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CURRENT VECTOR DISPERSION IN A RIVER OF FLUCTUATING DISCHARGE

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ABSTRACT

As water stage falls over a bedform covered sediment surface, local flow directions are increasingly controlled by the topography and if the bed material is still mobile, smaller surface features will reflect the control. Dispersion will increase as water stage falls. A bank in the bed of the Tana River, Norway, is used to illustrate this. Pebble features record high stage directions while sand features reflect falling stage modifications in direction of flow. Consideration of this effect might be important in using palaeocurrent distributions to specify channel type in fluviatile sandstones.

INTRODUCTION

In any hierarchy of superimposed three-dimensional bedforms, there is an inherent increase in the dispersion of the measurable current directions with decreasing scale of bedform (Allen, 1966). This general rule was initially formulated from a consideration of cases where superposition of forms could occur when the bed configuration was in equilibrium with the flow. In some natural situations, where the hydraulic parameters undergo wide temporal fluctuations, the dispersion might be expected to increase still further at low water stages. A relationship between the size of large-scale bedforms (dunes, large-scale ripple marks) and the depth of flow is suggested from theoretical considerations (Yalin, 1964) and by field observation (Allen, 1968, fig. 6.4). Smaller bedforms might therefore develop on the backs of larger ones in response to a fall in water stage as suggested by the work of Pretious and Blench (1951) and Neill (1969). The larger the bedform, and the more rapid the decrease in discharge, the less readily will the bedform adapt to the changing situation and the more likely it is to be abandoned as an active form. Indeed it is far from clear whether a reduction in the size of a bedform due to a reduction in water stage can take place at all. There are several descriptions of scale increasing during a rising stage but none, to the writer's knowledge of the reverse case.

Bedforms which are unable to change their shape and size in response to falling discharge, in a river or tidal channel for example, will exercise an increasing control over the configuration of the flow as the water is increasingly confined to the topographically low areas between the bedforms (cf. Collinson, 1970, fig. 10). The bedforms of a tidal area will have a better chance of being preserved in an undisturbed equilibrium state after abandonment by an ebbing tidal current than will similar sized bedforms in a river with a discharge fluctuation period of months. In a tidal environment, even the smallest forms such as ripples may be relatively undisturbed from the equilibrium state and may, therefore, provide reliable evidence of the eddy patterns associated with larger forms as, for example, the "ripple fans" in the lee of larger forms figured by Allen (1968, p. 86-87). It would, however, be unwise to put so much confidence in the interpretations of the orientations of ripples associated with large forms on an exposed

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river bed where the stage had fallen much more slowly (cf. C o l l i n s o n, 1970).

The variability of the current directions measured from smaller scale structures at low water stages, will both be related to the water stage and depend upon the shapes and spatial relationships of the larger forms. Two-dimensional dunes or transverse bars (e.g. S u n d b o r g, 1957), orientated with their crests perpendicular to the equilibrium flow direction could give a very high dispersion and possibly even a bimodal distribution to the directions of ripple marks superimposed upon them at low water stage. This will, of course, only apply if the surface over which the dunes or bars are migrating is essentially horizontal in the plane perpendicular to the flow direction. Commonly, such dunes and bars will be found on inclined surfaces such as point bars and then the flow between the bars and dunes will not be so great at low water stages. According to A l l e n (1968), two dimensional bedforms tend to conform more closely to Y a l i n 's (1964) suggested height/depth relationship (height = 1/6 depth) than do strongly three dimensional forms. These latter tend to have larger height/depth ratios and are therefore more likely to influence the flow pattern than the two-dimensional forms.

MEASUREMENT OF THE EFFECT

The orientations of ripples on the stoss-side of an exposed larger bedform are a reflection of the flow pattern at the time when the shear stress was still sufficiently high to mould the bed fairly readily. They will approximate to the situation at the moment of cessation of all grain movement only if the shear stress fell off rapidly. In order to estimate the importance of the changes in local current direction consequent upon a fall in water stage, it would be useful to be able to compare the vectors for both high and low flows from the same large form. However, with sandy bed material, the low stage flow, if it is to be recorded on the sediment surface, will tend to wipe out the high stage record at the surface. An area with a bed of mixed sand and pebbles may however record both high and low flow current directions, the pebbles recording a high stage and the sand a lower stage.

