seal quality.

Detritus was shed from a strongly monsoonal influenced hinterland (Vindelician High and Bohemian Massiv) in the south into the land-locked arid to semiarid germanic basin forming multiple stacked sandstone-mudstone-dolostone cycles. Towards the basin centre, sand tongues convert into mudstone-dolostone couplets of a playa system. Hierarchically organized lower order cycles are traceable basin-wide from the central playa to the stacked fluvial units of the alluvial plain. The meso-scale cycles at basin margin are typically 5-15 m thick and characterized by erosional bases, sediment bypass, channel-lags and coarse-grained sandstones of braided and meandering river deposits topped by suspension load deposits, which may show an intense pedogenic overprint causing seal leakage (pedoturbation and calcrete formation). Two to three stacked meso-scale cycles form a macro-scale cycle, and at least one overall mega-scale cycle is recognized

We introduce a genetic depositional model of fluvial and lacustrine interaction governed by orbital forcing of monsoonal activity. Increase in precipitation in the hinterland caused increase of transport capacity and sand tongues developed. In consequence, lake level raised and playa and lacustrine environments dominated facies proportions. Using evolutionary spectral analysis, frequencies of these basin wide traceable cycles are found to be in the 413 ka (E1) band, while 123 and 95 ka (E1 + E1) intervals are recognizable only in basinal areas. Individual mudstone-dolostone couplets represent the 18+21,5ka (P1+P2) precession cycle. Reservoir properties are directly related to that cyclicity so a forecast for unknown areas is possible: Coinciding with increasing palaeo-humidity along a macro-scale cycle, reservoir thickness in proximal areas reduces from 10m to 3m but reach farer out into the basin and seals tend to be thicker and less leaky. Typical values of reservoir properties comprise in distal areas from 0.1 to 50 mD (mostly around 1mD) and 8-23% porosity (mostly around 12%) and in proximal areas from 50 to 5000 mD (mostly around 1000mD) and 17-27% porosity (mostly around 23%).

With such datasets, it is possible to estimate rock properties and reservoir architecture from subsurface data to optimize the exploration process and risk analysis. Preservation potential governs reservoir and seal quality and can be forecasted in a regional scale by sequence stratigraphic techniques although it is obvious that due to the natural heterogeneity of fluvial systems no absolute forecast can be given beyond this scale yet.

# Coal seams, coarse grained channels and lacustrine river mouths: A lesson in alluvial depositional dynamics (Junggar-Basin, NW-China, Upper Triassic).

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In the Haojiagou valley (40km W of Urumqi, Junggar-Basin, Xinjiang, NW-China) a fluvial to deltaic succession of the Middle Triassic Huangshanjie and the Upper Triassic Haojiagou formation is exposed. The sedimentary inventory comprises gravely channel bodies, sheet like sandy and clayey units, as well as ferrocrete horizons and coal seams. Literature suggests that the whole section is related to a huge lake in a broken foreland basin of the ancestral Tian Shan.

A broad spectrum of different lithofaciestypes and architectural elements is recognized and related to four principal depositional environments: the lacustrine delta slope with turbiditic features, delta front and lakeshore, the coastal backswamps and the distal alluvial plain fed from a near hinterland. Depositional dynamics show an overall progradational trend of the alluvial plain resulting in a landward stepping of the section. Preservation potential is preferentially good in such a palaeogeographical position and suitable exposures make the section a natural laboratory.

Statistical evaluation of channel body size, geometry, interconnectedness and stacking patterns was done at a 600 m thick and 1 km wide two-dimensional section, which was composed from hundreds of small scale outcrop photos with a spectacular mounting and photo-surveying technique. In addition, 1.4 km of detailed lithological section was logged, accompanied by 4500 gamma ray measurements. This dataset show best the stacking patterns of the sedimentary architecture as a proxy for regional sequence stratigraphic cycles. Depositional trends show a clear four-fold hierarchy, while only the macro- and overall scale reveals sequence stratigraphic relevance. Micro- and meso scale cycles are likely to be governed or masked by autocyclic processes.

It could be demonstrated that gamma log interpretation cannot be done in a standard way, as there were recognized many unusual and misleading log shapes. An outcrop control is essential to detect the exact position, thickness and make up of the lithofacies. Additionally we attached porosity and permeability measurements to the rock types.

This data set may be used as an outcrop analogue. All kind of data gained from this easily accessible large scale outcrops can be transferred to inaccessible but comparable subsurface areas where less information is available or interpolation schemes for existing data sets are needed. Our research results are highly valuable to establish time lines at a regional scale and for prediction of facies transitions, geobody architecture and their petrophysical properties.

In particular, this is important as in some areas of the Junggar-Basin these units act as prominent hydrocarbon reservoirs and seals. Also, the up to 10m thick coal seams play an important economic role, so the study is planed to act as a basic reference for further investigations and facies predictions in the area.

# Revising assumptions about short-term hydrosedimentary processes and the preservation of river dune deposits

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Interactions between turbulent flow, sediment transport, and bedform development were extensively explained in many books and papers from e.g., John Allen, Mike Leeder, Jim Best, and John Bridge, and resulting stratigraphy was abundantly illustrated with experimental deposits or natural modern fluvial stratification. This presentation targets such processes at two short-time scales: 1) from seconds, to minutes and hours in the case of individual dune migration, and the passage of successive dunes, and 2) from weeks to months for dune-bed morphology at the channel scale over annual peak discharge. The objectives of this talk are to review a few recently rejected assumptions about the controls on fine-resolution stratigraphy, to present new observations from a large meandering river that question more of our common assumptions, and to discuss how these findings can be used to better understand short-term morphodynamics and to interpret fluvial stratigraphy.

Challenging our common assumptions about the controls on preserved stratigraphy can start just by an idea: Paola and Borgman (1991) though that variability in the height (or scour depth) of successive bedforms was sufficient to produce stratigraphy, without any aggradation. Yet their theory was based on our assumption that bedform amplitude spreads evenly around a mean bed level– but our experiments demonstrated that individual dune migration–and turbulent flow can cause deep bed scouring without change in dune crest elevation. Videos will be presented on this process–and others such as dune overtaking or climbing (and dying out), as well as examples of associated experimental deposits with sedimentary structures that are often erroneously interpreted when observed in nature.

Assumptions can also be invalidated by new observations: our results from a series of surveys along a 40-km reach the Mississippi River show that: 1) dunes up to 7 m-high from peak flow were not migrating in the deepest part of the channel– where dune height was only ~ 2 m in 26 m flow depth, and 2) these large dunes were entirely reworked in a 9-week interval (nothing like small dunes migrating on large 'remnant' ones), and hence probably not well recorded in the stratigraphy. Both results show that the complex flow field in meanders still require attention. The comparative analysis of successive bed profiles shows that limited stratigraphy would be preserved, consisting at places of the deposits from small dunes at low elevation, and at other places, of those from larger dunes about 10 m higher in the stratigraphic column. This is contrary to our present assumptions, and has important implications for correctly recognizing large rivers in the rock record.

# Jurassic and Cretaceous continental sedimentation in the West Siberian Basin, Russia: evolving fluvial systems and their preservation in the rock record

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In an "ideal" profile from source to basin, a bypass zone passes downtract via a depositional zone dominated by braided rivers (immature fluvial landscape) to a plain dominated by meandering rivers (mature fluvial landscape). Here, the evolution of the SE flank of the West Siberian Basin, Russia, during the Jurassic and Cretaceous, is discussed in this context by Western geologists in collaboration with Russian colleagues. Whilst the Jurassic-Cretaceous was extensively studied in the subsurface of this basin prior to our study, no papers on the basin flanking outcrops in the Mariinsk–Krasnoyarsk region were available in the international literature. Sedimentological analysis of these outcrops, in conjunction with palaeo-botanical data, reveals five facies associations corresponding to a range of continental environments. These include a mudrock facies association (organically enriched overbank deposits), a coal facies association (swamp and / or floodplain deposits), a silty sandstone facies association (sheet-like, parallel to ripple cross-laminated crevasse splay sediments), a fine to medium-grained sandstone association (scour-filling sandstones with cross-bedding and wood fragments interpreted as intra-channel deposits), and finally a coarse-grained sandstone facies association (laterally extensive, erosively based gravels and coarse sandstones: high velocity intrachannel deposits).

Interpretation of the lateral and vertical organisation of these facies associations allows us to propose a model of progressive peneplanation during the Jurassic. In the early Jurassic, coarse and channel-confined bedload (coarse-grained sandstone facies association) was dominant: braided fluvial systems infilling the relics of a Triassic palaeo-topography. In Mid to Late Jurassic times, better defined overbank areas had evolved (coal seams in mires >50 m thick, mud on floodplains), channel abandonment was frequent, crevasse splay processes significant, the volume of mud in the fluvial system increased, all pointing to a mature, meandering system. By Cretaceous times, however, a renewed influx of sand-grade sediment into the region saw a return to braidplain deposition. This latter event is tentatively linked to hinterland rejuvenation/ tectonic uplift, possibly coeval with the progradation of large deltaic clinoform complexes of the Neocomian in the subsurface of the basin.

# Braided rivers: a limit to depositional models

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Braided river deposits are common in sedimentary basins and form important hydrocarbon and water reservoirs. For decades fluvial sedimentologists have tried to improve depositional models of braided rivers, but lack of knowledge of the three-dimensional architecture of fluvial bedforms has limited the development of satisfactory models. Recent works have developed models based on modern braided rivers using ground-penetrating radar (GPR), multibeam echo sounding (MBES), aerial photographs and satellite imagery. They have given new insight and proposed new depositional models (e.g. Best et al., 2003; Bridge and Lunt, 2005) which need to be taken into account by geologists when interpreting ancient deposits and building new reservoir models.

However, application of these modern-based depositional models in ancient deposits is not straightforward. Geologists are confronted with specific issues like estimating the amount of erosion versus preservation potential and the scarcity of data, which are rarely three-dimensional, all of which can make interpretation fraught with difficulties. In addition, discrepancies in terminology and the understanding of the related processes between geologists and fluvial geomorphologists make the transfer of knowledge problematic and open to misinterpretation between these two groups of experts.

