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Facies Model - 3. Sandy Fluvial Systems

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Facies Models 3. Sandy Fluvial Systems

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Introduction

This article will follow the pattern established previously in this series. I will describe in general terms the depositional environments of modern fluvial systems, and attempt to formulate a general model. I will then show how the model acts, 1) as a *norm* for purposes of comparison, 2) as a *framework* and *guide* for future observations, 3) as a *predictor* in new geological situations, and 4) as a *basis for hydrodynamic interpretation.*

For reasons of space, I will consider here only the sandy systems. Gravelly and bouldery systems are less well understood, although their deposits are abundant in Canada and locally are economically important (e.g., the uraniferous conglomerates in the Elliot Lake area are generally considered to be fluvial).

Sandy rivers can be straight, meandering or braided, although natural straight rivers are very uncommon. There would appear to be a spectrum of types from meandering to braided; meandering systems are fairly well understood, and sandy braided systems less well understood. At the moment it seems best to consider them separately, and use two facies models. Comparison of new situations with the meandering norm and the braided norm should help to establish the range of variation between the two types of system.

Sandy fluvial deposits are known from all geological systems, Archean to recent. They form important hydrocarbon reservoirs, the meandering systems depositing elongate shoestring sands stratigraphically bounded by shales, and the sandy braided systems forming thicker and laterally more extensive sand bodies.

Meandering Systems

The main elements of a modern meandering system [exemplified by the Mississippi or Brazos (Texas) Rivers] are shown in Figure 1. Sandy deposition is normally restricted to the main channel, or to partially or completely abandoned meander loops; deposition of fines (silt and clay) occurs on levees and in flood basins. It is surprising that there are so few integrated studies of modern meandering systems in the literature of the last twenty years. The most important papers include those of Sundborg (1956; River Klaralven), Harms *et al.* (1963; Red River), Bernard *et al.* (1970; Brazos River), McGowan and Garner [1970; Colorado (Texas) and Amite Rivers] and Jackson (in press; Wabash River). Although the meandering river model is well established, its basis is somewhat dated. Further integrated work (not just on one point bar) would seem important.

a) The Main Channel. Meandering in the channel is maintained by erosion on the outer banks of meander loops, and deposition on the inner parts of the loops. The main depositional environment is the *point bar,* which builds laterally and downstream across the flood plain.

The channel floor commonly has a coarse "lag" deposit of material that the river can only move at peak flood time. This material would include the gravelly component of the clastic load, together with water-logged plant material and partly consolidated blocks of mud eroded locally from the channel wall. Above the lag, sand is transported through the system as bedload. During average discharge, the typical bedform on the channel floor consists of sinuous-crested dunes (Fig. 1) ranging in height from about 30 cm to one metre. Preservation of these dunes results in trough cross-stratification. In shallower parts of the flow, higher on the point bar, the bedform is commonly ripples (preserved as trough cross lamination; Fig. 1). As a broad generalization, we may propose that the preserved deposits of the active channel will pass from trough cross-bedded coarse sands to small scale, trough cross-laminated fine sands upward (Fig. 1).

The development of a plane bed (without ripples or dunes) is favoured by higher velocities and shallower depths, and deposition on the plane bed results in horizontal lamination. The particular combinations of depth and velocity required to produce plane bed can occur at various river stages, and hence parallel lamination can be formed both low and high on the point bar. It can therefore be preserved interbedded with

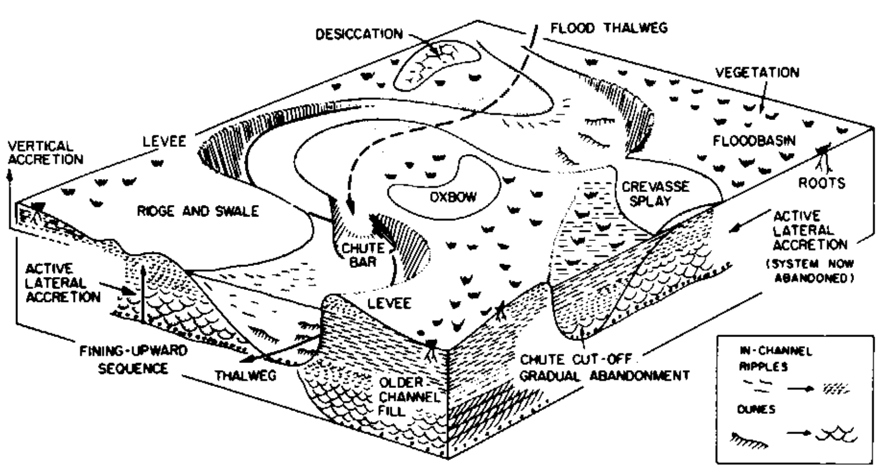

Figure 1
Block diagram showing major morphological elements of a meandering river system. Erosion on the outside bend of meander loops leads to lateral accretion on the opposite point bar - the dunes and ripples in the channel give rise to trough cross-bedding and ripple cross-lamination, respectively (inset, lower right), which are preserved in a fining-upward sequence. See text for details.

trough cross-bedding, or small scale trough cross-lamination (Figs. 2,3).

