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Fluvial Environments

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Definition

Sedimentary environments are places on the earth's surface characterized by distinctive physical, chemical, and biological processes. *Fluvial environments* are one type of sedimentary environment, describing where fluvial landforms (geomorphology) and fluvial deposits (facies) are created, modified, destroyed, and/or preserved through the erosion, transport, and deposition of sediment. *Modes* of fluvial sediment transport include bedload, suspended load, and dissolved load, and rivers are typically classified as bedload, mixed-load, or suspended load rivers based on the predominance of these modes. Dissolved load transport will not be discussed further in this section because it has a greater importance for water quality than for fluvial geomorphology and facies, with the exception of the importance of saline dissolved constituents in creating features and deposits in dryland environments. Most rivers also transport particulate and dissolved organic matter, and large woody debris (LWD) can be a major factor creating features and deposits in rivers, such as fluvial bars downstream of logjams.

Introduction

Studies of fluvial environments are sometimes split between *fluvial geomorphology* and *fluvial sedimentology*, but this distinction is artificial and should be avoided. Most observable features in streams (except small features such as ripple marks) formed under one set of flow conditions and were subsequently modified under different flow conditions; in other words, a large feature such as a bar has a history of multiple erosional and depositional events. Thus, the only way to correctly interpret fluvial geomorphic features is through sedimentological analysis. Similarly, the deposits (sedimentary facies) can only be understood by reference to features they form, for example, cross-bedded sands form from the downstream propagation of dunes. The trend today is to regard fluvial environments as entities constructed from a number of 3-D elements, where each *architectural element* (or morpho-stratigraphic unit) consists of a suite of related morphological features and sedimentary facies, separated from adjacent architectural elements by *bounding surfaces* (Miall 1996).

Fluvial environments are strongly affected by neighboring sedimentary environments, particularly *colluvial* (hillslope) *environments*, which introduce sediment into fluvial environments by various processes including rock fall, debris avalanches, slumps, debris flows, and sheet (unconfined) flows. In mountain environments, fluvial features such as rapids and bars are typically located proximal to sediment source areas, which are debris fans fed by colluvial processes. In dryland areas, ephemeral stream features are typically sourced by debris flows and sheet flows. Other important adjacent environments could include *volcanic environments*, *glacial environments*, *eolian environments*, *lacustrine environments*, and *deltaic environments*. Each of these could serve as major sediment sources or sediment sinks for fluvial environments. In some cases, such as natural lakes or dam-reservoir systems, lacustrine and deltaic environments might interrupt the continuity of a through-going fluvial system. The processes governing these sedimentary environments could have a major impact on the fluvial system, for example, wave resuspension of sediment deposited in reservoirs could significantly augment downstream suspended sediment loads.

Human impacts on fluvial environments are complex, and few fluvial environments can be understood without reference to historical changes in rivers due to human activity such as land clearance for agriculture, mining, or urbanization.

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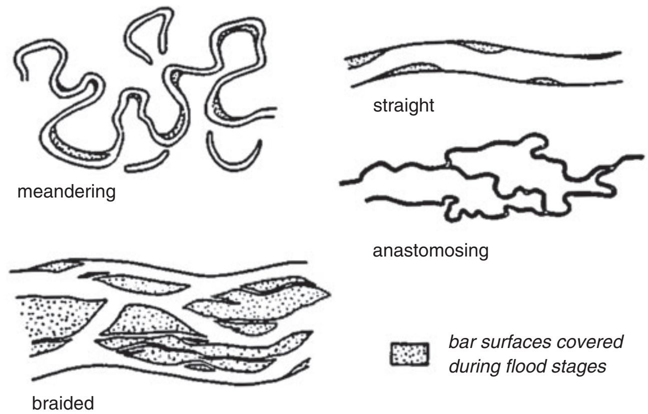


Fluvial Environments, Fig. 1 Types of channels based on platform geometry and sinuosity (Miall 1977)

A useful approach is to consider human impacts on *sediment budgets*, such that:

$$\text{Sediment Inputs} = \text{Sediment Outputs} + \Delta\,\text{Sediment Storage}$$

For example, there is widespread agreement that agricultural land clearance increases sediment inputs due to soil erosion from farm fields. Typically this increases both sediment outputs (bedload and suspended load) and sediment storage (aggradation of the fluvial system after exceeding conveyance capacity). The latter deposits are often referred to as *anthropogenic* or *legacy sediment*s (James 2013). For any river, reconstructing the causes of legacy sediment accumulation could provide key insights for river management and restoration (e.g., Webb-Sullivan and Evans 2015).