THE TANA RIVER BAR

In the lowest 30 km of the Tana River, Finnmark, Norway, the dominant bedforms of the entirely sandy bed are linguoid bars, which probably fall into the larger end of A l l e n's (1968) "large scale ripple mark" class (C o l l i n s o n, 1970). These normally have chord lengths of 200-300m and are up to 150m wide. Following the annual spring flood, the water stage of the river falls over a period of several weeks. In the summer, large areas of the bed become subaerially exposed and the reduced discharge is confined to low areas between bars. Details of the bedforms and the falling stage processes are described elsewhere (C o l l i n s o n, 1970). Ripple marks and dunes on the backs of the exposed linguoid bars probably record the flow pattern at a discharge less than that with which the linguoid bar was itself in equilibrium, because of the mobility of the bed material and the relatively slow fall in water stage.

Upstream of the sandy reach of the river, the bed material is dominantly pebbles and cobbles with a subsidiary amount of sand. At the junction between these two bed types, there occurs in the channel a bank which is pebbly at its upstream end and sandy at the downstream end. The bank is located near the west side of the channel some 500m. downstream of Tana Bridge. The bank is some 450m. long and 280m. wide (subaerially exposed at time of observation). It is widest at about its mid-point and the highest point occurs almost at the centre of the bank. The highest point was about 2m. above the water line at the time of measurement. The transition from pebbles to sand takes place fairly sharply across a line at about the widest part of the bank.

The whole of the bank area was surveyed by levelling in July, 1968, using 670 survey points. Maps of the area showing the distribution of sand and pebbles and pebble area features (fig. 1) and 50cm. contours of the pebble area with superimposed sand features (fig. 2) are presented. The hydrograph of the river for the period immediately prior to observation is presented in figure 3. This data is derived from a gauging station at Polmak, 20km. upstream of the bank and cannot be strictly applied to the study reach though it gives a qualitative picture of the discharge fluctuation pattern.

The pebble surface is essentially a rather flat surface sloping gently upstream and slightly to the sides from the highest point. The slope steepens slightly

