A Review of Some Fluvial Styles

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Abstract

Modern fluvial sedimentological studies classify fluvial systems (ancient or contemporary) based on sixteen process-related fluvial styles. For each fluvial style there are characteristic architectural elements and lithofacies relationships. The construction of stochastic fluvial models based on these fluvial styles requires a collection of characterization of these relationships. Information regarding several of these styles is derived from, The Geology of Fluvial Deposits*, and numerous fluvial geologic studies.*

Introduction

This work presents a compilation of exportable statistics and information from qualitative fluvial studies for application to stochastic fluvial models and fluvial training images. Quantitative information with respect to several fluvial styles is documented.

We review extensive interpreted modern and ancient examples for each fluvial style with reference to the observations made by Miall (1996). This quantitative information includes approximate distributions and geometries of lithofacies and architectural elements, spatial relationships, vertical and areal trends and specific surface correlation styles.

A scarcity of data is inherent to subsurface modeling. Reliable interpretation depends on the availability of data along with the professional judgment of the interpreter. The data available and its associated limits are discussed. The data may include aerial photography, outcrops, trenches and cuts, high frequency seismic, ground penetrating radar, core and log. It is recognized that reliable interpretations require the integration of a wide variety of data and methods. This work does not attempt to reclassify or assess the validity of the geologic interpretations.

Lithofacies and Architectural Elements

A wealth of qualitative information with regard to fluvial sedimentology is available. Miall (1996) has worked to construct facies models from this information. In this context the functional definition of facies model is a generalized model that captures the "pure essence" of an environment: its lithofacies and architectures. The local details should be filtered, so that these models and their statistics are exportable to similar settings.

The current methodology is to work in a hierarchical fashion. The *lithofacies* are identified. Then, the process-related assemblages of lithofacies, *architectural elements,* are identified.

Lithofacies are classified based on bedding, grain size, texture and sedimentary structures. Miall (1996, p. 79) has proposed a lithofacies scheme for fluvial deposits (see Table 1). This scheme includes facies such as matrix supported massive gravel (Gmm), and sand, fine to very coarse may be pebbly (St). While this scheme has become standard in the field, it is not an exhaustive list and other types may be added to fit a specific site.

Facies Code	Facies	Sedimentary Structures	Interpretation
Gmm	Matrix-supported, massive gravel	Weak grading	Plastic debris flow
Gmg	Matrix-supported gravel	Inverse to normal grading	Pseudoplastic debris flow
Gci	Clast-supported gravel	Inverse grading	Clast-rich debris flow
Gcm	Clast-supported massive gravel	-	Pseudoplastic debris flow
Gh	Clast-supported, crudely bedded gravel	Horizontal bedding, imbrication	Longitudinal bedforms and lags
Gt	Gravel-stratified	Trough cross-beds	Minor channel fills
Gp	Gravel Stratified	Planar cross-beds	Transverse bedforms
St	Sand, fine to very coarse may be pebbly	Solitary or grouped cross-beds	3D dunes
Sp	Sand, fine to very coarse may be pebbly	Solitary or grouped cross-beds	2D dunes
Sr	Sand, very fine to coarse	Ripple cross lamination	Ripples (lower flow regime)
Sh	Sand, fine to very coarse may be pebbly	Horizotnal lamination parting	Plane-bed flow (critical flow)
Sl	Sand, fine to very coarse may be pebbly	Low-angle cross beds	Scour fills, antidunes
Ss	Sand, fine to very coarse may be pebbly	Broad, shallow scours	Scour fill
Sm	Sand, fine to coarse	Massive, or faint lamination	Sediment-gravity flow
Fl	Sand, silt mud	Fine lamination, very small ripples	Overbank
Fsm	Silt, mud	Massive	Backswamp, abandoned channel, drape
Fm	Mud, silt	Massive, desiccation cracks	Overbank, abandoned channel, drape
Fr	Mud, silt	Massive, roots, bioturbation	Root bed
C	Coal, carbonaceous mud	Plant, mud films	Vegetated swamp
P	Paleosol carbonate	Pedogenic feature	Soil

Table 1 – Fluvial lithofacies classification scheme taken from Miall (1996).

The architectural elements are defined as components within the sediments that are characterized by a distinct facies assemblage, internal geometry and external form. These architectural elements are generally larger than individual facies units and are smaller than a channel fill (Miall, 1996, p. 89). They include lateral accretion, crevasse splays and down stream accretion deposits. Miall's (1996, p. 93) proposed list of architectural elements is included in Table 2.

Element	Symbol
Channel	CH
Gravel bars and bedforms	GB
Sandy bedforms	SB
Downstream-accretion macroform	DA
Lateral-accretion macroform	LA
Scour hollows	HO
Sediment gravity flows	SG
Laminated sand sheet	LS
Overbank fines	FF

Table 2 – Architectural elements proposed for fluvial depositional settings from Miall (1996).

These architectural elements may be classified based on the nature of bounding surfaces, external geometry, scale, lithology, internal geometry, and paleocurrent patterns (Miall, 1985). Interpretation of architectural elements is more demanding than traditional lithofacies methods. The identification of large scale geometries requires good exposure and sufficient data, yet their interpretation is more diagnostic of fluvial style than investigation of lithofacies alone.

Scale

Channel dynamics and deposits have been studied at scales ranging over five orders of magnitude (Bristow and Best, 1993). A large degree of self similarity has been identified over these scales. Due to this property, fluvial studies are amenable to flume experiments (some site studies include flute experiments) (Miall, 1996, p. 198).

This work assumes a nominal observation scale at the size of an individual architectural element. Current stochastic models and training images are constructed at this size support (Deutsch and Tran, 2002; Deutsch and Wang, 1996; Pyrcz and Deutsch, 2003; Viseur et al, 1998). Information with respect to lithofacies and internal geometries of architectural elements is reviewed since subsequent work will inject sub-element information in a hierarchical fashion. For Miall's table with the hierarchy of alluvial depositional scales see Miall (1996, p. 82).

Level of Detail

This work attempts to balance the desire to maximize information content with regard to the fluvial style and the ability to export this information beyond the specific case studies. Too much detail in modeling parameters will result in models that may be overly influenced by setting specific factors such as climate, tectonics etc., and may unrealistically constrain the modeled uncertainty. The cataloged information should reflect prior knowledge based primarily on determination of fluvial style. The resulting library of parameters may be updated in a Bayesian statistical context by site specific information a priori to modeling.

Geologic Classification of Rivers and Drainage Networks

The familiar geomorphologic classification of rivers (meandering, braided, anastomosed, and straight) was developed during the nineteenth century. Its dependence on geomorphology, and hence surface features, renders it unsuitable for sedimentological studies. Geomorphology does not completely constrain the preserved sediments.

The fluvial styles classification is based on channel controls. These controls include discharge, channel slope and sediment load. These channel controls have a direct influence on the formation and migration of ripples and bedforms (see Figure 1) and thus on the formation and preservation of lithofacies and architectural elements.