The preservation of all of these features is basically due to the lateral and downstream accretion of the point bars. Channel-floor dunes may be driven slightly diagonally onto the lower parts of the point bar, thus helping the point bar to accrete laterally on top of the channel-floor lag. The upper part of the point bar may be composed of a series of ridges and swales (Fig. 1), the swales acting to funnel flood waters across the point bar with a much straighter thalweg than the normal low-stage meandering thalweg. If coarse bed load is funnelled through the swales at high flow, it may be deposited at the downstream end in the form of "chute bars" (Fig. 1; McGowan and Garner, 1970). These chute bars act to lengthen the point bar in the downstream direction, hence constricting the flow and causing increased erosion immediately downstream.

Pure meandering streams rarely have exposed bars in the middle of their channels, and hence the sandy active-channel deposits can all be termed LATERAL ACCRETION deposits, related to lateral migration of point bars (Fig. 1).

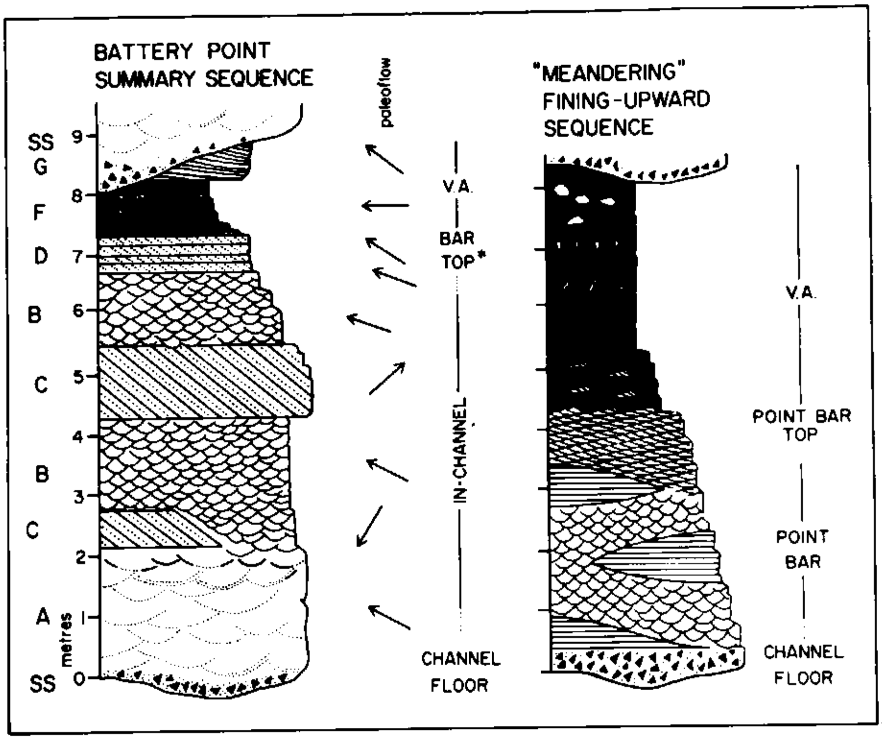

Figure 2
Comparison of a summary sequence of facies for the Devonian Battery Point Sandstone (Gaspé, Quebec: Cant and Walker, 1976) with the meandering river model. The model is redrawn to correct scale from data in Allen, 1970. Implications of the comparison are discussed in the text. Letters beside the Battery Point sequence refer to the facies of Cant and Walker (1976). V.A. indicates vertical accretion.

b) Channel Abandonment. Meander loops can be abandoned gradually (chute cut-off) or suddenly (neck cut-off) (Allen, 1965, p. 118-9, 156). During chute cut-off, the river gradually re-occupies an old swale, and simultaneously flow gradually decreases in the main channel. Gradual abandonment thus results in gradual flow decrease, and this could be reflected in the sediments by the development of a thick sequence of low-flow sedimentary structures - essentially ripple cross-lamination (Fig. 4). After complete abandonment, forming an ox-bow lake, sedimentation would be restricted to fines (silt, mud) introduced into the ox-bow during overbank flooding from the main stream (Fig. 1).

Neck cut-off involves the breaching of a neck between two meanders, and the sudden cut-off of an entire meander loop. Both the entrance to and exit from the loop tend to be rapidly plugged with sand. Flow diminishes to zero very quickly and the resulting sequence of deposits is dominated by later, flood-introduced silts and muds (Fig. 4).

c) Vertical Accretion Deposits. Outside the main channel, deposition in the flood basins, ox-bows and levees takes place by addition of sediment during flood stage when the river overtops its banks (Fig. 1). In contrast to the lateral accretion within the main channel, overbank deposition causes upbuilding of the flood plain, hence the term VERTICAL ACCRETION. Near to the main channel, where the flood waters sweep along as a stream, the vertical accretion deposits tend to be silty, and are commonly cross-laminated. Farther from the river, flood waters may stagnate and only mud is deposited. After retreat of the flood, the mud and silt commonly dry out, and dessication cracks are formed. The flood basins and levees of most river systems (post-Silurian) tend to be abundantly vegetated, and hence the deposits contain root traces (Fig. 5). In semi-arid or arid environments, the fluctuating water table and drying at the surface favour the formation of caliche-like nodules within the vertical accretion deposits.

During rising flood stage, the levees can be breached, causing the formation of a "crevasse-splay" (Fig. 1) - a wedge of sediment suddenly washed into the flood basin, and commonly containing some of the coarse bedload portion of the river sediment. The crevasse splay deposit may resemble a classical turbidite in having a sharp base, overall graded bedding, and a sequence of sedimentary structures indicative of decreasing flow during deposition.