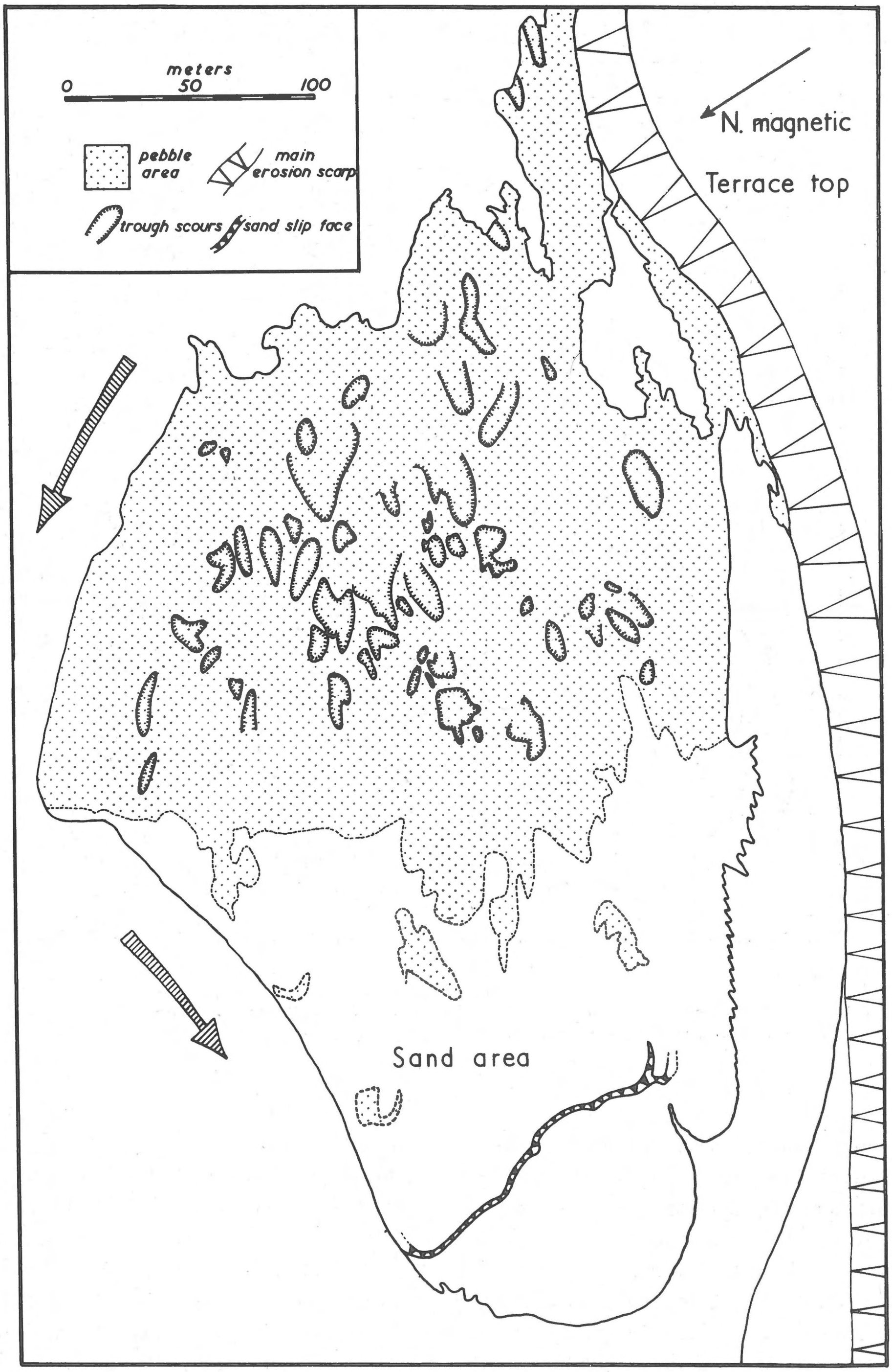

Fig. 1
Map of the bank, showing its relationship to the main erosion scarp, the distribution of exposed sand and pebble covered areas and the positions of the trough-shaped scours on the pebble area. The large arrows on the left indicate the general direction of river flow in the areas adjacent to the bank.

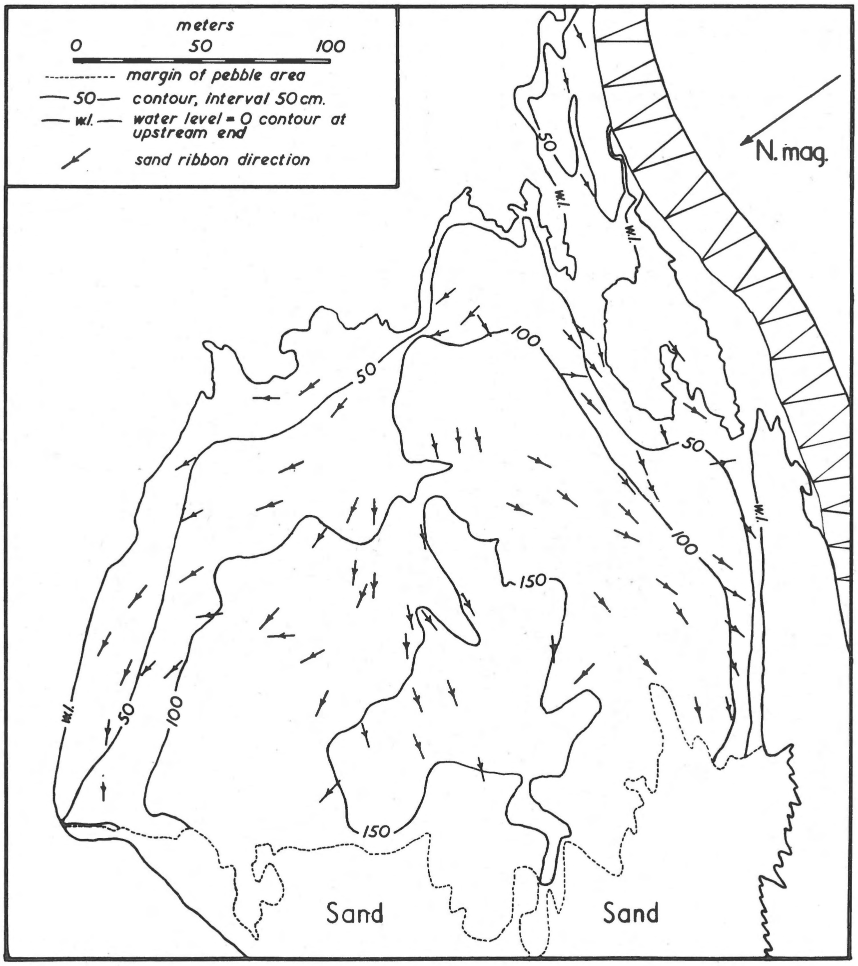

Fig. 2
Map of the pebble-covered area of the bank, contoured at 50 cm. intervals and showing the distribution and directions of sand ribbons on the pebble area.

towards the lateral margins. For the purposes of exploring the change in vector dispersion associated with linguoid bars, the surface can be considered rather similar to the stoss side of a linguoid bar.