The purpose of this paper is to discuss the applicability of modern depositional models to predict ancient sedimentary fluvial deposits, particularly addressing the difficulties with regard to extracting realistic data from outcrops, resulting from the general lack of available three-dimensional exposures, and the implications for building accurate reservoir models.

# Large-scale alluvial architecture and correlation in a Triassic pebbly braided river system (Fundy Basin, Canada).

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Determining what the controls are on the large scale (> 10 km) horizontal architecture of coarse-grained fluvial deposits is important for understanding subsurface fluid distribution and extraction from aquifers and hydrocarbon reservoirs. This contribution describes the architecture of coarse-grained fluvial sediments from a 27 km long by 115 m high almost continuous lateral profile within the Upper Triassic Wolfville Formation, (Fundy Basin, Nova Scotia). The lateral extent of exposure allows the development of a high-resolution correlation scheme and the definition of architectural elements.

The lower Wolfville Formation is dominated (80%) by pebbly sandstones deposited as part of a gravelly braided fluvial system and ends abruptly with a thin ephemeral lake margin facies association. Locally, alluvial fan deposits fill remnant topography within Carboniferous strata beneath the fluvial deposits in which two scales of erosion surface and cycle development can be recognised. The 'S' surfaces can be correlated across the full profile and show evidence of up to 10 m of erosion, a significant facies or grain size change, onlap and association with mature calcic palaeosols. The 'E' surfaces can be correlated between 5 and 17 km, display minor erosion, no significant grain size and may be associated with incipient palaeosols.

The 'S' surfaces provide an example of a robust, high-resolution correlation framework in coarse-grained braided fluvial deposits that could be applied elsewhere. In contrast the 'E' surfaces do not display any significant facies or grain size changes across them, such that many of the smaller scale cycles could potentially be miscorrelated. Although the controls on the 'S' surfaces formation are not clear, we interpret the high-resolution cycles and bounding 'E' surfaces to record a progressive decrease in runoff and fluvial transport capacity indicative of a drying upward, climatically-driven signal.

# Architecture and depositional style of fluvial systems before land plants: a comparison of Precambrian and Modern river deposits.

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As rooted vascular plants were not a significant factor in controlling bank stability or surface runoff before the late Silurian, it is not surprising that many modern humid and temperate climate river models are not represented in the Precambrian. Many pre-vegetation systems have features that are more closely allied to modern ephemeral and dryland systems, although direct comparison remains elusive. To date wandering gravel-bed rivers, low-sinuosity sandy braided systems with alternate bars, fine-grained meandering, and anastomosed systems have not been identified. Precambrian gravel-bed braided systems are common, and have similar architecture to modern systems, except that scour hollows are absent or difficult to identify. Systems with abundant matrix supported debris flow deposits may have formed on higher gradients than modern systems. Point bars in cobble-grade gravel-bed meandering systems are wider and have lower inclination than modern systems. Sandy meandering systems can be identified using the directional relations between foreset orientation and point bar inclination. Sandy braided systems are dominated by composite barforms with predominantly downstream accretionary elements. Evidence of periodic unit-bar development has been identified in at least one deep sandy-braided system, but is not common. Sandy ephemeral sheet-flood deposits are common, but lack many of the associated fine-grained components seen in modern systems.

Nearly all known Precambrian river deposits are dominated by channel and sheet-channel facies. Thick overbank and inter-fluvial deposits are under-represented, or where identified are suspect. Direct comparison with younger systems requires detailed architectural analysis, with specific attention to the relative inclination and directional variability of foresets and 1$^{st}$ to 6$^{th}$ order surfaces. Unfortunately many studies of Modern systems lack this attention to detail, especially of the small-scale morphology of submerged in-channel features, hence direct comparison and evaluation of the paleo-hydraulic characteristics, sinuosity and slope of older systems remains enigmatic.

# *Hydraulic-jump unit bars*: experimental architectures

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Where river discharge is highly variable or channels poorly confined, Froude-supercritical flow is not unusual and associated bedforms should be far more common than has been documented, or than is implied by classical fluvial facies models. A hydraulic jump is the transition to subcritical flow and in a sediment-transporting system any hydraulic jump will have a significant effect on deposition. The only sedimentary structure classically recognised as originating from hydraulic jumps is backset bedding, whereas flume experiments demonstrate that a far greater range of structures occur.

Experimental flume runs have determined a variety of depositional architectures that form at a hydraulic jump. The architectures of three runs with deposition over a non-erodible bed are described. 'Backset beds' did not form. Two runs used poorly sorted sand ($D_{50}$ 368 µm) with different sediment fluxes (4000 and 6000 kg per hour) and a third used well sorted sand ($D_{50}$ 250 µm, flux 4000 kg per hour). In all three a wedge-shaped layer of relatively fine sand was deposited from suspension and this was overlain by a coarser bed which developed from a discrete bed feature. The bed feature in poorly sorted sand, termed a *hydraulic-jump unit bar* consisted of: a relatively fine grained wedge of gently upstream-dipping laminae, passing downstream into a small volume of massive sand, and a foreset bed (with topset preservation) that changed downstream from coarser grained to finer grained. In the third run the upstream-dipping laminae and massive sand units were not observed. In the first run, multiple hydraulic-jump unit bars formed sequentially, producing a *hydraulic-jump bar complex*. The basal wedge is considered characteristic of deposition at a hydraulic jump and in the absence of bedload would be the only depositional signature of the hydraulic jump. In stream-parallel exposures, preservation of the particular unit bar anatomy could be diagnostic of deposition due to a hydraulic jump, as could be the deposit structure with the patterns of grain size segregation. A *hydraulic-jump bar complex* can form if bedload flux is low or intermittent. We would like to know: have you seen features like these in the rock record?

# Allogenic and autogenic controls on the upper Pleistocene-Holocene fluvial deposits of the Tevere River, Roma, Italy

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The late Quaternary deposits of the lower reach of the meandering Tevere River and tributaries belong to an incomplete fourth-order depositional sequence, the PG9 sequence (Milli, 1997). The sequence boundary was carved into the Pliocene-Pleistocene bedrock of the Roman Basin during the last glacio-eustatic sea level fall, between 116 and 18 ka. The paleo-valley is up to 2 km wide and 70 m in depth, and is strongly confined in the bedrock, because of local moderate uplift. A stratigraphic dataset from more than 1000 boreholes allows us to reconstruct the sequence's architecture through detailed stratigraphic and sedimentologic correlation of logs, up to 40 km inland from the present coastline.

The PG9 sequence consists of coeval and genetically related fluvial and wave-dominated deltaic depositional systems, organised into lowstand (LST), transgressive (TST) and highstand systems tracts (HST), with only TST and HST recorded in the subsoil of Roma, for the last 18 ka. In the fluvial system four facies associations (FA) are distinguished. The TST is composed of five stacked parasequences showing a retrogradational to aggradational stacking pattern, and is characterised by amalgamated pebbly channel deposits (FA1) and sandy channel deposits (FA2), embedded in floodplain organic rich mud (FA3). The HST deposits are constituted of floodplain mud with intercalated sands (FA4) and show a typical aggradational to progradational stacking pattern. The maximum flooding surface is approximately 5–6 ka old.

The primary allogenic control on sedimentation is the rapid post-glacial sea level rise, up to 14 mm/yr during the transgressive phase (Amorosi and Milli, 2001), with consequent rapid generation of accommodation space and net aggradational response of the river system, both in the main trunk and tributaries (Milli et al., 2008). Along with the lateral confinement of the valley, the tributaries exert a prominent autogenic control on the main trunk at their confluences, mostly located at the concave side of the meanders. Continuous lateral and downstream migration of meanders are indeed observed throughout the entire sequence, as a consequence of lateral inflows and topographic confinement.

# Dryland terminal fluvial reservoir architecture, Triassic Skagerrak Formation, UKCS

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The Triassic Skagerrak Formation is a locally prolific reservoir in the Central Graben of the North Sea. The Skagerrak was deposited as widespread sheets by fluvial systems draining off Fennoscandia and the UK during post rift thermal subsidence. Salt movement locally influenced accommodation during deposition, and more significantly dictated preservation beneath successive Jurassic unconformities. The overall climatic setting over NW Europe during deposition of the Skagerrak appears to have oscillated between semi-arid and arid- aeolian facies are limited in extent by the middle Triassic, palaeosols and palynology are indicative of widespread vegetation cover, lacustrine facies vary from perennial to ephemeral, and time equivalent marine facies are carbonate dominated with episodic desiccation and halite precipitation. Despite the prevailing dryland setting the episodic but widespread development of wetland facies suggests periods of sustained high water table and groundwater flow. These intervals appear to have been broadly contemporaneous with flooding events in the adjacent Muschelkalk seaway. Regional facies trends indicate that the Skagerrak fluvial systems were terminal in character, ultimately passing basinward into widespread playa, lacustrine and sabkha facies bordering the Muschelkalk sea. Palaeocurrent and provenance data point to the dominance of large transverse Fennoscandian systems interacting with both axial and transverse systems draining off the Scottish Highlands. The alluvial architecture of these systems in the UK sector is dominated by confined fluvial deposits interbedded with splay, floodplain and wetland facies. Individual fluvial bodies are generally less than a few metres thick and the overall metre-scale interbedding of facies suggests that major streams were absent in this area. Palaeosols are *generally* immature, with discrete horizons of dense, low diversity insect burrowing, suggesting that channel migration was rapid (but episodic) or avulsion rates were high with few stable interfluves. Dynamic production data are indicative of good lateral connectivity but limited vertical connectivity, suggesting sheet-like interfingering of floodbasin and terminal splay systems rather than a labyrinthine channel and overbank architecture. Well test data point to a dual permeability system of higher permeability fluvial sands connected via lower permeability splay sands, with lateral dimensions of this heterogeneity *possibly* of the order of tens to a few hundred metres. Typically well data upscaled in static models fails to capture the true permeability heterogeneity and effective Kh is overestimated, pointing to a more complex arrangement of baffles and connection 'windows'. This may reflect the presence of inclined baffles along bar accretion surfaces and/or restricted connectivity between avulsion bodies.