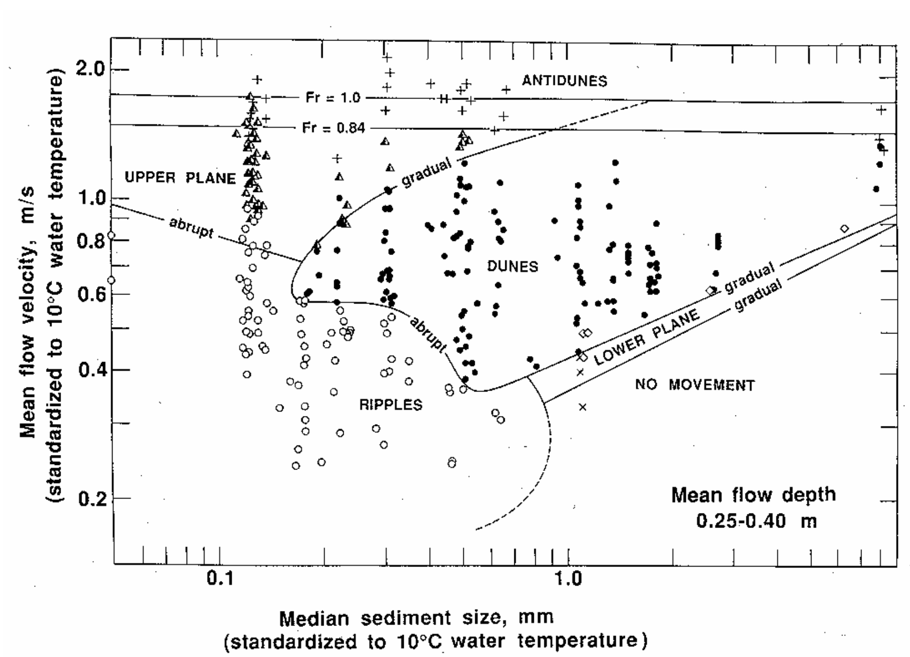

Figure 1 – The plot of mean flow velocity vs. median sediments size and the stability fields for difference sand beds (taken from Miall, 1996).

These fluvial styles are described by the relative sinuosity number, braiding parameter, sediment type and characteristic architectural elements. This method retains the flexibility to recognize intermediate cases that display characteristics of more than one of the fluvial styles.

This paradigm shift from geomorphological classes to fluvial styles recognizes a continuum of possible settings. In characterizing this continuum there is a compromise between coarse discretization with very few fluvial styles resulting in vague facies models and very fine discretization with each fluvial system and perhaps even each stream reach modeled as an unique system. The currently applied discretization of this continuum includes 16 common fluvial styles. This draft of the review includes the first 8 fluvial styles. Future work will include a complete survey of all 16 styles.

The link between the ancient and contemporary examples remains weak. For example there are some fluvial styles that are only found in the ancient record (Miall, 1996, p.202). The matter is complicated by the fact that the fluvial style may be transient with respect to time due to changes in the channel controls such as discharge, channel slope and sediment load.

Fluvial Styles

The following information on fluvial styles is based on Miall's work (1996) and is augmented by a review of some of the site studies identified by Miall (1996, p. 199). This work is ongoing and more fluvial styles and case studies may be considered in future drafts.

Gravel Dominant Fluvial Styles

There are some features common to all gravel dominated fluvial styles. In general, gravel dominated rivers occur along the proximal margins of basins. These settings are high energy and the majority of sediments are transported by traction as bedload.

There are a variety of trends that are common to these settings. There is a suite of proximal to distal trends. In the distal direction the mean and maximum clastic size decreases, there is a decrease in bed relief, there is an increase in sorting and there is a transition from horizontal bedding to cross stratification (Rust, 1972, p. 240). Bar morphologies shift from longitudinal to linguiodal bars in the distal direction (Boothroyd and Ashley, 1973, p. 202). Each of the gravel dominant fluvial styles is subsequently addressed.

1. Gravel-Bed Braided River with Sediment-Gravity-Flow Deposits

A typical example of this fluvial style is found in alluvial fans. These deposits are composed of colluvium that is the result of debris flows and slope washing. There is a continuum of transport mechanisms with the debris flow and water-laid being the end members. Hooke (1966, p. 453) identified the Shadow Rock Fan as being derived almost exclusively from water-laid deposition, while the Trollheim Fan was derived from almost exclusively debris flows.

The balance between debris flow and water-laid is the result of lithologic control. In the Shadow Rock Fan the parent material is a steep and resistant to weathering carbonate. This results in no accumulation of fines at the source and thus prevents debris flows. The source of the Trollheim Fan includes exposures of weak sandy dolomite, resulting in a build up of fines at the source. When both mechanisms are present there is a proximal to distal trend with the proximal area of the fan dominated by debris flows and the distal by water-laid with debris flow inter-fingering at the contact (Hooke, 1966, p. 453).

Texture is the major difference between debris flows and water-laid deposits. Debris flows result in poorly sorted unstratified textures (within a single event). These deposits are comprised of cobbles and boulders supported by a matrix of fines. The water-laid deposits result in two distinct textures. The first is typical of fluvial bedload with moderate to well sorted and well bedded gravels with tabular cross bedding. The second is imbricated clast supported with poor size separation; this is not characteristically fluvial, but may be due to slurry flows or post depositional infiltration of fines into the coarse imbricated clasts (sieving process) (Wasson, 1977).

Examples

Miall's review was principally based on studies of the Trollheim Fan, California.

Wasson (1977) studied the Pleistocene alluvial fans in the Lower Derwent Valley in southeastern Tasmania. Observations are based on exposures at road cuttings. These road cuttings exposed transverse and some longitudinal sections with the majority located midfan or in the apical areas. There is poor exposure of the fan toe and limited areal information making it difficult to estimate the lateral extent of the individual events.

Hooke (1966) surveyed over one hundred alluvial fans in the southwestern United States, constructed detailed maps of four fans from the desert regions of California and ran flute experiments. The flute study applied general scaling laws (somewhat uncertain but seemingly confirmed by consistency between field observations and the flute deposits) to approximate the external and internal geometries of the alluvial fan. The flute experiments provide excellent access for observation, given the scaling laws are sufficient.

Miall's model for this fluvial style is shown in Figure 2. A discussion of the associated lithofacies and architectural elements follows.

Lithofacies

Lithofacies are typically matrix-supported massive gravel (Gmm), matrix-supported gravel (Gmg), clast-supported gravel (Gci), and clast-supported massive gravel (Gcm). Minor thicknesses of sands and over banks fines are present as the result of low flow or over bank deposition.

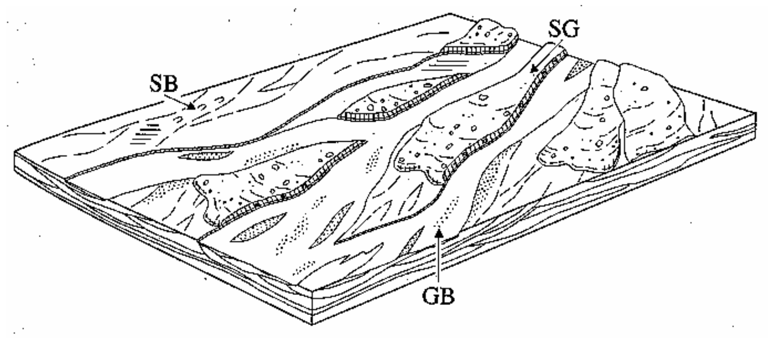

Figure 2 - Facies model of a gravel-bed braided river with sediment gravity flow deposits from Miall (1996, p. 207).