The pebble surface, as can be seen from the maps (figs. 1 and 2) is not entirely featureless. Quite large, scoop-shaped scours are cut into the surface and are elongated roughly parallel to the elongation of the bank. The scours are up to 35 m. long and 15 m. wide and may be as deep as about 50 cm. (fig. 4). They often have rather steeper downstream ends while the upstream ends are often weakly defined, giving them a profile not unlike a large flute mark, only reversed in respect to current direction. The origin of the scours is not known at present. The increased local turbulence around and under stranded blocks of ice at high water stage may be involved. The pebble surface includes material from sand size up to boulders of around 1 m. in maximum diameter. The modal size would appear to be in the range 10-20 cm. though no systematic measurements have been made.

The amount of sand is small and generally fills the interstices between pebbles. In some places, probably where there is more sand than the pebble framework can absorb, the sand accumulates above the pebble surface. The accumulations are in the form either of groups of sand ribbons or of sand shadows (B a g n o l d, 1941) (fig. 5) on the lee sides of larger cob-

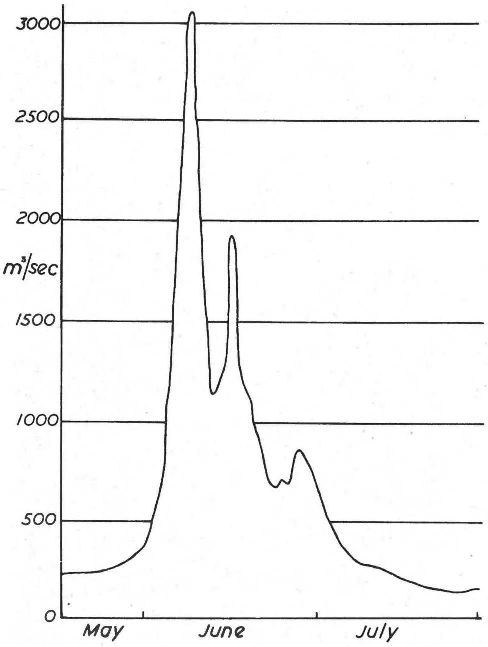

Fig. 3
Hydrograph for the 1968 flood at the gauging station at Polmak, 15 km. upstream from the bank. Ice damming may temporarily increase the water stage and therefore the apparent discharge in the early stages. No correction has been made for this factor in the curve.

bles and boulders. Both forms occur on the flat pebble surface and within the scoop shaped scours. The sand ribbons generally show a rather uniform spacing over small areas. They are comparable, though not necessarily in scale, with sand ribbons described from other situations (e.g. S t r i d e, 1959; A l l e n, 1966), where a contrast in erodibility of the transported material with that of the pavement over which it migrates seems to be a prerequisite to ribbon formation. Sand shadows may be as long as 15 m. downstream of particularly large boulders but are normally less than 1 m. long. They compare closely with the forms figured by K a r c z (1968) in having triangular profiles and sometimes having ripples superimposed on the sloping flanks. The mechanisms of formation of both these elongate sand features have been discussed elsewhere (e.g. K a r c z, 1969; B a g n o l d, 1941; A l l e n, 1966), and are not the concern of this paper. Small patches of rippled sand are also found within the pebble areas.

ORIENTATION OF THE FORMS AND ANALYSIS OF THE DATA

The orientations of the scooped shaped scours are measured from the map. The directions of the sand ribbons, shadows and ripples were measured in the field by compass. All directions are estimated as accurate to ± 5°. The data is presented as histograms in figure 6. Only the orientations of sand features on the flat areas outside the scours have been included, in order to eliminate dispersion due to local relief associated with scours.

