The preservation of fluvial sediments and their subsequent interpretation

Edited by Stephanie K. Davidson, Sophie Leleu, and Colin P. North
From River To Rock Record: The Preservation Of Fluvial Sediments And Their Subsequent Interpretation

Stephanie K. Davidson, Sophie Leleu, and Colin P. North, Editors

CONTENTS

Introduction
From River to Rock Record: The Preservation of Fluvial Sediments and Their Subsequent Interpretation
STEPHANIE K. DAVIDSON, SOPHIE LELEU, AND COLIN P. NORTH ................................................................. 3

Lessons from the Modern
Interpretation of Ancient Fluvial Channel Deposits: Review and Recommendations
FRANK G. ETHRIDGE ................................................................. 9

Architecture and Depositional Style of Fluvial Systems before Land Plants: A Comparison of Precambrian, Early Paleozoic, and Modern River Deposits
DARREL G.F. LONG ................................................................. 37

River Terraces in the Rock Record: An Overlooked Landform in Geological Interpretation?
STUART G. ARCHER, REYNIR FJALAR REYNISSON, AND ANNE M. SCHWAB ............................................................. 63

Short Term: Autogenically Dominated?
Fluvial Systems and Their Deposits in Hot, Seasonal Semiarid and Subhumid Settings: Modern and Ancient Examples
CHRISTOPHER R. FIELDING, JONATHAN P. ALLEN, JAN ALEXANDER, MARTIN R. GIBLING, MICHAEL C. RYGEL, AND JOHN H. CALDER ................................................................. 89

Interpreting Fluvial Hydromorphology from the Rock Record: Large-River Peak Flows Leave No Clear Signature
SUZANNE F. LECLAIR ................................................................. 113

Pedogenic and Sedimentologic Criteria for Recognition of Overbank Sub-Environments in a Triassic Anabranching-River Deposit
PARTHASARATHI GHOSH AND SOUMEN SARKAR ................................................................. 125

Stratigraphy of Counter-Point-Bar and Eddy-Accretion Deposits in Low-Energy Meander Belts Of The Peace-Athabasca Delta, Northeast Alberta, Canada
DERALD G. SMITH, STEPHEN M. HUBBARD, JASON R. LAVIGNE, DALE A. LECKIE, AND MILOVAN FUSTIC .... 143

Fluvial Paleotransport Derived from Trough Cross-Bedding: Example from the Lower Clair Group, West of Shetland, Using Oriented Whole-Core Images
ANDREW SMALLEY ................................................................. 153

Downstream Changes and Associated Fluvial-Eolian Interactions in an Ancient Terminal Fluvial System: The Permian Organ Rock Formation, SE Utah, U.S.A.
STEPHEN A. CAIN AND NIGEL P. MOUNTNEY ................................................................. 167
Medium Term: Complex Control Interactions

Architecture and Behavior of Dryland Fluvial Reservoirs, Triassic Skagerrak Formation, Central North Sea
TOM MCKIE

Avulsion and Its Implications for Fluvial-Deltaic Architecture: Insights from the Holocene Rhine–Meuse Delta
ESTHER STOUTHAMER, KIM M. COHEN, AND MARC J.P. GOUW

A Tidally Influenced, High-Latitude Coastal-Plain: The Upper Cretaceous (Maastrichtian) Prince Creek Formation, North Slope, Alaska
PETER P. FLAIG, PAUL J. McCARTHY, AND ANTHONY R. FIORILLO

Role of Scouring and Base-Level Change in Producing Anomalously Thick Fluvial Successions: An Example from the Tana River, Northern Norway
RAYMOND S. EILERTSEN AND GEOFFREY D. CORNER

Depositional Dynamics and Preservation Potential in a Progradational Lacustrine Fluvio-Deltaic Setting: Implications for High-Resolution Sequence Stratigraphy (Upper Triassic, Northwestern China)
JENS HORNUNG AND MATTHIAS HINDERER

Pedogenic and Non-Pedogenic Calcretes in the Devonian Ridgeway Conglomerate Formation of SW Wales, UK: A Cautionary Tale
ROBERT D. HILLIER, SUSAN B. MARRIOTT, AND BRIAN P.J. WILLIAMS

Alluvial Facies Distributions in Continental Sedimentary Basins—Distributive Fluvial Systems
GARY S. WEISSMANN, ADRIAN J. HARTLEY, GARY J. NICHOLS, LOUIS A. SCUDERI, MICHELLE E. OLSON, HOLLY A. BUEHLER, AND LAUREN C. MASSENGILL

Long Term: Allogenically Dominated?

Preservation of a Long-Lived Fluvial System in a Mountain Chain: The Tagliamento Valley (Southeastern Italian Alps)
GIOVANNI MONEGATO AND CRISTINA STEFANI

Lateral and Vertical Variability of Channel Belt Stacking Density as a Function of Subsidence and Sediment Supply: Field Evidence from the Intramountaine Köröś Basin, Hungary
ANNAMÁRIA NÁDOR AND ORSOLYA SZTANÓ

Deposystems, Paleosols, and Climatic Variability in a Continental System: The Upper Triassic Chinle Formation, Colorado Plateau, U.S.A.
RUSSELL F. DUBIEL AND STEPHEN T. HASIOTIS

Alluvial Valleys and Alluvial Sequences: Towards A Geomorphic Assessment
MARTIN R. GIBLING, CHRISTOPHER R. FIELDING, AND RAJIV SINHA
ABSTRACT: Holocene rivers have a high degree of morphological variability, and many researchers see a continuum of channel forms that are transitional between end-member planforms such as braided, meandering, or straight. Individual rivers also show a high degree of longitudinal and vertical (through time) variability, as a result of changes in base level, climate, tectonics, tributary contribution, and/or valley slope. This high degree of variability in planview morphology of Holocene rivers is generally not reflected in interpretations of ancient fluvial deposits, which continue to be interpreted as meandering or braided. Many of these interpretations are suspect because of myths about modern rivers and because the characteristics described bear little relationship to plan-view morphology. Modern fluvial facies models are built around the nature and type of channel bars. Knowledge of the architecture of bar forms and their occurrence in Holocene river channels has been greatly enhanced in the past two decades with data gained from ground-penetrating radar (GPR) studies. In spite of our expanded data base for modern rivers and their deposits we still need additional data on width-to-thickness ratios and architecture of deposits of aggrading river systems.