There is a general fining trend along the fan radius from apex to toe. In general there is a transition from unbedded to poorly bedded cobbles and boulder conglomerate with a matrix of sand to clay to fluvial bedded conglomerate, to well-bedded, rarely cross-bedded, sandstone with interbedded shale interfingering into shales at the toe (Hooke, 1996, p. 453). The distal region of the fan to the toe may be dominated by sand and clays. This fluvial style is limited to the gravel dominated settings: therefore, only the gravel dominated regions of the alluvial fan is currently considered.

Architectural Elements

Architectural elements include sediment gravity flows (element SG) with some minor thicknesses of sand bedforms and fine-grained deposits (elements SB and OF). These minor components represent overbank sediments and low-water periods. Some gravel bars and bedforms (element GB) may be present in channels.

The sediment gravity flows fill in irregular eroded surfaces while preserving a smooth top surface with abrupt concave margins. Successive flows are recorded as thin wide sheets that are parallel to sub-parallel with respect to each other. There is no mixing with previously deposited material (see Figure 3). Wasson (1977, p. 785) observed that the bases are nonerosional because of the lack of entrainment between flow events of different colors and textures.

Trends include a decrease in the thickness of debris flows towards the distal and coarsening towards the edges of flow. There may be pronounced levees with course material (boulders and cobles). In general there is a low preservation potential of the sediment gravity flow margins. These are commonly reworked by other debris flows or streams. Also, flow tops may be incised by subsequent stream flow processes (Wasson, 1977, p. 790).

Wasson (1977, p. 784) conducted a study to determine the variability in thickness within and between flow events. Within flow thickness variation is the result of the filling nature of the debris flows and the irregular bases and smooth tops (see Figure 3), and the decrease in flow thickness downstream. The proportional effect was observed when the sample means were plotted against the variance for thickness.

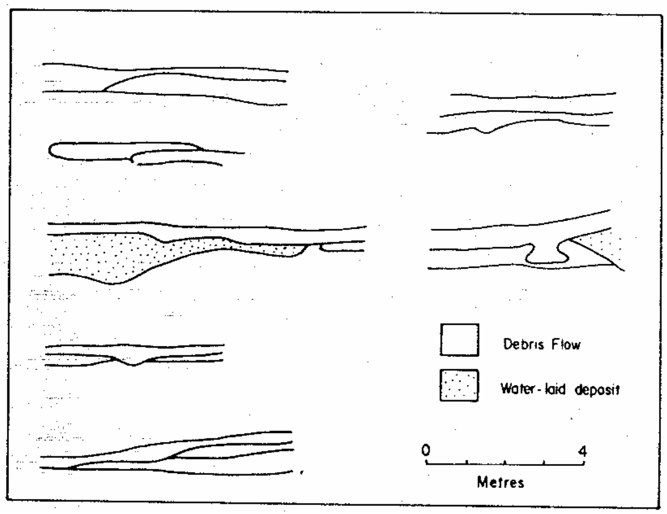

Figure 3 – Cross sections demonstrating the characteristic geometry of debris flow deposits. Irregular topography is filled in without mixing and the tops are smooth. Taken from Wasson (1977, p. 788).

Also the variability of texture between flow events was analyzed. There was a significant difference found between subsequent flows in about 86% of occurrences. This variance is due to variability in the source, mobilization and mixing processes, flow processes and variance in spatial distribution of the individual events. Variability in the spatial distribution of successive flows is due to obstacles, different directions of flow, and different distances of flow. The distance traveled is a function of the slope and the viscosity of the flow (Wasson, 1977, p. 790).

Gravel bars and bedforms are deposited by streams and rest on irregular or channelized erosional bases. This element is the result of high energy streams and exhibits imbricated tabular bedding and becomes dominant in the distal direction. Flute experimental results that demonstrate a variety of features that are observed in this fluvial style are shown in Figure 4.

Proposed model

- stochastic debris flow events with fill geometry and coarsening towards the lateral extents, incised by subsequent streams and debris flows in the proximal (Einsele, 2000, p. 37).
- these debris flows inter-finger into water-laid longitudinal to linguiodal bars.

2. Shallow, Gravel-bed Braided River (Scott-type)

These deposits occur in proximal gravel-bed rivers and braid deltas, in which sediment-gravity flows are rare to absent. The environment consists of shifting network of unstable, low sinuosity, shallow (generally less than one meter deep) channels (Miall, 1996, p. 208; Miall and Gibling, 1977, p. 110).

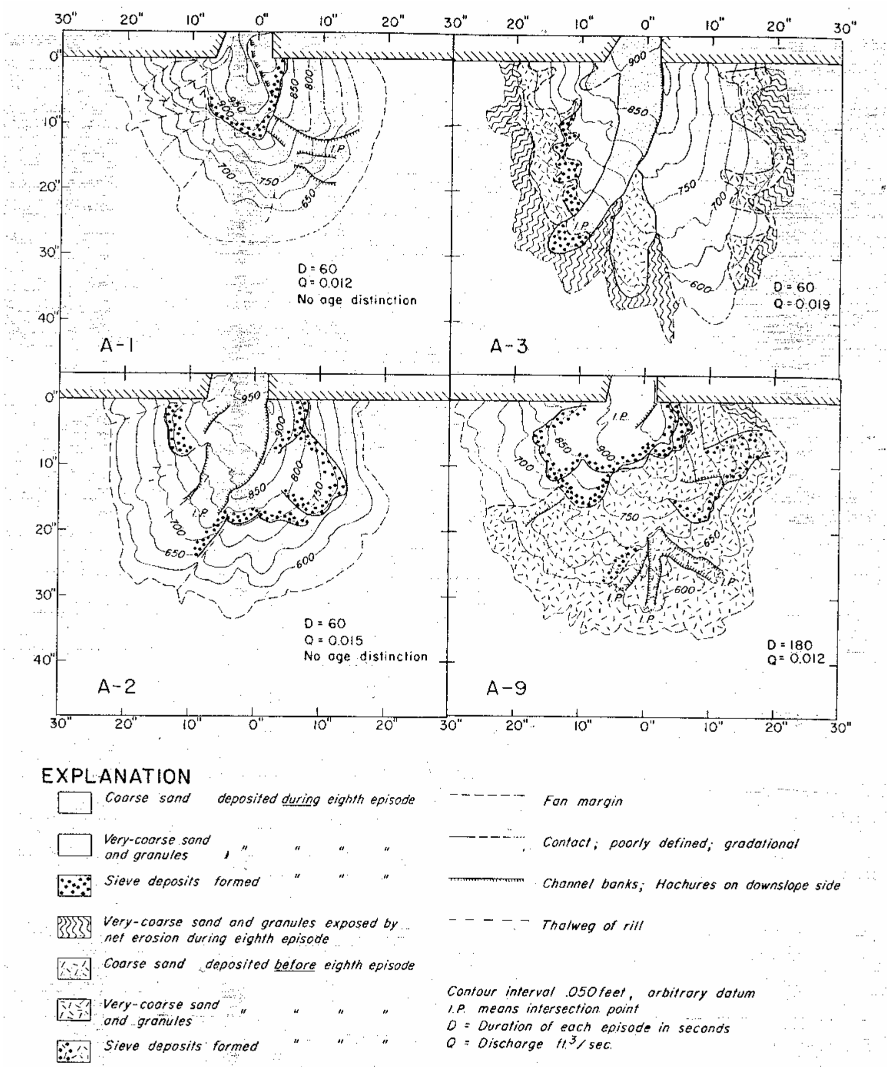

Figure 4 – Flute experiments with each case representing the result of eight depositional events from Hooke (1966, p. 448).

