DISCUSSION

ALLUVIAL FANS AND THEIR NATURAL DISTINCTION FROM RIVERS BASED ON MORPHOLOGY, HYDRAULIC PROCESSES, SEDIMENTARY PROCESSES, AND FACIES ASSEMBLAGES—DISCUSSION

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Blair and McPherson's implicit definition of alluvial fans will undoubtedly create problems for earth scientists, especially geomorphologists, because it is too restrictive to encompass the wide diversity of natural depositional conditions. Moreover, by trying to establish an integrated classification for alluvial fans and deltas it fails to emphasize the essential and fundamentally different nature of the depositional processes in these two environments. Deposition occurs on a fan because of a decrease in competence due to loss of confinement of flow. In contrast, deposition occurs on a delta primarily because of a decrease in competence due to a river entering a standing water body. The processes on the subaerial part of an alluvial fan are independent of whether or not the fan is prograding into a standing body of water. What we propose to do is use the Okavango "fan", which represents an extremely unusual depositional setting, and which Blair and McPherson classify as a "mud-dominated river delta", as a test case of fan classification in order to illustrate the shortcomings of their classification scheme.

Before discussing the Okavango "fan", it is necessary to examine briefly the basis for Blair and McPherson's distinction between "alluvial fans" and "rivers", and specifically their figure 5, a plot of grain size against slope, which purports to show the distinction between "fans" and "rivers". On this diagram, the Okavango "fan" falls in the domain of "rivers".

Clast size and slope can be related by the empirical equation (Blair and McPherson's eq 8)

$$\gamma DS = 0.056d^{1.213}$$

where γ is the specific weight of the fluid. D is the depth of flow. S the

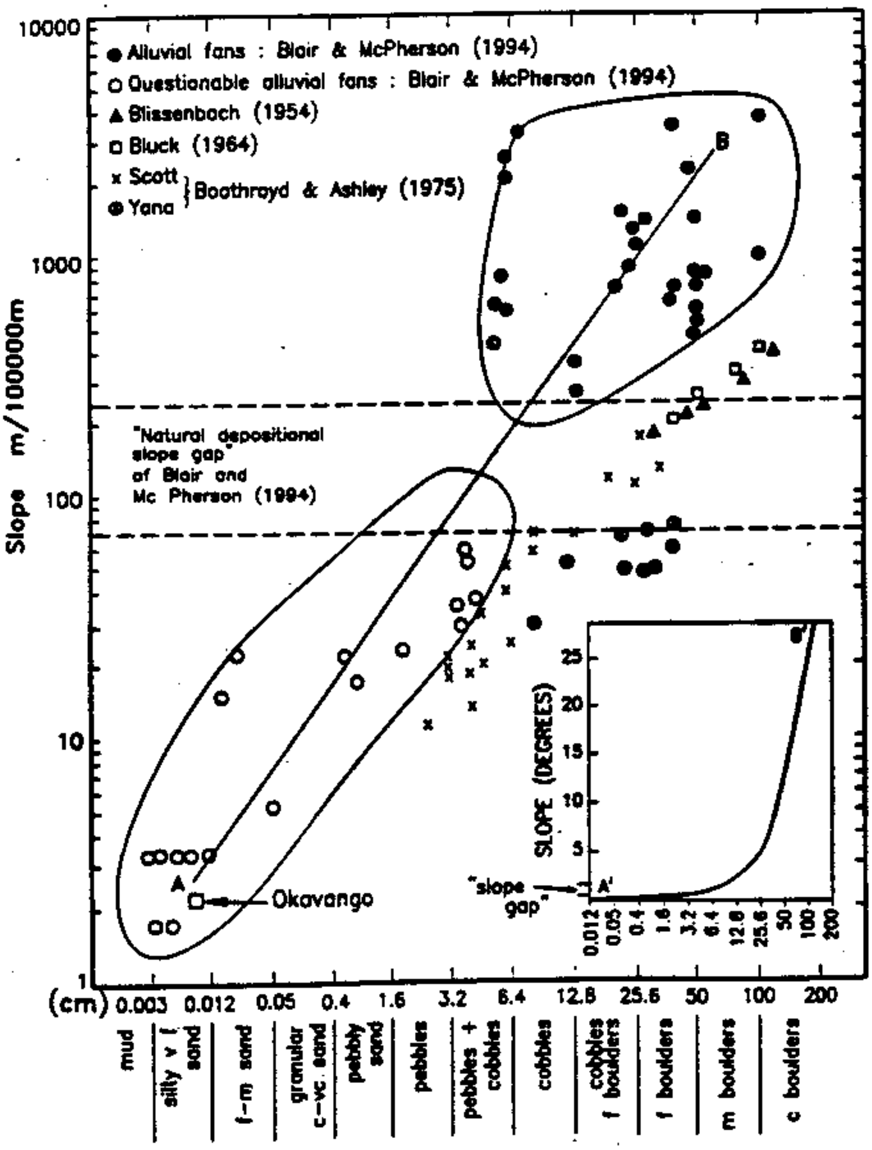

FIG. 1.—Semiquantitative plot showing the relationship between particle size (as used by Blair and McPherson 1994) and slope for a variety of alluvial-fan environments. The inset shows line AB of the main diagram plotted as particle size against slope in degrees. See text for details.