# Climatic controls on the fluvial sedimentology, architecture, and cyclicity of the Jurassic Kayenta Formation, northern Arizona, U.S.A.

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The Kayenta Formation crops out throughout the Colorado Plateau in the southwestern United States and comprises a spectrum of fluvial in- and extra-channel deposits, and minor lacustrine and eolian deposits. The Kayenta forms part of the lower to middle Jurassic Glen Canyon Group, which consists of the basal Moenave Formation, Kayenta Formation and Navajo Sandstone. The first two of these units contain a variety of fluvial features, which are driven largely by abrupt discharge changes as well as in the case of the Kayenta, basin-wide aridity. Superb 3-D exposures allow lithofacies and architectural analyses across large areas and permit reconstruction of the spatial and temporal evolution of channel and floodplain environments into erg margin systems.

There are two dominant sandy fluvial lithofacies associations within the study area that attest to transitions from more perennial to ephemeral flow conditions within channels and on the floodplain. One association consists of deposits of moderate sinuosity streams characterized by a variety on in-channel and channel-margin large-scale architectural elements that are separated by stacked channel scours and cuts. In addition to deposits of dune migration and bars, evidence of pronounced upper flow regime conditions is evident in the form of horizontally stratified sandstones capping most macroforms. The second major association consists largely of planar-bedded sandstones exhibiting a sheet-like geometry and separated from the first association by planar to gently undulating bounding surfaces. These sand bodies represent crevasse splay deposits as well as sheet-flood deposits within and adjacent to main channels. Small channels also occur in this association and represent networks of ephemeral tributaries that crossed the Kayenta floodplain. The second association becomes more common near the top of the formation and intertongues with the margins of the overlying Navajo Sandstone. Ultimately, repeated episodes of flooding resulted in inundation of interdunal corridors and development of ephemeral mixed siliciclastic and carbonate ponds.

Cyclic variation within the slowly subsiding Kayenta basin resulted in deposition of 12 high frequency and 3–4 low frequency drying-upward cycles. All low-frequency cycles and most of the smaller scale cycles can be traced throughout the study area. Smaller-scale, high frequency cycles are the most common and are represented by stacked sequences or isolated sand bodies that formed due to flooding followed by prolonged periods of aridity and degradation. Large-scale, low frequency cycles commence with fluvial channels and/or sheet flood deposits at their base at their base and terminate with eolian dune or sand sheet deposits at their tops and regional erosional surfaces.

# Stratigraphy and evolution of the long-lived Tagliamento fluvial system in the southeastern Alps (NE Italy)

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The conglomerate succession of the valley of the Tagliamento River (southeastern Alps) is a rare example of long-lived fluvial system in the Alpine Chain. The main succession is 25 km long and has an average thickness of 150 m; the sedimentary bodies are mainly made by intra-valley coarse-grained fluvial and piedmont alluvial fan deposits, related to braided fluvial systems, with minor Gilbert-type delta conglomerates and sandstones. Five allostratigraphic units were distinguished; their deposits and bounding surfaces recorded the evolution of the drainage basin from the Messinian to the Pleistocene. The presence of abandoned segments of valley at different elevations indicates the changes in the drainage network happened during the last millions years, during the exhumation of the eastern Southalpine Chain. Angular unconformities that bound the units, as well as the deformations that affected the deposits, indicate a tectonic activity of the chain during the deposition time span. Sandstone and pebble petrography supported the stratigraphic subdivision evidencing the evolution of the catchment.

The first modification in the drainage basin took place during the dramatic sea level drop triggered by the Messinian Salinity Crisis, when rapid uphead erosion caused the deepening of the valley floor, the northwards shifting of the middle segment and the widening of the drainage basin. Subsequently, the early Pliocene sea level rise allowed the retrogressive infilling of the valley. Middle Pliocene and early Pleistocene tectonic phases are marked by angular unconformities bounding the units in the trunk valley. The second main change happened during the middle Pleistocene enhanced by sub-glacial carving and likely favoured by strike-slip tectonics in the middle segment. The trunk valley shifted north-eastwards, abandoning the previous path for several kilometres, allowing the preservation of the sedimentary succession in the subsequent times.

# Are the Channel Country rivers of central Australia a suitable modern analogue for the lower Old Red Sandstone, U.K.?

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Studies of the mudrock facies of the late Silurian – early Devonian lower Old Red Sandstone (ORS) have shown that deposits within these successions were formed by the bedload transport of sand-sized mud aggregates. Macroscopic features include: mudstone layers interbedded with coarser sediments (inclined heterolithics); mudstones with sharp erosive bases; cross-stratified mudstones; and inclined gravel lenses within massive mudstones. These have been interpreted as sinuous channel and bar-form floodplain deposits from dryland river systems, and the rivers and floodplains of the Channel Country in central Australia have been cited as a modern analogue for these deposits. This paper presents a detailed comparison of structures observed within the lower ORS and within trenches dug into sediments of the modern Diamantina River and its floodplain, one of the large Channel Country rivers. Fieldwork was conducted at two sites, 50 km and 500 km from the headwaters (floodplain widths of 2 km and 15 km). New data from the St Maughans Fmn of the lower ORS will be presented, along with data from published localities of the Freshwater East Fmn and Moor Cliffs Fmn.

In the Diamantina River sediments, mud aggregate deposits were frequently observed to be interbedded with sandy laminae within planar and cross-bedded sediments. Mud aggregate sizes ranged from fine sand to gravel. These were observed in recent deposits (e.g. in-channel bars) and older deposits currently being eroded into by the modern channel. Within in-channel bars, cross-bedded deposits consisting of predominantly mud-aggregates were also observed, with coarser mud aggregates and an increased sand component towards the base of each foreset. Mud deposits overlaying sharp erosive bases were observed in several locations within fluvial successions. The lower ORS contains numerous conglomerate facies composed of reworked carbonate nodules interpreted as having formed within floodplain vertisols, and are typically gravel to pebble-sized clasts. Very few, sand-sized, reworked carbonate nodules were observed in the Diamantina River sediments. This could indicate greater floodplain or bank erosion in the ORS, assuming similar carbonate nodule occurrence within floodplain soils, or that floodplains in the ORS were more mature than those in the Channel Country. Similar sedimentary structures from the Diamantina River and ORS will be presented and their thicknesses, extent and composition will be compared.

# Permo-Triassic low net to gross fluvial systems: An analogue for subsurface reservoirs

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The development of fluvial reservoirs is notoriously challenging, due to the often low net to gross ratio and intricate architecture of such facies. A key aim of this research is to discover how the complex interactions of allocyclic and autocyclic controls influence these systems. The understanding of these controls has important implications when modelling fluvial reservoirs for correlation purposes and imputing the correct parameters especially in low net to gross reservoirs.

The research will focus on the Central Iberian Basin (CIB), an intracratonic rift basin in central eastern Spain developed in Early Permian times. Syn-rift Upper Permian to Middle Triassic continental fluvial red beds will be studied in two key locations - Riba de Santiuste & Rio De Gallo Gorge, where outstanding quality of outcrops allows a three-dimensional study of the fluvial systems to be undertaken. The red beds were deposited in once tectonically active half grabens with episodically changing rates of basin floor subsidence. Fluvial sedimentation during this time took place in coexisting braided and meandering channels together with ephemeral episodes. The considerable vertical and lateral extent provides the closest available analogue to many of the main Triassic producing sequences in the Skagerrak Formation of the East Central Graben, North Sea, in terms of both sandbody scale and gross architecture. The interbedding of fluvial channel sandstones and floodplain facies compares favourably with logged sections in the Skagerrak sandstone members and therefore provides the opportunity to extend interpretations away from the one dimensional aspect of the borehole in order to gain an appreciation of three dimensional reservoir heterogeneity, correlation and a better understanding of the main controls on fluvial evolution.

This paper will present preliminary results from the use of a terrestrial laser scanner in the CIB, Spain. The results when combined with field sedimentological analyses demonstrate the complexities of low net-to-gross fluvial systems. The aims for the future will be to establish a successful methodology for applying analogue data to large scale reservoir models.

# Architecture of ephemeral fluvial successions and their interaction with distal aeolian dune fields: implications for reservoir characterisation

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Ephemeral fluvial systems that are characterised by a systematic downstream decrease in discharge, channel size, and lateral and vertical connectivity of channel elements are widespread in semi-arid climatic settings where they commonly interact in their distal parts with aeolian sand sheets and dune fields. In low relief sand sheet environments, unconfined, non-channelized flows associated with ephemeral flood-out events are free to spread across broad alluvial plains, but their deposits are typically later at least partly reworked by aeolian processes. In cases where the water table lies sporadically in the shallow subsurface, nodular and laminar calcrete and silcrete palaeosols readily develop and the resultant preserved sheet-like sedimentary architectures are typically heterogeneous, with subtle yet significant changes in sediment porosity and permeability character reflecting: i) the provenance, calibre and process of transport of the fluvial sediments, ii) the degree of subsequent aeolian reworking and 'cleaning' via winnowing, and iii) the extent and style of palaeosol development. By contrast, in cases where distal fluvial flood waters penetrate into aeolian dune fields with significant topographic relief, a variety of complex styles of interaction occur, including: i) flow diversion along linear interdune corridors, which encourages the refocusing of flood waters and their penetration deep into dune fields, ii) flow ponding, either within closed interdunes or along the leading edges of dune fields, iii) the fluvial cannibalisation and reworking of aeolian dune sands, and iv) the post-flood burial and reworking of former fluvial deposits via renewed aeolian processes. The complex preserved 3D sedimentary architectures resulting from these styles of interaction can typically only be confidently determined by study of well exposed outcrop analogues. The Pennsylvanian-Permian Cutler Group of the Paradox foreland basin, southern Utah, is one such example that records the long-lived development of a large ephemeral fluvial system, which for much of its history was characterised by flow that was terminated in a variety of styles of fluvial-aeolian interaction. These interactions are significant because they exert a fundamental control on the distribution of net reservoir intervals within hydrocarbon provinces.

