

ALLUVIAL FANS IN THE NORTHERN BRAHMAPUTRA

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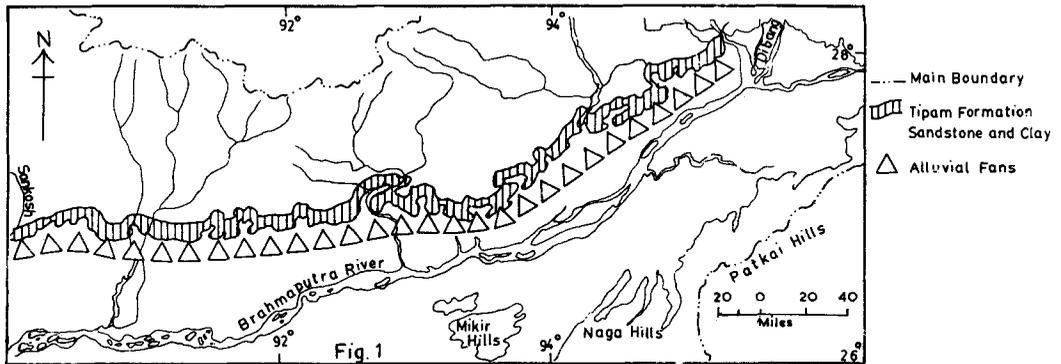
ABSTRACT : The paper attempts a morphological and locational analysis of alluvial fans in the Northern Brahmaputra Valley in Assam, related to their climatic and tectonic characteristics. The fans have smaller catchment drainage basens in relation to their size. Most fans have uniform planar slopes and are irregular. Genetically, the fans are related to the last phases of the Himalayan orogeny.

INTRODUCTION

For a long time in the development of geomorphology, alluvial fans received, at best, scant attention from geologists and geographers, in comparison with that received by other landforms. Further, almost the entire emphasis on the study of alluvial fans has been restricted to those occurring in the arid and semi-arid regions. Thus, they have been treated as an integral part more of arid geomorphology than of any other geomorphologies. Only recently has there been an effective realisation of the occurrence of alluvial fans in humid or sub-humid climates as well. Clearly, the arid and humid zone, alluvial fans are homogenetic and homomorphic in terms of the basic processes of formation and evolution and fundamental geometrical attributes and the knowledge of both types are necessary for a fuller understanding of alluvial fans.

Despite their large numbers and their occurrence in a climatic zone where they have not been expected following the heavy concentration of scholarly efforts on the arid zone counterparts, the Assam alluvial fans have escaped even brief mention in major geological, regional geomorphological, and regional geographical research publications. Wadia, Gansser, Saklani, Geddes, and Spate in their detailed discussions on the regional geology and geomorphology of the Eastern Himalaya and Assam valley have not mentioned them even once. There is only one one-line reference to their presence in the northern Bengal *duar*.

It is obvious that the alluvial fans of the northern Brahmaputra valley in Assam deserve attention because of, and derive their significance from the following facts : (a) they occur in a region where the Cwg (Koeppen) climate is really a modification of monsoonal (Am) type with very heavy rain-



fall ranging from 50 to over 100 inches; (b) the streams forming these cones and fans are dry for a large part of the year and carry discharge during the period of summer monsoon when the intensity of rainfall is very high; (c) the fans reflect the climatic changes and tectonic events which have characterised the Eastern Himalaya from the Pleistocene age onwards; and (d) their high frequency of occurrence along the foot of the southern Himalayan front. Together with those occurring at the foot of the western Himalayan front the northern Brahmaputra valley fans contribute to an understanding of the Himalayan foot-hill fans.

The present discussion is a preliminary presentation of the locational and morphological attributes of the fans of the northern Brahmaputra valley in Assam and their related climatic and tectonic meanings.

PHYSIOGRAPHIC SETTING

The alluvial fans of varying shape, size, and morphometric properties, including the fourteen from whose detailed analysis have generalisations been formulated, occur in the northern Brahmaputra valley on the

narrow, eight to ten miles wide piedmont overlooked by the steep, southern frontal slopes of the Himalaya and extending for a distance of about 400 miles from Sankosh in the west to the Dibang river in the east.

In the field, in the aerial photographs and large scale topographical sheets, the most striking element of the setting is the sharp contact formed by the long line of the break-in-slope (knickpoint) along which are juxtaposed the bold, highly scarp-ed topographic slopes of 20° to 50° or even more on the north and 3° to 5° piedmont facet on the south.