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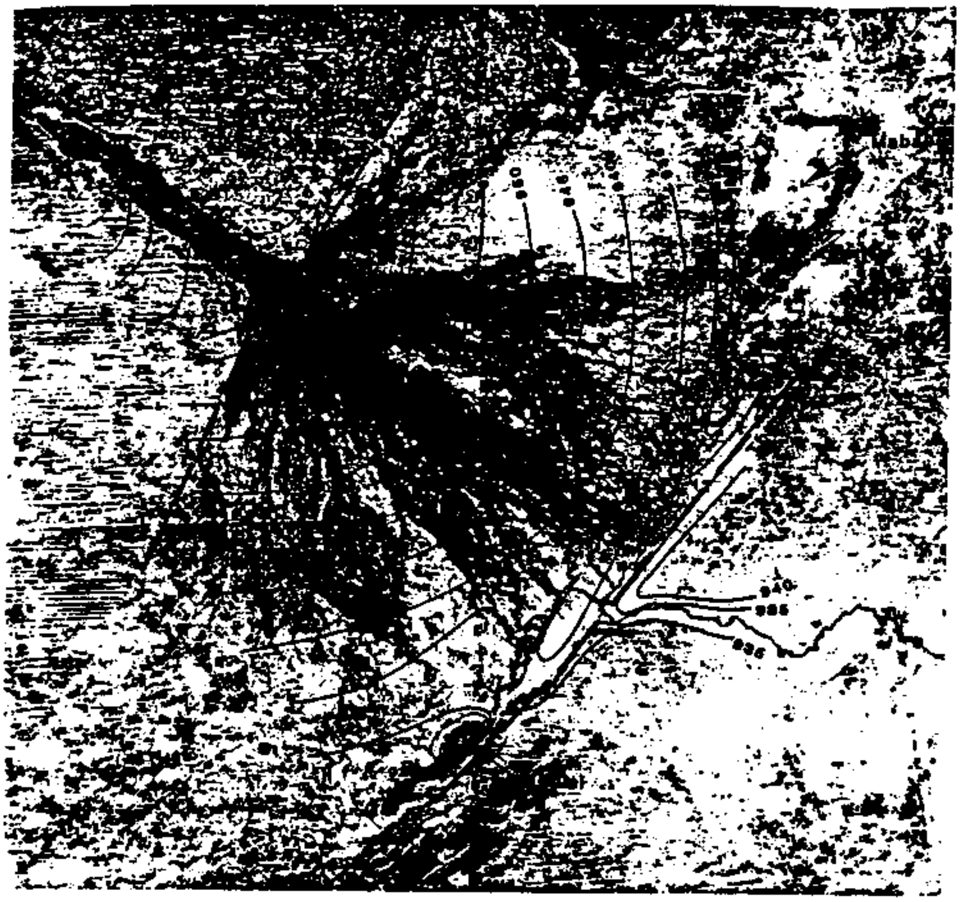

FIG. 2.—LANDSAT MSS image of the Okavango fan during the seasonal flood maximum, with topographic contours superimposed (contours from UNDP 1976). Darker areas are inundated; M is the town of Maun.

slope (in distance/distance units), and d the intermediate clast diameter. This can be rewritten as

$$\log S = 1.213 \log d + \log \frac{0.056}{\gamma D}$$

or

$$\log S = 0.365\ \text{phi} + \log \frac{0.056}{\gamma D}$$

A plot of log S against log d or phi will yield a straight line (assuming γ and D are constant) of gradient 1.213 or 0.365, respectively, and intercept $\log(0.056/\gamma D)$.

Figure 1 shows a plot of log S against particle size for Blair and McPherson's data on "alluvial fans" and, in their words, "rivers or river deltas questionably classified as alluvial fans or fan-deltas". The data define a single, linear relationship (AB in Figure 1), as expected from the above equations, albeit with a wide scatter of data points. The apparent separation of the gradients generated by these two groups in Blair and McPherson's figure 5 is an artifact of their choice of axes, i.e., slope in degrees against a quasi phi scale, which is logarithmic. Theirs is, in effect, a semilog plot, which generates pronounced curvature in the graph (Fig. 1, inset). Their diagram is further complicated by the fact that their particle size scale is partly arbitrary in the small size range (see Figure 1) although the effects of this are relatively insignificant. The log-log plot shown in Figure 1 is, of course, not new (e.g., Boothroyd and Ashley 1975) and is the more appropriate form for portraying exponentially related variables.

