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Grain fabrics of natural and experimental low-angle aeolian sand deposits

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Abstract

This paper considers the two-dimensional grain fabrics of 23 natural and 3 experimental aeolian sand deposits. The generally low strength of the fabrics is thought to be an inherent characteristic of the investigated sediment type rather than a result of postdepositional disturbance. On a statistical basis, the 26 fabric plots can be grouped into three types of distribution patterns. In the first type, unimodal preferred orientation of elongate grains is unambiguous. In the second type, unimodal preferred orientation is either weakly developed or absent. In the third type, preferred orientation is bimodal or polymodal.

The natural fabric samples are from three different exposures of Weichselian aeolian coversand. The fabric data from these sites do not contradict other available information on the paleodirection of the sand-transporting wind. The experimental fabric samples were produced in a wind tunnel. The experiments suggest that particle alignment by wind occurs almost instantaneously and that fabric strength does not depend on mode of deposition.

Introduction

Compared with glacial tills and fluvial gravels, wind-deposited sands are underpresented in literature on particle fabrics of clastic sediments (e.g. Ballantyne & Cornish, 1979; Reineck & Singh, 1986). This is not altogether surprising as the fabric analysis of unconsolidated sandy sediments is definitely more laborious than that of pebbly material. Moreover sandy grain fabrics are easier disturbed by postdepositional events and, according to Reineck & Singh (1986), less usable as regional-scale indicators of flow direction than their coarser counterparts.

To reduce the imbalance noted above, the present paper concentrates on grain orientations in aeolian sands. The pertinent data are based on 23 samples from natural aeolian sands and 3 samples from deposits that had formed as a result of wind-tunnel experiments. Samples of the first type are all from Weichselian periglacial coversands. In succeeding paragraphs, the corresponding grain fabrics will be referred to as B1–B4 (site Black Walk Nook, north Lincolnshire, England, H1–H7 (site Helmerhoek, Twente, The Netherlands) and N1–N12 (site Nordlohne, Emsland, Federal Republic of Germany). The stratigraphic context of the three sample sites is shown in Figs. 1–3. The grain fabrics of the experimental sand deposits are designated T1–T3. Particulars on the wind-tunnel work will be given further on in this text.

Method

During the sampling procedure the bottom of the box or tube was kept parallel to the bedding of the sediment. North direction and top side of the sam-

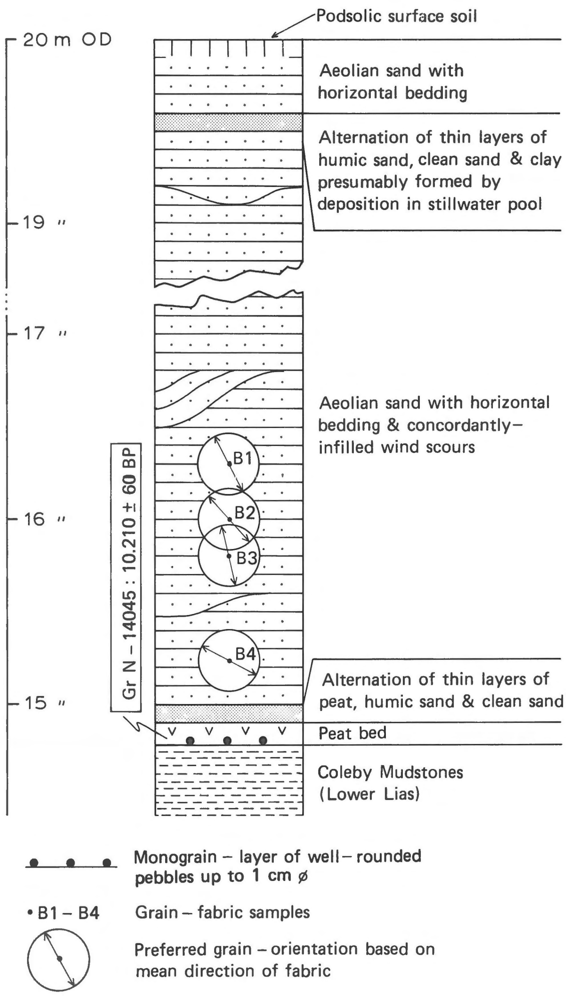

Fig. 1. Site Black Walk Nook, north Lincolnshire, England. OD is approximately mean sea level.