The region experiences a combination of Cwg (Koppen) and Am (Koppen) types of climate. While the annual rainfall ranges from 80 to 100 inches of which almost 70 per cent is concentrated during the four summer months of May, June, July, and August, the humidity of climate differentiates the Assam fans from those occurring along the western and northwestern Himalayan ranges.

GEOLOGICAL SETTING

The valley of Brahmaputra or Assam valley is clearly an intermontane

basin. The most spectacular and persistent patterns of alluvial fans are, however, revealed along the northern piedmont of the Brahmaputra valley. There were large scale block movements concurrent with the rise of the Himalaya during the Miocene. During the Pliocene, the drainage of the Himalaya was diverted to the Assamese foredeeps. During this period the foredeep began to be filled and the filling process continued till the Pleistocene. On this Pleistocene fill surface one finds alluvium and high level terraces. Alluvial fans form the principal features of this alluvium.

Most of the valley is composed of alluvium. Along the margins and the foot of the Himalaya there is a narrow belt of shelf sediments which form the Tipam formation. The Tipam formation is of Mio-Pliocene age. It is mainly composed of sandstone and clay. The Tipam formation belongs to both shelf and geosynclinal sediment stock. The Tipam of the southern borders of the Himalaya is juxtaposed with the Brahmaputra Supergroup. The Supergroup consists mainly of fluvial and deltaic sediments of Neocene age and has sandstones and clays.

All the alluvial fans of the northern Brahmaputra valley are located in a tectonically unstable zone. This is also an earthquake-prone zone, a seismically active belt with a large number of reported earthquakes concentrated here. The presence of the Frontal Himalayan Thrust zone has been identified by several geologists. It has been mapped by Mathur and Evans (1964). The rightangular bend of Alakuri River and offsetting of the terrain units at this site coincide with the regional fault. The tectonic movements of the Upper Pleistocene and Recent periods have played a significant role in the genesis, evolution, and survival of the fans.

Most of the fans have their apices located within the thrust zone along the

parallels of 26°N and 27°N , as is firmly supported by a careful and thorough scrutiny of one inch to one mile Survey of India toposheets and the relevant geological maps. Along these parallels the thrust zone has been identified by Mathur and Evans (1964). The faults are located along the Tipam series. Also, the faults that run at the foot of the Himalaya are coincident with alluvial boundary. Each thrust-mass presents a scarp face. Most of the detrital material that forms the fan is derived from the Tipam series beyond the fault by high-energy trunk streams of the present times or were brought by them during the more humid phases of the Upper Pleistocene and post-Holocene times.

LOCATIONAL PATTERN

The locational pattern of the alluvial fans can be identified and analysed at two different scales of observation and generalisation : (a) distribution of the sites which constitutes the small-scale, gross pattern, and (b) location of the individual sites which forms the large-scale, micro-pattern.

Easily, the most striking feature of the gross pattern is the linearity - parallelism, linear along and parallel to the Himalayas. Most of the fans have their principal axes and major extent aligned in the north-south direction. This is largely explained by the alignment of the axial streams of the fans orthogonal to the foot of the Himalayan slopes. The toe-edges or the lower boundaries of the distal fans are parallel to the Himalaya. The bold linearity of the major slope surfaces and of the piedmont is obviously related to the Main Boundary Fault which separates the Himalaya from the ramp valley of the Brahmaputra. Further, almost all the fans have their apices located in the zone of the Main Boundary Fault with their major extent on the upper, northern part of the piedmont and a little portion beyond on the upper part of the terai.

Essentially, the alluvial fan is the gravelly piedmont feature and much of its genesis and properties are derived from this location. The fans are hardly ever flooded for three reasons: (a) the slope of the proximal fan adjacent to the apex is steep and facilitates the quick flow of the discharge, (b) the trunk rivers are deeply entrenched and do not overflow their banks, and (c) the gravelly composition of the sedimentary deposit has a high infiltration capacity which reduces the surface run-off. Because the locational pattern promotes continuous fluvial deposition and also colluviation and mud-flow slope-wash the fan tends to persist over a long period, with their shape and size unimpaired.