# Correlation of large scale sedimentary cycles: controls on sediment supply and storage in the Pannonian Basin, Hungary

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Studies of long-term evolution of Quaternary fluvial systems in the Pannonian Basin and their responses to climate changes and tectonics significantly contribute to the fuller understanding of Late Neogene basin development of the Intra-Carpathian area. About 2 Ma ago a major change from the former extensional to compressional stress field led to basin inversion, which caused uplift of the marginal flanks and the western part of the Pannonian Basin, and increased subsidence of different sub-basins, which became areas of continuous fluvial sedimentation. The drainage pattern development of the Danube and Tisza rivers and their tributaries was primarily controlled by differential subsidence rates at various parts of the basin, thus vertical motions were fundamentally responsible for the accumulation of alluvial strata in diverse thicknesses. The subsiding basins are excellent archives of long-term fluvial sequences which record changes in sediment supply and storage over time-scales of $10^3$ – $10^5$ years, manifested in large scale stratigraphic cycles in the alluvial architecture.

The 300-500 m thick cyclic fluvial basin fill succession at the SE-ern part of the Pannonian Basin has been studied by stacking pattern analysis of SP and resistivity logs of several hundreds of water prospecting wells. Characteristic lithostratigraphic units comprise single- to amalgamated channels, upward fining pointbar sequences, crevasse splays and thick aggradational floodplain muds. Various successions of these units define large scale symmetrical and asymmetrical cycles which record stratigraphic base rise and fall, thus times of increasing and decreasing accommodation/sediment supply ratio.  These large scale cycles can be regionally correlated and define basin scale fluvial architecture.

# Genesis of the submarine Malita Valley: A closed-contour, tidally enhanced fluvial incision, Joseph Bonaparte Gulf, Australia.

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The development of incised valleys is often related to fluvial incision during lowstands of sea level, which results in open contour morphology where the depth of maximum incision continuously increases seaward. A 200km long valley (the Malita Valley) in the Bonaparte Gulf, Northern Australia, significantly deviates from this pattern. The valley is anomalously scoured to a depth of 120m in an area where it partially dissects a relatively shallow shelf rim (a carbonate reef atop the shallow Sahul and Van Diemen Rises), with depth of scour decreasing in both seaward (20m) and landward (50-100m) directions. Such a scour pattern describes a closed contour valley morphology that cannot be readily explained by low-stage fluvial scour alone.

The Darnley Valley (offshore southern Papua New Guinea) has a similar longitudinal profile to the Malita Valley. It extends for 93km and while for the majority of its length it has scoured to a depth of 40-60m, it terminates as a 120m deep valley at the seaward end on the relatively shallow shelf. This deep incision was modelled and attributed by other authors to tidal scour which occurred under various modelled sea level scenarios. The enhanced tidal scour was a product of a confining shelf-edge topography that caused bottom shear stresses to peak at sea levels between 30 to 50m below present.

The Malita Valley shelf edge demonstrates similar confining topography at approximately 70m below present day sea level, which corresponds to the region of maximum depth of scour. Furthermore, eustatic sea level curves indicate pauses in sea level at -70m during OIS-3 and OIS-4. The constriction of the tidal wave in the Joseph Bonaparte Gulf for extended periods likely produced similar scour peaks near the shelf edge, resulting in a morphologically similar submarine valley. Since the Bonaparte region has also undergone a complex tectonic history over the past 10 Ma, we are currently investigating both the roles of topographically enhanced tidal scour and regional tectonics in the development of the Malita Valley's closed contour morphology.

# Sandstone body architecture in ancient distributary fluvial systems

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Basins of internal drainage (endorheic basins) can be the sites of accumulation of hundreds to thousands of metres thickness of continental deposits. Under very humid climatic conditions these successions will be mainly lacustrine, and in very arid settings aeolian facies will dominate, but a basin with an intermediate climate will be dominated by fluvial deposits. River systems in large endorheic basins show a distinctive, fan-shaped depositional pattern formed by the repeated avulsion of channels. Evaporation and infiltration of water results in a decrease in channel dimensions down-flow, a decrease in grain size and an increase in the proportion of sand deposited as splays on the floodplain. These distributary fluvial systems may be tens to over a hundred kilometres in radius.

A model for the architecture of the channel and overbank facies of these fluvial systems indicates that they display marked changes in characteristics between the proximal and distal areas:

- Close to the apex of the system coarse channel deposits may be almost completely amalgamated, but in the proximal areas large channels may be incised into the alluvial plain with only moderate interconnectedness.
- In medial zones a combination of lateral channel migration, moderate incision and a relatively poor preservation of overbank facies results in a highly interconnected architecture of channel-fill sandstone bodies.
- With increasing distance from the apex the channel deposits are sheet-like, deposited by sandy bedload channels which underwent extensive lateral migration but little incision resulting in limited vertical connectivity.
- Approaching the distal regions there is more evidence of meandering channels and a higher proportion of floodplain deposition, including lateral splays. A tendency for the meander belts to occur at certain locations on the floodplain results in localised interconnectedness of sandstone bodies.
- A predominance of thin sheet sandstones deposited mainly as terminal splays and a very low proportion of channel-fill sandstone bodies results in very poor connectivity in the distal parts of the system.

This conceptual model for the architecture of the deposits of terminal distributary fluvial systems is based on two Cenozoic systems from the Ebro Basin, Spain, but with adjustments for scale and climate in different settings it is believed to be applicable to a number of fluvial successions in the stratigraphic record.

# Reconstructing the palaeo-Colorado River

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The history of the Colorado River has captured the imagination of geoscientists for well over a century. On its course from its headwaters in the Rocky Mountains to its delta in the Gulf of California, it traverses some of the most remarkable scenery in North America, most notably incising the mile-deep Grand Canyon in Arizona. However, the age and integration of the river system is still a subject of debate and disagreement. It is now thought that the Colorado Plateau is a relatively young geological feature, having been uplifted within the last 6 million years, and that the integration of the river system is inextricably linked with that event. The first arrival of Colorado-derived sediments in the Salton Trough at around 5.3 Ma seem to support this “young” river model. However, the means by which this happened are still uncertain. Several competing hypotheses have been proposed: 1. headward erosion and river capture of a pre-existing fluvial system on the Colorado Plateau; 2. drainage diversion and rapid lake spillover from the Colorado Plateau to the Gulf of California; and 3. decapitation of old fluvio-deltaic deposits by the San Andreas fault system to the north of the current delta. We have tested these hypotheses by logging sections through the first Colorado-derived sands in the Salton Trough (concentrating on the relationship between Colorado-derived and locally derived sands); by carrying out detailed petrographic analyses of the modern Colorado River and palaeo-Colorado sands; and by comparing these to samples from the Los Angeles Basin where older Colorado-derived sands are inferred to be present.

This study highlights the value of using a variety of sedimentological and mineralogical data to understand the provenance of fluvio-deltaic sediments, and to provide constraints on the evolution of the drainage network. Our results suggest that an older Colorado River system may have flowed into the Los Angeles Basin in Miocene times, when the basin lay farther south.

# Alluvial Hierarchy: Description of Alluvial Strata in the Rock Record

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A hierarchical approach for the description of alluvial strata in the rock record, based on the physical characteristics of depositional elements and their stratal bounding surfaces, provides a systematic method for characterization of the strata and interpretation of the sequence stratigraphic architecture. The proposed approach facilitates the spatial and temporal comparison of alluvial systems at multiple scales, thereby enabling delineation of the intrinsic and extrinsic controls on alluvial deposition.

The alluvial hierarchy encompasses the physical description of the strata and their bounding surfaces and the recognition of genetically-related depositional elements. It is independent of depositional style, channel planform geometry, channel sinuosity, fill-type, etc., and is applicable at all scales. The alluvial hierarchy spans from the smallest depositional elements of lamina and laminaset, which may form locally over relatively short time periods; to intermediate-scale elements of channel fills and channel complexes that develop over larger areas and are deposited over longer time periods; to large-scale elements of sequence sets and composite sequences that span the depositional basin and accumulate over millions of years.

Alluvial hierarchical elements coalesce to form amalgamated, semi-amalgamated and non-amalgamated depositional elements. The style of stratal stacking pattern reflects variations in relative rates of accommodation and sediment supply within the basin. Amalgamated alluvial elements cluster vertically or laterally to form sand-prone deposits and correspond to low rates of accommodation relative to sedimentation. Conversely, non-amalgamated alluvial elements are weakly clustered within floodplain deposits and correspond to relatively high rates of accommodation relative to sediment supply. Stratal stacking patterns of the hierarchical elements within a chronostratigraphic framework enable delineation of the alluvial sequence stratigraphic architecture, thus enabling prediction of the spatial and temporal distribution of key hydrocarbon reservoir elements.

Application of the alluvial hierarchy to subsurface reservoirs enables: 1) prediction of reservoir and seal lithofacies variations at the local scale; 2) characterization of reservoir continuity, connectivity, and producibility properties at the field scale and; 3) evaluation of the relative influence of allogenic controls in the basin-scale depositional history for identification of untested areas for future exploration.

# Causes of lateral and vertical facies variability in fluvial successions and their implications for exploration, appraisal and development of fluvial reservoirs

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Fluvial reservoirs typically exhibit vertical lithofacies variability that is easily determined in downhole data. Lateral variability of lithofacies is impossible to be determined in the subsurface using downhole data and other geophysical techniques, such as seismic data are often too coarse in resolution. Both vertical and lateral lithofacies variability leads to net-to-gross (NTG) uncertainty. However, NTG uncertainty needs to be managed properly as it has a profound impact on oil and gas in place (OGIP) and also affects the extraction strategy of the hydrocarbons.