A review of the literature suggests that data on channel bar deposits is lacking in most studies of ancient fluvial deposits. The few research efforts that describe paleochannel bars in 3D and 2D exposures of ancient fluvial deposits suggest that there was considerable variability in paleochannel form within a given formation. Our focus in the study of ancient fluvial deposits should shift from interpreting planforms to description and interpretation of preserved bar forms and how river systems evolved. In this regard many ancient fluvial sheet sandstones need to be re-examined.
ARCHITECTURE AND DEPOSITIONAL STYLE OF FLUVIAL SYSTEMS BEFORE LAND PLANTS:
A COMPARISON OF PRECAMBRIAN, EARLY PALEOZOIC, AND MODERN RIVER DEPOSITS

DARREL G.F. LONG
Department of Earth Sciences, Laurentian University, Sudbury, Ontario, P3E 2C6, Canada
e-mail: dlong@laurentian.ca

ABSTRACT: 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 systems are not represented in the Precambrian or early Paleozoic sedimentary record. 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, and fine-grained meandering and anabranching systems have not been positively identified. Precambrian gravel-bed braided systems are common, and have architecture similar to that of modern systems, except that scour hollows are typically absent or difficult to identify. 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. Sandy ephemeral channelized upper-flow-regime elements and unconfined sheetflood deposits are common, but they lack many of the associated fine-grained components seen in modern systems.

Most known pre-vegetation fluvial systems were preserved within rifts, along continental margins, or in foreland-basin settings. Nearly all known Precambrian and early Paleozoic river deposits are dominated by channel and sheet-channel facies, and have high lateral continuity and high net-to-gross ratios. Thick overbank and interfluvial deposits are underrepresented, or where identified, are suspect and may represent channel abandonment. Direct comparison with younger systems requires detailed architectural analysis, with specific attention to the relative inclination and directional variability of foresets and first-order to sixth-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 evaluation of the paleohydraulic characteristics, sinuosity, and slope of older systems remains enigmatic.
ABSTRACT: Fluvial incision and terracing produces a scale of architectural complexity that is often overlooked in geological interpretations and the construction of subsurface reservoir models. Results of a 2D seismic forward modelling study demonstrate the difficulties and limitations in resolving terraces seismically. We propose that terraced sequence boundaries fall readily into a subsurface data resolution gap between seismic and core to wireline log scale.

Due to limitations in seismic resolution, sequence boundaries are usually interpreted as simple, single surfaces of erosion, for example at the bases of incised-valley fills. However, modern analogues show that sequence boundaries are in fact often compound in nature. The stratigraphic response to pulses of incision and aggradation in an incision-dominant phase can result in flights of stair-stepping terraces. In this paper we recognize two distinct architectural styles: attached and detached terrace flights. Their formation depends on the interplay between the magnitudes of incision versus aggradation.

We suggest that terraced sedimentary architectures, the nature of the terrace-fill lithology, and any associated pedogenesis impacts upon mesoscale to macroscale reservoir permeabilities and therefore have implications for subsurface fluid flow. The existence of terraces, in conjunction with the inherent lack of temporal control in fluvial successions, may help to explain correlation difficulties often encountered and to an extent the compartmentalized production behavior of some fluvial hydrocarbon reservoirs.
FLUVIAL SYSTEMS AND THEIR DEPOSITS IN HOT, SEASONAL SEMIARID AND SUBHUMID SETTINGS: MODERN AND ANCIENT EXAMPLES

CHRISTOPHER R. FIELDING
Department of Earth & Atmospheric Sciences, 214 Bessey Hall, University of Nebraska–Lincoln, Nebraska 68588-0340, U.S.A.
e-mail: cfielding2@unl.edu

JONATHAN P. ALLEN
Department of Earth & Atmospheric Sciences, 214 Bessey Hall, University of Nebraska–Lincoln, Nebraska 68588-0340, U.S.A.
Present address: Chevron North America Exploration&Production, 9525 Camino Media, Bakersfield, CA 93311, U.S.A.

JAN ALEXANDER
School of Environmental Sciences, University of East Anglia, Norwich, Norfolk, NR4 7TJ, U.K.

MARTIN R. GIBLING
Department of Earth Sciences, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada

MICHAEL C. RYGEL
Department of Geology, 44 Pierrepont Avenue, State University of New York at Potsdam, Potsdam, NY 13676, U.S.A.

AND

JOHN H. CALDER
Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia B3J 2T9, Canada

ABSTRACT: Observations and data from modern streams and recent deposits demonstrate that river systems in subhumid and semiarid seasonal settings in tropical and subtropical latitudes can have deposit characteristics very different from those predicted from previously published facies models based on other climatic settings. The differences result primarily from the extremely variable discharges that are typical of these climatic settings and contribute to a distinct fluvial style. Five critically important characteristics of the deposits are illustrated by data from NE Australia. The deposits with these characteristics occur in streams with variable discharge and are independent of channel size. (1) The channel-fill lithosomes are erosionally based and exhibit complex lateral facies changes. (2) Within the channel-fill lithosomes there are abundant mud partings, some of which are pedogenically modified. (3) In most cases the complex internal architecture lacks the macroform elements, such as lateral-accretion cross bedding, typical of other fluvial sediment bodies. This is the case even within point bars. (4) Sedimentary structures formed under high flow stage are abundant and frequently preserved in the lithosomes. (5) Trees and other vegetation adapted to occasional inundation by fast-flowing water may colonize channel floors (not only on banks), and these both generate organic sediment and influence the flowand resulting sediment deposition patterns. In addition to the characteristics of the channel-fill deposits, the overbank deposits may have diagnostic character and the sand petrography may differ from that in other settings. The same features are identified in the rock record and a detailed case study from the Pennsylvanian of the Maritimes Basin Complex of Atlantic Canada illustrates the distinction between the seasonal tropical and other fluvial styles. The upper Namurian (Yeadonian) Boss Point
Formation shows a transition from perennial to subhumid to semiarid, seasonal tropical fluvial styles within a succession of sheet-like braidplain channel bodies. The overlying, basal Westphalian (Langsettian), Little River Formation is composed entirely of more lensoid channel bodies displaying the subhumid to semiarid, seasonal tropical fluvial style, and associated overbank deposits. The overlying coal-bearing Joggins Formation shows a gradual return to a perennial fluvial style with channel body geometries similar to the underlying unit. A clear signal of paleoclimate change can be deconvolved from variations in accommodation regime, providing a hitherto unavailable discriminant for interpreting fluvial successions. Recognition of the strongly seasonal, tropical to subtropical fluvial style in the rock record, and of changes in character through vertical successions, will aid paleoclimate interpretation and subsurface reservoir analysis in fluvial successions.
ABSTRACT: Most recent studies on dune in large rivers focus on bedform development and sediment transport, and little consideration is usually given to the preservation potential of dune deposits. In this study, the Leclair-Bridge (2001) and the Paola-Borgman (1991) models are combined to estimate the thicknesses of bedform-scale deposits within channel-scale deposits in a large river at the end of annual high flows. Modeling relies on high-resolution bed elevations measured on 15-km-long 2-D lines during five successive surveys in the Lower Mississippi River.