Perhaps the most widely commented-upon feature of alluvial fan is its site at the foot of a mountain slope near the point of debouchement of the trunk river onto the adjacent plain. A careful look on the serial photographs and the large scale topographical sheets immediately reveals that the major part of the site does indeed spread away from the mountain slope foot. Depending upon whether they are enclosed on two or three sides by the transverse ridges, outliers, and hill headlands the sites can be classified into the following groups: (a) almost complete, enclosing on the lateral sides which join at the apex and thus form a perfect two-dimensional, planimetric cone; best exemplified by the Pagladiya Fan; (b) no enclosing at all on the lateral edges and the apex located inside of the point of debouchement but even though not enclosed the lateral spread is not irregular but corresponds to a perfect fan; exemplified by Khural Fan; (c) enclosed on the lateral edges only upto half of their sides by ridges and with a straight frontal slope at the upper end appearing as a trapezoid; exemplified by Bhur Fan; (d) enclosed by lateral ridges only very near the upper parts (proximal fan); exemplified by Dimabori-Baladi Fan; and (e) funnel-shape, lateral

edge enclosement; exemplified by Rakti-Khola Fan. The sites do not occur everywhere, all through, along the slope-foot and along any particular segment there is no regularity of spacing. On the other hand, along some segments several fans occur in close contiguity of each other.

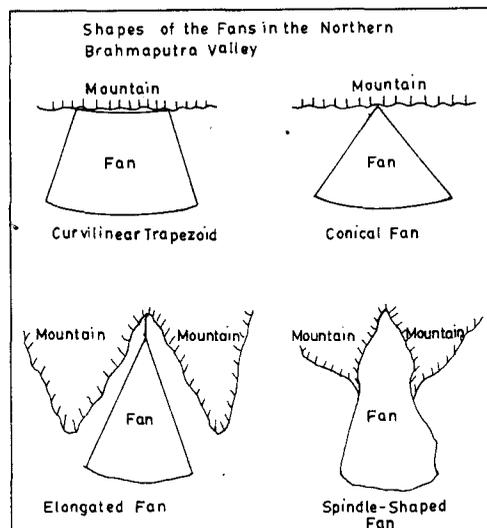


Fig. 2

The sites are everywhere located on steeply sloping older Brahmaputra shelf zone of Pliocene-Pleistocene age. It is clear that a majority of the sites are constricted between the ridges which in most cases diverge increasingly with increasing distance from the apex permitting the longitudinal growth and lateral expansion of the fan. The site is everywhere located below a gorge and overlooked by the frontal slopes. How the sites have influenced the genesis, spatial growth, shape, size, and alignment will become clear in the following pages.

THE DRAINAGE LINES

With steep south-facing slopes, heavy rainfall, and high water divides the region of the adjacent Himalaya has spawned innumerable streams of varying orders forming a network of high drainage density and supplying an enormous stream load to the system. Despite the loss of a considerable proportion of the load through high discharge in the downstream direction because of the high monsoonal rainfall and its intensity, there is more than adequate amount of load available to the streams to spread it out at the point of debouchement and create the fans.

As is well known, the southern edge of the Assam Himalaya, against which have developed the cones and fans, rises abruptly on a steep slope from the Brahmaputra valley. Most of the rivers originate from the Bhutan and Arunachal Himalaya and after flowing for about 80 to 150 miles over steep gradients debouch onto the Brahmaputra plain.

While the streams are deeply entrenched and flow through meanders with the basins in the Himalaya, they are invariably braided, wide, and anostomotic on the fans, suggesting that here they are inefficient and have low hydraulic radius. Their competence as is common to fans is low. The rivers are deeply entrenched near the apex (40 to 80 ft. deep) and with increasing distance from it the banks, although still scarped, are only 15 to 30 ft. high. In the distal fan the trenches are replaced by furrows. Most of the larger rivers, such as Pagladiya throw out several distributaries, all radiating out and contributing to the expansion of the fan. The entrenchment is more marked in the larger rivers while the smaller distributaries remain deep linear scratches. The distributaries do form a hierarchical organisation system of various orders related to the angle of divergence as was proposed and worked out by Mukerji (1976). Although the streams are one to about ten miles long, their number is small, thus the drainage density and ruggedness index values are small, more strikingly so when contrasted with those of their associated headwaters drainage basin. The actual wetted perimeter is small indeed with channels upto 3 feet deep.