The primary example of this fluvial style is the upper reaches of the Scott and Yana glacial outwash fans on the northeastern Gulf of Alaska. Along the length of these outwash fans there is a general fining from clasts > 10 cm to silt and clays at the tidal mud flats at the terminus of the outwash fans (Boothroyd and Ashely, 197, p. 193). An aerial photograph of the Scott outwash fan is shown in Figure 5.

Examples

Miall's observations are principally based on studies of the contemporary Scott and Yana glacial outwash fans in Alaska.

Boothroyd and Ashley (1973) studied the contemporary Scott and Yana glacial outwash fans in Alaska. Their study was limited to near surface features. Profiles were surveyed by theodolite, grain sizes sampled at surveyed stations and internal structures of bedforms were observed by cuts. This modern example provides a wealth of readily observable information on the development of this fluvial style.

Figure 5 – An aerial view of the Scott outwash fan. The view is upstream towards the glacial terminus (a distance of 13 km). The stream was in high stage of flow at the time of the photograph. Taken from Boothroyd and Ashley (1973, p 196).

Vos and Tankard (1980) studied the Piekenier Formation, Cape Province, South Africa. Their work was based on areas of good outcrop along the west coast margin of South Africa. These extensive outcrops allowed for observation of vertical and some lateral continuity in the lithofacies and sedimentary structures.

Miall and Gibling (1977) studied the Peal Sound Formation in Artic Canada. Their work was based on outcrops and paleocurrent analysis data.

Miall's model for this fluvial style is shown in Figure 6. A discussion of the associated lithofacies and architectural elements follows.

Lithofacies

This fluvial style is characterized by thick, multistory conglomerate deposits consisting of tabular gravel bodies with many minor internal erosional surfaces. Channels margins are infrequently identifiable in outcrop. There is a minor component of sand lenses due to channel abandonment. Overbank deposits are rarely preserved.

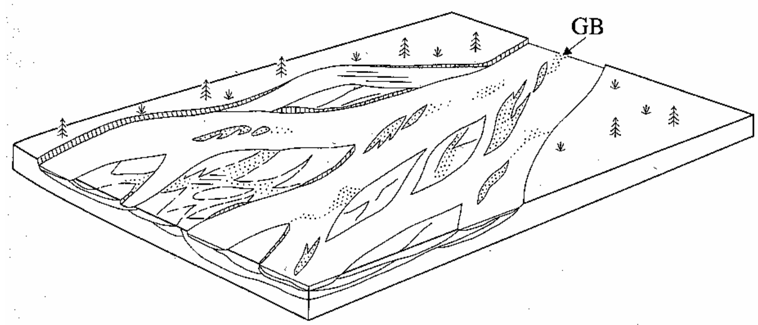

Figure 6 - Facies model of a shallow, gravel-bed braided river from Miall (1996, p. 209).

Lithofacies are traction deposited clast supported, crudely bedded gravel (Gh), stratified gravel with planar cross beds (Gp), and stratified gravel with trough cross-beds (Gt). Channels abandoned in low stage may result in thin lenses or wedges (at bar margins due to run off, on lee surfaces and in channels during waning flow) of sand lithofacies (about 5% of total). The gravels have a strongly imbricated texture and the sandy bedforms are generally flat bedded.

Architectural Elements

The architectural elements are mainly gravel bars and bedforms (GB) and a small proportion of sandy bedforms (SB) which forms lenses and wedges as abandoned channel fills and rarely on the lee surface of the gravel bars. The gravel longitudinal bars form between incised channels and generally have a diamond shape in plan and low relief (height of the largest clasts <30 cm) and rarely exhibit slip faces (Boothroyd and Ashley, 1973, p. 202).

Vos and Tankard (1980) in their investigation of braided fluvial sediments in the Lower Paleozoic Cape Basin, South Africa provided further details with regard to the sandy bedforms. They identified additional sand in the form of bar top sheets and marginal sand waves. Near the upperfan to midfan transition they noted less packed conglomerate with abundant sandstone matrix (Vos and Tankard, 1980, p. 181). An example outcrop sketch from their study is shown in Figure 7.

Repeating linguiodal bars were identified in the midfan regions by Boothroyd and Ashley, 1973, p. 206) and by Munoz et al. (1991, p. 261) in their first stage of deposition in Upper Buntsandstein, Triassic, central Spain. They characterized these bedforms as simple pebbly-sandy tabular units with internal coset bounding surfaces (2^{nd} order surfaces) and accretion surfaces (3^{rd} order surfaces).

Contact and Difference Matrices

Miall and Gibling (1978, p.106) studied this fluvial style in the Peal Sound Formation of Iceland. They applied a contact matrix (matrix with the transition count between lithofacies) to quantify facies ordering and a difference matrix to quantify the nature of facies contacts (gradational to erosional).

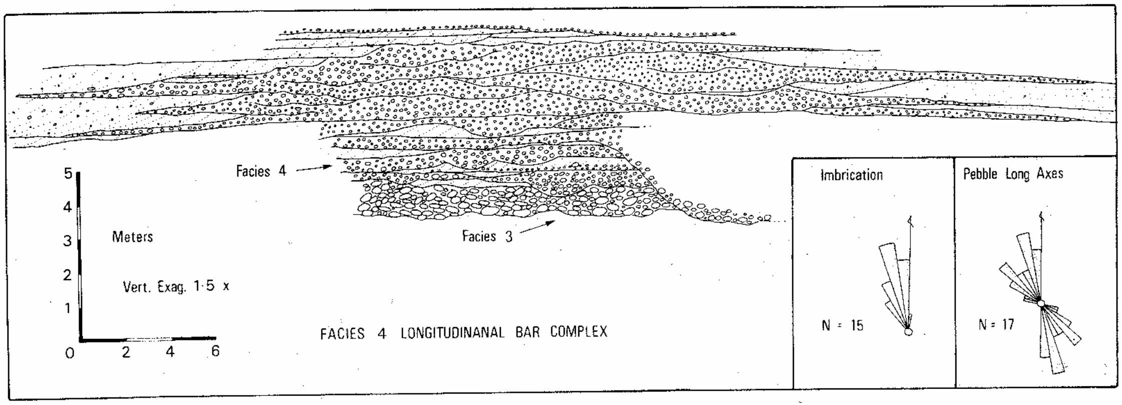

Figure 7 – An outcrop sketch from the Piekenier formation, Elands Bay. Gravel bars and bedforms with imbrication indicated by inset. Taken from Vos and Tankard (1980, p. 182).

Proposed Model

- nested gravel linguiodal bars with sand channel fills and bar top sheets.

3. Deep, Gravel-Bed Braided River "Donjek type"

This style occurs in proximal gravel dominated streams. This style is distinguished from the shallow, gravel-bed braided style by the presence of several distinct topographic levels, including major and minor channels, bar surfaces and the flood plain that may span several meters vertically. This style often occurs in reaches undergoing degradation.