Results from this study challenge our common assumptions: peak-flow deposits are not preferentially preserved, and dune height does not scale with flow depth even on a single survey. The model predicts that only few peak-flow deposits would be preserved in the deep parts of the channel (and would be from small dunes); instead, synchronous large-dune deposits would be found at elevation up to 10 m above the bend-scor level. Therefore, even full preservation of peak-flow dune deposits would lead to incorrect paleo-hydraulic reconstruction. Moreover, peak-flow deposits would hardly be distinguished from other deposits due to short-term partial erosion and overlap in thickness distributions of stacked channel-scale cosets and dune sets. If such dune deposits would be seen in an outcrop, the estimated mean dune height, based on measurements from several vertical sections where mean set thickness varies only by ~ 30%, would represent average seasonal flow conditions, not peak flows (methodology based on analysis of natural and experimental deposits presented in this paper), and the large size of the system would not be recognized.

Our interpretation problems are not methodological, but fundamental. Future research should integrate fluvial morphodynamics and sedimentology, in rivers of various sizes and patterns. Datasets are presented as supplementary material for teaching, eventual comparative studies, and for developing stratigraphic models.
ABSTRACT: A variety of sub-environments associated with geomorphologic features like splay systems, floodplain ponds/lakes, and abandoned alluvial ridges commonly occur in the overbank areas of modern river valleys. Though the overbank areas are generally characterized by lower flow strength, supply of finer-grained detritus and increased landform stability compared to the channels, the subtle differences among different overbank subenvironments may at times impart discernible lithologic and pedologic characteristics to their deposits.

Based upon the sedimentology of the channel-fill bodies, the upper part of the Triassic Denwa Formation of a central Indian Gondwana basin has been interpreted as the deposit of an anabranching fluvial system comprising a number of virtually coexistent channels of different orders and characters that operated in a wide, low-gradient plain. Earlier studies had identified the preservation of very thick deposits of pedogenically modified fluvial overbank sediments in this succession. Most of the paleosols preserved within the overbank deposits are similar to modern Vertisols and calcic Vertisols, suggesting a seasonal semiarid to subhumid climatic setting. Though in terms of carbonate accumulation most of these paleosols are immature to at best submature, they display a wide variation in the organization of vertic features.

This case study attempts to delineate the deposits of different overbank sub-environments within the upper Denwa Formation with the help of paleosol profile characters, stacking pattern of the profiles, and the nature of the host sediments. The sedimentologic and pedogenic characters of extra-channel deposits, taken together, led to the identification of three distinct associations representing three overbank sub-environments. The association comprising alternations of sheet bodies of heteroliths and mudstones, with simple or compound, paleosol profiles, with weak accumulation of carbonate, is interpreted as the deposits of splay complexes. The second association that comprises thicker mudstone intervals, virtually devoid of sand, and have cumulate to composite stack of vertic features without carbonate concretions, has been interpreted as deposits of distal floodplain depressions. The third association comprising mudstones with slightly mature paleosols that contain up to small-pebble-size calcareous concretions has been interpreted as deposits of sediment-starved elevated sites within the distal floodplain.

The deposits of Denwa fluvial system show marked differences with the existing humid anabraching models. Again, in spite of having a semiarid to subhumid climate this system differs from the Cooper Creek, Australia, in having a mixed sediment load, resulting in the development of channel–levee–floodplain geomorphology and contrast between the in-channel and overbank lithologies. On the other hand, Denwa does not show a consistent trend in paleosol maturity away from the channel areas as suggested from the study of Willwood Formation. This deviation can be attributed to the multichannel character of the fluvial system, which allowed distal floodplain sites to receive sediment input from multiple sources. This caused a rather continuous pattern of sedimentation in distal sites and inhibited the widespread development of mature paleosols. The variability observed between the distal floodplain paleosols reveals the influence of the factors like local floodplain topography, sediment accretion pattern, and drainage conditions.
ABSTRACT: Previously termed concave bank-bench deposits, point-bar-tail deposits, and distal point-bar deposits, counter-point-bar deposits have received little research attention, and their stratigraphy and sedimentology is poorly understood in modern and ancient river meander belts. The stratigraphy and lateral continuity of counter-point-bar deposits were studied in the modern Peace River Delta, northeast Alberta, Canada. Morphology of counter-point-bar deposits was identified as having concave-shaped scroll-bar and vegetation patterns, and they are always located immediately downriver from sandy point bars. Stratigraphy of counter-point-bar deposits, composed of 55 to 86% silt, were studied using a vibracorer to depths of 6.5 m and channel-bottom grab samples to depths of 20 m over a river distance of 1800 m. This contrasts with 95 to 100% sand in adjacent point-bar deposits. Like point bars, counter point bars are also lateral-accretion deposits, but are composed of inclined heterolithic strata. Counter-point-bar deposits can form in short-radius meanders, as well as in wide-radius broad meanders. Counter-point-bar deposits formed where channels impinge at low angles (10 to 40°) against bedrock valley sides or other erosion resistant sediment.

Within the Athabasca River Delta, a different feature called an eddy-accretion deposit, was studied and compared to counter-point-bar deposits. Eddy-accretion deposits formed as short-radius, pronounced concave scroll-bar and vegetation patterns that notably arc up-valley. In contrast to the counterpoint-bar deposits analyzed, these deposits are thicker, sandier, and not as laterally extensive for a channel of a given size. Eddy-accretion deposits formed where river flow impinges more directly against (40°-140°) a valley side or channel margin composed of bedrock or resistant sediment such as an oxbow-lake fill, abandoned-channel fill or, as in this case, a Holocene prodelta deposit. The eddy-accretion deposit studied is up to 500 m wide and 24 m thick, although probably closer to 34 m thick during near-bankfull discharge. It is composed of up to 80% sand.
FLUVIAL PALEOTRANSPORT DERIVED FROM TROUGH CROSS-BEDDING: EXAMPLE FROM THE LOWER CLAIR GROUP, WEST OF SHETLAND, USING ORIENTED WHOLE-CORE IMAGES

ANDREW SMALLEY
Task Geoscience Inc., 10375 Richmond Avenue, Millenium Tower, Suite 1300, Houston, Texas 77042, U.S.A.
e-mail: andy.smalley@taskgeoscience.com