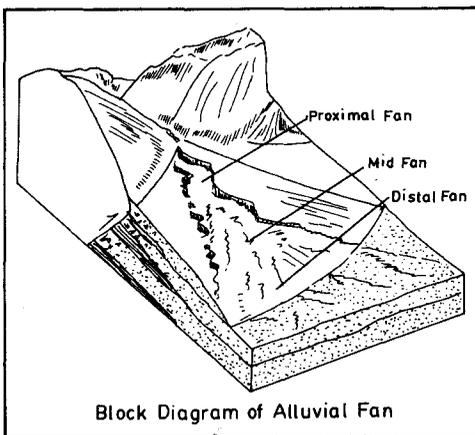


Fig. 3

Few of the alluvial fans of the region have perennial drainage. Only the larger rivers are perennial while most of the distributaries, which are radial, reconvergent or divergent, are seasonal and within the seasons intermittent. Many of these have been generated after the creation of alluvial fans. In some fans tributary system is noticeable in the proximal fan and divergent distributary system in the middle and distal fans. This is revealed in Bhur River Fan. In others, such as Dimabori-Baladi Fan the distributaries are divergent in the proximal and mid-fan and reconvergent in the distal parts. However, in most cases, the higher order tributary confluences occur in the mid and distal fan portions. Not all the

streams of the alluvial fan are distributaries. Many of these are independent, originating and terminating at points on all the three components, proximal, mid, and distal. Where they join each other they form the boundary of distal fan. In all but one the major streams flow along the lateral edges but debouch onto the plain near the apex. Their diversion is a part of the genetic and evolutionary processes of the alluvial fans and will be explained later. Six kinds of streams are identifiable on the alluvial fan: (a) the trunk stream which generally forms the lateral edge but originally debouches near the apex and generates the fan, (b) the abandoned stream, truncated as a distributary from the trunk, (c) the distributary or truncated distributary that joins other stream of the same order or higher order, (d) the resultant stream produced by the joining of the two tributaries, (e) flowing along the axis on the fan, and (f) flowing radially on the fan.

The most characteristic feature of the drainage lines of the fan is their radial flow. The streams are under the influence of gravity from two directions, lateral and longitudinal, towards both of which the fan surface is sloping. The resultant direction is radial, between the longitudinal and lateral, away from the axis and away from the apex. This is the explanation of the radial stream direction.

SHAPE OF THE FAN

At least four, if not more, kinds of shape have been identified: curvilinear trapezoid, conical, elongated, and spindle. (Fig. 2). These are exemplified by Baumk Nala, Dimabori-Baladi, Chamguri-Jora, Garuchara-Rabang, and Deopani fans; Pagladiya, and Bhur and Sukhan Jan-Gubarkunda fans respectively. All the shapes are, however, modifications, in planimetric plan, of the conical.

The shapes are determined by the following factors : (a) the number of distributaries or the radiating streams, (b) the angle of divergence, (c) the alignment of the lateral ridges, (d) the alignment of the lateral bounding streams, (e) the angle that the axial stream makes with the mountain-plain contact line at the point of debouchment, (f) the presence of a clearly identifiable axial stream, (g) stream-channel shifts across the fan and along the radial lines of the fan, (h) changes in the direction of the accumulating material, and (i) radial pattern of surface distributaries

Larger number of radial distributaries diverging out at higher angles of divergence toward the lower parts of the fan effect an increase in conicality of the shape. Whether the fan will be high or low, steep or flattish, will be determined essentially by the high or low angle of divergence. Where the lateral bounding streams have come nearer to each other because of the lateral enclosing ridges the fan becomes elongated. A high angle divergence associated with low, flattish fan is observed in Khural Fan. Perfect conically-shaped fan is created where the stream debouches at right angles to the hill-plain contact plane. None of the fans in which the axial stream is not clearly identifiable has a regular shape. Stream-channel shifts have been suggested as the principal reason of the conicality of the fan. Lateral migration of the area of deposition across the fan occurs when deposition has raised the fan surface sufficiently to favour shifting of the stream to an adjacent lower part of the fan. Minor shifts in stream-channel position near the fan apex may cause large changes in channel position on the downslope parts of the fan. These changes in the area or locus of fan deposition along the radiating streamflow lines from the fan apex are largely responsible for the fan-shaped plan view of the resulting deposit. Changes in the direction of the

accumulating material controlling the shape has been proposed by many investigators. The radial pattern of distributaries also is important in regulating plan shape. A convincing example is provided by Deopani.

SHAPE MEASUREMENTS

Alluvial fan is a three-dimensional solid (Fig. 3). Thus, it is a segment of a cone. If an alluvial fan is rotated around its apex the resultant solid would be a cone. The geometrical elements used in morphometric analysis have been shown in Fig. 4.

The volumetric fan shape index (VFSI) is to be found by comparing the volume of the actual fan with the volume of the equivalent ideal fan. This is computed by the formula being proposed here:

$$VFSI = \frac{C}{D}$$

in which C is the volume of the actual fan and D is the volume of the equivalent ideal fan.