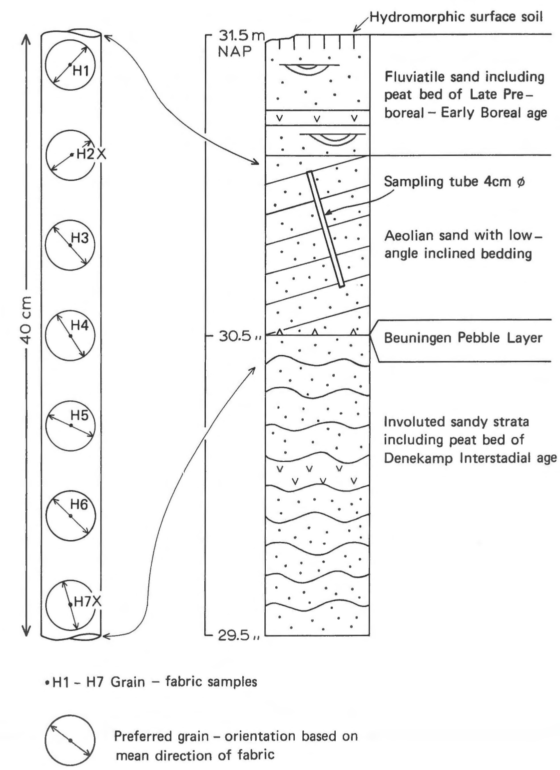

Fig. 2. Site Helmershoek, Twente, The Netherlands. NAP is approximately mean sea level. Samples marked with X are bad fits with Von Mises distribution.

ple were marked. In the case of the wind-tunnel experiments, the north direction was replaced by the down-wind tunnel-axis direction. In order to prevent desiccation the sampling box was wrapped in cling film. Shocking that could have disturbed the fabric of the sample, was avoided. It was found that perspex tubes are slightly affected by the chemicals used in the hardening process. Thin-wall boxes of stainless steel, on the other hand, fully resisted this treatment.

The oriented thin-sections for grain elongation measurement (thickness 25 μm) were prepared according to the method of Miedema et al. (1974). Under the microscope the apparent long-dimension elongation of, on average, 305 grains per sample was measured following the rotation method (Bonham & Spotts, 1971). Selection of grains was on the basis of an axial ratio of at least 1.5. Elongate quartz grains meeting this requirement abound in the investigated sediment which has a modal grain size ranging from 105 to 210 μm. For each sample, the grain-orientation measurements were grouped into 18 class intervals with widths of 10°. By computer, the 18 frequencies were plotted as radii of a semi-circle and subsequently replotted on its other half after rotation over 180°. The circular frequency polygon with central symmetry so obtained, emphasises the axial nature of the data. Along with the plotting of the polygon, the following parameters were computed:

$\bar{x}$ = Mean direction in degrees. For natural samples $\bar{x}$ refers to the north direction and for experimental samples it refers to the down-wind tunnel-axis direction. $\bar{x}$ = 0.5 inv. tg