ABSTRACT: The use of cross-bedding to determine sediment dispersal patterns in ancient river systems has long been established. From well data, such measurements can be made but require a degree of inference and conceptualization due to the limited coverage of the wellbore and the quality of the data available. This study presents results derived from whole-core image data acquired in a horizontal well. The orientation of this well is approximately perpendicular to sediment transport direction in an ancient braided river system, from the Devonian Lower Clair Group. This provides a unique borehole view of fluvial sandstones, where trough cross-bedding is sampled in transverse section. Where whole trough sets are sampled, the orientation of the hydraulic dune axes which formed them can be determined. Although these data are invaluable, all borehole measurements are subject to the effects of borehole bias, which in this case, is not significant in terms of bedding dip but has a significant effect in terms of bedding strike. Essentially dunes with axes which trend oblique to the well path, which is likely to occur given the direction of the well and the expected braided sinuosity of channel-ribbons, will be poorly sampled. Despite this, trough axes form an orthogonal set when plotted together on a stereonet, which is the geometry expected as channel-ribbons converge at bar fronts, where hydraulic dunes are most likely to be preserved within a river system. Based on this assumption, the bisector of this trend could represent the channel braid axis of the preserved river system, which trends to the SSE. However, given that data were acquired from a horizontal well oriented approximately perpendicular to the paleotransport direction, it will more likely reflect lateral variation within the river system. Based on this assumption, and inferences from elongate-bar geometries, an investigation of lateral variation in braid axis orientation was carried out. This revealed divergent patterns in channel braid axes, reminiscent of terminal fan geometries. From these patterns, at least two terminal fan systems of more than 100 m in width and with axes to the SSE and SSW have been identified, which overlap at their margins.
DOWNSTREAM CHANGES AND ASSOCIATED FLUVIAL-EOLIAN INTERACTIONS IN AN ANCIENT TERMINAL FLUVIAL SYSTEM: THE PERMIAN ORGAN ROCK FORMATION, SE UTAH, U.S.A.

STEPHEN A. CAIN
Earth Sciences, School of Physical and Geographical Sciences, Keele University, Staffordshire, ST5 5BG, U.K.
Present address: Lukoil Overseas UK Ltd, Charles House, 5-11 Regent Street, London, SW1Y 4LR, U.K.
e-mail: scain@lukoiloverseasuk.com

AND

NIGEL P. MOUNTNEY
Earth Sciences, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, U.K.
e-mail: n.mountney@see.leeds.ac.uk

ABSTRACT: 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 southwestwards (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, high-energy, bed-load sedimentation, 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 eolian dune elements are dominant.

A suite of high-resolution architectural panels detailing stratigraphic relationships across a range of outcrop sections totaling 5 km in length were integrated with a set of broader regional stratigraphic panels based on correlations between 84 vertical sedimentary logs. These were together used to propose two possible paleogeographic models that account for the observed systematic downstream variability in fluvial architecture and associated style of fluvial–eolian interactions across the region. The first paleogeographic model represents the Organ Rock fluvial system as a channel network that is continuous from its source (Uncompahgre Highlands) to its point of termination on a low-relief desert plain in the distal part of the basin. This model is comparable, in part, to the processes responsible for downstream changes in channel morphology predicted by current models of terminal fluvial systems. By contrast, the second paleogeographic model represents the Organ Rock fluvial system as two separate channel networks that occupied more proximal and more distal parts of the basin, respectively, and which were separated by an intermediate floodout zone in which channel competency and physical expression was lost. This latter model, which is supported by field observations, does not conform to current models of terminal fluvial systems and has implications for the hydrological controls on the evolution of such systems and for the transportation and distribution of sediment within such systems.
ARCHITECTURE AND BEHAVIOR OF DRYLAND FLUVIAL RESERVOIRS, TRIASSIC SKAGERRAK FORMATION, CENTRAL NORTH SEA

TOM MCKIE
Shell UK Exploration and Production, 1 Altens Farm Road, Nigg, Aberdeen AB12 3FY, U.K.
e-mail Tom.Mckie@Shell.com

ABSTRACT: Fluvial reservoirs are inherently heterogeneous. They typically have a complex connectivity between sandbodies of limited predictability and have highly variable reservoir properties at a range of scales. Attention is typically focused on the connectivity of fluvial channels because this primarily determines the feasibility of hydrocarbon recovery. However, in sand-rich fluvial reservoirs, where connectivity is less of an issue, the internal heterogeneity related to deposition and preservation of the fluvial deposit still results in uneven fluid movement and presents a challenge for prediction of reservoir behavior. The Triassic Skagerrak Formation provides an example of a sand-rich, dryland fluvial reservoir that would, prior to production, be regarded as having no critical issues relating to depositional architecture. The Skagerrak was deposited as widespread, coarsening-upward sheets by terminal fluvial systems extending several hundred kilometers from the basin margins. These sheets are typically playa and splay dominated in the lower part and become increasingly channel dominated upwards. Multistory channel-belt packages at the top of coarsening-upward sheets form the main producing intervals, and were likely to have been the product of mobile, avulsive, multiple channel systems which generated kilometer-scale channel belts. Well-test and pressure data indicate that these channel belts constitute a dual-permeability system consisting of a network of higher-permeability bodies that are variably distributed within a lower-permeability matrix. This behavior is a product of the channel belts comprising discontinuous, coarse-grained thalweg and lower bar bodies embedded in a finer-grained matrix of upper bar and splay sands. Intervals where these coarse-grained facies are well connected form high-permeability pathways which dominate early production, and these tend to be located at the bases of multistory units. However, long-term production rates are ultimately determined by inflow to these depleting pathways from the finer-grained, lower-permeability upper bar and splay facies. Well tests typically encounter boundaries, which reflect the common presence of internal barriers and baffles within the channel belts. These boundaries are composed of abandonment plugs, bar-draping fines, mud-chip conglomerates, and cemented calcrite-clast lags. However, despite the apparent abundance of flow baffles, long-term production indicates that the channel belts are fully connected laterally and that such features are likely to be discontinuous. Whilst the high sand–shale ratio of the Skagerrak would suggest that there should be few problems related to the connectivity of the fluvial sandbodies, the vertical connectivity is considerably reduced as a result of compartmentalizing shales. The origin of these shales is variable. Predictable shale packages of semi-regional extent mark intervals of terminal fluvial contraction, resulting in regional interfingering of fluvial sand sheets and floodbasin fines. In addition, more localized bar-top and floodplain shale remnants which scale with the areal extent of a field introduce more random flow barriers which are less predictable. Despite developments in the conceptual understanding of the facies architecture of such fluvial reservoirs, prediction of reservoir behavior is hindered by a paucity of quantitative and qualitative data on the geometry of preserved fluvial lithosomes with which to construct 3D models of complex bar architectures at a sub-channel-belt scale. This is particularly important when such belts are larger than the field extent, and the heterogeneities which need to be modelled are therefore at a finer hierarchical scale. The prediction of effective permeability of the reservoir requires information on the grain-size architecture within these
lithosomes, together with the geometry and distribution of flow-baffling fines drapes and mud-chip lags. However, there are currently insufficient data from good-quality outcrops to be able to fully capture the potential impact of the natural variability of this architecture and construct predictive, quantitative models with a range of realistic geometries and properties.
AVULSION AND ITS IMPLICATIONS FOR FLUVIAL-DELTAIC ARCHITECTURE: INSIGHTS FROM THE HOLOCENE RHINE–MEUSE DELTA

ESTHER STOUTHAMER
Department of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht
e-mail: e.stouthamer@geo.uu.nl

KIM M. COHEN
Department of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht and Deltares | Applied Geology and Geophysics, Princetonlaan 6, Utrecht

AND

MARC J.P. GOUW
Department of Physical Geography, Faculty of Geosciences, Utrecht University, P.O. Box 80.115, 3508 TC Utrecht

ABSTRACT: Avulsion is a principal process in the formation of fluvial-deltaic successions and a primary control on deltaic architecture. It determines the distribution of sediment and water and hence influences which location in the delta receives clastic sedimentation in what amounts for what time. It also determines channel network configuration and recurrence interval of channel belts in the sedimentary succession. Starting from an overview of the depositional history and (quantified) boundary conditions of the Holocene Rhine–Meuse delta, The Netherlands, this paper discusses the implications of avulsions for fluvial-deltaic architecture based on extensive field data, highlighting the geometric properties, channel-deposit proportion (CDP), channel-belt connectedness (CR) and channel-belt width to thickness ratios (W/T).