If the value of VFSI is 1, which is not possible in nature, the fan would have a perfect conical shape. Values higher or lower would indicate departures from the ideal shape.

$$\text{Volume of actual fan} = \frac{A \cdot h \cdot d}{360}$$

in which A is the area of the alluvial fan, 'h' is the difference between the height of the apex and the height of the toe-edge, 'd' is the angle of divergence between the two laterals meeting at the apex.

$$\frac{1}{3} \left(\frac{r^2 h d}{360} \right) = \text{Volume of the equi-}$$

valent ideal fan in which 'r' is the length of the longest axis, 'h' is the height differential and 'd' is the angle of divergence.

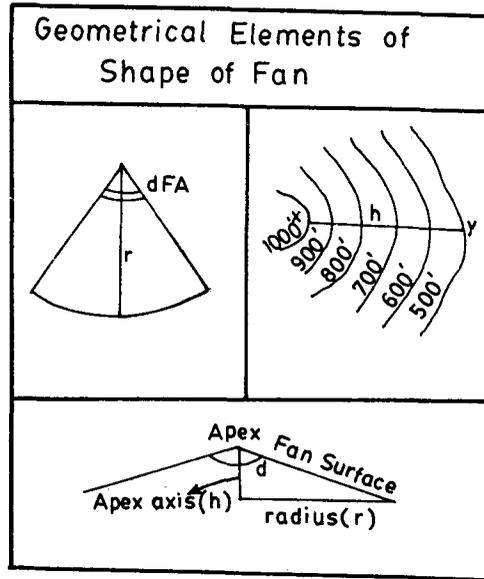


Fig. 4

As table 1 shows the values of VFSI range from the minimum of 0.39 to the maximum of 1.79. There are several fans which have values near 0.5. In all of them the longitudinal profile along the principal axis reveals two clearly recognisable segments, the upper, narrow, steeper part and the lower, wider, gentler part, the two forming a concave slope facet. Only one fan, Khural, has an almost ideal volumetric shape indicated by the VFSI value of 1.02.

Earlier 'fan conicality index', a measure of the planimetric shape, was introduced by Mukerji. He proposed that -

$$FCI = \frac{\text{Area of Equivalent Ideal Fan (AIF)}}{\text{Area of Terminal Fan (ATF)}}$$

ATF is measured with a planimeter.

$$AIF = \frac{r^2 d F A}{36}$$

in which 'r' is the distance between the fan apex and the point farthest from it on fan base, and dFA is the angle of divergence at fan apex.

The nearer to 1 is the value of FCI the more does the terminal fan shape approximate that of the equivalent ideal fan.

As table 1 reveals only two fans, Alalkuri and Khural approximate the shape of the ideal fan. In both the axial streams flow more or less along the principal axis and the fan has developed on both sides of it in equal extents. Also, the fans have gentle gradients and the distributaries forming radial pattern have originated almost near the apex. Fans having values of FCI of about 0.5 reveal elongated shapes. In these fans the lateral extensions have been prevented by the ridges and lateral indentations and embayments have removed a considerable volume of fan material. In most other fans longitudinal digitations have created vacant embayments along the toe-edge.

MORPHOMETRIC PROPERTIES

It is assumed that a fan will have a large number of morphometric properties on the basis of whose values one can distinguish the fans and classify them but equally important is their inter-relationships. The correlations of several of the properties flow from and contribute to the understanding of hypotheses of geometry, genesis, and evolution.

Axial length of the fan, it is being proposed, would be determined by the velocity and discharge of the axial stream below the fan apex. Both velocity and discharge are related to the volume of water available as surface run-off in the basin, the gradient of the fan, the gradient of the basin, the depth of entrenchment near the apex, the number

of distributaries spawned, and the infiltration capacity of the fan deposit. As a first major principle it can be stated that the larger velocity and discharge would generate a longer axial stream and greater axial length. The average gradient and axial length of the fan are inversely but weakly correlated.

The area of the fan is directly proportional to the area of the basin. The coefficient of correlation for these variable is 0.825. Although the angle of divergence is a significant determinant of the area the correlation supports the hypothesis but the coefficient has a low value (+ 0.262). Larger area of the basin supplies a larger amount of load, thus, contributing to the increase in the area of the fan. Also, although the area and gradient of the fan are inversely correlated, as would be logically expected, the correlation is rather weak. Axial length and area of the fan are positively, strongly correlated (+ 0.814).