Morphologic Features

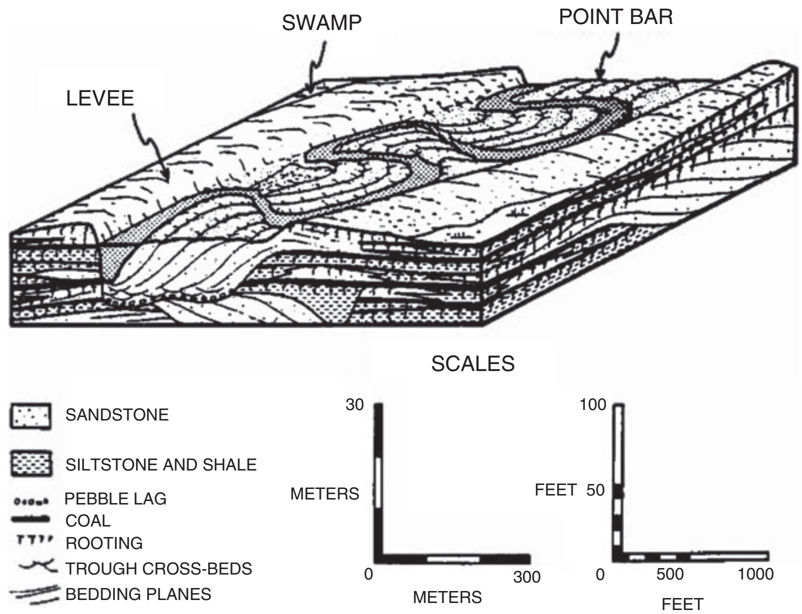
Fluvial environments are typically divided into *channels* (the location for both bedload and suspended load transport) and *floodplains* (typically dominated by suspended load transport). Each of these can be subsequently divided into proximal and distal sub-environments. Proximal channel environments include main stem and tributary channels, pools, riffles, channel bedforms (ripples, dunes, and bars), and features on channel banks. Distal channel environments include chute channels, scroll bars, levees, crevasse splays, and oxbows and outwash plains (sandurs) in glacio-fluvial environments. Proximal floodplain environments include floodplains, floodplain channels, flood-basin lakes, and wetlands. Distal floodplain environments are transitional to non-floodplain environments or may include infrequently inundated terrace surfaces.

Channels are commonly subdivided into length segments called *reaches* defined by changes in discharge (such as tributary inflows), bed and bank materials, or channel pattern. The four recognized channel patterns are shown in Fig. 1. *Straight* channels are relatively rare and more typical of high-energy, gravel-rich rivers or bedrock-confined rivers. *Anastomosed* channels may represent initial stages in avulsions, as described below.