The only other deposits that may rarely be preserved as part of the vertical accretion sequence are windblown, and may be either loess, or coarser sandy deposits blown in as large dunes.

d) Meandering River Facies Sequence. The distillation of observations from a large number of modern meandering streams, and from many ancient formations interpreted as meandering-fluvial, allows a general facies sequence to be formulated. One version of this sequence is shown in Figure 2; it was distilled by Allen (1970) and is redrawn to scale here. In its simplest form, the sequence is FINING-UPWARD and consists of in-channel deposits (lateral accretion), followed by overbank fines (vertical accretion) (Figs. 6, 7).

In this particular sequence, the facies relationships were determined statistically for a large number of Devonian outcrops in Britain and North America, but application of the model has demonstrated that it can be used appropriately in many other areas. The lag deposits are overlain by trough cross-bedding, which is in turn overlain by small scale trough cross-lamination. Horizontal lamination can occur at several places within this sequence (Fig. 2), depending on the river stage at the time when the depth/velocity criteria for plane bed were met.

After the channel migrated away laterally, the facies sequence continued with vertical accretion deposits introduced at flood stage. The diagram (Fig. 2) shows root traces, dessication cracks and caliche-like concretions. Using the data presented by Allen (1970, Table 9), it can be seen that the vertical and lateral accretion deposits in the meandering model are on average roughly equal in thickness.

Allen's model serves excellently as a norm with which to compare other fining-upward sequences (see particularly Allen, 1964). In its construction, Allen apparently used a

Figure 3
Coarse, sandy portion of a Devonian fining-upward sequence (Appalachians, Western Maryland), with stratigraphic top to left. Note low angle cross-stratification in lower part, and abundance of horizontal stratification in centre (hammer). Uppermost part is very fine sandstone with ripple cross-lamination (R): above here (under leaves) are the vertical-accretion deposits.

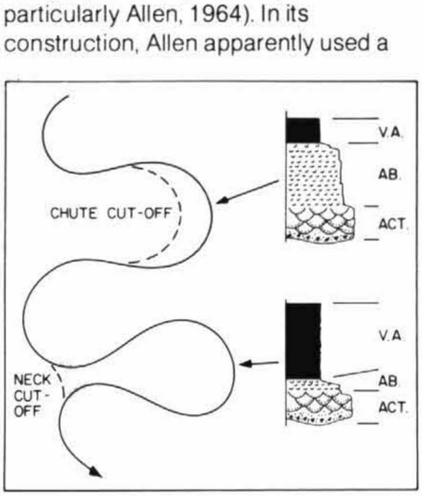

Figure 4
Meander loops can be abandoned by chute or neck cut-off. Old channel shown solid, new channels dashed. Chute cut-off involves reoccupation of an old swale and gradual abandonment of the main channel. The stratigraphic sequence will consist of some trough cross-bedded deposits of the active river (ACT) and a thick sequence of ripple cross-laminated fine sands representing gradual abandonment (AB). After cut-off, the sequence is completed by vertical-accretion (V.A.) deposits. By contrast, after neck cut-off, the meander loop is suddenly abandoned and sealed off by deposition of sand plugs (stipple). After the active deposits, the ripple cross-laminated fine sands representing low flow during abandonment (AB) are very thin, and the bulk of the sequence consists of vertical-accretion (V.A.) deposits washed into the abandoned loop at flood time. Compare with the active lateral-accretion sequence (Fig. 2).

Figure 5
Large root system in fluvial overbank deposits, part of the U. Devonian (Catskill) clastic wedge of the Appalachians. Photo from River Road, West Virginia (near Hancock, Md.).

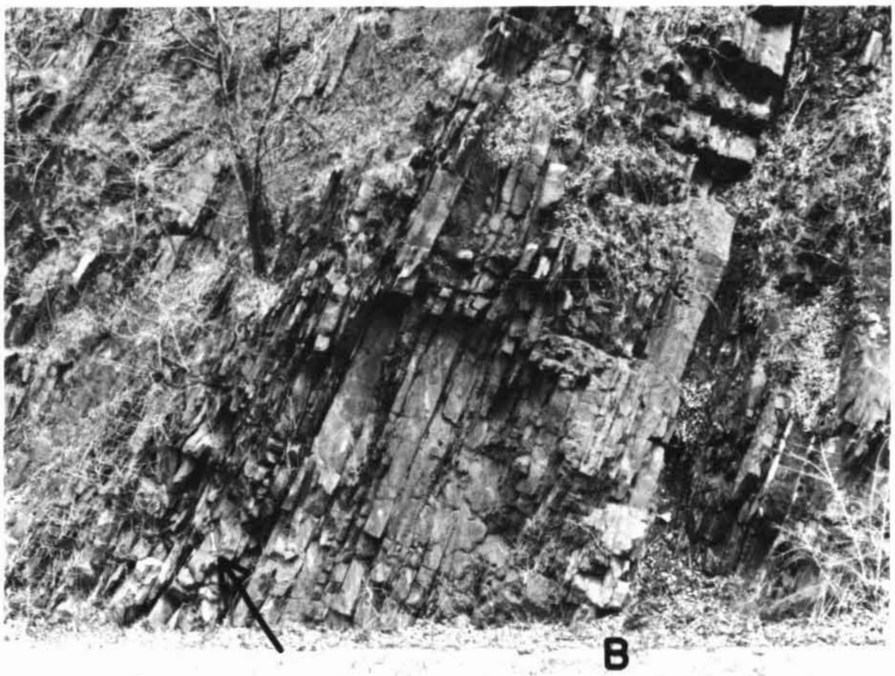

Figure 6
A complete fining-upward sequence from the U. Devonian (Catskill) clastic wedge, Western Maryland. Base rests upon red mudstones with rootlets. The in-channel coarse member grades up into vertical-accretion siltstones about at the level of the small tree. Coarse member about 10 m thick, hammer (arrowed) for scale. B is the base, stratigraphic top to left.