Lateral and vertical reservoir variability occurs at the lithofacies, depositional architecture and stratigraphic scale, all effecting NTG. At and below the channel belt scale lateral variability is caused by the style of the river as well as the style of splay belt and floodplain deposition. It is hence the depositional architecture of the channel belt that is important to quantify if this level of variability is important (ie heavy oil). Outcrop and subsurface analogue data coupled with appropriate facies models for different river styles are typically deployed to reduce the uncertainty of facies variability at and below the channel belt scale. Most of this uncertainty is characterised late in the appraisal, or early in the development stage.

Above the channel belt scale lateral and vertical variability is caused by the stratigraphic stacking of channel belts. Causes for variability at this scale are accommodation space variations (subsidence / uplift / eustasy) as well as discharge and sediment load variations. Stratigraphic variability is often important to quantify in light oil or gas reservoirs where it leads to sandbody connectivity uncertainty between channel belts, especially in overall low NTG systems. At the stratigraphic level, the differentiation of accommodation space variation vs discharge/sediment load variation is of highest importance, as the two process groups frequently lead differing vertical and lateral stacking patterns. While accommodation space variations often lead to sheet sand formation, especially following a base level fall (sequence boundary), variation in discharge/sediment load can lead to channel avulsion clustering, an important, but often misinterpreted from of reservoir formation.

# Distributary channels and/or incised valley fills: Interpretations for the fluvial facies of the Marar formation

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The Early Carboniferous Marar formation of western Libya mainly records siliciclastic shallow marine sedimentary deposits. Two fieldwork seasons undertaken in the studied area highlight the presence of thick discrete sandstone bodies up to 50m thick. They are interpreted as fluvial facies because of the sedimentary structures they contain, the absence of marine fossils and bioturbation, the dominant paleocurrent direction, which conforms with the proximal distal facies trend, their presence of a basal eosion surface above shallowing upward cycles. In addition, smaller thin isolated channel forms are observed, together with thin amalgamated sheet-like sandstones containing brachiopods. These latter facies always overlay delta front facies but do not always occur on the top of shallowing upward cycles. They are interpreted as being deposited in a shallow marine context.

In this study we compare the concepts of incised valleys and distributary channels as possible mechanisms for generation of the channel forms recognised. Incised valley fill systems are precisely defined to be the product of a relative sea level fall, and can be characterised within a sequence stratigraphic framework. Distributary systems are less well-defined in the literature, and approximate with the terminal fan model. The implications of both models in term of paleocurrent patterns, distribution and size of channel bodies, which has significant impact on hydrocarbon exploration, as well as the limitations of each model are discussed.

By comparing the features of each model with the field case study, we interpret the isolated small channels and the thin marine amalgamated sandstones facies as part of a distal distributary system. The thicker discrete channel forms in the Marar sandstones are interpreted to be incised valley fills. The incision thickness trend suggests these features were most probably formed by fast relative sea level falls.

# The influence of glacial-interglacial climatic variations on coarse-grained braided river deposits

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River response to climate events, which occur on a variety of scales from local advances and retreats to interhemispheric glacial-interglacial cycles, is broadly due to the changes in sediment and discharge supply that control allogenic processes such as aggradation/incision and avulsion. These changes may be recorded in the stratigraphic record by changes in grain size, channel flow depth, the abundance and distribution of depositional facies, and the occurrence of local and regional erosive surfaces. The rate of change in response to climate will vary along the sediment transport path, creating a basin-wide lag in response to climatic forcing.

The Canterbury Plains of eastern central South Island, New Zealand are made up of coarse-grained braided fluvial sediment that has been deposited by systems active through the Last Glacial Maximum (22-18 ka) to the present day. New Zealand is a key site for the study of Quaternary climate change and the interhemispheric linkage of glaciations, with a well-constrained, high-resolution climatic chronology. The three major basins under investigation, the Rakaia, Ashburton and Rangitata, have experienced differing degrees of glaciation through the LGM, and changes in drainage area driven by transfluent ice. It is expected that periods of high sediment production and deposition occur at climate transitions and that temporal changes from glacial- to fluvial-dominated systems leads to sediment with distinct volume and grain size characteristics, resulting in differing flow regimes and process response between these climate conditions. Stratigraphic panel construction from surveyed, orthorectified photomontages at four sites along a 70 km section of the incisional Canterbury coastline provides ~15 m vertical sections of braided river gravels spanning ~30-7 ka. Depositional architecture has been recorded, and at least six major erosive surfaces have been identified. Samples have also been taken for palynology and OSL in order to tie the stratigraphy to New Zealand’s climate history. This study aims to provide a high-resolution, chronologically constrained, field-based model of changes in braided fluvial transport and depositional processes in response to climate change that can be usefully compared to established laboratory and numerical models.

# The problems involved in interpreting fluvial reservoirs Bridging the gap between sedimentologists and reservoir engineers

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Recent developments in fluvial sedimentology have shown the growing interest of sedimentologists and petroleum engineers in understanding the variety of fluvial depositional responses existing between the classical "end-members" (e.g. braided, meandering, anastomosed). They are of particular importance in term of reservoirs heterogeneity and channels geometry, and it clearly appears a lack of detailed study and well describe facies suite to discriminate, for example terminal fans from braided river and point bars versus & low sinuosity river; there is also few examples of coarse grained point bars properly described, so there relative importance are probably underestimate.

The second key element when interpreting fluvial deposits is to be sure that the system is purely fluvial, in other words it is very important to define the tidal limit. Tidal influence in fluvial deposits, introduce lot of small scale heterogeneities and also tends to modify the channels geometry.

The third element of importance when you intend to model fluvial system is their stratigraphic evolution in the sense that it can provide and external derive to the models. Compared to their marine counterparts, stratigraphy of fluvial systems is less understood and subject to almost opposite interpretation. Our experience suggests that the Jervey model's is robust because it links stratigraphy and geomorphology.

In the same time, reservoir characterization has shown the growing interest of geoscientist in reliable reservoir model construction. From a period of divorce between geologist and reservoir engineers, we are now grading to a period of common and parallel evolution. This result in a profusion of modelling techniques which actual tendency is to include conceptual geological information or three-dimensional seismic data in reservoir characterisation workflows, bridging the gap between reservoir geology and stochastic simulation practices. This thorough integration leads to complex modelling approaches, involving a variety of modelling tools, which are necessary for characterizing complex reservoirs. Most recent workflows, also refereed as "hybrid approaches" and composed of mixed process-based, pseudo-genetic and stochastic methods prefigure the future of geomodelling techniques.

These recent evolutions and multiple possibilities offered by nested modelling approaches show the flexibility required for modelling fluvial reservoir geology regarding the high variability of available data sets (e.g. LiDAR Acquisitions, Seismic geomorphology). It is therefore necessary to link sedimentological knowledge, outcrop database and geobody ratio laws with reservoir modelling workflows, in order to construct reliable predictive reservoir models.

The above address challenges are not only oil industry concern but tend to become one of the main way of progress for $CO_2$ trapping, in situ recovery for Uranium as well as long term management of water resources.

# Which present is the key to the past? : new insights from the South Saskatchewan River, Canada, concerning flood magnitude, preservation potential and the resultant sedimentary architecture

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The notion that the 'present is the key to the past' is a central tenet within geological thinking, but we need to know which 'present' is important - that which occurs daily, once in 50 years or once in 1000 years? A major problem in addressing this question is that, due to the inherently unpredictable nature of extreme flow events, little sufficiently long-term sedimentological data exists from which the relative impact of annual floods, as compared with larger events, can be quantified.

Due to the logistical issues of collecting pre- and post-flood data, much knowledge of modern braided rivers relates primarily to data gained during low flow and annual-scale flooding. This paper reports results from a long-term project on the South Saskatchewan River, Canada, that aims to examine the nature of the subsurface sedimentary architecture in relation to the *formative* flow events. We have documented braidplain evolution and channel change since 2000, using aerial photography and field survey. Of most significance, in 2005 a 1-in-40 year event provided a unique opportunity to evaluate the effects of a large flood, by comparison with detailed datasets taken the year before the flood. The integrated application of ground penetrating radar (GPR) and photogrammetric analysis has allowed quantification of the relative importance of different flow events in the evolution of the geomorphology and subsurface sedimentology of the South Saskatchewan River.

An assessment of the impact of the large flood on the sedimentary architecture is possible by comparing ground penetrating radar data taken before the flood with that collected over identical survey lines (located using DGPS) after the flood. The data strongly suggests that high-magnitude, low-frequency, events will leave little discernible signature in the alluvial architecture and that this may be a common feature of many rivers that are laterally unconstrained. Thus, although high-magnitude floods can have a significant impact, for instance by cutting new channels and generating new barforms, these will be of similar style and dimensions to those developed during lower magnitude events, such as annually occurring bankfull floods. This highlights a startling conclusion: that while the preserved alluvial architecture in the geological record will be generated by a range of low- and high-magnitude floods, discriminating between the two may not be a trivial matter, or may often be impossible.

# Developing a new classification scheme for mud-rich facies in drylands, Lake Eyre, central Australia.

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Mud-rich facies in contemporary drylands such as the Lake Eyre Basin are potential modern analogues for the increasingly important source, intra-formational baffle and seal rocks in ancient dryland hydrocarbon systems, including the Triassic of Algeria and the North Sea, yet they remain poorly understood. Through the analysis of modern and Pleistocene mud-rich sediments from a range of depositional environments within the Lake Eyre Basin, a classification scheme is being developed which it is hoped will improve their identification in core, the prediction of their spatial distribution in the subsurface and the development of robust facies and reservoir models.