Examples

Miall's observations are based on the study of the distal reaches of the Donjek River, which is located on a glacial outwash fan in southwestern Yukon, Canada. The river occupies a valley formed by Pleistocene glacial erosion.

Rust (1972) conducted a study also of the Donjek River. His work focused on the lithofacies and bedforms present in this river. This work includes some generalized trends for all gravel based rivers, a facies classification scheme and a description of the morphology and migration of gravel bedforms. The data collected included areal photographs and direct observation during low stage. Rust (1972, p. 243) noted that the gravel beds migrate only during high stage and turbidity makes direct observation of bedform migration impossible. He suggested that further long term investigation based on areal photography and painted gravel is required to better assess gravel bed migration.

Miall (1984) defined unit G_2 of the Ereka Sound Formation of the Lower Cenozoic, Canadian Artic Islands as fluvial sediments of the Donjek type. This study was based on outcrops and specifically dealt with large scale paleocurrent analysis and characteristic vertical profiles.

Miall's model for this fluvial style is shown in Figure 8. A discussion of the associated lithofacies and architectural elements follows.

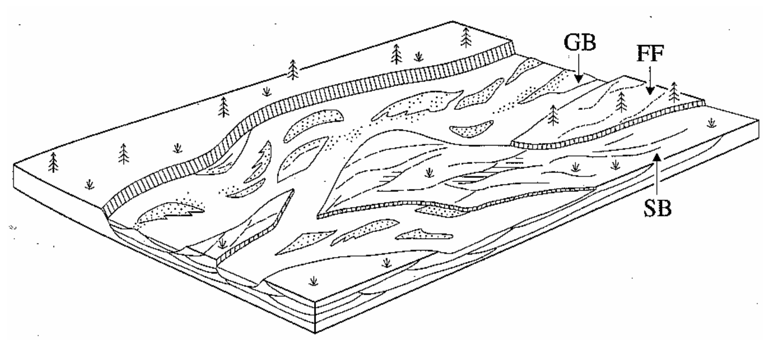

Figure 8 - Facies model of a deep, gravel-bed braided river from Miall (1996, p. 213).

Lithofacies

In the lowest level, active channel during low stage, the lithofacies are similar to the shallow, gravel-bed braided stream. These include traction deposited clast supported; crudely bedded gravel (Gh), stratified gravel with planar cross beds (Gp) and stratified gravel with trough cross-beds (Gt). During low stage thin lenses or wedges of sand lithofacies are deposited at bar margins due to run off, on lee surfaces and in channels during waning flow. The gravels have a strongly imbricated texture and the sandy bedforms are generally flat bedded. The evolution of a longitudinal gavel bar is shown in Figure 9.

The upper levels are recognized as floodplain in this style. These regions are classified as stable by Rust (1972, p. 229). Deposition during high stage on the upper levels results in sandy to fine facies similar to over bank deposits. The presence of vegetation anchors these smaller clasts and results in a fair preservation potential.

Architectural Elements

The architectural elements in the lower levels are similar to the shallow, gravel-bed braided rivers. These include mainly gravel bars and bedforms (GB) and a small proportion of sandy bedforms (SB), which forms lenses and wedges as abandoned channel fills and rarely on the lee surface of the gravel bars. The gravel longitudinal bars form between incised channels and generally have a diamond shape in plan and low relief (height of the largest clasts <30 cm) and rarely exhibit slip faces (Boothroyd and Ashley, 1975, p. 202). Preservation of complete bars is unlikely as they are commonly incised and reworked.

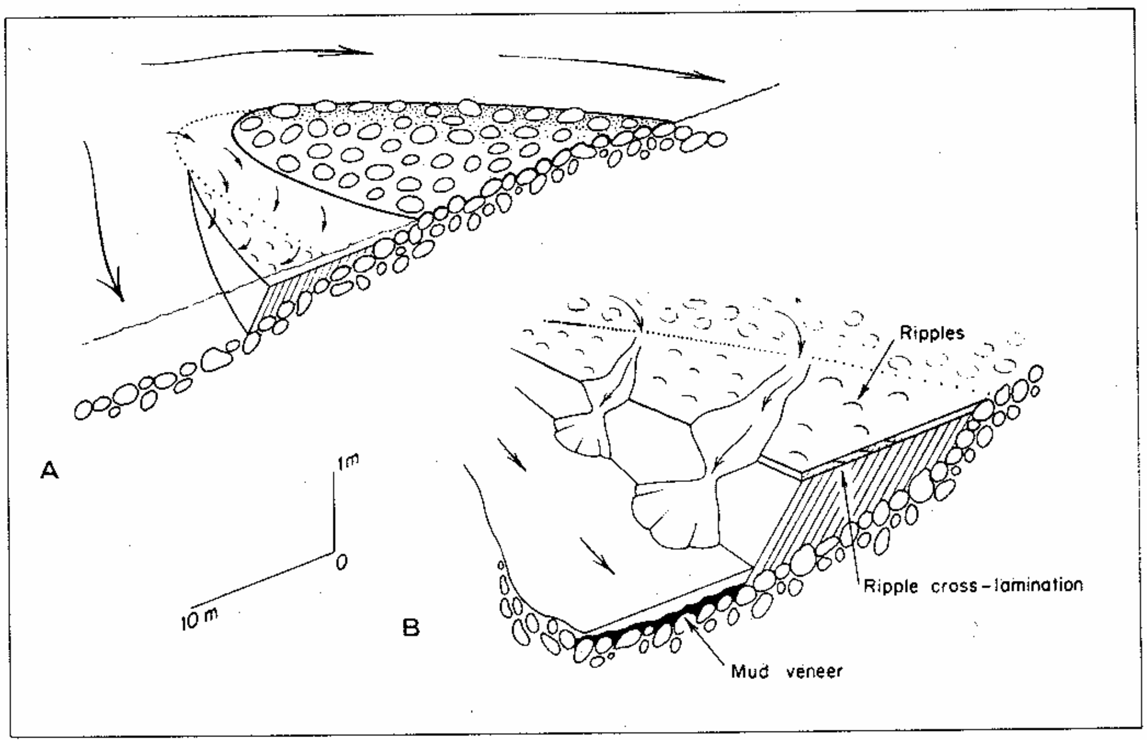

Figure 9 – Longitudinal gravel bar and the evolution of sand and mud deposits during high and low stage. Taken from Rust (1972, p. 241).

This style exhibits an increase of sinuosity. This results in the formation of large-scale architectural elements such as lateral accretion (element LA) and downstream accretion (element DA).

Vegetation anchoring fines on the upper terraces leads to increased representation of flood plain. This is reflected in a greater proportion of sandy bedforms (element SB) and overbank deposits (element FF) such as crevasse splay within the sediments.

Cycles

Miall (1996, p. 211) has identified a hierarchy of vertical cycles that may be present. A cycle occurring on meters to tens of meters resulting from distributary migration and fan evolution, cycles up to a few meters resulting from subsequent channel fills, and cycles up to a few decimeters representing bar progradation or flood events.