Figure 7
A complete fining-upward sequence from the upper part of the Battery Point Formation (L. Devonian) at Penouille (near Gaspé), Quebec. Base (B) rests on massive red mudstones (the vertical-accretion deposits of the underlying sequence). The coarse member is cross-bedded (above figure) and passes up into thick vertical-accretion red siltstones. A new fining-upward sequence begins on the left of the photo.

wide variety of fining-upward sequences. Comparison of sequences such as those in Figure 4 with Allen's norm immediately shows that the trough cross-bedding is very reduced in thickness, that one of the sequences contains an abnormal thickness of ripple trough cross-lamination, and that both contain unusual thicknesses of vertical accretion deposits. The comparison with Allen's model suggests the interpretations shown in Figure 4; without the model, we would not be so conscious that the sequences in Figure 4 differed significantly from the sequence developed by lateral accretion in an active channel.

e) Sand Body Geometry and Flood-Plain Aggradation. One of the essential components of a meandering model is the fact that meander loops are cut off, abandoned, and ultimately filled with fines - silt and clay. Through time, these clay plugs may become abundant enough to confine the meander belt, because the plugs are relatively hard to erode. Once confined, the entire meander belt may become raised above the general level of the flood plain by vertical accretion (Fig. 8A). This situation can persist until one catastrophic levee break results in the sudden switch of the entire river to a lower part of the floodplain ("avulsion", Fig. 8A). Thus the sand body geometry of a highly sinuous meandering stream will be *essentially elongate ("shoestring")*, bounded below and on both sides by flood-basin fines. The shoestring will also stand a good chance of being covered by overbank fines from the active river in its new position. Thus the *high sinuosity meandering model* predicts that, given continuing supply and basin subsidence, a series of sand lenticles interbedded with shales should be developed. The internal structure of *the sand lenticles themselves should* conform roughly to the pattern shown in Figure 1. The vertical scale in Figure 8A is considerably exaggerated, and individual shoestrings will probably be many times wider than they are thick.

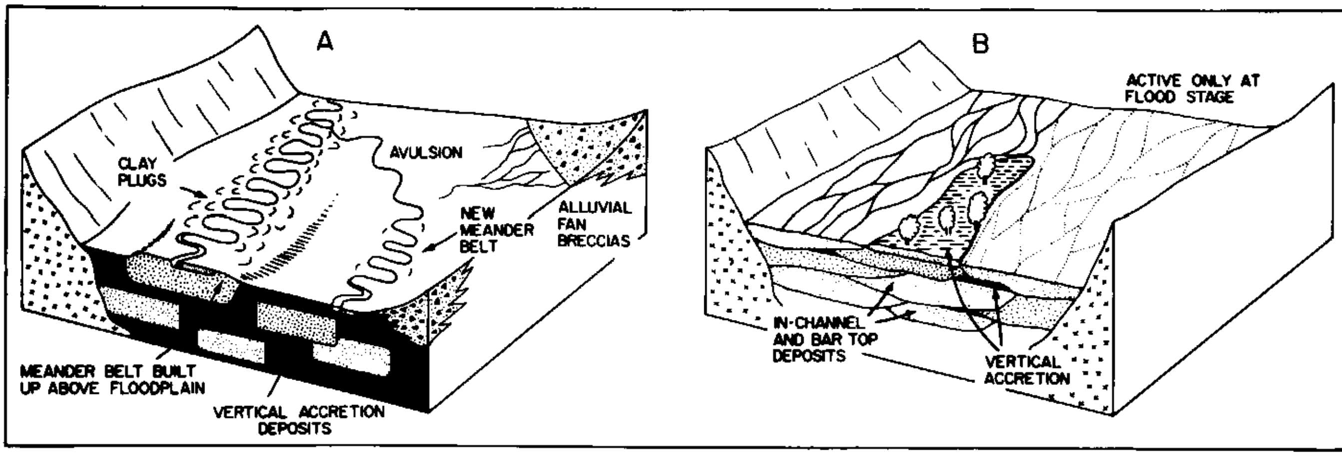

Figure 8
A, Block diagram of flood-plain aggradation with very sinuous rivers. Shoestring sands are preserved, and are surrounded by vertical accretion siltstones and mudstones. Vertical scale is highly exaggerated. Compare with B, block diagram of a braided sandy system with low sinuosity channels. Vertical accretion can occur during flood stage, for example on the vegetated island, but deposits are rarely preserved. Diagrams modified from those in Allen (1965).