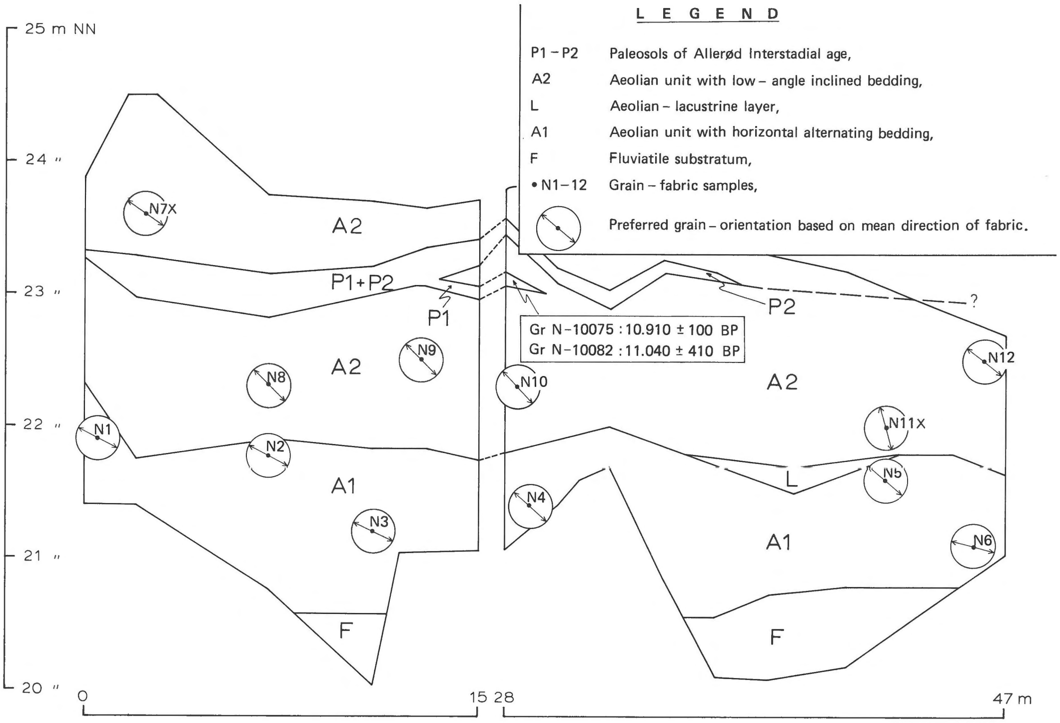

Fig. 3. Site Nordlohne, Emsland, Federal Republic of Germany. NN is approximately mean sea level. Samples marked with X are bad fits with Von Mises distribution.

(S/C) + K.90° with K = 0,1 or 2. Since the orientation data are non-vectorial, a mean direction of $\bar{x}°$ corresponds to an azimuth of either $\bar{x}°$ or $(\bar{x} + 180)°$.

$\bar{R}$ = Mean resultant length. $\bar{R}$ is a measure of fabric strength ranging from 0 to 1. $\bar{R} = \{(C/n)^2 + (S/n)^2\}^{0,5}$ with n = sample size.

C = $\sum_{i=1}^{18} f_i \cdot \cos 2\alpha_i$ with f_i = number of readings in i th class interval and α_i = class mid-point; α_i = 4.5°, 14.5°, ... 174.5°.

S = $\sum_{i=1}^{18} f_i \cdot \sin 2\alpha_1$. Symbols as for C.

Table 1 gives the values of the above parameters for each of the 26 samples. Orientation measurement was restricted to the plane parallel to bedding, so that the resulting data are of the two-dimensional type.

Fabric strengths

Strength of a fabric is the degree of preferred orientation of the measured element (e.g. trend of A-axes or dip direction of AB-planes). Mean resultant length ($\bar{R}$) is a measure of concentration about the mean direction and as such it represents fabric strength. The higher the concentration is, the closer is $\bar{R}$ to the value 1. In Table 2, the $\bar{R}$-values of fabrics in four different sediment types are compared. The fabrics of the two sandy sediments are much weaker than those of the glacial till and the glaciofluvial gravels. At least in part, this difference must have to do with the size of the particles whose orientation was measured. In the case of the till a minimum A-axis length of 1 cm was adhered to (Schwan & Ritzema, 1982) and for the outwash gravels the same requirement had been set at 3 cm (Rust, 1975). As far as the blown sands are concerned, there is little ground to believe that the general weakness of their fabrics results from post-depositional disturbance. Sites that showed even

Table 1. Grain-orientation data of 26 samples. n = sample size. Other symbols explained in text

Sample	n	$\bar{x}$	$\bar{R}$	C	S
B1	300	153.7	0.0798	14.56	− 19.01
B2	302	138.2	0.1445	4.92	− 43.36
B3	301	167.4	0.1092	29.71	− 14.04
B4	305	117.5	0.0846	− 14.78	− 21.16
H1	300	43.3	0.0389	0.68	11.66
H2	306	54.0	0.0857	− 8.12	24.93
H3	317	139.1	0.1665	7.55	− 52.25
H4	306	146.7	0.1581	19.16	− 44.42
H5	304	115.4	0.1857	− 35.63	− 43.81
H6	321	134.0	0.1684	− 1.94	− 54.02
H7	327	165.3	0.1585	45.19	− 25.38
N1	302	116.5	0.1241	− 22.55	− 29.95
N2	302	117.8	0.1742	− 29.75	− 43.40
N3	298	114.8	0.1501	− 29.03	− 34.03
N4	298	132.3	0.2431	− 6.85	− 72.11
N5	303	130.4	0.2757	− 13.51	− 82.45
N6	306	104.9	0.1241	− 32.96	− 18.84
N7	304	124.5	0.0475	− 5.20	− 13.49
N8	307	134.7	0.0963	− 0.32	− 29.57
N9	305	134.8	0.0628	− 0.15	− 19.16
N10	308	136.6	0.1863	3.14	− 57.29
N11	291	165.0	0.0470	11.85	− 6.83
N12	302	128.6	0.0506	− 3.41	− 14.91
T1	303	168.6	0.0761	21.25	− 8.94
T2	300	165.5	0.1434	37.63	− 20.83
T3	299	176.5	0.1547	45.91	− 5.57