Our study area stretches over 150 km downstream distance and covers fluvial, lagoonal, and estuarine reaches of the Holocene delta. Delta width and thickness increase considerably in downstream direction, from 15 km x 4 m at the apex to 60 km x 20 m at the river mouth.

Overall, the architecture and avulsion history is governed by relative base-level rise until 3000 years ago and by human-increased sediment delivery thereafter. Channel-belt CDP, CR, and W/T ratios decrease downstream within the wedge-shaped fluviodeltaic sequence. Their spatial variation is due to differences in provided accommodation space and inherited floodplain geometry, and due to distribution of stream power over branches. Initial high avulsion frequencies decreased with dropping rates of sea-level rise since 9000 years until ~ 3000 years ago. Thereafter avulsion frequency increased again due to increased delivery of fine sediment. This multi-millennial trend in avulsion frequency is overprinted with an ~ 600 year periodicity, attributed to intrinsic avulsive behavior occurring in the distributary network.

The highest avulsion frequencies occurred in the areas with highest CDP. Differential tectonics between the upstream and downstream delta interrupt overall downstream architectural trends, with a local minimum in W/T and a maximum in CDP and CR over the relative upthrown block. This downstream change favored nodal avulsion immediately downstream of the block.

Amalgamated channel belts formed along the sandy margins of the wide backfilled paleo-valley. In contrast, channels of an anastomosed river system in the western–central part of the delta formed isolated channel belts, encased in cohesive floodplain sediments until it was abandoned ~ 4000 years ago. In the last 3000 years, when the situation in the delta changed dramatically, major channel belts
became established due to major avulsions in the apex region, leading to a substantial increase in channel-deposit proportion.

Seven sequences of avulsions, shifting upstream along a feeder branch, have been recognized. Depending on the mechanism creating these sequences, the sequences may influence fluvial-deltaic architecture. Based on the observations in the Rhine–Meuse delta, these sequences seem to be caused mainly by the backwater effect after an avulsion occurred downstream and not by continued growth of alluvial ridges as was suggested by Mackey and Bridge (1995). Therefore, the high CDP and CR in the upper Rhine–Meuse delta is not related to a particular avulsion-sequence-driving mechanism being dominant.
A TIDALLY INFLUENCED, HIGH-LATITUDE COASTAL-PLAIN:
THE UPPER CRETACEOUS (MAASTRICHTIAN) PRINCE CREEK FORMATION,
NORTH SLOPE, ALASKA

PETER P. FLAIG
Dept. of Geology and Geophysics, and Geophysical Institute, University of Alaska Fairbanks,
P.O. Box 755780, Fairbanks, Alaska 99775, U.S.A.
Current address: University of Texas at Austin, Bureau of Economic Geology,
Quantitative Clastics Laboratory, 10100 Burnett Rd, Austin, Texas 78758, U.S.A.
e-mail: peter.flaig@beg.utexas.edu

PAUL J. MCCARTHY
Dept. of Geology and Geophysics, and Geophysical Institute, University of Alaska Fairbanks,
P.O. Box 755780, Fairbanks, Alaska 99775, U.S.A.
e-mail: mccarthy@gi.alaska.edu

AND

ANTHONY R. FIORILLO
Museum of Nature and Science, P.O. Box 151469, Dallas, Texas 75315, U.S.A.
e-mail: tfiorillo@natureandscience.org

ABSTRACT: The Prince Creek Formation is an Upper Cretaceous, dinosaur-bearing, high-latitude alluvial succession deposited on an ancient coastal-plain that crops out in bluffs along the Colville, Kogosukruk, and Kikiakrorak Rivers of northern Alaska. Studies that document the complex stratigraphy and architecture of high-latitude alluvial systems deposited under greenhouse conditions are extremely rare. It is exceptionally uncommon to find extensive, accessible outcrops that also contain numerous Arctic dinosaur fossils; hence the Prince Creek Formation is of great significance not only to sedimentologists but also to paleontologists involved in reconstructing high-latitude dinosaur habitats.

Maastrichtian strata of the Prince Creek Formation record deposition on a tidally influenced high-latitude coastal-plain in (i) first-order meandering trunk channels, (ii) second-order meandering distributary channels, (iii) third-order fixed (anastomosed?) distributary channels, and (iv) on floodplains. Conglomerate and medium- to coarse-grained multistory sandbodies are found exclusively in regionally restricted 13–17-m-thick fining-upward successions (FUSs) that display inclined heterolithic stratification (IHS) capped by finer-grained, organic-rich facies. These relatively thick FUSs are interpreted as first-order meandering trunk channels. Thinner (2–6-m thick), single-story, heterolithic sheet sandbodies composed predominantly of IHS and including abundant mud-filled channel plugs are the most frequently encountered channel form. Trough cross-lamination at the base of the IHS records paleoflow at high angles relative to the dip of the inclined beds, indicating that lateral accretion of point-bars was the principal depositional mechanism. These single-story sandbodies are interpreted as second-order meandering distributary channels. Fine-grained, 1.5–3.0-m-thick, ripple cross-laminated ribbon sandbodies deposited mainly by vertical accretion above an arcuate erosion surface and containing only minor IHS are interpreted as third-order fixed (anastomosed?) distributary channels. Thinner (0.2–1.0-m-thick) current-ripped sheet sands and silts are interpreted as small-scale crevasse splays and levees. Organic-rich siltstone and mudstone, carbonaceous shale, coal, bentonite, and tuff are interpreted as deposits of lakes, ponds, swamps, marshes, mires, paleosols, and ashfall on floodplains.
Heterolithic sheet sandstones deposited by small, sinuous meandering distributary channels typically appear lenticular along strike, commonly incise into pre-existing distributary channels, and interfinger with and incise into organic-rich floodplain facies. Fixed, ribbon-form (anastomosed?) distributaries incise either into meandering distributaries or into floodplain facies, with numerous ribbons typically preserved in tiers at the same stratigraphic level. Spatial relationships between channel types, and between channels and floodplain facies, indicate that the bulk of deposition took place on crevasse-splay complexes adjacent to trunk channels. Crevasse-splay complexes were constructed by the lateral migration of sinuous meandering distributaries and the vertical filling of fixed (anastomosed?) distributaries, with splay complexes separated from each other by organic floodplain facies. Flow in meandering distributaries and fixed (anastomosed?) distributaries may have been contemporaneous. Alternatively, fixed (anastomosed?) distributaries may record the initial or waning stages of flow during splay-complex formation or abandonment.