Sandy Braided Fluvial Systems
In contrast to meandering rivers, sandy braided systems have received relatively little study. The best known rivers include the Durance and Ardèche (Doeglas, 1962), Brahmaputra (Coleman, 1969), Platte (Smith, 1970), Tana (Collinson, 1970) and South Saskatchewan (Cant, 1975). The morphological elements of these rivers (Fig. 9) are complex, and include (in increasing scale) individual bedforms, small "unit" bars, bar complexes (or sandflats), and mature vegetated islands. The river itself flows over and between these sand accumulations in a constantly branching and rejoining braided pattern. The finer material (silt and clay) tends to be transported through the system without accumulation; vertical accretion deposits are rarely preserved, and deposition in flood basins is not such an important process as it is in meandering systems.

a) Braiding vs Meandering - Controls. The fundamental processes that control whether a river has a braided or meandering pattern are not completely understood, but we do know that braiding is favoured by rapid discharge fluctuations, of a greater absolute magnitude than in meandering rivers. Braided rivers also tend to have higher slopes, a coarser load, and more easily erodable banks. In combination, these features would suggest that braiding is more characteristic of the upstream reaches of a river, with meandering becoming more common downstream as the slope and coarseness of load decrease.

b) Braided Channels and Sand Accumulations. The channels tend to be very variable in depth and width, and do not conform to the simple pattern shown by meandering rivers. The channel floor commonly has a lag deposit, and above the lag, sand is transported through the system as bedload. Bedforms in the deeper channels (5 m or deeper) tend to be sinuous crested dunes that give rise to trough cross-bedding when preserved (Fig. 9). In shallower channels, and on bar tops when they are submerged at flood stage, the bedforms now known as sandwaves are common (see Harms *et al.*, 1975, p. 24, 47-49). Sandwaves tend to be straight crested, and have a very long wavelength (many metres) compared with their height (20-50 cm); they give rise to planar tabular sets of cross bedding when preserved (Fig. 9 beneath letter B).

In contrast to meandering systems, point bars are very uncommon in

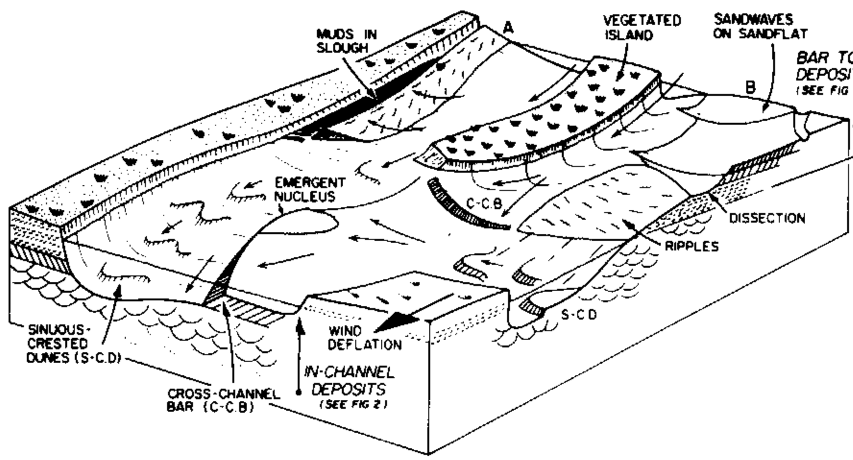

Figure 9
Block diagram showing elements of a braided river (based upon the South Saskatchewan). Stippled areas exposed, all other features underwater. Bar A is being driven laterally toward the far bank and is forming a slough in which mud is being deposited. Sandflat B is a complex area, with dissection features and flood-stage sandwaves. Large sandflats may develop by growth from an emergent nucleus on a major cross-channel bar (see Fig. 10). The vertical fining-upward sequence resulting from preservation of this system would include in-channel deposits overlain by bar-top deposits. See Figure 2 and text for details.*

braided systems. Instead, bars tend to occur within channels, and if the bar is single and represents only one episode of growth, it can be termed a "unit" bar (Smith, 1970). Unit bars can be longitudinal (elongated parallel to flow) or transverse; in the South Saskatchewan transverse bars can extend across the entire width of channels and have been termed cross-channel bars by Cant (1975; Fig. 10 of this article). In the Platte, Tana and Brahmaputra, many of the transverse bars are linguoid (tongue) shaped, and there is a wide spectrum of intermediate shapes. The term diagonal bar has been given to those which have a foreset trending at an angle to the main direction of the channel.

The cross-channel bars shown in Figure 9 are forms of transverse bars. In the South Saskatchewan, many cross-channel bars have a "nucleus" that is emergent at low stages (Figs. 9, 10; Cant, 1975). The nucleus grows by lengthening downstream as sand is swept around in two "horns" or "wings" (Fig. 10), and it also grows in the upstream direction as dunes and sand waves are driven up from the channel floor. As the nucleus grows, possibly with other bars coalescing onto it, the original unit bar expands into a large sandflat (Cant, 1975; Fig. 11). The South Saskatchewan sandflats are complex, and their original shape has been obscured by dissection and redeposition during changing river stage (Fig. 9; sandflat B is the entire exposed area in the right hand corner of the diagram). They are one to two km long in the South Saskatchewan, three km in the Tana (Collinson, 1970) and up to 10 km in the Brahmaputra (Coleman, 1969). In the South Saskatchewan, they remain constant for at least five to six years, and because of their size, they would seem the most likely parts of the braided system to be preserved in the stratigraphic record.