the slightest sign of disturbance (by soil formation, plantroot penetration, cryogenic activity or other agent) were excluded from sampling and samples selected for thin-section preparation were as well as possible protected from shock and desiccation. Thus, the state of the fabrics found in the aeolian sands must be entirely attributed to conditions prevailing during the depositional process.

Fabric distribution patterns

Although 26 fabric plots (= circular frequency polygons with central symmetry) show a great deal of variation, they can in principle be grouped into three classes on a statistical basis. Each set of fabric data is subjected to two single sample tests which, together, determine its class. Under the null hypothesis it is assumed that the fabric is a sample from a circular population with respectively Von Mises distribution and uniform distribution.

For the first assumption, the Chi-square test for Goodness of Fit has been used (Mardia, 1972). At 5% level of significance and 15 degrees of freedom the critical value of the statistic is 25.00. The requirement that the expected frequencies be at least equal to 5, is met in all but one case. For the second assumption, several different tests are available e.g. Chi-square test for Goodness of Fit, Rayleigh test and Hodges-Ajne's test. The value of the sample statistic obtained in the first-mentioned test, depends on the choice of the class intervals into which the orientation measurements are grouped. In other words, this test is not invariant under change of the zero direction (Ballantyne & Cornish, 1979). The Rayleigh test gives misleading results for empirical distributions that are not unimodal (Batschelet, 1965). With these restrictions

Table 2. Mean resultant lengths ($\bar{R}$-values) of two-dimensional fabrics in four sediment types.

1	2	3	4	5
Dip directions of AB-planes in glaciofluvial gravels	37(19)	0.5917	0.1370-0.9533	Rust, 1975
Trends of A-axes in glacial till	7(39)	0.5632	0.2312-0.7513	Schwan & Ritzema, 1982
Trends of A-axes in aeolian sands	26(305)	0.1283	0.0389-0.2757	This paper
Trends of A-axes in coastal sands	33(512)	0.0716	0.0396-0.1237	Curray, 1956

1 = Measured element and sediment type,
2 = Number of samples with mean sample size in ( ),
3 = Mean value of $\bar{R}$,
4 = Range of $\bar{R}$,
5 = Source.

Table 3. Tripartite classification of 26 fabric distribution-patterns in aeolian sand

	Type I	Type II	Type III
Test result at 5% level of significance	Sample is from population with Von Mises distribution and not from a population with uniform distribution	Sample could be either from population with Von Mises distribution or from population with uniform distribution	Sample is not from population with Von Mises distribution and may or may not be from population with uniform distribution
Value of $\overline{R}$ (= mean resultant length)	$\overline{R}$ is greater than 0.1 in 15 out of 16 cases	$\overline{R}$ is smaller than 0.1	$\overline{R}$ is either greater or smaller than 0.1 depending on number and angular distance of modes
Shape of centrally symmetric frequency polygons	Elongate	Roundish	Star-like
Interpretation	Unimodal preferred orientation of grains is unambiguous	Unimodal preferred orientation of grains is either weakly developed or absent	Preferred orientation is bimodal or polymodal
Number of samples out of a total of 26	16	6	4

in mind, the Hodges-Ajne's test of Uniformity seemed the most appropriate tool for the task in hand. At 5% level of significance the critical value of its sample statistic is 2.53. As a result of the above operations, three types of distribution pattern could be defined. They are described in Table 3 and exemplified in Fig. 4.