The fan height is most significantly and positively correlated with Fan Conicality Index (+ 0.569). It is not clear as to why it is so. May be the greater height generates a more regular radial pattern of distributaries leading to the emergence of a more regular fan.

Average fan gradient is positively correlated with both basin gradient and fan conicality index, strongly with the former and weakly with the latter.

Of the three variables, area, height, and gradient, it is the second that is the most significantly correlated with the fan conicality index. A greater height produces a more regular fan. On the other hand it is the area of the fan that produces the regularity in the three-dimensional form.

TABLE 1 : MORPHOMETRIC PROPERTIES OF THE FAN

Name of the Fan	Axial length	Basin length	Area of the fan	Area of the basin	Angle of divergence	Fan height	Basin height	Average gradient (fan)	Average gradient (basin)	FCI*	VF SI**
	Miles	Miles	Sq.Miles	Sq.Miles		Feet	Feet				
	1	2	3	4	5	6	7	8	9	10	11
Chamguri	1.9	1.3	6.79	4.50	90°00'	500	1400	2.99	11.30	0.41	1.79
Jhora											
Garuchara	1.9	1.1	2.06	0.31	99°30'	950	2250	5.68	21.00	1.51	0.54
Rabang											
Bhur	6.7	5.3	27.10	19.54	85°30'	1050	5050	1.78	10.00	1.47	0.57
Alakuri	2.7	1.8	6.41	2.13	109°00'	400	3450	1.68	19.00	1.08	0.83
Deopani	5.6	8.0	12.85	18.40	86°00'	700	2550	1.42	19.30	1.83	0.39
Chel	3.6	2.7	7.36	6.35	89°00'	350	1550	1.10	6.52	1.36	0.54
Rakti Khola	2.9	1.3	3.52	3.90	76°00'	400	1450	1.57	12.00	1.42	0.39
Dimabori	3.4	1.1	6.02	0.60	69°00'	150	450	0.50	4.65	1.15	0.49
Baladi											
Mutanga	3.1	1.2	6.13	2.01	83°00'	350	750	1.28	7.10	1.13	0.60
Bogajuli											
Pagladiya	3.5	7.3	16.89	24.13	140°00'	150	5650	0.49	9.00	0.65	1.31
Baumk Nala	3.8	1.7	8.83	3.59	112°00'	950	1300	2.84	8.00	1.59	0.58
Khural	3.6	2.3	13.91	13.75	126°00'	200	1250	0.63	6.16	1.02	1.02
Chorpuli	1.3	2.3	1.09	1.70	99°00'	500	2750	4.37	13.00	1.33	0.61
Richangra											
Sukhan Jan	3.9	2.1	7.42	3.65	72°00'	1200	2900	3.50	14.30	1.28	0.46
Gubar Kunda											

* Fan Conicality Index

** Volumetric Fan Shape Index

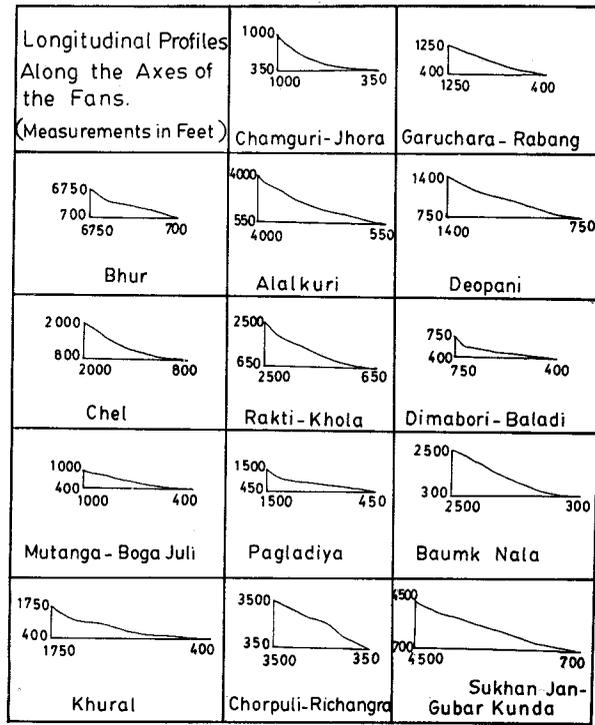


Fig. 5

LONGITUDINAL PROFILE OF THE FANS

Longitudinal profiles of fans are almost everywhere concave but the degree of concavity varies among the fans and also between the three parts, proximal, mid, and distal, of the same fan (Fig. 5). The general concavity reflects a state of dynamic equilibrium with reference to both episodic tectonic uplift and climatic oscillations.

