A NEWLY-IDENTIFIED PROCESS OF POINT BAR FORMATION IN NATURAL STREAMS

EDWARD J. HICKIN
Department of Geography, The University of Sydney, Sydney, New South Wales, Australia 2006

ABSTRACT. Sedimentation on stream bends developed at supercritical flow in a sand bed flume is examined in terms of a five-stage model. The model, an extension of previous work by Wolman and Brush in 1961, outlines the process by which deposits on the convex sides of meanders (point dunes) are formed. This mode of deposition, distinctly different from overbank and lateral accretion, also occurred at existing bends of the flume channel when the flow was subcritical and non-meandering.

Point dunes, which are examples of a feature in dynamic equilibrium, may also occur naturally when streams flowing over coarse noncohesive material are forced to change direction at valley bends. Field evidence, including a pilot mechanical analysis of sediment from a natural point dune, is presented which strongly supports the possibility.

The significance and implications of the possible occurrence of point dune and flood plain surfaces are discussed briefly.

Flood plains are generally considered to be the results of two related processes: deposition on the convex sides of stream meanders and deposition from overbank flooding. As a stream migrates laterally, erosion of the concave sides of meanders is matched by deposition of point bar material on the convex sides; thus channel width is maintained (for discussion, see Wolman and Leopold, 1957). Should the stream rise above the level of its banktops, material will be carried over the flood plain, often resulting in overbank deposition. Although material associated with lateral accretion is typically coarser than that of overbank deposits, nature can provide many exceptions: a large literature exists on the sedimentary properties of deposits left by each process (for review, see Leopold, Wolman, and Miller, 1964, p. 322-332).

POINT BAR FORMATION AT SUPERCRITICAL FLOW

There is, however, another mode of point bar and thus of flood plain formation. In 1961, Wolman and Brush used a flume in coarse noncohesive sand to examine channel characteristics at various slopes and discharges. During some phases of their experiments the artificial stream exhibited highly turbulent, shooting (or supercritical) flow (see Vennard, 1961, p. 364-365) and initiated meander development in the channel. Associated with the pseudomeanders, as they were called, was a unique pattern of sedimentation. Wolman and Brush concluded that pseudomeanders only occurred when the ratio \( V/\sqrt{g\bar{d}} \) (\( V \) and \( \bar{d} \) are respectively mean velocity and mean depth) approached or exceeded unity, and that the channel produced was in a disequilibrium state. Furthermore, the same authors added that the special case of pseudomeandering is not at all related to the usual process of meandering and that since the ratio \( V/\sqrt{g\bar{d}} \) (Froude number, \( F \)) in natural streams rarely exceeds 0.5, natural supercritical flow is almost non-existent.
Flume experiments were designed and conducted by the present writer to examine further the pseudomeandering process and the conditions under which it occurs. Detailed quantitative information on the experimental procedure, flow conditions, and channel geometry are reported elsewhere (in preparation). However, a qualitative description of the process is given below to provide a basis for further discussion.

In the present study five stages of pseudomeander development are recognized.

At the first stage, water at supercritical flow was passed through a straight channel molded in coarse noncohesive sand. Undulations in

![Diagram of five stages of point dune development](image)

**Fig. 1.** A five-stage model of point dune development in a flume.
the free water surface, unlike the wave trains described by Wolman and Brush (1961, p. 197), conformed to no ordered pattern (see fig. 1A and pl. 1-A). The flow conditions were associated with vigorous sediment movement over the whole channel bed.

The second stage was marked by the development of regularly spaced mobile dunes on the stream bed. Many observations suggest that the first dune to form is at the head of the flume and that this creates the flow conditions necessary for the formation of the next dune downstream and so on. At first the dunes are simply local tongues of sediment which develop in the center of the channel. They consist of relatively coarse material in the center grading into finer sediments at the banks. Lateral extension of the bars continues until one side of the channel is reached; the opposite side is left as a small gutter or inner channel between the bank of the original moulded channel and the fore-edge of the dune (see fig. 1B). The pattern of stream flow, at first straight, describes a slightly sinuous path during this second stage.