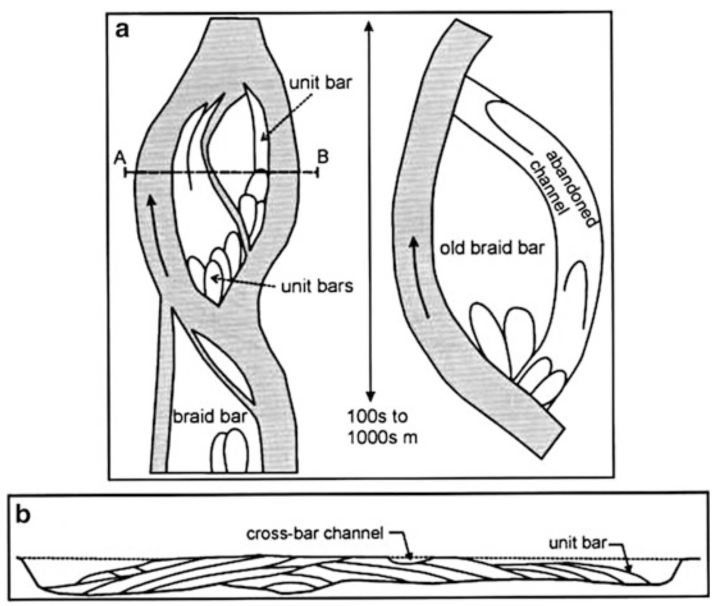
Meandering channels have a sinuous pathway with cutbanks and pools at the outer part of bends, point bars on the inner part of bends, and riffles across the channel between sequential bends (Fig. 2). Lateral channel migration (erosion on the outer bend and deposition on the point bar) occurs episodically due to cutbank failure, typically on the falling stage. In the geologic record, these shifts in channel position produce *lateral accretion surfaces* (low-angle surfaces indicating sequential position of the *point bar*) in cross section and *scroll bar* topography in plain view (Fig. 2). At any location, point bar migration produces an overall fining-upward sequence as coarse-grained pool deposits are sequentially overlain by medium-grained sandy dune deposits in the lower point bar, fine-grained sandy ripples in the upper point bar, and finally silty-clay deposits from the floodplain. Channels might also shift position by *chute cut-offs* (reoccupation of swales in the scroll bar), by *neck cut-offs* (where loops of adjacent channels intersect), or by *channel avulsions* (where levee breach and sequential growth of a crevasse splay result in relocation of the channel). *Oxbow lakes* are abandoned portions of the channel resulting from neck cut-offs and display an infilling history where channel substrates are overlain by suspended-load sediment from introduced flood waters, interspersed with (and eventually replaced by) lacustrine gyttjas and peat.

Braided streams are often divided into sandy braided streams (primarily sand dunes) and gravel braided streams (primarily gravel bars with some sand dunes). Classification of fluvial dunes and bars is mostly based upon long-axis orientation of the feature with respect to flow direction, for example, *longitudinal bars* are oriented long-axis parallel to

Fluvial Environments, Fig. 2 Sub-environments of a meandering stream showing morphostratigraphic units (Walker and Cant 1979; Horne et al. 1978)



Fluvial Environments, Fig. 3 Unit bars and compound bars in multiple-channel streams (Bridge 2003)



flow, while *transverse bars* are oriented long-axis perpendicular to flow (Ashley et al. 1990). However, large fluvial features commonly have complex histories where they formed in one hydrologic event and were subsequently modified. A useful approach (Fig. 3) is recognizing *unit bars* which formed under certain flow conditions versus *compound bars* where one or several unit bars amalgamated within the channel or attached to the channel banks (Bridge 2003). Internally, sand dunes consist of cross-bedded sands reflecting downstream migration of the avalanche face of the dune. Gravel bars can be organized into bar-head, bar-platform, bar-margin, bar-tail, and supra-bar platform settings. Typically, bar-head deposits often contain imbricated gravels, bar platform deposits consist of crudely stratified gravels, and avalanche-face deposits at the bar margin or bar tail produce cross-bedded gravels (Bluck 1979).

Facies Analysis

Facies are the basic building blocks of any sedimentary deposit and are both descriptive and genetic, for example,

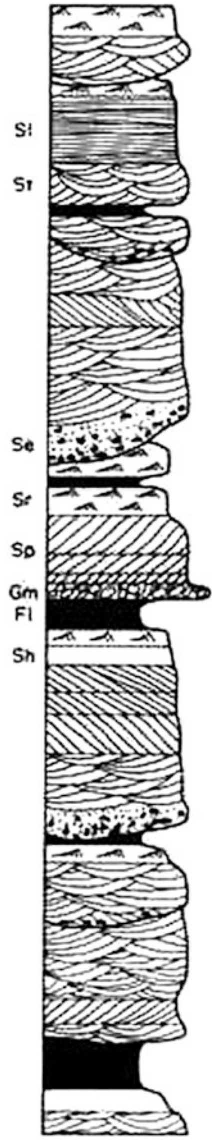
Fluvial Environments, Table 1 Common fluvial lithofacies