In all the profiles the upper (proximal) part is steeper and more concave than the middle and distal parts. Perfectly concave profiles are rare. Only Chamguri-Jhora reveals such a profile. In some at least there is a decrease in slope that is clearly exponential and answers to the description of Friedman. In others the slope profile is more or less linear and uniform. Strikingly different are the profiles having short scarps near the apex. They appear to be segmented, the segmentation being related to local faults.

On the whole, the profiles reveal a small average gradient of the fans, ranging from 0.49° to 5° , with one exceptionally high of 5.68° . These gradients are characteristic of wet climates of the present day and also of the post-Holocene times. In the Sikkim and Bhutan region the gradients are slightly steeper, 5 to 8° .

GENESIS

The morphometric properties and the locational attributes coupled with the geological lineaments of the alluvial fans already have provided certain major clues to the understanding of the fan genesis and evolution.

Fan genesis can be generalised from an analysis of some of the typical, individual fans and this can also contribute toward the resolution of the controversy about the primary of the reduction in slope over the reduction in competence or vice-versa.

Basically, there are two schools of thought on the causes of deposition of material by the river at the foot of the mountain or hill slope. The first school can be thought of as break-of-slope and the second as loss of competence at the foot of the mountain slope. In both there is a loss of velocity leading to a reduction in transportation capacity; in the first this is due to a flattening of gradient and in the second this is due to the widening of the channel at the foot of the mountain slope.

The school of thought that proposes that the formation of fan is not contingent upon a marked change in slope at the point of debouchment is not supported by our finding. Patton (1970) and Denny (1965, 1967) could be right for the fans of the arid and semi-arid regions. But the eastern Himalayan piedmont fans are related to the processes operating in the tropical humid zone. Here, in every fan we find a sharp contrast between the slopes, the slope of the drainage basin being far steeper than that of the fan itself. In this zone the rainfall and discharge are high and without a sharp break in slope the bed load would have been easily transported in the downstream direction, far away from the point of debouchement.

However, the decrease in competence as a result of the sudden widening of the channel below the fan-head trench section leading to a loss of competence and deposition has also been an important process. There can be no disagreement with Bull (1964, 1977) that channel widening leads to a reduction in channel depth and flow velocity and thus, to transportation capacity. Sudden widening of the channel below the apex where the head-water trench terminates and braiding begins is clearly revealed in several fans. This is precisely the point where in most of the fans the first major bifurcation of the channel and forma-

tion of distributaries takes place, processes which are crucial in the initiation and expansion of the fan.

In the case of the Deopani fan, at its initiation, the Deopani Nadi, which now forms its western lateral, flowed through the axial belt. On the fan the truncated axial stream is easily identified at present. At the point of debouchement and a little below this the river got choked, the channel bed was raised and there was a wide, sweeping shift toward the west. The almost coincidental location of the point of debouchement with the point of truncation and the origin of the existing axial stream, the large size of its channel, and its orthogonality with the contours suggest that this was indeed the genesis of the fan and the evolution of the fan. It was at this stage that distributary formation was very active. Two other facts need to be observed : (a) the upper parts of Deopani and the entire reaches of Ammaya and Yapio, both tributaries of the former, indicate, rightangular bends and confluences and absolutely straight channels, and (b) the gorge-like trenches at the point of debouchement. Both facts are suggestive of tectonic movements related to an echelon faults in northeast-southwest direction and an eastwest trending master fault. Fault alignments are clearly indicated in the bends and straight channels.

The alluvial fans must be contemporaneous with the Sub-Recent and Recent river terraces which are as widespread as the fans. Warping and deformation of the terraces are clearly indicative of the neotectonic movements of these times. High humidity and large discharges *pari passu* with tectonic movements characterised the Sub-Recent and Recent periods and provided the necessary conditions for the genesis of both the terraces and the fans. Tectonic uplift not only accelerated erosion in the mountain basin and increased the sediment yield of the

streams to be deposited in the fan but also contributed to the creation of knickpoint and trenching of the stream. The widespread steep slopes generated by erosion and the resultant scarped topography in the mountain basin is a strong evidence.

Faulting effects two genetic process : (a) creating a break in slope where the point of debouchement, the apex, and the locus of initial deposition are located, and (b) maintains the break in slope and thus helps in the continuation of the process of fan formation through deposition. Many fans originate at the abrupt change of slope caused by block faulting. Thick fan deposits that accumulate adjacent to fault scarps are extremely coarse-grained, a significant characteristic of fans.