The third stage, described by figure 1C and plate 1-B (see also, Wolman and Brush, 1961, fig.124C), is marked by slight vertical and lateral erosion at the sides of the dunes in contact with the banks, a process that establishes an outer channel which thereafter contributes most to discharge (usually more than 90 percent of the total flow). Flow through the inner channel is reduced considerably, a fact that suggests the term dead slough for the feature (Wolman and Brush, 1961, p. 197).

The fourth and fifth stages, not represented in the work of Wolman and Brush, are shown in figures 1D and 1E, and in plate 2. The outer channel meanders around dunes covered by a thin veneer of water and sediment. Although the outer channel is well-defined at the meander bends, at and slightly downstream of the points of inflection, it is often quite shallow and defined only by the borders of the high velocity filament of water. Although sediment continually passes through the dunes, they maintain their basic form. The rate at which sediment is supplied to the dune fronts exceeds the stream’s capacity for removal, resulting in downstream migration of the fronts and erosion of the banks opposite; the outer channel width remains constant.

The amplitude of the meanders increases until the outer channel of the fourth stage, now quite unstable, degenerates into a multichannelled system of braids, indicating the onset of the fifth stage.

The equilibrium channel.—An analysis of channel character, to be meaningful, must be referred to an equilibrium channel. A channel can be considered as in equilibrium when changes in cross-sectional area and shape become negligible for a given set of flow conditions. It is unlikely that these criteria will be satisfied if the channel is not also in equilibrium with respect to the rate of bed load movement (compare Wolman and Brush, 1961, p. 186).

Wolman and Brush consider a third criterion for equilibrium: a smooth water surface profile. Although this requirement is relevant to
A. The first stage of pseudomeander development. Note the standing waves on the water surface.

B. A channel bend at the third stage of pseudomeander development.
the case of subcritical flow ($F < 1.0$), it cannot be considered in the case of supercritical flow. This mode of flow necessarily involves water surface undulations and sometimes distinct discontinuities (hydraulic jump). It follows that those channels considered by Wolman and Brush in which the Froude number exceeded unity, were by their own definition in disequilibrium. Where these two authors have applied the term equilibrium to such channels, it has been interpreted as meaning equilibrium with respect to channel area and shape but not to water surface slope.

The destruction of the outer channel and the development of braids suggest that pseudomeandering represents a disequilibrium condition. A channel can, however, be quite unstable and yet still be in equilibrium. For example, a low-flow stream in a large channel formed at higher discharge may not possess the energy to change the channel to a form compatible with its low discharge; thus the channel is quite stable but is not in equilibrium with the flow passing through it. On
the other hand, the flume channel can be regarded as representing the 
case where the channel form is fully adjusted to the discharge (a con-
clusion based on an analysis of quantitative data on channel form), but 
where the very process of channel development involves the destructive 
mechanism of braiding. After considerable meander development, the 
low-slope flume stream must, at the points of inflection, traverse the 
initial higher slope channel at almost right angles, involving a quite un-
stable condition. Where the channel is established *across* a sloping sur-
face, slight downstream movement of the channel results in erosion of 
the downslope bank and the failure of the channel to contain all the 
flow.

**POINT BAR FORMATION AT SUBCRITICAL FLOW**

Although point bars of the dune type (called point dunes) usually 
form only at supercritical flow in noncohesive material, they are not, 
however, unique to these conditions. A subcritical stream (F<1.0) in 
noncohesive material will also produce point dunes at *existing channel 
bends*. In the present study, point dunes were readily produced at estab-
lished channel bends of 45 to 180° (for example, see pl. 3). This fact is 
of considerable importance: point dunes are of more than academic in-
terest, for they may well occur on natural streams.

**THE CHARACTER OF POINT DUNES**

Point dunes at established bends of streams at subcritical flow, un-
like those associated with pseudomeanders, are not mobile in the down-
stream direction. Sediment supply to the dune fronts is matched exactly 
by sediment removal. The form is static. The feature is said to be in 
dynamic equilibrium with the hydrologic environment. In most other 
respects, the fixed point dunes are identical with their mobile counter-
parts.