In the South Saskatchewan, one other type of bar is commonly developed. The bar is elongated parallel to the channel trend, but flow is diagonally across the bar, resulting in a foreset slope dipping almost perpendicularly to the channel trend (bar A, Fig. 9). They form in areas of flow expansion (*not* shown on Fig. 9), and commonly isolate a quiet slough between the bar and an adjacent bank or vegetated island. The slough is an area

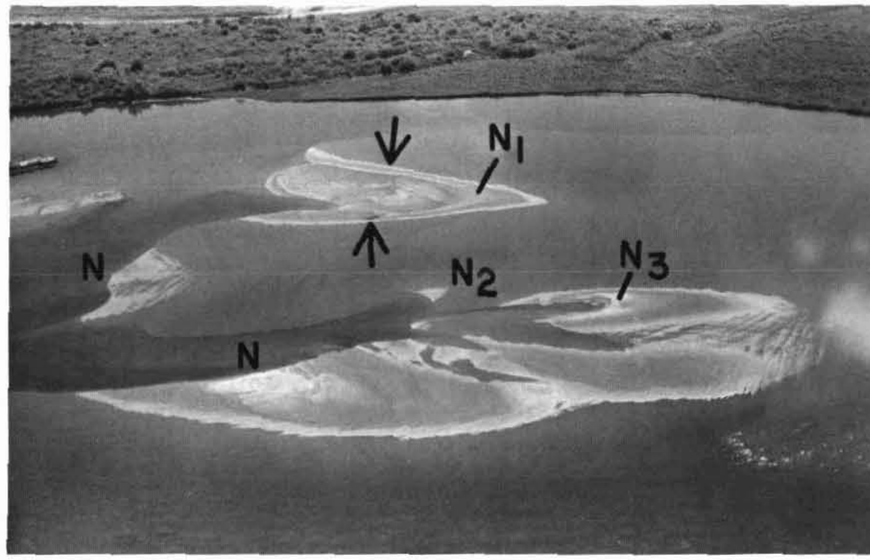

Figure 10
Cross channel bar with several nucleii (N). South Saskatchewan R., near Outlook, Sask., flow to left. Nucleus N_1 has the well-developed "wings" or "horns" that have grown downstream. Foreset avalanche faces dip in direction of arrows. Nucleus N_2 is in its earliest and simplest state, and N_3 has grown wings downstream but has also aggraded considerably on the upstream side. Photo courtesy of Douglas J. Cant.

Figure 11
Compound sandflat in South Saskatchewan R., at Outlook, Sask., flow to left. In foreground, nucleus N has extensive "wings" growing downstream. Upstream from nucleus large sandwaves can just be seen through the water. As they are driven onto the nucleus, it will aggrade and grow in the upstream direction. Photo courtesy of Douglas J. Cant.

of mud deposition at low stage, or may be a passage for sandwaves at high stage.

From our understanding of the South Saskatchewan (Cant, Ph.D. thesis in prep.), we propose a possible stratification sequence that might characterize the preserved deposits of this type of river. Above the lag, trough cross-bedding would represent the passage of sinuous-crested dunes in the deeper channels (Fig. 9). After aggradation, the style of deposition could change if a cross-channel bar were developed. It would first deposit a set of planar tabular cross-bedding, possibly at a high paleocurrent angle to the underlying dunes (Fig. 9), and overlying planar tabular sets could characterize smaller bedforms being driven up onto the nucleus. These deposits can be termed "in-channel" (Figs. 2, 9), to contrast them with the "bar top" deposits (Figs. 2, 9). Once essentially emergent, the bar suffers modification during flood stage. Typical bar top bed forms include ripples, sandwaves, and small sinuous-crested dunes, giving rise to the features shown as "bar top" in Figure 9. The bar top* (with asterisk) implies that deposition and modification are not restricted to the exposed bar tops, but may also take place in shallow dissection channels. The terminology of in-channel and bar top* was first used for ancient rocks (Cant and Walker, 1976; Fig. 2 of this article); it is important that the same terms be used for ancient and recent sediments where possible.

c) Vertical Accretion Deposits. In contrast to meandering streams, the vertical accretion deposits of braided streams are less commonly deposited and only rarely preserved. At low stage, the river may only occupy one or two of the available channels on the flood plain (Fig. 8B). It adjusts to flood stage by re-using the empty or abandoned channels, and only during major floods does the river spill from its main channel system onto the surrounding flood plain. In the South Saskatchewan between the Gardiner Dam and Saskatoon, the flood plain is very narrow and the braided portion is essentially confined between Pleistocene bluffs. Consequently, the narrow flood plain and the vegetated islands can relatively easily be submerged and receive vertical accretion deposits.

The Brahmaputra spills into its flood basins every year, but the clays settling from the flood waters are deposited slowly, with thickness of two cm or less per annum. However, vegetation is abundant in these flood basins, and peat deposits one to four m in thickness are forming (Coleman, 1969, p. 232-3). These various sub-environments of the braided sandy system are sketched in Figure 9, but there is certainly more complexity in the deposits than is indicated in the diagram.

d) Ancient Sandy Braided Fluvial Deposits. Very few ancient sandy systems have been positively identified as braided (or low sinuosity) rivers. The best studies include those of Moody-Stuart (1966; Devonian of Spitsbergen), Kelling (1968; Coal Measures, South Wales) and Cant and Walker (1976; Devonian of Quebec Appalachians). I will briefly comment on the Cant and Walker (1976) study of the Battery Point Sandstones because I am familiar with it.