Those who argue that faulting has played no role in the initiation, evolution, and preservation of fan are simply ignoring the incontrovertible fact that throughout the world most of the fans are located in the fault-bounded piedmont zones and their apices in the fault zone itself. Uplift on the faults may create a precipitous landscape and a source area that provides a persistent supply of coarse debris and increases the competency of streams. The rate and magnitude of uplift of the adjacent highlands controls the site, rate, and magnitude of deposition of the fans.

When and where the fan has attained the state of equilibrium two conditions prevail, (i) in the proximal fan with its upper trench there is no erosion of fan material nor is there much of deposition and there is accumulation of colluvial material and debris flow, and (ii) in the distal fan with its non-entrenched reaches both erosion and deposition operate simultaneously. The fans which have attained the state of dynamic equilibrium tend to retain themselves over a considerable period of time.

The entire sequence, not always and not necessarily chronological, consists of the following events : (a) debouchement on the piedmont, (b) channel widening, (c) bifurcation and distributary formation, (d) deposition of alluvial sediments, (e) channel shifting, and (f) reduction in velocity and discharge in the down-fan direction.

It is clear from the preceding discussions that the alluvial fan does indeed form a part of a system which has three components, (i) the mountain basin which is the area of erosion and the source of sediments, (ii) the alluvial fan which is the locus of deposition, and (iii) the principal stream which erodes in the first and deposits in the second area and which transports energy, water, and sediments and forms the link between the two.

Debouchement on the piedmont initiates the genesis of a small, rather triangular fan built almost entirely of load brought down by the principal stream. The deposition operates concurrent with the widening of the channel and bifurcation and formation of distributary system. The latter distributes the load both longitudinally and laterally. Meanwhile, the un-trenched principal stream and its distributaries shift their channels and swing and sweep widely redistributing the deposits from the locus of deposition to the farthest parts in increasingly smaller quantities. Once the stream is entrenched its genetic role is taken over by various processes of mass-wasting, mainly mud-flow and debris flow. The entrenchment is *pari passu* with orogenic and fault uplifts on the one hand and a markedly fluvial phase on the other. A good evidence of the fluvial succeeded by and integral component of the Eastern of the fans is provided by laterites and lateritic soils. These soils have been observed and documented by Banerjee (1954). Yellow sandy soils (Mal sands) and Red

earths (Red bank soils) characterise the upper parts of the alluvial, gravel deposits of terraces and fans of the region. The former soil is rich in organic matter and yields the interpretation that the parent material of sand, gravels, and boulders were waterlogged and densely colonised by vegetation. The latter soil is more typically lateritic. It does suggest a heavy rainfall phase followed by less rainy one and since the formation of the fan a stability in climate. The upper fan could develop soil while the mid-fan and distal fan continued to grow and hence provided no favourable condition for pedogenesis.

CONCLUSIONS

Despite the lack of attention given to them by geomorphologists, geographers, and geologists, alluvial fans constitute a recurrent and integral component of the Eastern Himalayan piedmont geomorphic landscape. Unlike their world-wide occurrence in arid and semi-arid regions these fans occur in a region of heavy annual and monsoonal rainfall. They do not coalesce along the entire length of the Himalaya-Brahmaputra valley contact, and at many places they are absent.

Compared to the fans of the Western Himalaya the Assam fans discussed here have smaller catchment drainage basins

for their size because the rainfall is much larger. Most fans have uniform planar slopes but few have concave, indicating a state of equilibrium and some have apex scarps suggesting local faulting. With the fan conicality index (Mukerji, 1976) and volumetric fan shape index (constructed by the present author) the two-dimensional and three-dimensional shapes were measured. Most fans are irregular but those which reveal regularity have medium angle of divergence, an axial stream, and have regular lateral and toe edges. Radial pattern of distributaries and the length of the axis are important variables of both the size and shape. Unlike their western Himalayan analogues the fans under discussion have higher density of distributaries as also larger fan height and volume of fan detritus.

Much of the individual fans are composed of boulders, gravels, pebbles, sands, and clays of Tipam sandstone formation which are similar to the Siwaliks. Their erosion and deposition operated in humid conditions and considerably thick vegetation cover. Genetically, the fans are related to the last phases of the Himalayan orogeny, uplift along the Main Boundary Thrust, and Upper Pleistocene and Holocene climatic episodes. Gentle gradients and dissection by main channel wash are both indicators of humid climatic conditions.

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