Comparison by inspection of the two histograms for total data suggests that the mean directions may be quite similar while the sand features show a rather more widely spread distribution. Calculation of the estimator of the vector mean, $\hat{\gamma} = \tan^{-1} \frac{\Sigma \sin x}{\Sigma \cos x}$, for the two populations shows that they differ by 10° (291° (troughs) vs. 301° (sand features) (Table I). A χ^2 test to the two populations with the data grouped in 40° classes shows that there is a highly significant difference between the two populations and in the light of the relatively close vector means, this difference can largely be attributed to differences in the dispersion of the two populations. Values of R/n were computed for each population where $R = \sqrt{\Sigma(\sin x)^2 + \Sigma(\cos x)^2}$ and n is the size of the sample. For data which conforms to the circular normal distribution, R/n gives a measure of dispersion, G u m b e l *et al.*, 1953). Inspection of the histograms suggests that the sand feature data, at least, diverges somewhat from the circular normal distribution and so there must be some reservation about accepting the values of R/n as strictly comparable. However, the two values, 0.92 for the trough axes and 0.75 for the sand features do tend to support the foregoing conclusions that the orientations of the trough axes have a lower dispersion than the sand features. If we are correct in assuming that the sand features reflect a lower water stage than the troughs cut into the pebbles, then the prediction that lower stage water stage should be associated with higher dispersion in current direction is borne out.

To test further the idea that dispersion increases with falling water stage, the population of sand feature orientations was subdivided into four groups, each corresponding to a zone bounded by 50 cm. contours on the pebble area. The histograms for these topographically defined populations are shown in

Fig. 5
A group of three ribbons on the pebble area of the bank. Scale is 1 m. long.

figure 6. Inspection of the four histograms suggests that the data from Zone 4, the highest one, has a lower dispersion than the data from the other three zones, amongst which it is not possible to see any obvious differences. None would appear to approximate to a circular normal distribution and so there are no tests which can be applied to compare their dispersions. We can compare the values of R/n (table 1) and this suggests that Zones 1 and 2 both have higher dispersions than Zones 3 and 4, but the statistical validity of the conclusion cannot be established. Comparison of the two largest zonal populations, Zones 2 and 3, by a χ^2 test using 50° class intervals, failed to show a significant difference between the two populations. Inspection suggests that vectors of zone 2 may be bimodally distributed, as might be expected due to splitting of the flow with reduced water stage.

TABLE 1

Area and Structure	n	$\hat{\gamma}$	R/n
All Scour troughs	47	291	0·92
All sand ribbons outside Scours	73	301	0·75
Zone 1 (below 50 cm)	15	302	0·70
Zone 2 (50–100 cm)	23	315	0·52
Zone 3 (100–150 cm)	28	296	0·80
Zone 4 (above 150 cm)	7	282	0·93

CONCLUSIONS

The lack of statistical theory to deal with non-normally distributed circular data unfortunately prevents this analysis from coming to any but rather general conclusions. The higher dispersion of current directions of the sand forms compared with the direc-