In the field area near Gaspé, Quebec, we found a 110 m sequence that could be divided into at least 10 generally fining-upward sequences. Within the section, we were also able to define eight distinct facies, characterized by their various scales and combination of sedimentary structures. The sequence of facies was "distilled" (Walker, 1976) in order to look for a general facies sequence that could act as a general basis for interpretation. I did not discuss the distillation process in my introduction to this series of articles on facies models (Walker, 1976), but interested readers should study the method described by Miall (1973), Harms *et al.*, (1975, p. 68-73) and Cant and Walker (1976, p. 111-114). The end result of the Battery Point distillation was the sequence shown here in Figure 2. It is *not* a model - it is only a summary of a local example that could, in the future, be re-distilled with local examples from other areas to produce a general facies model (Walker, 1976). In the Battery Point summary sequence, we identified a channel-floor lag overlain by poorly defined trough cross-bedding (Facies A, Fig. 2). The in-channel deposits consisted of well-defined trough cross-bedding (B) and large sets of planar-tabular cross-bedding (C) that commonly showed a large paleocurrent divergence from the trough cross-bedding (Figs. 2, 9; Cant and Walker, 1976, Fig. 7). The bar-top* deposits consisted mainly of small sets of planar-tabular cross-bedding (D), and the thin record of vertical accretion included cross-laminated siltstones interbedded with mudstones (F), and some enigmatic low-angle cross-stratified sandstones (G).

Upon developing this summary sequence, our first reaction was to compare it to the existing fluvial (meandering) norm (Fig. 2). Although both sequences showed channelled bases, followed by fining-upward sequences, there appeared to be sufficient differences that the norm would *not* act reliably as a basis for interpretation (Walker, 1976). In other words, the meandering model seemed inappropriate for the Battery Point Sandstone.

Comparison with the norm nevertheless highlighted the major differences, and this gave us added understanding of the Battery Point. Similar comparisons of other systems with the two sequences in Figure 2 should also give added understanding. For example, the vertical-accretion deposits in the Battery Point are very thin compared with the meandering norm, both in absolute terms, and in proportion to the amount of in-channel sandstone. The in-channel sandstones do not contain parallel lamination, but planar-tabular sets of cross-bedding are common, and show high paleocurrent divergences from the main channel trend. All of these points of comparison aided in making our "braided" interpretation (Cant and Walker, 1976, p. 115-8).

e) Sand Body Geometry and Flood-Plain Aggradation. One major point of contrast with the meandering system is that braided rivers tend to have easily erodible banks, and no clay plugs. The area occupied by the braided river may therefore be very wide, and coalescing bars and sandflats will result in a laterally continuous and extensive sand sheet, unconfined by shales (Fig. 8B). Vertical accretion deposits (if formed) will tend to be quickly eroded because of the comparatively rapid lateral migration of channels. Consequently, any shales preserved in the section will tend to be patchy, laterally discontinuous, and relatively ineffective barriers to vertical hydrocarbon migration. This will not be the case for meandering systems.

Sandy Fluvial Facies Models

The meandering model effectively does all of the things a facies model should. It is a well-established *norm*, and serves as a *guide* for future observations. It has been used as a *basis* for hydrodynamic interpretation (Allen, 1970; Cotter, 1971), and has served many oil companies as a *predictor* in new situations. The braided "model", in as much as one exists, does none of these things very well.

Comparisons of new braided examples with the existing meandering norm will be instructive, but will not add to the braided "norm". What is needed is a well-established braided norm, so that new examples can be placed within a spectrum of fluvial types. The establishment of this norm will require much more detailed field description, accompanied by careful analysis and distillation.

Acknowledgement

The descriptions of the South Saskatchewan river are based upon an almost complete Ph.D. thesis by Douglas Cant, at McMaster University. I am indebted to him for use of this material, and for supplying the air photos.

Basic References on Sandy Fluvial Sedimentation

Reineck, H. E. and I. B. Singh, 1973, Depositional Sedimentary Environments: New York, Springer-Verlag, 439 p.

The basic, up-to-date summary of all fluvial types of sedimentation can be found in the section on Fluvial environment, p. 225-263. This is a good, well-illustrated review for readers unfamiliar with fluvial sedimentation, and is recommended over Allen, 1965 (below), which is too long and a little out-of-date.

Harms, J. C. and R. K. Fahnestock, 1965, Stratification, bed forms and flow phenomena (with an example from the Rio Grande), *in* G. V. Middleton, ed., Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontol. Mineral., Spec. Publ. 12, p. 84-115.

This paper is a basic source of information on bed forms, stratification and flow regimes in rivers. Some of the more recent ideas can also be found in chapters 2, 3 and 4 of Harms *et al.*, 1975 (below).

McGowan, J. H. and L. E. Garner, 1970, Physiographic features and stratification types of coarse-grained point bars: modern and ancient examples: *Sedimentology*, v. 14, p. 77-111.

This is one of the most recent integrated descriptions of meandering systems, and the comparison of ancient and modern sediments is particularly useful.

Smith, N. D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: Geol. Soc. Amer. Bull., v. 81, p. 2993-3014.

Good description of downcurrent changes in bar type, on a regional scale, and comparison with ancient rocks.

Cant, D. J. and R. G. Walker, 1976, Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Quebec: Can. Jour. Earth Sci., v. 13, p. 102-119.

Distillation of a local summary facies sequence from an ancient sandstone, emphasizing facies descriptions, analytical methods, and comparisons with a meandering norm.