Code	Lithology	Textures	Sedimentary structures	Interpretation
Gms	Gravel	Coarse to fine grained, poorly sorted	Massive	Debris flow deposit
Gm	Gravel	Coarse to fine grained, moderately sorted	Massive	Bar platform deposit
Gh	Gravel	Coarse to fine grained, moderately sorted	Planar bedded	Bar platform deposit
Gt	Gravel	Coarse to fine grained, moderately sorted	Trough cross-bedded	Supra-bar platform minor channel fills
Gp	Gravel	Coarse to fine grained, moderately sorted	Planar-tabular cross-bedded	Linguoid bars or bar-margin avalanche face (small bar-pool deltas)
Sm	Sand	Coarse to fine grained, moderately sorted	Massive, destratified	Rapid deposition, or homogenized by roots
Sh	Sand	v.cos. to med. grained, moderately sorted	Planar bedded	Upper/lower flow regime plane bed
Sl	Sand	Coarse to fine grained, moderately sorted	Low-angle ($<10^0$) cross-bedded	Scour fills, crevasse splays, antidunes
St	Sand	v.cos. to med. grained, moderately sorted	Trough cross-bedded	3-D dunes (lower flow regime)
Sp	Sand	v.cos. to med. grained, moderately sorted	Planar-tabular cross-bedded	2-D dunes (lower flow regime)
Sr	Sand	cos. to v. fine grained, moderately sorted	Ripple marks or ripple laminated	Ripples (lower flow regime)
Se	Sand	v.cos. to fine grained, moderately sorted	Erosional scours with mud intraclasts	Scours and scour fills
Ss	Sand	v.cos. to fine grained, moderately sorted	Shallow scours	Scours and scour fills
Fl	Sand, silt, mud	Range of fine sizes, typically well sorted	Planar lamination, flood couplets	Overbank or waning flow deposits
Fsc	Silt, mud	Range of fine sizes, typically well sorted	Laminated to massive	Backswamp deposits
Fcf	Mud	Range of fine sizes, typically well sorted	Massive with freshwater molluscs	Backswamp pond deposits
Fm	Silt, mud	Range of fine sizes, typically well sorted	Massive, destratified, desiccation cracks	Overbank or drape deposits, soils
Fr	Silt, mud	Range of fine sizes, typically well sorted	Massive, with rootlets	Mineral soils (various types)
C	Carbonaceous mud, peat/coal	Mixture of fine-grained sediment/organic matter	Peats, leaf litter layers	Organic soils (incl. histosols)
P	Pedogenic carbonate	Soil hosted in sand/mud	Carbonate nodules or rhizoliths	Calcisols

Source: Modified from Miall (1977)

trough cross-bedded sands are interpreted as the deposits of 3-D sand dunes. For fluvial environments, the most common form of facies analysis designates *lithofacies* (based on the physical characteristics of the geologic material) as shown in Table 1 (e.g., Miall 1977). However, there are alternative approaches, such as designating *radar facies* analysis using a ground-penetrating radar (e.g., Hickin et al. 2009), *seismic facies* analysis using environmental seismic methods (e.g., Grimm et al. 2013), and *pedofacies* analysis using properties of soils (e.g., Wright and Marriott 1996). Although not fully developed, there is also the potential of *biofacies* analysis, using properties of both living organisms (ecosystem structure) and dead organic materials (such as wood loads).

Lithofacies analysis of a particular river system would start with establishing a lithofacies classification system similar to Table 1. This classification system is then used to describe vertical and lateral trends observed in surficial deposits, trenches, or cores. As shown in Fig. 4, use of lithofacies codes helps organize observations and appreciably speeds up the description process. Surfaces, which are transitions between adjacent lithofacies, are particularly important because these might represent time gaps (unconformities)



Fluvial Environments, Fig. 4 Example of facies analysis of braided stream deposits (Miall 1977)

due to erosion (such as scours) or due to nondeposition (such as weathered surfaces, soils, or paleosols).