IHS composed of rhythmically repeating, coarse-to-fine couplets of current-rippled sandstone and siltstone or mudstone is found in all three types of channels. The rhythmic and repetitive nature of these couplets together with relatively thick, muddy fine-grained members in couplets suggest that flow in channels was likely influenced by tidal effects.

Drab colors in fine-grained sediments, abundant carbonaceous plant material, and common siderite nodules and jarosite suggest widespread reducing conditions on poorly drained floodplains influenced, in more distal areas, by marine waters. However, carbonaceous root traces found ubiquitously in all distributary channels and most floodplain facies along with common Fe-oxide mottles indicate that the alluvial system likely experienced flashy, seasonal, or ephemeral flow, and a fluctuating water table. The flashy nature of the alluvial system may have been driven by recurring episodes of vigorous seasonal snowmelt in the Brooks Range orogenic belt as a consequence of the high paleolatitude of northern Alaska in the Late Cretaceous.
ROLE OF SCOURING AND BASE-LEVEL CHANGE IN PRODUCING ANOMALOUSLY THICK FLUVIAL SUCCESSIONS: AN EXAMPLE FROM THE TANA RIVER, NORTHERN NORWAY

RAYMOND S. EILERTSEN
Geological Survey of Norway, Polarmiljøsenteret, N-9296 Tromsø, Norway
e-mail: raymond.eilertsen@ngu.no

AND

GEOFFREY D. CORNER
Department of Geology, Faculty of Science and Technology, University of Tromsø, N-9037 Tromsø, Norway

ABSTRACT: An anomalously thick (> 30 m), multistory, Holocene fluvial succession exposed in a 600-m-long, postglacially raised river-terrace section at Masjoksletta, in the lower Tana River in northern Norway, is more than five times thicker than the “normal” single-story fluvial unit (3–5 m) found elsewhere in the lower part of the valley. We describe the facies composition, depositional architecture, and basal relief of the succession based on studies of exposures and ground-penetrating-radar data, and reconstructs the shoreline trajectory in order to evaluate the role of base-level change and deep scouring during deposition.

The succession at Masjoksletta comprises three, stacked, sandy, fluvial units erosionally overlying deltaic sediments. The lowermost unit (I) is 20 m thick and composed of relatively thick cross-beds of uniform grain size, in contrast to the overlying units (units II and III), which are 8–8.5 m thick and characterized by fining-upward grain size and decreasing-upward bed thickness. Unit I formed following rapid base-level fall but is interpreted as a scour-fill unit based on the following properties: (1) anomalous thickness (> 20 m) compared with a local norm of 3–5 m, (2) erosion and deposition up to 28 m below contemporaneous sea level, compared with modern channels depths of < 10 m, and (3) thick beds and uniform grain size compared with overlying fining-upward units. The middle (II) and uppermost (III) units are interpreted as having formed in response to a stillstand in relative sea-level related to the regional early-to-mid-Holocene Tapes transgression, which, combined with rapid delta progradation, caused the river bed to aggrade.

A comparison of channel flow depths for units I–III, derived from cross-bed set thickness and our regional data, shows that the methodology of using cross-bed thickness to derive flow depth may give a useful approximation but underestimates channel depth for scours and possibly also other high-aggradation settings. We suggest that the characteristics reported here for scour-and-fill sediments (unit I) at Tana, such as great thickness, uniform bed thickness, and uniform grain size, can be used to identify scour-fill deposits in other areas and for distinguishing between autogenic, localized channel scouring and allogenically controlled incision.
DEPOSITIONAL DYNAMICS AND PRESERVATION POTENTIAL IN A PROGRADATIONAL LACUSTRINE FLUVIO-DELTAIC SETTING: IMPLICATIONS FOR HIGH-RESOLUTION SEQUENCE STRATIGRAPHY (UPPER TRIASSIC, NORTHWESTERN CHINA)

JENS HORNUNG AND MATTHIAS HINDERER
Technische Universität Darmstadt, Institut für Angewandte Geowissenschaften, Schnittspahnstrasse 9, 64287 Darmstadt, Germany
e-mail: hornung@geo.tu-darmstadt.de

ABSTRACT: Lacustrine deltaic systems differ in several ways from marine ones, and classic sequence stratigraphical concepts need to be modified. This study uses a quantitative outcrop analogue approach with an exceptionally high-resolution record of a lacustrine delta complex (centimeter to decimeter) of the Upper Triassic at the southern margin of the Junggar Basin (Xinjiang, northwestern China). Sedimentological logging of lithofacies and architectural elements were combined with gamma-ray measurements and two-dimensional maps of outcrop faces. The data are analyzed and interpreted in terms of depositional dynamics, cyclicity, stacking pattern, accommodation vs. sediment supply, and preservation potential. The sedimentary inventory comprises various types of gravelly channel bodies, sheetlike sandy and clayey units, as well as ferrocrete horizons and coal seams organized in four depositional environments: Delta slope, delta front, delta top and distal alluvial plain. In contrast to existing fan-delta models, weakly incised, coarse-grained channel fills reaching far beyond the delta front are intercalated into fine-grained delta-slope deposits. Thus, we propose a new type of a mixed-load fan delta, which might be common in other very large lake systems. A fourfold cycle hierarchy with systematic superposition of cycles was identified. It shows a closely linked control of sediment transport, depositional processes, and accommodation space typical for lake systems. According to preservation of cycles and regional geodynamic data, tectonic rates did not change markedly in the Late Triassic. However, a decrease of bisaccate pollen and biodiversity but an increase of spores suggests an increase in humidity, but also in climate “extremes” towards the Jurassic–Triassic boundary. Preservation potential and cycle symmetry are related to the accommodation space by the sediment supply (A/S) ratio, which shows an overall decrease during Norian times with a subsequent increase during the Rhaetian. Gamma-ray measurements (GR) also show a distinct cyclicity, however frequently independent of grain sizes. Channelized coarse-grained sediments show increased natural gamma-ray emission (total counts) due to 40K in claystone clasts. The U/Th ratio is often higher in the delta-front environment due to interaction of fresh river water and lake water.
PEDOGENIC AND NON-PEDOGENIC CALCRETES IN THE DEVONIAN RIDGEWAY CONGLOMERATE FORMATION OF SW WALES, U.K.: A CAUTIONARY TALE

ROBERT D. HILLIER
Department of Geology, National Museum of Wales, Cardiff, CF10 3NP, U.K.
e-mail: robhillier@aol.com

SUSAN B. MARRIOTT
School of Earth Sciences, University of Bristol, Queen’s Road, Bristol, BS8 1RJ, U.K.