Other References Cited in Text

Allen, J. R. L., 1964, Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin: Sedimentology, v. 3, p. 163-198.

Contrasts the features of six fining-upward sequences, and interprets their origin in terms of river type, behaviour, and sub-environment. An interesting and well illustrated detailed comparison.

Allen, J. R. L., 1965, A review of the origin and characteristics of Recent alluvial sediments: Sedimentology, v. 5, p. 89-191.

An excellent review, with abundant citations, of fluvial systems. Because of its length, I recommend readers begin *with Reineck and Singh (quoted above)* before working through Allen.

Allen, J. R. L., 1970, Studies in fluviatile sedimentation: a comparison of fining-upward cyclothems, with special reference to coarse-member composition and interpretation: Jour. Sediment. Petrol., v. 40, p. 298-323.

Good technical discussion of the internal structures of the coarse member, and their hydrodynamic interpretation.

Bernard, H. A., C. F. Major, Jr., B. S. Parrott, and R. J. LeBlanc, Sr., 1970, Recent Sediments of Southeast Texas: Bur. Econ. Geol. Texas, Guidebook No. 11.

The first part of the guidebook contains a very brief description but abundant illustrations of the Brazos River.

Cant, D. J., 1975, Sandy braided stream deposits in the South Saskatchewan River: Geol. Soc. Amer., Abst. with Programs, v. 7, no. 6, p. 731.

Abstract outlining morphological elements in the South Saskatchewan, and their relationships.

Coleman, J. M., 1969, Brahmaputra River: channel processes and sedimentation: Sedimentary Geol., v. 3, p. 129-239.

Excellent description of the Brahmaputra system. The best, most detailed (but longest) description of a braided river yet published.

Collinson, J. D., 1970, Bedforms of the Tana River, Norway: Geograf. Ann., v. 52A, p. 31-56.

Good description of bedforms and their interaction with changing river stage.

Cotter, E., 1971, Paleoflow characteristics of a late Cretaceous river in Utah from analysis of sedimentary structures in the Ferron Sandstone: Jour. Sediment. Petrol., v. 41, p. 129-138.

An example of the type of hydrodynamic predictions that can be made from ancient fluvial sediments.

Doeglas, D. J., 1962, The structure of sedimentary deposits of braided rivers: Sedimentology, v. 1, p. 167-190.

A pioneering paper on fluvial stratification in braided systems; contains excellent descriptions and illustrations that are still useful.

Harms, J. C., D. B. MacKenzie, and D. G. McCubbin, 1963, Stratification in modern sands of the Red River, Louisiana: Jour. Geol., v. 71, p. 566-580.

One of the first full descriptions of the internal structures of point bars, and still one of the best.

Harms, J. C., J. B. Southard, D. R. Spearing and R. G. Walker, 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. Econ. Paleontol. Mineral., Short Course 2 (Dallas, 1975), 161 p.

Summary of modern ideas on bedforms and stratification in Chapters 2 and 3.

Jackson, R. G., II., in press, Largescale ripples of the lower Wabash River: Sedimentology.

The paper emphasizes bedforms, their hydrodynamic conditions of stability, and the resulting stratification.

Kelling, G., 1968, Patterns of sedimentation in Rhondda Beds of South Wales: Amer. Assoc. Petrol. Geol., Bull., v. 52, p. 2369-2386.

Emphasizes fining-upward sequences and paleocurrent variations in late Pennsylvanian (Coal Measure) braided stream deposits.

Miall, A. D., 1973, Markov chain analysis applied to an ancient alluvial plain succession: Sedimentology, v. 20, p. 347-364.

Discussion of analytical methods of sequence analysis, applied to Devonian rocks in Arctic Canada.

Moody-Stuart, M., 1966, High and low sinuosity stream deposits with examples from the Devonian of Spitsbergen: Jour. Sediment. Petrol., v. 36, p. 1102-1117.

Description of rocks in Spitsbergen, with a general discussion of low and high sinuosity models.

Sundborg, A., 1956, The river Klaralven: a study of fluvial processes: Geog. Ann., v. 38, p. 127-316.

Walker, R. G., 1976, Facies models - 1. General Introduction: Geosci. Can., v. 3, p. 21-24.

Canadian Examples

There is an astonishing absence in the Canadian literature of detailed interpretations of ancient sandy fluvial depositional environments. A quick review of the total contents of the *Canadian Journal of Earth Sciences* and *Bulletin of Canadian Petroleum Geology* gave no references at all. There are obviously great thicknesses of terrestrial deposits in the clastic wedges of the Cordilleran, Arctic Island, and Appalachian foldbelts, but if detailed interpretations of the sandy fluvial systems exist, they are in government reports. There are, of course, many examples described as fluvial, with some petrographic and paleocurrent information. However, none contains the necessary data on sedimentary structures and their sequence, integrated with paleoflow data in such a way that they contribute to sandy fluvial facies models.

Appalachian Area

Belt, E. S., 1968, Carboniferous continental sedimentation, Atlantic Provinces, Canada, *in* G. DeV. Klein, ed., Late Paleozoic and Mesozoic continental sedimentation, northeastern North America: Geol. Soc. Amer., Spec. Paper 106, p. 127-176.

Discusses four facies - fanglomerate, fluvial, lacustrine and mixed fluvial/lacustrine. Many formations discussed and citations given.

Cant, D. J. and R. G. Walker, (see above).

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