The next steps in facies analysis look for which facies are commonly found adjacent to one another vertically or laterally. Such *facies associations* represent key components in the depositional environment, for example, certain lithofacies would be commonly found in the downstream migration of a gravel bar. Statistical techniques can be used to improve the robustness of these binning efforts. Repetitive vertical successions, or *facies sequences*, can be interpreted as the evolution (through time) of certain features and deposits, such as the fining-upward point bar sequence (Fig. 4). Statistical methods, such as Markov chains, can improve these interpretations. Facies associations do not cross major unconformity surfaces because those time gaps interrupt the continuity of the related fluvial processes that produced any specific association of lithofacies.

Architectural Element Analysis

Architectural element analysis is reviewed by Miall (1985). Each *architectural element* is a three-dimensional facies association separated from adjacent architectural elements by *bounding surfaces* (surfaces of erosion or nondeposition). The most common architectural elements are shown in Table 2. In scale, each architectural element can be up to meters thick and hundreds of meters in lateral dimensions, and understanding their full extent and contact relations requires exceptional exposures or correlating numerous trenches and cores (Fig. 5). Other important aspects of the internal fabric of an architectural element include the vertical sequences, presence or absence of minor erosion surfaces, orientation of features, paleoflow directions, and relationship of internal bedding features to the enclosing bounding surfaces (which are described using terminology such as onlap, downlap, parallel orientation, or truncation).

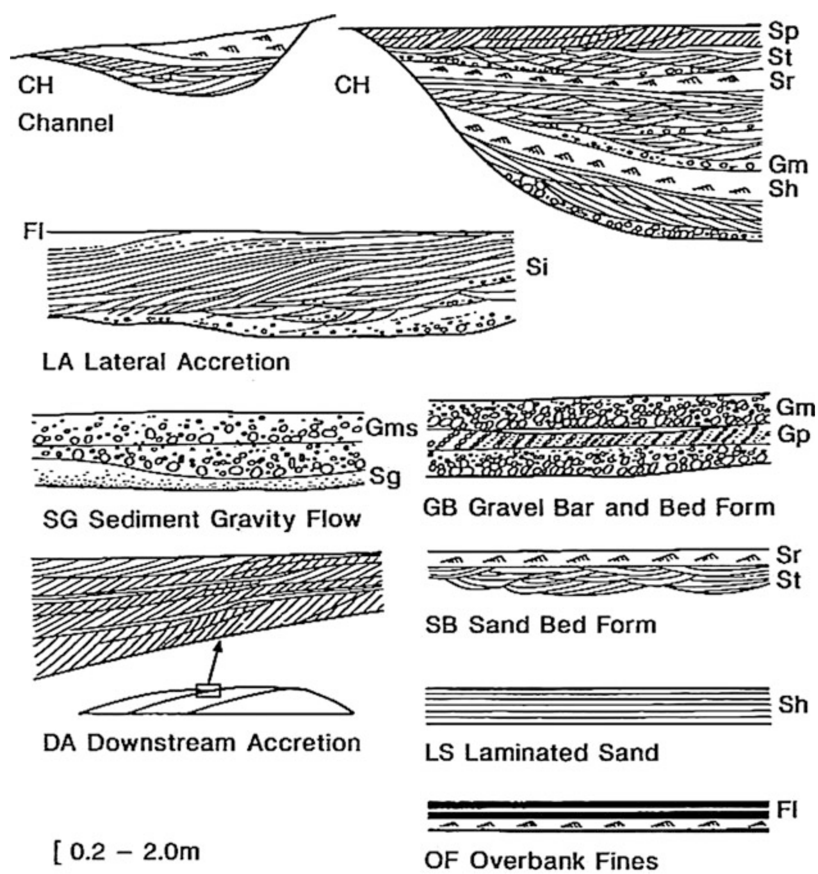
Architectural elements will exhibit a hierarchy based upon the *rank* of the bounding surfaces. Relatively minor changes between sequential elements would be indicative of a *first-order bounding surface*, such as the transition from one cross-bed set to another, indicating changes in transport energy or flow direction between hydrologic events. A more significant change would be represented by *second-order bounding surfaces* (which truncate all first-order bounding surfaces), such as sequential positions of lateral accretion surfaces. The bounding surface ranking system continues to increase in number, representing larger-scale combinations of features and deposits, with each higher rank cross-cutting all lower rank surfaces, until finally reaching the scale of the largest element, such as the valley or paleo-valley.