AND

BRIAN P.J. WILLIAMS
Department of Geology and Petroleum Geology, University of Aberdeen, Kings College, Aberdeen, AB24 3UE, U.K.

ABSTRACT: Calcic pedocomplexes in the Siluro-Devonian Old Red Sandstone (ORS) of the Anglo-Welsh Basin (UK) have traditionally been interpreted as paleosols 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, recognizing that many calcretes were not developed in soil horizons. The RCF was deposited as part of a dryland alluvial fan and axial fluvial valley complex. Regionally, structural blocks and basins were defined by a series of extensional faults, with the RCF being deposited in a half-graben as a hanging-wall alluvial fan.

The RCF is heterolithic, comprising conglomerates, sandstones, and mudstones that reflect differences in processes, suggesting sheetfloods, low-relief lateral accretion, and cohesive debris flows across the alluvial fan. Pedogenic calcretes are common in all areas of the fan and axial fluvial zone. In mudstone and sandstone-grade lithofacies they comprise common horizonated nodules and subhorizontal crystallaria sheets in association with pedogenic indicators such as drab haloes, desiccation cracks, and ped textures. Also observed are both horizontal and vertical root traces, some of which have been the focus of micrite nodule growth (rhizogenic calcretes). Wedge-shaped peds are absent. Pedogenic profiles display upward-increasing percentages of nodules, and may be capped by blocky, massive calcrete and laminated micrite that developed in small ponded areas. In gravel-grade lithofacies, the pedogenic expression is different, and comprises carbonate-coated clasts with pendant and pore-occluding calcrete fabrics.

Pedogenic calcretes are best developed in proximal areas of the fan, possibly on terraces adjacent to fan-channel entrenchment zones (the pedofacies concept). Proximal fan areas may also have had increased soil residence times due to reduced sedimentation rates compared to distal fan and axial fluvial valley zones.

In distal fan and axial alluvial zones, thin layerbound micritic groundwater calcretes are common, typically being sharp based with upper surfaces comprising vertical and cylindrical nodules that possibly developed in the capillary-fringe zone. Inclined heterolithic bedsets, the deposits of laterally accreted ephemeral channels also commonly contain layer-bound micritic calcretes, again interpreted as having a
groundwater origin. Lake-margin calcretes comprising centimeter-thick, laminated micrite, represent possible calcretized matgrounds in fan-toe, ephemeral ponds.

The identification of common non-pedogenic calcretes in the RCF begs the question: 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.
ALLUVIAL FACIES DISTRIBUTIONS IN CONTINENTAL SEDIMENTARY BASINS—DISTRIBUTIVE FLUVIAL SYSTEMS

GARY S. WEISSMANN
University of New Mexico, Department of Earth and Planetary Sciences, MSC03 2040, 1 University of New Mexico, Albuquerque, NM 87131-0001, U.S.A.

ADRIAN J. HARTLEY
Department of Geology & Petroleum Geology, School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UE, U.K.

GARY J. NICHOLS
Department of Earth Sciences, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, U.K.

LOUIS A. SCUDERI, MICHELLE E. OLSON, HOLLY A. BUEHLER, AND LAUREN C. MASSENGILL
University of New Mexico, Department of Earth and Planetary Sciences, MSC03 2040, 1 University of New Mexico, Albuquerque, NM 87131-0001, U.S.A.

ABSTRACT: Fluvial depositional patterns in modern continental sedimentary basins from different tectonic settings are dominated by distributive fluvial systems (DFSs). A review of satellite imagery from over 700 modern continental sedimentary basins from different tectonic and climatic settings shows that rivers on DFSs are generally not confined to valleys and have a clear apex from which active and abandoned channelbelts radiate outward to form a positive topographic feature centered on this apex. Channels have no tributaries on the DFSs and commonly decrease in size downstream on the DFSs due to bifurcation, infiltration, and evaporation. In contrast, fluvial systems in sedimentary basins that are confined within a valley, such as those held between adjacent or opposing DFSs, incised into a DFSs, or that lie in an axial position in a basin, typically have less area for floodplain development and display coarse-grained-dominated facies. These confined rivers appear to be more similar to tributary rivers that are commonly described for present fluvial facies models. Because sediments deposited in continental sedimentary basins are those that constitute the rock record, this work suggests that many of the fluvial rocks observed may have formed on DFSs. This strongly suggests the need to develop new facies models that account for processes on DFSs.
ABSTRACT: The continental succession filling the valley of the Tagliamento River (eastern Southern Alps) is one of the best examples of long-lived fluvial system in the Alpine Chain. The sedimentary record, divided into a number of allostratigraphic units, covers the Messinian–Quaternary time interval and allows the unravelling of the evolution of the drainage basin in the most tectonically active sector of the Alps. The timing of the tectonic activity was compared with the ages of the sedimentary units and its influence on the sedimentation along the valley, and the preservation of the sedimentary bodies was evaluated. After the deep incision determined by the Messinian Salinity Crisis the sedimentation along the valley was firstly driven by the late Zanclean marine transgression; subsequently the strike-slip deformation along the valley, caused by the western segment of the Idrija Fault, created reaches of local subsidence, in which there were unit superposition, or uplift, where the units are nested. Strike-slip movement contributed to the northeastern migration of the trunk valley at its present location. Finally, the onset of the Quaternary glaciations determined the increase of sediment discharge of the catchment and enhanced the erosion during the glacier advances.
LATERAL AND VERTICAL VARIABILITY OF CHANNEL BELT STACKING DENSITY AS A FUNCTION OF SUBSIDENCE AND SEDIMENT SUPPLY: FIELD EVIDENCE FROM THE INTRAMOUNTAINE KŐRÖS BASIN, HUNGARY

ANNAMÁRIA NÁDOR
Geological Institute of Hungary, H-1143 Budapest, Stefánia 14., e-mail: nador@mafi.hu

AND

ORSOLYA SZTANÓ
Eötvös Loránd University Budapest, Dept. of Geology, H-1117 Budapest, Pázmány Péter 1/c, e-mail: sztano@ludens.elte.hu

ABSTRACT: Late Neogene–Quaternary inversion of the Pannonian basin created subsidence of several sub-basins coupled with uplift of the surrounding mountainous regions, which facilitated accumulation of Plio-Pleistocene fluvial sequences up to a thousand meters thick. The location of the main channel belt zones in the Pleistocene fluvial succession in the Kőrös basin at the eastern part of the Pannonian basin was determined by analysing well-log patterns from more than fifty water-prospecting wells, and their proportion to floodplain alluvium has been quantified also. The main aim of the paper is to compare channel belt stacking density patterns from Kőrös basin data sets with various model predictions on alluvial architecture and thus contribute to the better understanding on disparities between them. The vertical changes of the channel/floodplain ratios along seven sections show that the proportion of channels is generally lower for the deeper parts of the sections, indicating that subsidence rate was relatively high, creating enough accommodation to store fluvial deposits, including their thick vertical aggradational floodplain sediments, while the proportion of channel belt deposits increased at the expense of floodplain sediments in the upper 300–180 m part of the sedimentary succession representing the last ~ 1.3 million years, indicating less accommodation available and/or more sediment supply to the basin. This pattern is principally in agreement with the LAB models on alluvial architecture (Leeder 1978; Alexander and Leeder 1987; Bridge and Leeder 1979) concerning the inverse correlation of stacking density and subsidence.