**PLATE 3**

A point dune on an existing channel bend in a flume.
The writer's flume experiments suggest that point dunes may be recognized in the field by considering three factors: the form of the bar, internal structures, and sediment character.

The form of point dunes differs very little from that of the point bar of lateral accretion. In plate 3 it can be seen that the fixed point dune is distinctly asymmetrical, the main body of sediment occurring downstream of the channel bend axis. The downstream edge of the point dune is abrupt, usually quite straight and steeply sloping to the channel bed. It is often difficult to locate the upstream edge of the point dune since there is a gradual blending of dune material with the bed material. An idealized section through the point dune parallel with the channel axis is shown in figure 3. As indicated, more than one dune front may be present; smaller secondary fronts occurring upstream of the main dune front also face downstream. If more than one front is present, the crests of the fore-edges are all at approximately the same height above the channel bed. Like the point dunes associated with pseudomeanders, fixed point dunes also have an inner channel or dead slough zone.

Point dunes developed at supercritical flow are never very extensive, rarely exceeding more than three or four times the bankfull channel width. The limited evidence available suggests that fixed point dunes are even less extensive, perhaps no more than twice the bankfull channel width.

The internal structures of point dunes are very different from those in normal point bars (see fig. 2); they are not dissimilar to the structures found in barchans. At supercritical flow sand is removed from the upstream end of the point dune and passes over it in the form of an accretion layer. At the downstream end of the dune, sand from the accretion layer spills down the dune front to produce an encroachment layer, often involving the process of slumping. Since upstream encroachment layers are eroded and transported through the accretion layer to be deposited once again as encroachment layers, the whole dune may be reworked many times as it moves downstream. On the other hand, in a fixed point

![Fig. 2. An idealized cross section through a point dune. The section parallels the channel axis.](image-url)
dune only the accretion layer and the encroachment layer of the dune front are active; layers further upstream within the point dune are older than the frontal layers and are quite inactive. The thickness and angle of repose of the encroachment layers depends on the nature of the dune material and the stream flow, a set of relations that are outlined elsewhere (in preparation).

It seems likely that the sediment of each encroachment layer will be comparable in size distribution. However, it is also likely that the size distribution of the sediment of the point dune will differ significantly from that of the channel bed. Sediment samples obtained from a vertical bore through a point dune should reveal a marked change in sediment character at the junction of the point dune and the channel bed.

FIELD EVIDENCE OF POINT DUNES

Point dunes have been identified by the writer on several tributary streams of the lower Hawkesbury River on the central coast of New South Wales, Australia (see pl. 4-A). It is likely that many more streams in the area exhibit point bars of the fixed dune type. The streams in question all flow in coarse noncohesive sand display underfitness of the Osage type (see Dury, 1964; 1966, p. 17-25); that is, they do not meander but are forced to change direction at valley bends. Since meander development by present-day streams is not common, all point dunes are narrow, usually no more than the width of the bankfull channel. It is perhaps significant that all the streams concerned exhibit braided reaches.

In mid-1967, two of the streams (Wheeny Creek and the Colo River) were at bankfull stage. Fortunately the writer was able to observe and photograph the point dunes forming in the manner described above (see pl. 4-B). When the streams subsided, a section was cut in a point dune on the Colo River at Upper Colo, and sediment samples were taken from a number of vertical bores on a straight line across the dune normal to the section and the channel axis. The section through the point dune revealed the predicted encroachment layers dipping downstream at an angle of about 30°. The sediment samples were analyzed for size distribution, and values were determined for mean size, sorting, skewness, and kurtosis. The parameters, graphed with depth below the point dune surface (for example, see fig. 3), show clearly the expected change in trend at the level of the channel bed, effectively distinguishing between dune and bed material. Although the size analysis is only exploratory, several tendencies have become apparent. Typically, the material of the point dunes is finer and better sorted than that in the channel beds (for example, see fig. 3C and 3D). Multiple plots of skewness/kurtosis, sorting/mean size, and skewness/mean size can be used to test the appropriateness of the location of the point dune-channel bed junction established by independent criteria such as form and structure. The plots, one set of which is presented in figure 4, reveal trends that accord with the helical pattern outlined by Folk and Ward (1957, p. 3-
A. A point bar of the dune type on the Macdonald River, New South Wales.
B. A point dune forming on Wheeny Creek, New South Wales.
Fig. 3. Plots of sediment size parameters with depth below a point dune surface. The change in trend at the channel bed is clearly indicated.