Surficial sediment samples were collected from known mud-rich depositional sub-environments across the Kalaweerina terminal splay complex, a fluvial-lacustrine interface on the north-eastern shoreline of Lake Eyre, and its surrounds. Outcrop samples were collected from the Pleistocene Ghost Yard Beds, at an exposure close to the western shore of Lake Eyre. The Ghost Yard Beds have been previously interpreted as predominantly ephemeral lake sediments, deposited during a previous highstand of the palaeo-Lake Eyre. A suite of textural, mineralogical and compositional analyses were applied in order to generate a comprehensive dataset of variables. These analyses included grainsize analysis (wet sieving and Malvern Mastersizer laser particle analysis), sequential loss on ignition, x-ray diffraction, QEMSCAN®, micropalaeontology (diatoms) and palynology. Multivariate statistical analysis (cluster analysis) was then used to integrate the dataset and identify significant groupings or ‘facies’.

The distribution of individual variables and the spatial arrangement of ‘facies’ obtained from the modern sediments are presented as a series of contour and point maps, enabling comparison with a map of the depositional sub-environments. Initial results indicate that depositional sub-environments are characterised by a higher than expected facies complexity. Interdune muds may be distinguishable from muds within the fluvial-splay system on the basis of mineralogical complexity. Poor preservation of diatoms due to the harsh environmental conditions on the splay is inferred for the lack of diatoms in splay sediments, as upstream locations contain diverse fluvial diatom assemblages. Planned future work includes testing these results by conducting similar analyses on sediments collected from other fluvial-splay-lake localities around Lake Eyre, and comparison of these results against core data from ancient dryland mud-rich deposits.

# The morphology of fluvial systems draining orogenic plateaux

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Rivers draining from the Turkish-Iranian and Tibetan plateaux are shown to deviate from the graded form associated with a river in topographic equilibrium. Reaches within the plateaux interiors show abnormally low curvature and gradients, while those that pass through the mountains at the boundary of the plateaux show abnormally high curvature and gradients. This produces a sigmoidal longitudinal profile, which appears to be characteristic of rivers that have a significant amount of their course on either side of a tectonically determined dividing line between non-thickening plateau interior and active plateaux margin.

Numerical modelling of river evolution was used to understand the formation of these sigmoidal rivers as an orogenic plateau expands laterally. The modelling indicates that the primary control on this deviation from a graded profile is climatic. The development of arid conditions in a plateau interior lowers stream power within a river's upper reaches. This reduces the river's ability to incise into material uplifted in the orogen. This rain shadow control on the river's form is further exaggerated by the tectonic discontinuity between the actively uplifting plateau margins and non-thickening plateau interior.

Low gradient, low curvature reaches within the plateau interior represent the possibility of a fluvial, depositional environment away from the alluvial plains at the bottom of mountain ranges. They would result in sedimentation atop an orogenic plateau. Long term preservation potential of these sediments is dependent on further plateau evolution.

Continuing work is investigating fluvial systems that are internal to orogenic plateaux. In particular the nature of alluvial fan deposits and their tectonic and climatic controls.

# Counter Point Bar Deposit Lithofacies Model and Reservoir Significance in Meandering Rivers, Alberta, Canada

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Counter-point bar deposits (CPBD) in the modern meandering Peace River, north-central Alberta, Wood Buffalo National Park, are distinct from point bar deposits (PBD) in terms of morphology, lithofacies and reservoir potential for fluids. Previously referred to as distal-most parts of point bars, point bar tails and concave bank-bench deposits, CPBD have concave morphologic scroll patterns rather than convex as with point bars. The Peace is a large river (bank-full discharge 11,700 $m^3 s^{-1}$, width 375-700 m, depth 15 m, gradient 0.00004 or 4 cm/km) in which CPBD are dominated by silt (80-90%), which contrasts with sand-dominant (90-100%) PBD. Beginning at the meander inflection (transition from convex to concave), CPB stratigraphy thickens as a wedge-like architecture in the distal direction until the deposit is as thick as PBD. Such low permeable silt-dominant lithofacies in CPBD will limit reservoir quality, extent and movement of fluids in both modern and ancient meander belts.

In the exploration and extraction of bitumen and heavy oil in subsurface meander river rocks, identification and mapping of reservoir potential of PBD and CPBD is now possible in the fluvial-dominated Lower Cretaceous Middle McMurray Formation, northeast Alberta. Recent geophysical advances have facilitated imaging of some ancient buried PBD and CPBD, which on the basis of morphologic shape of sedimentary bodies observed from seismic amplitude, can be interpreted and mapped as depositional elements or blocks that contain associated sandstone or siltstone dominant lithofacies, respectively. Since CPBD exhibit poor permeability and thus limit reservoir potential for water, natural gas, light crude, heavy oil and bitumen, CPBD should be avoided in resource developments. Geophysical imaging, interpretation and mapping of PBD and CPBD elements provide new opportunities to improve recovery of bitumen and heavy oil and reduce development costs in subsurface cyclic steam stimulation (CSS) and steam assisted gravity drainage (SAGD) projects by not drilling into CPBD.

## Cretaceous Shoreline-Attached Fluvial Systems within Source-to-Sink Transects

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Fluvial systems are major components of non marine-to-marine clastic wedges that emanate from thin- and thick-skinned uplifting mountain belts in Wyoming. The fluvial deposits in the core of tectonically generated wedges that built into shallow-water seas (Campanian) and deepwater seas (Maastrichtian) have been re-examined. The supply drive by rivers in each case was able to partition sand down into highstans/forced-regressive shorelines, and ultimately far (100's of km) into the basin as lowstand shorelines and as turbidite packages respectively. In cases such as the Ericson fluvial systems (Trail and Rusty members) in the Campanian shallow-water seaway, the shorelines repeatedly regressed and transgressed in up to 80km transits, and that the effects of the transgressions were felt a further 150km landwards on the coastal plains. The 80km shoreline transgressions were achieved by the landward movement of barrier-lagoon and estuarine channels, and the linked effect of this farther landwards was the movement and superposition of brackish-water fluvial-tidal systems (lower coastal plain) back onto sandy, low-sinuosity channel systems (alluvial plain). The large landward movements of the brackish-water and tidal rivers are recognized by brackish trace fossils and tidal signals within the upper parts of erosionally-based, 15-40m thick sequences. Yet farther landwards (250-300km from the maximum regressive distance of the shorelines) the alluvial succession loses most of the tidal and brackish signals, and becomes medium to coarse-grained, amalgamated fluvial-channel deposits. This spectrum of alluvial deposits is discussed. A sequence stratigraphic interpretation of the succession suggests that most of the fluvial deposits accumulated during high-frequency base-level rise and transgression of the shorelines.

# Avulsion and its implications for fluvio-deltaic stratigraphy

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Avulsion is a principal process in the formation of fluvio-deltaic successions and strongly influences deltaic architecture. It determines the distribution of sediment and water and hence influences the location of clastic sedimentation, channel belt configuration and recurrence interval of channel belts on the floodplain. The objective of this presentation is to discuss the implications of avulsion for fluvio-deltaic stratigraphy with respect to channel deposit proportion (CDP), channel belt connectedness (CR), and channel belt width to thickness ratios (W/T) based on field data from the Holocene Rhine-Meuse delta, The Netherlands.

Important boundary conditions for deltaic architecture are floodplain width and the amount of accommodation space created by sea level rise and tectonic subsidence. The upstream delta is characterized by a relatively narrow floodplain (15-25 km) and a thin Holocene sequence (0-6 m). Sequence thickness increases in a downstream direction due to increasing subsidence rates and a high rate of relative sea level rise. The downstream delta is characterized by a wide floodplain and a thick sequence (6-20 m). In general, CDP, CR and W/T ratios decrease in a downstream direction. A positive correlation seems to exist between CDP and avulsion frequency. These trends are interrupted at the location of the uplifted Peel Block. Channel belts are relatively narrow, and CDP and CR are higher. This is probably related to the presence of several avulsion sites at the main faults; CDP and connectedness may be high directly downstream from avulsion sites.

An important new observation is the occurrence of avulsion sequences. During a sequence, avulsion sites shift progressively upstream with a simultaneous decrease in interavulsion period. Seven avulsion sequences may have occurred in the Holocene Rhine-Meuse delta, suggesting a periodicity of ~500-600 yr. The occurrence of avulsion sequences could have important implications for the fluvial succession. Theoretically, this leads to few avulsions in the distal (near-coastal) part of the delta. This is contrary to the idea that anastomosing rivers that occurred in the distal part of the Rhine-Meuse delta are characterized by high avulsion frequencies.

# Fluvial response to stepwise sea-level rise: a case study from the latest Pleistocene to Holocene incised-valley fills under the Tokyo Lowland, central Japan

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In this study, we examine a fluvial architecture in relation to stepwise sea-level rise associated with filling of incised valley since after the Last Glacial Maximum. Since 2003, Geological Survey of Japan has been collected 19 sediment cores and 18,000 borehole logs to evaluate ground amplification from earthquake in the Tokyo Lowland. And these data have been also used to clarify the distribution and stratigraphy of the incised-valley fills under the lowland. On the basis of sedimentary facies and 430 radiocarbon dates from the sediment cores, the valley fill sediments, which thicken seaward to more than 70 m, can be divided into braided river, meandering river, estuary, spit and delta systems in ascending order. And the meandering river system, which distributes -60 to -35 m below the present sea level, consists of floodplain mud and channel/crevasse-spray sand isolated in the mud. The meandering river system yield radiocarbon dates ranging from 14,000 to 10,000 cal BP. At around -50 m and -40 m below the present sea-level, the channel/crevasse-spray sand form highly amalgamated sand sheets, thicken 1 to 3 m, and they yield radiocarbon dates of about 12,000 cal BP and 11,000 cal BP, respectively. The depositional age of the sand sheet at -50 m below the present sea level coincides with the timing of the Younger Dryas sea-level stillstand. These phenomena indicate that a deposition of channel/crevasse-spray sand is dominant during a sea-level stillstand, and a deposition of floodplain mud and channel/crevasse-spray sand isolated in the mud is dominant during a sea-level rise.