The analysis of lateral variability on changes in the ratio of accommodation to sediment supply as a control on stacking density showed that the proportion of channel belt deposits is higher close to the northwestern and southwestern margins of the basin, especially in the upper part of the sedimentary succession, and values become significantly lower coming closer to the depocenter to the south, showing that rivers do not necessarily flow towards the subsidence maximum as suggested by the LAB model. The thickest point-bar units (11–20 m) at the northern and western margin of the basin were deposited by the paleo–Tisza River, which was forced to flow along a transtensional strike-slip fault zone. Another somewhat smaller river, the paleo-Kettős–Kőrös at the southeastern margin of the basin was fed by high sediment supply from the uplifting Apuseni Mountains, which thus could pass without deviating towards the laterally subsiding basin center, proving model predictions of Hickson et al. (2005).

Our results clearly indicate that the primary control on channel density was driven by variations in subsidence and uplift of the hinterland, thus sediment supply. The increased channel stacking density

...
since about 1.3 Ma in the Körös basin is related to a waning compression in the Pannonian–Carpathian realm, manifested in decreased subsidence of the Körös basin coupled with the erosion-driven isostatic uplift of the Apuseni Mountains source area. The Körös basin example shows that basin evolution is more complex than all variables controlling fluvial architecture could be described by a single model.
DEPOSYSTEMS, PALEOSOLS, AND CLIMATIC VARIABILITY IN A CONTINENTAL SYSTEM: THE UPPER TRIASSIC CHINLE FORMATION, COLORADO PLATEAU, U.S.A.

RUSSELL F. DUBIEL
U.S. Geological Survey, MS 939 Box 25046 DFC, Denver, Colorado, 80225 U.S.A.

AND

STEPHEN T. HASIOTIS
Department of Geology, University of Kansas, 1475 Jayhawk Blvd., 120 Lindley Hall, Lawrence, Kansas, 66045 U.S.A.

ABSTRACT: The Upper Triassic Chinle Formation of the Colorado Plateau in the western United States was deposited as a continental fluvial-floodplain-lacustrine-eolian depositional system near the west coast of Pangea just north of the paleoequator. The deposystem evolved in response to regional tectonics and long-term climate change. Clastic and volcanic sediment was supplied by uplifted highlands and arc magmatism on the margins of the basin. Climate changed from a Pangean megamonsoon regime in the early Late Triassic to an arid climate setting at the close of the Triassic. Chinle fluvial discharge and sediment load varied through time in response to climate, producing degradational and aggradational cycles. Degradation eroded paleovalleys, and aggradation filled them with both meandering and braided fluvial systems, as well as varying amounts of floodplain mudstones. Paleosols developed on paleovalley fills, interfluves, and floodplain siltstones and mudstones, all of which combine to define several scales of degradational and aggradational cycles. An upward stratigraphic trend in Chinle paleosols from Oxisols and Gleysols, to Alfisols (Argillisols) and Vertisols, culminating in Inceptisols (Prototsols) and Aridisols (Calcisols), supports previous interpretations that climate evolved from monsoonal or humid conditions at the beginning of Chinle deposition to progressively more arid climate conditions at the end of deposition.
ALLUVIAL VALLEYS AND ALLUVIAL SEQUENCES: TOWARDS A GEOMORPHIC ASSESSMENT

MARTIN R. GIBLING
Department of Earth Sciences, Dalhousie University, Halifax, NS B3H 3J5, Canada

CHRISTOPHER R. FIELDING
Department of Geosciences, 214 Bessey Hall, University of Nebraska-Lincoln, NE 68588-0340, U.S.A.

AND

RAJIV SINHA
Department of Civil Engineering, Indian Institute of Technology, Kanpur 208016, Uttar Pradesh, India

ABSTRACT: Criteria for identifying alluvial-valley fills in the geological record have commonly been derived from coastal areas, where high-magnitude glacioeustatic fluctuations generate predictable systems tracts. In contrast, inland alluvial valleys formed in response to climatic, tectonic, and intrinsic events of varied magnitude and duration. Sequence boundaries and architecture reflect a variety of causes, typically mediated through changes in the river’s equilibrium profile and equilibrium floodplain height. We evaluate valley and sequence models using Quaternary examples from southern Asia and Australia. For these areas, proxy records are well established for climate and sea level, but the scarcity of records for tectonic activity and intrinsic channel changes hamper an interpretation of stratigraphic events.

On the large alluvial plains of northern India and central Australia, climatic changes have radically affected sediment and water discharge on timescales as short as $10^3$ to $10^4$ years. Periods of incision and aggradation generate discontinuity-bound sequences (aggradational–degradational rhythms), and reaches may vary between valley and channel morphology over short periods and distances. Across Asia, changes in monsoonal precipitation have caused near-synchronous incision and aggradation in varied tectonic settings. However, mature interfluve paleosols correlative with valley bases may be local or absent on these large plains, where small interfluve channels, eolian dunes, and lakes aggrade while mainstem valleys incise. Gullied floodplains, adjacent to valleys and tributaries, and terrace deposits are useful indicators of incised systems. Climatic effects appear to be underrepresented in interpretations of ancient alluvial sequences in general.

Angular unconformities, channel diversion, and incised and tilted fans near major faults reflect tectonic controls on architecture, and soft-sediment deformation and rare surface ruptures testify to earthquake events. In smaller basins such as the Rio Grande Rift of southwestern U.S.A., alluvial architecture reflects both tectonic and climatic controls. Channel-body amalgamation may not be a good proxy for tectonically induced subsidence, especially for megafans at upland exits where a low degree of amalgamation may reflect rapid accumulation rather than rapid subsidence and accommodation creation.

Multistory valleys and extensive multistory and single-story sheets are present in inland and coastal alluvial areas. However, below the Australian continental shelf, seismic profiles identify entrenched channels and channel belts rather than the valley fills that are commonly assumed to form under such conditions. This example shows that sea-level fall and river extensions need not generate deeply incised fluvial valleys in coastal settings.