Fig. 4. Multiple plots of size parameters of sediment samples obtained from a bore through a point dune. The bed and point dune samples tend to occupy quite different regions of the scatter.

26). The present pilot study suggests that sediment character can be used to separate the two sedimentary environments and indicates the need for systematic study of the sediment in these features, taking into account a variety of hydrologic conditions and parent materials.

STABILITY OF POINT DUNES

Generally, point dunes are little disturbed by flows greater than those which formed them. On several occasions during the period of observation, the Colo River point dunes were left unaltered by the passage of floodwaters. The point dunes are, however, subject to extensive modification by wind action. At low flows the loose sand of the point dunes is exposed to the gusty winds of late winter and early spring, and the features are often almost obliterated. The point dunes on the Colo are in a sense seasonal, being best developed during the early to mid-winter months. In other areas where they are located at sites protected from seasonal winds, the point dunes are virtually permanent features.
SIGNIFICANCE AND IMPLICATIONS

The occurrence of point dunes is probably restricted to the coarse noncohesive material that makes up the fills in old winding valleys. The strong rectangular jointing (and faulting) in the Hawkesbury Sandstone of the coastal plateaux of central New South Wales has produced structurally controlled valleys in which complete reversals of drainage direction over quite short distances are not uncommon. The rectangular drainage pattern together with the coarse quartz sand fills in the valley bottoms have provided ideal conditions for point dune formation.

Experimental and field evidence strongly suggests that point dunes are formed at flood plain level and that they can be used as an indication of bankfull stage. If the crest of the dune fore-edge is taken as banktop, measurements of bankfull channel dimensions can readily be made. With the dune crest as a basis for measurement, it has been shown that a flume stream at supercritical flow produces a bankfull channel, the hydraulic geometry of which is quite consistent with that obtained for natural streams (unpub. data). Furthermore, the same technique of measurement applied to natural streams has yielded a consistent relationship between bankfull discharge and drainage area which accords with the corresponding relationship based on flood plain heights (Hickin, 1968, p. 274).

Of considerable importance here, is the fact that point dune and channel bed deposits can be distinguished on the basis of sediment type. Most natural channels on the central New South Wales coast are to some degree incised, and the true bankfull depth is often not easily determined. Sedimentary analysis of point dunes can provide a reliable guide to maximum and mean channel depth at bankfull stage.

Since it is unlikely that point dune formation was not also active in the past, relict point dunes may furnish new techniques for unravelling the geomorphic history of certain drainage basins. The coincidence of the dune crest and bankfull level, along with likely relationships between dune structure and the magnitude of the discharges that produced them, provide useful tools for the analysis of former hydrologic conditions. Coupled with these possibilities is the convenient fact that the features provide ideal sites for radiocarbon age determination. In New South Wales, summer bushfires supply the coastal streams with abundant quantities of ash to be stored, free from outside contamination, in the encroachment layers of point dunes.

The reason why point bars on certain streams are of the dune type rather than of the type formed by lateral accretion is not known. Initial observations suggest that point dunes do not form in cohesive material, nor do they occur on actively meandering streams—facts that may not be unrelated. The mode of formation, character, and significance of point dunes are the subjects of experimental and field work being conducted at the Department of Geography, University of Sydney.
ACKNOWLEDGMENTS

The writer wishes to thank Professor G. H. Dury for his comments on the manuscript and Mr. A. Bartlett for assistance with the illustrations. This paper is based on a research project financed by the University of Sydney.

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