# Fluvial process-product linkages in the wetlands of the Okavango Delta, Botswana: can we recognize these in the geological record?

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Previous studies in the arid-zone wetlands of the Okavango Delta, Botswana, have shown that their structure and functioning are the result of complex interactions between the geosphere, atmosphere, hydrosphere, and biosphere. The Delta has been cited as a modern analogue for various ancient sedimentary rock successions and palaeoenvironments, but understanding of the controls, timescales, and rates of geomorphological changes in the wetlands remain poorly documented, and the links with the character, patterns, and preservation potential of sedimentary deposits are not fully understood. Here, we report on investigations in the seasonal wetlands in the Xugana region, northeastern Delta, which harbours a remarkable range of active and relic fluvial features. At least four channel belts, and numerous scroll bars and oxbow lakes attest to a long history of channel change by meander migration and avulsion, with many sinuous abandoned channels having significantly larger dimensions than the straighter modern channels. Preliminary OSL dating results suggest that many channel belts are Holocene in age, with changes having been driven by a combination of autogenic controls (in-channel sedimentation), allogenic controls (hydroclimatic fluctuations), and biological activity (hippopotami trails, vegetation encroachment). Active channels transport sand as bedload between banks formed mainly of peat and sedges, but following avulsion and abandonment, the flanking organic deposits are reduced by fires to thin mud and ash layers, leaving the abandoned sandy channel beds and adjacent scroll bars in positive relief. These potential reservoir seals and associated ribbon sand bodies can be preserved at surface for thousands of years, but owing to low rates of vertical aggradation, widespread bioturbation, active chemical sedimentation (displacive subsurface silica and carbonate crystallization), and partial reworking by later channel and/or aeolian activity, such features eventually are modified or erased. Although there is little information regarding sediment character at depth, fluvial process-product linkages in the Okavango likely contrast with wetlands with different sediment calibre and lower bedload to suspended load ratios (e.g. the Pantanal, South America). Improved understanding of the complex mix of controls that determine wetland geomorphology and sedimentology over Holocene and longer time scales is needed to ensure rigorous application of these environments as analogues for the geological record.

# Pliocene rivers in the Pannonian Basin, Hungary

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Following the infill of the Late Miocene Lake Pannon, a widespread alluvial plain was formed in the Pannonian Basin during Late Miocene and the Pliocene. Quaternary uplift has inverted the basin fill, hence the Pliocene alluvial deposits are excavated along the rim of the recent mountainous areas. Outcrop conditions are quite poor, but as it is demonstrated, a detailed reconstruction of the Pliocene fluvial paleoenvironment could have been achieved even based on field data from a few small outcrops. The aim of our study was to identify individual channels and bars buliding up the succession visible in each outcrop, and to reconstruct the features of the ancient river system by using these local observations for two study areas. The field observations were supplemented with borehole data and electrical resistivity ground imaging.

Sedimentary structures were interpreted and palaeocurrent directions were measured in seven outcrops, where chiefly trough cross-stratified sand appears. In some cases, decreasing thickness of cross-sets and fining upward can be also noticed. In the western study area, the bulk of the sand seems to be deposited by vertical accretion in laterally stable channels, while point bars of meandering channels are common throughout the eastern area. Unlike the outcrops, the subsurface methods show that the bulk of the fluvial sediments are floodplain silts and muds, which surround sand ribbons interpreted as active channel fills. A few thinner sandy units were described as ancient crevasse splays.

Channels flowing across the Pliocene alluvial plain had bankfull depth about 5–7 m in both areas, as estimated on the basis of bedform sizes. Based on palaeocurrent data and the strike of elongated sandbodies, rivers generally flew from northwest to southeast, supporting that these parts of Pannonian Basin were infilled from the direction of Western Carpathians, fitting in the generally accepted model for the infill of the basin. However, significant variance of paleocurrent directions show the effect of local tectonic elements and palaeotopography. In the western study area, an anastomosing fluvial system was reconstructed, while meandering rivers of the same scale were crossing the eastern area. This difference might indicate that the palaeoslope of the western area was more gentle and it was located closer to the base level during the deposition of the studied sediments.

# Peat compaction and formation, key processes controlling fluvial-deltaic architecture

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Peat compaction and formation are key processes in the evolution of fluvial-deltaic areas, especially in the distal parts with relatively high accommodation rates where thick peat layers are formed in the flood basins. So far, research in fluvial-deltaic areas was mainly focused on channel dynamics, fluvial sedimentation and alluvial architecture. The role of peat compaction and formation has seldom been investigated at delta scale in Holocene settings and seems to be underestimated. This study shows how peat compaction and formation influence delta architecture, which will be illustrated by examples from the Mississippi delta (USA), the Rhine-Meuse delta (NL) and the Cumberland Marshes (CAN). The way and magnitude by which peat compaction and formation influence architecture strongly depend on temporal and spatial scale. Peat compaction and formation influence the following aspects:

1) ***Channel belt elevation.*** In a situation of groundwater table lowering, subsidence due to compaction and oxidation of peat above the groundwater table in flood basins leads to relief amplification of sandy channel belts or inversion of former creeks filled with sand. Relief amplification might lead to avulsion.

2) ***Channel belt geometries.*** Vertical aggradation, resulting in channel belts with low width/depth ratios, is favoured by I) the high cohesiveness of peat inhibiting bank erosion and II) peat compaction underneath a channel belt creating accommodation space for fluvial deposition. Contrary, if a relatively thin peat layer is intercalated in between less cohesive sediments, an incising channel will first erode to the depth of the peat layer, which due to its resistance prevents further vertical incision resulting in channels belts with a high width/depth ratio.

3) ***Channel belt configuration and distribution of fluvial deposits.*** A decrease in the rate of accommodation space created by peat compaction underneath a channel belt increases the tendency for lateral migration and hence, the channel becomes more prone to avulsion. The combination of a high bank stability, low regional gradients and low stream power in peatlands favours crevassing, which is an important mechanism initiating avulsion. At a larger scale, invasion of a river system onto a new part of a floodplain is stimulated by I) variations in compaction rate across a floodplain and II) a sudden drop in gradient a river experiences when it enters a peatland.

Obviously, peat compaction and formation have important implications for the rock record, as it influences the shape and distribution of sandstone bodies and carbonaceous and coal layers within fluvial-deltaic sequences.

# A Quantitative 3D Outcrop Model of a Late Triassic Gravel Dominated Braided Fluvial System (Minas Basin, Nova Scotia, Canada)

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The continental Wolfville Formation was deposited in a rift basin setting during Anisian to Carnian age, and belongs to the Newark Supergroup basins. It is superbly exposed in both cliff sections and on extensive wave-cut platforms along the Minas Basin shore (Nova Scotia, Canada). The nature of the exposure provides unique three-dimensional sections, offering a valuable insight in the sedimentology and the facies geometries and distribution of a red bed braided fluvial-aeolian facies suite.

The study area is located on the southern Minas Basin shore and measures 400 m by 350 m. It comprises Carnian aged sediments that show a cyclicity of coarse pebbly sandstone / conglomerate to (pebbly) sandstone. The limited amount of preserved mud to silt material throughout this gravel dominated system contains faunal remains and palaeosol horizons. The base is characterised by the discordant contact with the Carboniferous and a thin alluvial derived pebbly sandstone / conglomerate unit.

Quantitative outcrop data, collected with LiDAR and DGPS is integrated with traditional geological field and laboratory data (sedimentological logs, palaeocurrent information, structural and petrophysical measurements) into a digital outcrop model (DOM). The DOM is then used for mapping the observed geological objects, and to evaluate their geometries and distribution. The results offer a better understanding of the depositional system, and provides a geological framework for reservoir models. Such information aids improved reservoir characterisation and geostatistical modelling, as well as help explain seismic reflection data and improve flow model simulations for subsurface reservoirs.

# Hyperconcentrated alluvial facies of the Miocene Teruel Basin (Spain): Controls and implications for basin analysis.

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Alluvial fan facies typically comprise poorly organized deposits from catastrophic, sediment-laden flows triggered by slope instability and exceptional meteorological events. Such deposits span a whole range of transport processes, from plastic-laminar to turbulent-newtonian, depending on sediment/water ratios of parent flows. In fluvial systems, on the other hand, protracted, high volumes of water reduce sediment concentration, allowing for highly organized facies, on scales variable from bedforms, to macroforms to larger-scale architectural elements. Such generalizations, nonetheless, may not always hold true for stratigraphic prediction within particular settings.

The Tertiary Teruel Basin (Spain) is an association of half-grabens developed under semi-arid climate. In the central sub-basin, fine clastic to carbonate facies are intercalated by coarse alluvial deposits sourced from the tectonic margins. Alluvial fan successions from the footwall-block present only minor debrisflow and waterflow facies, but a striking prevalence of unconfined hyperconcentrated flow conglomerates, with traits characteristic of deposition from both fully turbulent and plastic flows (such as diffuse to fully amalgamated bedding; weak basal scouring; extremely poor sorting; variable clast- to matrix-support; disorganized fabrics, but locally graded or imbricated domains; no bedforms or macroforms; outsized clasts). Over the opposite hanging-wall block, ephemeral rirver systems produced extensive outcrops with distinct, single to multi-storey channel fills and overbank deposits. Prevalent disorganization of channel fills and their analogy with fan deposits suggest that prevalent hyperconcentrated flows distributed coarse alluvium along these drainage pathways.

Elevated sediment concentration probably resulted from high volumes of Triassic claystones in the basement. Excess of suspended fines raised flow viscosity, inhibiting sorting and development of fully tractive fabrics. Coarse bedload was filtered out within proximal alluvial systems at basin margins, but clay became a very important component both proximally and distally. Despite the distinctiveness of fine, basinal deposits and high-energy clastic facies at basin scale, the overwhelming volume of clay present in alluvial units significantly lowers their potential for subsurface fluid flow. Active tectonics and a semi-arid climate made the Teruel Basin a favorable setting, with poorly integrated catchments, sporadic runoff and high sediment supply. With special reference to fluvial systems, such facies appear  more common in the stratigraphic record of tectonically active settings than reported in the literature.