The net effect of these superimposed cycles is cyclic sequence of pebble to cobble conglomerate on a scoured base, fining up to a laminated or cross bedded sandstone and with a possible silty mudstone cap. These cycles were observed with thickness of 2.5 to 37.0 m in the Eureka Sound Formation (Miall, 1984, p. 513).

Proposed Model

- nested gravel linguiodal bars with sand channel fills and bar top sheets and LA and DA elements in a matrix of overbank fines.
- fining upward trends represented in hierarchical porosity and permeability models.

4. Gravel-Bed, Wandering River

This fluvial style represents a transitional class between classic braided river with low-sinuosity and multiple channels and the classic meandering river with high sinuosity and a single channel. This fluvial style may alternate between these end cases on a by-reach basis (Miall, 1996, p. 211).

Examples

Miall's survey is primarily based on a variety of examples from British Columbia.

Brierley and Hickin (1991) conducted a study of the Squamish River floodplain, British Columbia. Interestingly, their study was an attempt to prove that it was not possible to differentiate between braided, wandering gravel-bed and meandering reaches based on sampling bedforms by trenches. Their study attempted to prove that classifications, such as the fluvial styles, do not provide information with regard to sedimentological structures and are limited to geomorphological features. Miall responded that this study demonstrates the need for complete studies with a variety of sampling methods and paleocurrent analysis to thoroughly characterize the present architectural elements.

Miall's model for this fluvial style is shown in Figure 10. A discussion of the associated lithofacies and architectural elements follows.

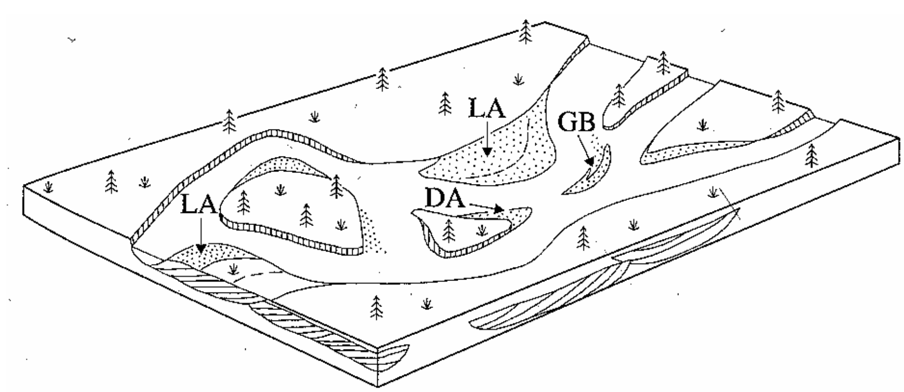

Figure 10 - Facies model of a gravel-bed wandering river from Miall (1996, p. 217).

Lithofacies

Channels contain traction deposited clast supported gravel bedforms; crudely bedded gravel (Gh), stratified gravel with planar cross beds (Gp), and stratified gravel with trough cross-beds (Gt). The gravels have a strongly imbricated texture. A minor component of sand lithofacies occur in upper bar deposits and overbank fines occur between channels. The sands and fines are also deposited during low stage in the form of thin lenses or wedges on bar margins due to run off, on lee surfaces and in channels during waning flow. Fining upward sequences are observed. These lithofacies include sand, trough cross bedded (St), planar cross bedded (Sp), ripple cross-lamination (Sr) and horizontal laminated (Sh).

The islands and overbank have typical floodplain deposits. Preservation potential is increased by the presence of vegetation. Deposition during high stage on these upper levels results in sandy to fine facies similar to overbank deposits. With a fair preservation potential these fine grained layers represent a thin, but a significant portion of the deposition.

This style results in the deposition of large, flat topped point bar and side bar complexes that illustrate a fining trend towards the distal. They often have gravels at the head and sands at the tails. Fining upward trends are observed in point bar deposits.

Architectural Elements

Lateral accretion deposits (element LA) are dominant with downstream accretion (element DA) and gravel bedforms (element GB) are also represented. Overbank fines are well represented as thin fine grained layers (element FF).

Proposed Model

- nested gravel linguiodal bars with significant LA and DA elements.
- fining distal trends within the DA elements represented in hierarchical porosity and permeability models.
- net is preserved along sinuous geometry within the matrix of over bank fines.

5. Gravel-Bed, Meandering River

This style is defined by a single main active channel and possibly some secondary channels. The majority of sediments are included in large point bars (Miall, 1996, p. 214).

Examples

Miall's survey is primarily based on the Babbage River, Yukon and the Endrick River, Scotland.

Gustavson (1978) conducted a study of the contemporary Nueces River in southern Texas. This study focused on the bedforms and stratification types and on near surface features of the point bars. Their study relied on sampling of clasts and the dissection of bed forms. The focus is geomorphological and limited information is provided on the sedimentological record of this fluvial style.

Ori (1982) conducted a study of the distal Quaternary alluvial fan deposits for the Reno River, Po Plain of northern Italy. The study relied on anthropogenic outcrops (multiple quarries of 20-30 m in depth) and exploration wells, although there were no cores in the Quaternary deposits and the logs were incomplete. The outcrops provided good vertical information but limit lateral information with regard to the geologic structures.

Miall's model for this fluvial style is shown in Figure 11. A discussion of the associated lithofacies and architectural elements follows.

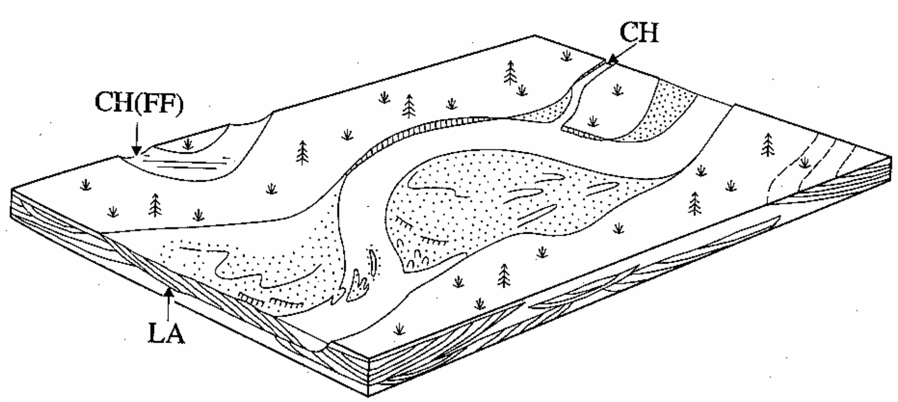

Figure 11 - Facies model of a gravel-bed, meandering river from Miall (1996, p. 219).

Lithofacies

Channels contain traction deposited clast supported gravel bedforms; crudely bedded gravel (Gh), stratified gravel with planar cross beds (Gp), and stratified gravel with trough cross-beds (Gt). During low stage thin lenses or wedges of sand lithofacies are deposited at bar margins due to run off, on lee surfaces and in channels during waning flow. Sand lithofacies occur in upper bar deposits. Thin successions of mud and clay are deposited in the overbank. These lithofacies include sand, trough cross bedded (St), planar cross bedded (Sp), ripple cross-lamination (Sr) and horizontal laminated (Sh).

This style results in the deposition of large, flat topped point bar and side bar complexes that illustrate a fining trend in the distal.

Architectural Elements

Lateral accretion (element LA) is dominant and fine abandoned channel fills (element CH) form a minor component. It has not been determined whether crevasse splay events are common.