Plotting an entire fan or river reach as a single point on the diagrams, as Blair and McPherson have done, is, at best, semiquantitative, as they correctly admit. It is well known that particle size decreases down a fan, as does slope. Some examples of this are shown in Figure 1. Two of these examples are arid alluvial fans (Bluck 1964; Blissenbach 1954), which would be classified as "alluvial fans" in Blair and McPherson's scheme. The examples cited define linear arrays, as expected, but are shifted to the right relative to Blair and McPherson's compiled data, because the former data represent maximum clast size. The two other examples are from glacial outwash fans (Scott and Yana; Boothroyd and Ashley 1975), which Blair and McPherson would probably classify as "rivers". These data sets also define linear arrays and, because they represent maximum clast size, are likewise displaced to the right relative to Blair and McPherson's compiled data. It is significant that these two examples, and especially the Scott "fan", close the "natural depositional slope gap" between Blair and McPherson's "alluvial fans" and "rivers" (Fig. 1), indicating that this gap is actually an artifact of the choice of data, and arises from plotting entire fans as single points. Had data been collected on the distal reaches of the fans studied by Bluck (1964) and Blissenbach (1954), it is likely that these "fans" would have shown a significant degree of overlap with the Scott in Figure 1. Therefore, separating "fans" from "rivers" purely on a basis of clast size and slope characteristics is suspect, although there may, under certain conditions, be some natural separation (e.g., Boothroyd and Nummedal 1978).

Now let us consider the case of the Okavango "fan". This "fan" has developed in an extensional graben related to the East African Rift System (McCarthy et al. 1993a). Its upper limit is determined by the Gomare Fault (Fig. 2), essentially a dip-slip fault. There is no high-relief upland catchment because the rift has developed within the intracontinental Kalahari depositional basin, which is characterized by low gradients. No catastrophic floods are generated in the catchment because of its size (ca. 180,000 km^2) and relatively high rainfall (ca. 1000 mm/yr), and the hydrograph shows steady seasonal rises and falls (McCarthy et al. 1991). The catchment is underlain mainly by eolian sand, so the sediment delivered to the graben by the Okavango River consists of fine to medium sand, with little suspended load (bed load/suspended load ratio = 6; McCarthy et al. 1991). At the graben boundary fault, the Okavango River loses confinement, and the water spreads out over an angle of 180° (Fig. 2). Sediment deposition resulting from this loss of confinement has created a broad, conical "fan" (Fig. 2) with plano-convex form. This "fan" is perennially flooded in its proximal reaches and seasonally flooded in the distal region. Distributary channels in the proximal area experience frequent avulsion (McCarthy et al. 1988), distributing sediment radially over the "fan". These form ribbon sand bodies, flanked by finer deposits formed from burning of sediment-laden peat accumulations (Stanistreet et al. 1993). The water that reaches the distal part of the "fan" contains little clastic material, and in these regions sedimentation is dominated by calcrete and silcrete formation because of the semiarid environment (McCarthy and Ellery 1995). The accumulation of calcrete and silcrete causes aggradation of the "fan" surface. Gradients on the "fan" are low because sediment load is low.

Small lakes (Ngami and Mababe, Fig. 2) occasionally form against the fault scarps that define the distal limit of the "fan", but these generally develop only during pluvial periods (Shaw 1988). The total area of these lakes is a small fraction of the area of the fan (Fig. 2), and their presence in no way influences, and is essentially irrelevant to, depositional processes on the fan itself. It is totally erroneous to regard the Okavango "fan" as prograding into these ephemeral lakes. The nature of lake sedimentation in the Okavango region has been described by McCarthy et al. (1993b), and is characterized by an unusual form of delta formation. Depositional processes on the "fan" are caused entirely by loss of confinement, and are completely independent of the existence of these lakes.

On both the Okavango "fan" and the debris-flow-dominated fans of Blair and McPherson, the ultimate cause of deposition is loss of confinement of flow (associated with a fault scarp). The result is a fan-shaped accumulation of sediment, with a plano-convex form. In both cases, aggradation is essentially vertical and radially distributed. This is quite different from deposition in a deltaic environment, where deposition occurs due to river discharge into a standing body of water. Blair and McPherson's classification of the Okavango "fan" as a "mud-dominated river delta" is therefore nonsensical and fails to recognize the nature of the depositional processes involved. In terms of sedimentary processes, the Okavango "fan" has far more in common with debris-flow-dominated fans than with deltas and belongs in a classification system along with debris-flow-dominated fans rather than with deltas. Any definition of alluvial fans should be sufficiently inclusive to accommodate both types.

The Okavango fan and debris-flow-dominated fans represent end members of a spectrum of fans. At one extreme are deposits formed by rivers with nonflashy, continuous discharge and low suspended load, typic with subdued relief in the catchment area. At the other extreme are depo formed by rivers with flashy discharge, high sediment load, and p nounced topographic relief in the catchment. The gross morpholog the alluvial fans produced by these contrasting rivers is the same, but t differ in size, gradient, sediment size, and sorting. The classification sche proposed by Stanistreet and McCarthy (1993) recognizes this divers and is therefore more inclusive and universally applicable.

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