The analysis of a fluvial system, using architectural element analysis, would reveal lateral changes in the type, scale, and orientation of three-dimensional fluvial features and their related deposits and also vertical changes indicative of the evolution of the fluvial system through time. Such an analysis provides a solid understanding to base interpretations about controlling factors acting on the fluvial system. These might include the effects of tectonics (uplift and subsidence), changes in sea level position (baselevel), changes in sediment supply, changes in climate, or historical changes due to human impacts (Horn et al. 2012). Predictive models have been constructed to determine the variations in channel types and stacking patterns (single-story channels or multistory channels) and sand-body connectivity under a range of different combinations of controlling factors (Bridge and Mackey 1993).

Fluvial Environments, Table 2 Lithofacies composition and geometry of architectural elements

Element	Symbol	Principal facies assemblage	Geometry and relationships
Channels	CH	Any combination	Finger, lens or sheet; concave-up erosional base; scale and shape highly variable; internal concave-up third-order erosion surfaces common
Gravel bars and bedforms	GB	Gm, Gp, Gt	Lens, blanket; usually tabular bodies; commonly interbedded with SB
Sandy bedforms	SB	St, Sp, Sh, Sl, Sr, Se, Ss	Lens, sheet, blanket, wedge, occurs as channel fills, crevasse splays, minor bars
Upstream-accretion macroform	UA	St, Sp, Sh, Sl, Sr, Se, Ss	Lens, resting on bar remnant or LA/DA deposit. Accretion surfaces dipping gently upstream
Downstream-accretion macroform	DA	St, Sp, Sh, Sl, Sr, Se, Ss	Lens resting on flat or channeled base, with convex-up third-order internal erosion surfaces and upper fourth-order bounding surface. Accretion surfaces oriented downstream
Lateral-accretion macroform	LA	St, Sp, Sh, Sl, Se, Ss – less commonly Gm, Gt, Gp	Wedge, sheet, lobe; characterized by internal lateral-accretion third-order surfaces. Accretion surfaces oriented across channel. Typically downlaps onto flat basal erosion surface
Scour hollows	HO	Gh, Gt, St, Sl	Scoop-shaped hollow with asymmetric fill
Sediment gravity flows	SG	Gmm, Gmg, Gci, Gcm	Lobe, sheet, typically interbedded with GB
Laminated sand sheet	LS	Sh, Sl – minor Sp, Sr	Sheet, blanket

Source: modified from Miall (1996)



Fluvial Environments, Fig. 5 Architectural element analysis (Miall 1985)

Summary and Conclusions

Fluvial environments have been widely studied, but unfortunately the literature is highly and artificially compartmentalized, such as making a strong distinction between features (fluvial geomorphology) and deposits (fluvial sedimentology). A more recent approach is to recognize that fluvial environments are constructed from distinctive combinations of genetically related features and deposits (*architectural elements*) separated laterally and vertically from adjacent architectural elements by *bounding surfaces* of different rank. Each architectural element is described by its facies association (group of related lithofacies), scale, geometry, and orientation. *Architectural element analysis* provides an understanding of the processes acting at a particular place and time on a fluvial system. Tracking spatial and temporal changes in architectural elements provides insights into changes of the external and internal factors controlling the fluvial system (tectonics, eustasy, sediment supply, climate, and human activity).

Cross-References

- ▶ Alluvial Environments
- ▶ Dams
- ▶ Facies
- ▶ Glacial Environments
- ▶ Lacustrine Environments
- ▶ Landforms
- ▶ Mountain Environments
- ▶ Reservoirs, Sediments
- ▶ Volcanic Environments

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