Gustavson (1978, p. 422) determined that the lateral accretion was the only structure with a significant preservation potential. He provided a vertical profile based on disected point bars indicates a sequence of roughly 10 m with a base of gravels Gh or Gp, then interbedded muddy sand and sandy gravel and then possibly capped by silty and sandy mud (element FF) (see Figure 12). There is no internal normal grading within individual units.

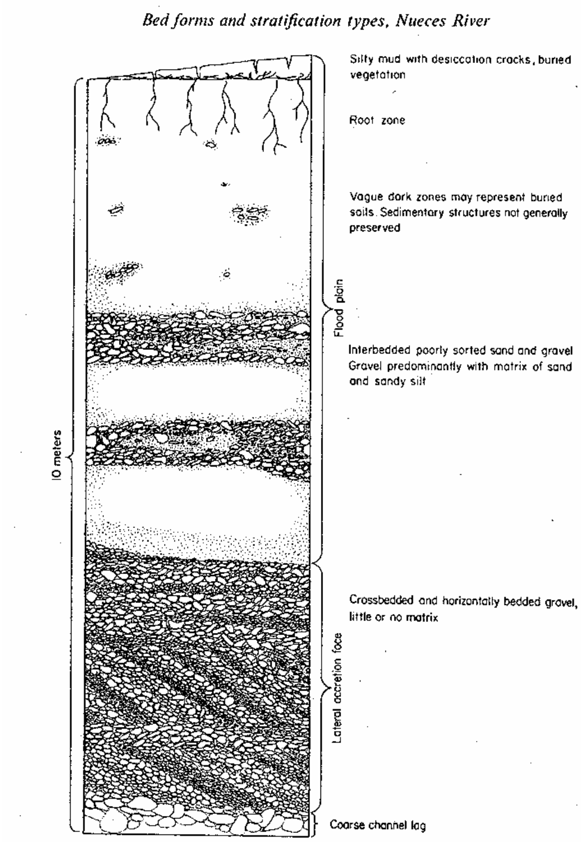

Figure 12 – Composite vertical profile indicating a transition from channel to floodplain based on the Nueces River.

Ori (1982, p. 239) noted a similar structure to the lateral accretion (element LA) deposits and estimated a lateral extent of 40 - 300 m, and a lateral to vertical ratio of greater than 15. He also observed abandoned channel fills of clay to pebbly-sandy with widths of 20 – 40 m and depths of 2 – 5 m.

Model of Horizontal of Vertical Ratio of Channel Bodies

A model indicating a transition in the horizontal to vertical ratio of gravel and sand bodies is indicated. This result is based on the study of the proximal, intermediate and distal fan regions and is based on the geometry of braid bars, lateral bars and point bars respectively (Ori, 1982, p. 244) (see Figure 13).

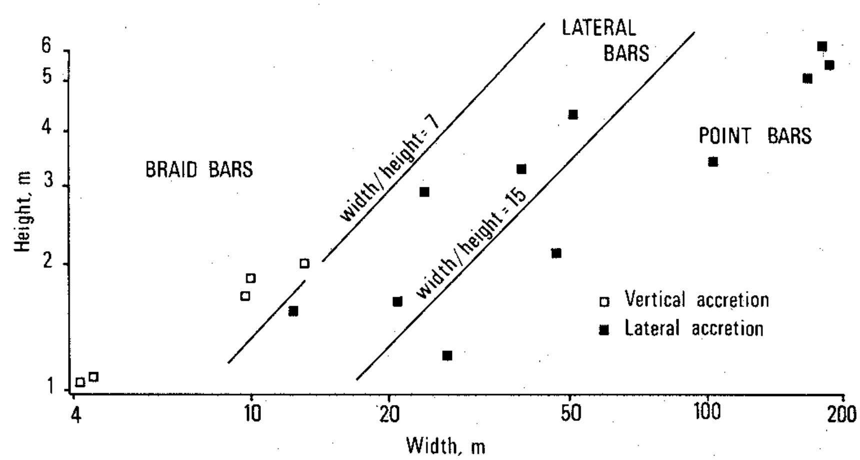

Figure 13 – The scatter height vs. width for a variety of channel bodies. Taken from Ori (1982, p. 244).

Proposed Model

- extensive LA and DA elements with fining towards the distal and an absence of vertical trends forming stacked sinuous ribbon sand bodies in a matrix of overbank fines.

6. Gravel-Sand Meandering River

These rivers are also known as coarse grained meandering. Their channels are composed of sand with gravel lags. During high stage the channel bottom is covered by a variety of bedforms. A fathometer trace of the Congaree River, South Carolina revealed three types of bedform. These included transverse bars (2m in height), large, straight-crested dunes on point-bar surfaces, smaller straight-crested dunes or sandwaves (average of 85 cm in height) in straight segments, and superimposed straight to sinuous-crested dunes or megaripples (average of 18 cm in height).

Miall's model for this fluvial style is shown in Figure 14. A discussion of the associated lithofacies and architectural elements follows.

Lithofacies

This fluvial style is composed of a wide variety of lithofacies. Gravels sheets and lags (Gh) form at the base of point bars, and cross bedded sands (St) form major components.

Thinly bedded mud and clay (Fm) form drapes in meander scars and overbank deposits. There are generally fining trends upward, distal and away from the active channel (Miall, 1996, p. 215).

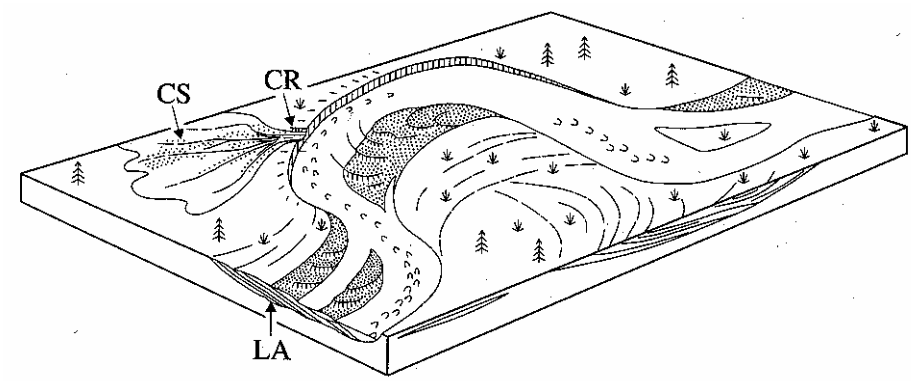

Figure 14 - Facies model of a gravel-sand meandering river from Miall (1996, p. 222).

Architectural Elements

This style is dominated by lateral accretion (element LA) in the form of well developed point bars with meander scrolls or scars. The lower part of the point bar may consist of gravel sheets, dipping across the channel at accretionary angles of 5 degrees or less and inter fingering with overlying finer facies. These overlying facies consist of cross-bedded sands and pebbly sand. There is a variety of fining trends within the point bars as identified by Thomas et al. (1987, p. 133). Crevasse splays are common (element CS).

Proposed Model

- well developed, stacked LA elements with internal fining upward trends including high porosity lag gravel at the base and low permeability mud drapes on top.
- with crevasse splays in a matrix of over bank fines.