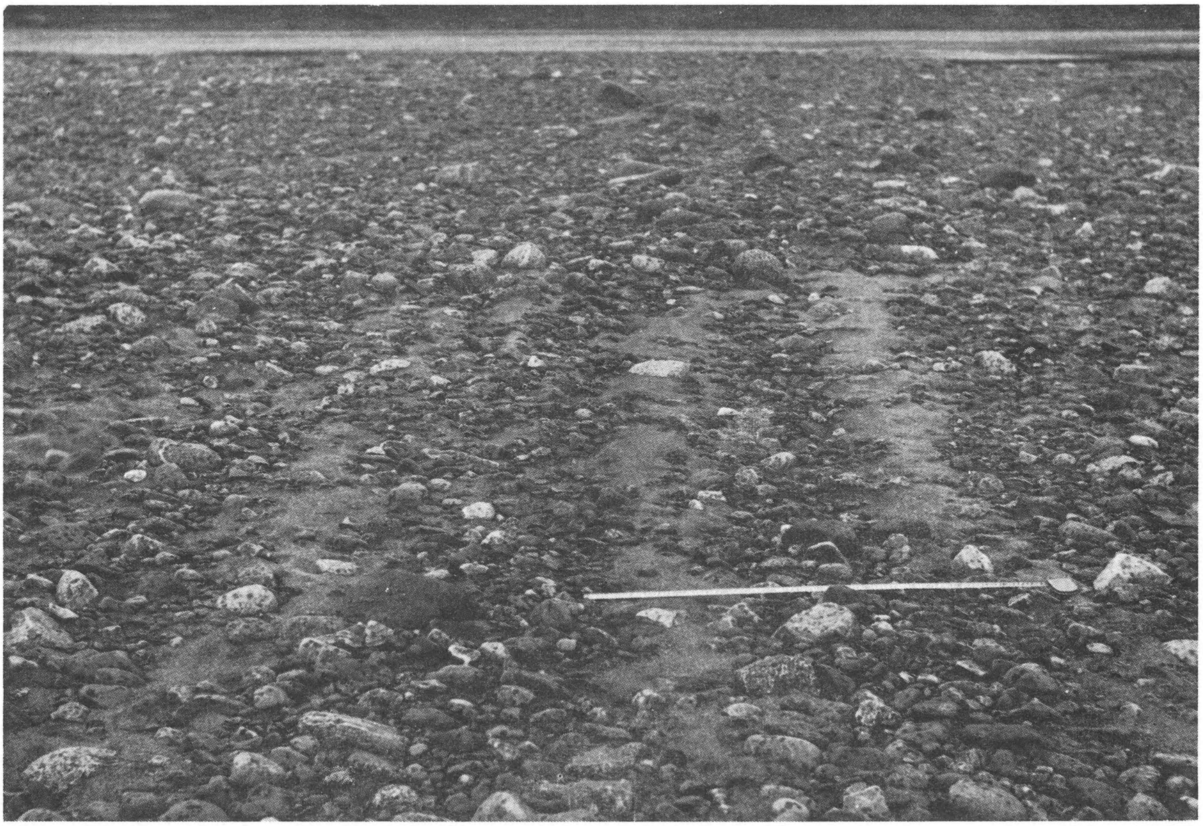

Fig. 4
Large trough shaped scours near the centre of the pebble area of the bank. The thin veneer of rippled sand within the trough in front of the figure is coated with a thin layer of silt.

tions derived from pebble features and the apparent increase in the dispersion of sand form directions with lower topographic level both bear out the prediction of increasing dispersion with falling water stage. The results also give some idea of the orders of magnitude of dispersion differences involved for flow around a bank of linguoid bar scale. From this isolated example no general quantitative conclusions can be drawn. The changes in dispersion of recorded current direction at any given location will depend on the interaction of a complex of factors among which are the shape, size and topographic positions of the larger forms, the mobility of superimposed small forms and the rate of fall of the water stage. Studies of larger areas covering several large scale forms and involving direct measurement of structures at all water stages will be needed to come to more general conclusions, and to assess the relative importances of the factors involved. Both fluviatile and tidal environments should yield valuable information.

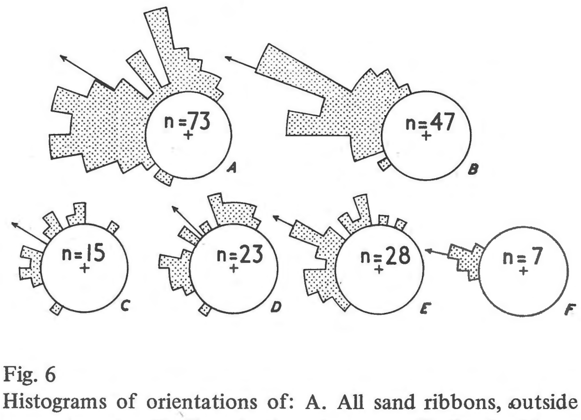

Fig. 6
Histograms of orientations of: A. All sand ribbons, outside scour troughs, B. Trough shaped scours, C. Sand ribbons below 50 cm. contour (Zone 1), D. Sand ribbons between 50 cm. (Zone 3) and 100 cm. contours (Zone 2), E. Sand ribbons between 100 cm. and 150 cm. contours (Zone 3), F. Sand ribbons above 150 cm. contour (Zone 4).

The preservation potential of small bedforms on a river bed is low as they are liable to erosion during the next rising stage. Forms which develop and have time to be buried while water stage is still relatively high have a much higher preservation potential, and these, as has been shown, tend to be less dispersed. Caution should therefore be exercised in comparing directional data from an exposed river bed as presented, for example, by Williams and Rust (1969) with directional data from within an ancient fluviatile sandstone. For comparable environments, the data from a sandstone might be expected to have a somewhat lower dispersion than that derived from the sediment surface. Some correction factor for this predicted dispersion difference should therefore be applied when comparing ancient and recent sediments. It will not be possible to quantitatively specify this factor until much more directional data has been collected in close association with water stage measurements, but, as there is sometimes a temptation to specify channel type on palaeocurrent dispersion data from fluviatile sediments this further complicating factor should be borne in mind.

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