# Where does sediment come from? Characterising the links between catchment erosion, sediment export and deposition in tectonically perturbed landscapes

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Sediment routing systems represent the entire integrated erosion–transport-depositional system from source to sink. The depositional characteristics of any basin fill (the sink) are fundamentally a product of the coupled system of sediment release from hinterland catchments (the source) and its evolution during transport downstream. Changes to the tectono-climatic boundary conditions governing the dynamics of erosion and sediment transport should therefore determine the locus, nature and magnitude of sediment supply to basins. While recent advances in tectonic geomorphology demonstrate the coupling between tectonic uplift and landscape denudation, few studies quantify when, how and with what characteristics sediment is released from tectonically-forced catchments, the way in which this supply is 'sampled' downstream, and subsequently deposited by the fluvial system. This is unfortunate because a full understanding of the temporal and spatial behaviour of sediment routing systems raises the prospect of developing predictive models of basin stratigraphy in terms of differing conditions of hinterland tectonics and transport variables. We address this challenge by exploring the extent to which volume and grain-size characteristics of sediment release from modern rivers draining across active normal faults vary as a function of tectonic forcing. We demonstrate that catchments responding to an independently-constrained increase in fault throw rate within the last 1 My show significant volumetric export of material locally derived from the zone upstream of the fault, producing bi-modal grainsize distributions with elevated $D_{84}$ values within this reach. In contrast, the headwaters of these catchments have low fluvial transport capacity, and transport mono-modal material with $D_{50} < 4$ cm. We also evaluate the length-scale over which this transient grain-size signal propagates beyond the fault, and we compare this attenuation length with the calibre of material found within genetically-related basin deposits. We find that the coarse-fraction sediment released is likely to be retained in the proximal hangingwall if rates of tectonic subsidence are high, and if the axial river system is small, or far from the fault-bounded mountain front. Our results challenge the idea that basin sediment is sourced uniformly from upstream catchments in either space or time, demonstrate that sediment release is highly sensitive to tectonic and transport variables, and show that recent advances in landscape dynamics ought to be incorporated more readily within the fields of sedimentology and stratigraphy.

# The Distributary Fluvial System (DFS) Paradigm: Re-evaluating Fluvial Facies Models Based on Observations From Modern Continental Sedimentary Basins.

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When we think of fluvial systems and their preservation in the rock record, we typically draw upon our experiences with tributary rivers most common in the world. Indeed, most facies models that we use to interpret the ancient rock record have been developed on tributary rivers that exist outside active sedimentary basins or, if the river studied lies within a sedimentary basin, the models developed typically do not place the studied reach into the context of the basin. A review of approximately 700 modern continental sedimentary basins around the world (e.g., those that have a chance to be preserved in the rock record) showed that rivers in these basins are not tributary in nature; rather they form either (1) distributary fluvial systems (DFS), commonly called megafans, fluvial fans, and alluvial fans in the literature, or (2) axial stream systems that parallel the basin trend, with the vast majority of sedimentation in the basin occurring on the DFS (up to 95%). In these continental sedimentary basins, we have identified ~400 fluvial megafans (defined as DFS that are greater than 30km in length), with countless smaller DFS filling the basins. Thus, most sedimentary basins undergoing aggradation do not contain tributary fluvial systems. The implications of this observation could significantly affect our ability to reasonably interpret ancient fluvial deposits. Rivers on DFS differ from tributary rivers in many, potentially significant ways, including the following:

- A radial pattern of channels away from an apex (or intersection point) exists on DFS, though many of the DFS rivers do curve to become subparallel to the basin strike distally. In contrast, tributary systems tend to form dendritic patterns.
- Channel systems commonly decrease in width and discharge and thus cross-sectional area distally, while tributary systems tend to increase in size downstream.
- Meanderbelts tend to be more laterally mobile on the open DFS, forming “simple” meanderbelts rather than “compound” meanderbelts during aggradational phases on the DFS, where avulsion processes in “compound” meanderbelts are dominated by chute and neck cutoffs and “simple” meanderbelts switch nodal avulsion before developing to the point of having many chute or neck cutoffs (though some exceptions exist). Tributary systems, or those confined in valleys, tend to be dominated by chute and neck cutoffs.

- Floodplain deposits on DFS are often dominated by avulsion deposits, especially in distal portions of the DFS.
- Greater preservation of floodplain deposits appears to occur on DFS dominated by braided streams than found in braided streams of tributary systems.
- Axial streams in a basin, if confined laterally, and rivers that are incised into the DFS appear to be similar in character to tributary systems.

In this presentation, we show several examples of river system patterns commonly observed in continental sedimentary basins to illustrate these key differences between tributary and aggradational river systems.

# Where Do Meanderbelts Form in Modern Continental Sedimentary Basins?

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Since meanderbelt deposits are typically sand dominated, they form important features in petroleum reservoirs and fresh-water aquifers. Facies models reasonably describe the internal structure of these units; however, the rivers typically used to formulate these facies models are not aggradational nor are they in active sedimentary basins (thus, they will not be preserved in the rock record!). A comprehensive review of over 690 modern continental basins shows that fluvial deposition in basins occurs on either distributary fluvial systems (DFS) or along axial streams, with the DFS dominating basin deposition. Though a braided pattern is typically cited as dominant on DFS, meandering rivers are also common. Meandering rivers form both compound (or amalgamated) meanderbelts and simple meanderbelts. In a compound meanderbelt, the channel is held in one location for a sufficiently long period of time to create a complex sandstone unit with coalesced vertically and laterally stacked point bar deposits. Avulsion style is dominated by chute and neck cutoff processes. These are observed (1) within incised river reaches on the DFS, (2) along axial streams in the basin, and (3) on some DFS that are anamolous but may be experiencing low accommodation space or transition between aggradation and degradation (e.g., the Beni River system). In the first two cases, the river is confined in a valley so that fine-grained sediment is winnowed out through reworking of the floodplain. Rivers in degradational settings produce similar meanderbelts. In the latter case, the compound meanderbelt stacking pattern may be more diffuse. 'Simple' meanderbelts are formed where a channel develops a meandering pattern but avulses through nodal avulsion to a new position on the DFS prior to developing a compound meanderbelt. Chute and neck cutoff avulsions are rare in simple meanderbelts. We present several examples of meanderbelts on DFS from modern sedimentary basins around the world. Through evaluating river form in modern continental sedimentary basins, we can begin to place fluvial facies models in a basin context, thus improving our ability to interpret and predict facies distributions in the rock record.

# Pedogenic and non-pedogenic calcretes in the Devonian Ridgeway Conglomerate Formation of SW Wales, UK: a cautionary tale.

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Calcic pedocomplexes in the Siluro-Devonian Old Red Sandstone of the Anglo-Welsh Basin (UK) have been traditionally interpreted as palaeosols developed in dryland depositional environments. Their recognition has been used to indicate a range of controls, including climate, landscape stability, sedimentation rate, soil residence time and proximity to alluvial channels (the pedofacies concept). A study of the Devonian Ridgeway Conglomerate Formation (RCF) in Pembrokeshire, Southwest Wales has however challenged some of these notions, recognising that many calcretes were not developed in soil horizons.

The RCF was deposited as part of a dryland alluvial fan/axial fluvial valley complex. Regionally structural blocks and basins are defined by a series of extensional faults, the RCF being deposited in a half-graben as a hanging-wall alluvial fan. The RCF is heterolithic, comprising conglomerates, sandstones and gritty mudstones that reflect differences in processes, suggesting sheetfloods, low relief lateral accretion and cohesive debris flows. A number of calcrete types have been identified:

Non-pedogenic calcretes:

1. Cm-dm thick, layerbound micritic calcrete, typically having a sharp base with upper surfaces comprisisng vertical and cylindrical nodules, believed to have developed in the capillary fringe zone (groundwater calcretes).
2. Gully bed cements: Sparry, meniscus cements occluding pore space in conglomerates and coarse-grained sandstones. Developed in permeable fan sediments prone to infiltration and subsequent evaporation.
3. Lake-margin calcrete: micritic, laminated calcretes and rare teepee structures representing possible calcretised matgrounds in fan-toe ephemeral lakes.

Pedogenic calcrete:

1. Common cm-dm diameter nodules and sub-horizontal crystallaria sheets in association with pedogenic indicators such as drab haloes, desiccation cracks and ped textures. Also observed are micritic calcified root traces (rhizogenic calcretes).

The RCF is anomalous in that there is an absence of wedge-shaped peds as detailed in other ORS formations- was the mineralogy of the RCF provenance different and not conducive to shrink-swell phenomena?

The identification of common non-pedogenic calcretes in the RCF begs the question as to how much of the ORS calcretes are similarly non-pedogenic in nature? Our analysis may act as a cautionary check for subsurface work where carbonate horizons in alluvial suites are being modelled solely in accordance with the pedofacies concept.

# Fluvio-marine facies characteristics of the Quaternary rift Sediments between Wadi Um Gheig and Wadi Assal, South Quseir, North Red Sea Coast, Egypt.

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The Quaternary sediments were studied at Wadi Um Gheig (17 km south Quseir city) and Wadi Assal (42 km south Quseir city) north Red Sea Coast. The sediments of the coastal area between these two wadis, about 25 km long were also studied. These sediments are represented by different heights of terraces. The facies characteristics of these sediments are mainly consists of mixed siliciclastic sediments and reefal carbonate; marine conglomerates; cross-stratified and cross bedded sandstone and gravel of braided river; conglomerates of debris flow; and local evaporite deposits. The distribution of these facies is controlled by tectonic rift, or by base level change and climate. Textural and mineralogical characteristics of these facies were attributed to the provenance. The Quaternary sequences are characterized by transgressive (siliciclastic and reefal carbonate facies and lagoonal evaporite) and regressive (alluvial fan facies) cycles, may be related to the global eustatic system during Quaternary period

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