7. Sand-bed Meandering

This fluvial style represents the first setting to be studied. Its model is the classic meandering stream model.

Miall's model for this fluvial style is shown in Figure 15. A discussion of the associated lithofacies and architectural elements follows.

Lithofacies

Channels and bars are dominated by sand with some coarser conglomerates preserved as channel floor lags resulting from cut bank erosion and bank slumping.

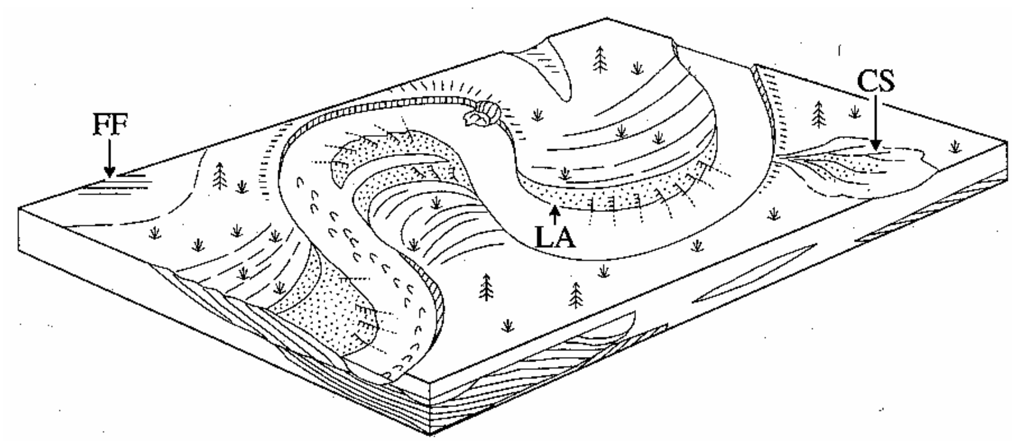

Figure 15 - Facies model of a gravel-sand meandering river from Miall (1996, p. 222).

Architectural Elements

The architectural elements are similar to the gravel-sand fluvial style except for the shift to finer lithofacies in the channel bedforms (element SB) and lateral accretion (element LA) deposits and the greater occurrence of crevasse splays (element FF). The overbank fines (element FF) are well developed.

Proposed Model

- well developed, stacked LA elements with internal fining upward trends including high porosity lag gravel at the base and low permeability mud drapes on top.
- with crevasse splays in a matrix of over bank fines.

8. Ephemeral, Sand-bed Meandering River

This fluvial style is similar to sand-bed meandering except for subtle difference in the lithofacies due to the climatic differences including aridity and flashy flow events.

Miall's facies model for this fluvial style is shown in Figure 16. A discussion of the associated lithofacies and architectural elements follows.

Lithofacies

Ephemeral flow results in numerous internal scour surfaces, with mud drapes (Fm) occurring on coset bounding surfaces and on acretionary surfaces (2nd and 3rd order surfaces). Also, there may be wedges and sheets of eolian sand present with distinctive wind deposited texture and eolian ripples. Channels and bars are dominated by sand, as with sand-bed meandering rivers, but the sand facies are more pebbly due to high energy shallow flow (lithofacies Sh and Sl). Shales are found in abandoned channels (Fm).

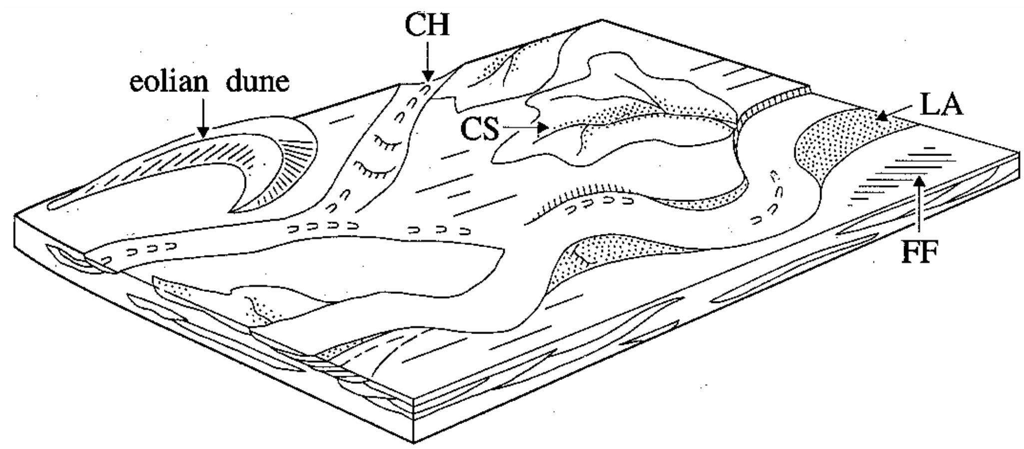

Figure 16 - Facies model of a ephemeral, sand-bed meandering river from Miall (1996, p. 227).

Architectural Elements

Sandstone ribbons from channel fills (element CH) and sandstone sheets from lateral accretion (element LA) are dominant. The overbank fines are punctuated by thin sheets of sand from laterally coalesced lenses from an anastomosing network of ephemeral flood plain channels. The sandstone sheets have irregular tops due to subsequent scour and fill.

Stear's (1983) study of Beaufort Group of the Karoo Basin, South Africa identified a lack of well defined levee deposits. Low relief levees in the form of wide wedges of alternating sandstone and siltstone outline some channel sands.

Proposed Model

- mix of sandstone sheets and ribbons within a matrix of overbank fines.
- the sandstone sheets are comprised of thin LA elements with fines forming in abandoned channels.

Conclusions

There is a wealth of case studies, based on ancient and contemporary examples that may be surveyed to collect prior description with respect to the geometries and characteristics of lithofacies and architectural elements for the purpose of constructing stochastic fluvial models. Tailored stochastic models will be constructed based on this descriptive information.

Future Work – Sequence Stratigraphy

While this study focuses on fluvial styles and their respective sedimentological patterns, future work will address the effect of allogenic cycles such as eustacy on the architectural element model parameters. Sequence bounding surfaces such as those defined by the Exxon production research model, maximum regression, maximum flooding, basal surface of forced regression, subaerial unconformity and correlative conformity, may be mapped. These time surfaces segment the sediments into system tracts such as low stand, transgressive, high stand, and falling stage. Each system tract has unique characteristics with respect to the change in accommodation space, preservation potential of sediments and the nature of the sediments (Catuneanu, 2003).

The preserved sedimentological record is dependent on accommodation space; therefore, the destruction of accommodation space during the falling stage system tract may result in a hiatus in the terrestrial sediment record. Subaerial unconformities result as river channels are incised. During the transgressive system track accommodation space is rapidly created and this results rapid aggradation of river channels and a high preservation potential for overbank environments and the potential for poorly connected reservoir sands.

During low and high stand system tracts, accommodation is generated at a slower rate than during the transgressive system tract. The net result is the lateral amalgamation of sandstone units and good reservoir sands (Catuneanu, 2003). The preservation potential is lower for overbank fines. Subsequent work will explore the direct injection of this sequence stratigraphic information into stochastic models and training images. It will likely be necessary to tailor each system tract within the overall model in order to reproduce these allogenic features. This documentation does not directly address these allogenic constraints.

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