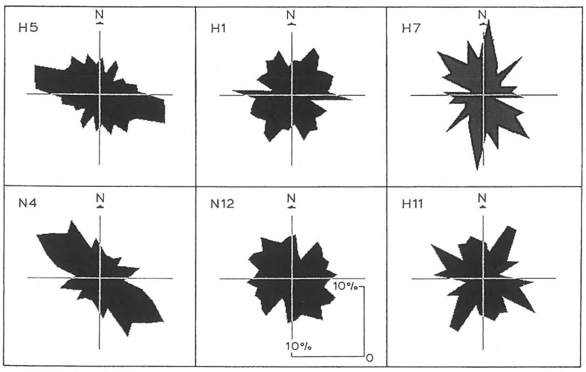

Fig. 4. Three types of fabric distribution-pattern in aeolian sand. H5 and N4: type with elongate shape; H1 and N12: type with roundish shape; H7 and H11: type with star-like shape. See also Table 3.

Within-site variation

The variation in mean direction and strength of the fabrics has been evaluated for each of the sample sites with the help of a multi-sample test. The null hypothesis assumes that the fabric samples collected at a particular site are from one and the same population. Since a circular population with Von Mises distribution is defined by both mean direction and concentration parameter, the test uses two different sample statistics designated as U and U1. Full definitions of these statistics are given on pages 164 (U) and 166 (U1) of the book of Mardia (1972). Applicability of the tests is limited by the condition that the mean resultant length of the combined sample should be less than 0.45; for the four sites under consideration this requirement is amply fulfilled. The sampling distributions of U and U1 are approximated very closely by the Chi-square distribution if (i), the sample size is large and (ii), the data are random samples from a continuous circular population. Again, these conditions are satisfied in the case of our fabrics. The results of the tests are discussed in the next lines and summarised in Table 4.

Site Black Walk Nook. For stratigraphy see Fig. 1; for fabric data see Table 1. All four samples were good fits with the Von Mises distribution. Therefore, none of them had to be excluded from the multi-sample test which rejects equality of mean direction at 5% level of significance. The four mean directions are all in the NW/SE quadrants. When the possibility of eastern provenance is disregarded, this would agree with the suggestion of Matthews (1970) that during the Loch Lomond Stadial northwesterly winds prevailed in Britain.

Site Helmerhoek. For stratigraphy see Fig. 2; for fabric data see Table 1. This set of data consists of two subsets viz. H1 and H2 with mean directions in the first quadrant and H3–H7 with mean directions in the second quadrant. For that reason, the multi-sample test was restricted to samples H3–H6 with fabric H7 being left out as it failed to fit a Von Mises distribution at 5% level of significance. As with the previous group of fabrics, equality of mean direction was rejected by the test. The low-angle aeolian beds from which the samples derive, presumably represent a part of a low, buried dome dune (Schwan, 1988). When once again, deposition from easterly sources is ruled out, the vertical succession of fabrics shows a trend for the wind to back from approximately NW (H3–H7) to SW (H1 and H2). Maarleveld (1960) demonstrated that in the Netherlands a change in the direction of the sand-transporting winds occurred during the Allerød Interstadial. This he inferred from the orientation of low duneforms which suggest the preponderance of northwesterly to westerly winds during the Early Dryas Stadial and westerly to southwesterly winds during the Late Dryas Stadial. However, it is not known whether this theory may be applied to the profile under consideration since markerbeds indicative of the Allerød Interstadial are lacking.

Table 4. Multi-sample tests for equality of mean directions and concentration parameters. Samples are two-dimensional fabrics in aeolian sand from four different sites

Fabrics	$\overline{R}$	Df	Cr	U	Ho.MD	U1	Ho.CP
B1–B4	0.0856	3	7.81	8.67	–	1.60	+
H3–H6	0.1561	3	7.81	10.99	–	0.25	+
N1–N6, N8–N10 N12	0.1399	9	16.90	15.13	+	30.04	–
T1–T3	0.1226	2	5.99	0.86	+	2.20	+

$\overline{R}$ = Mean resultant length of combined sample,
Df = Degrees of freedom,
Cr = Critical value of chi-square at 5% level of significance and degrees of freedom as given in previous column,
U = Value of statistic for testing equality of mean direction,
Ho.MD = Null hypothesis that samples are from population with equal mean direction; + = accepted, – = rejected,
U1 = Value of statistic for testing homogeneity of concentration parameter,
Ho.CP = Null hypothesis that samples are from population with homogeneous concentration parameter; + = accepted, – = rejected.

Site Nordlohne. For stratigraphy see Fig. 3; for fabric data see Table 1. All samples of this group have their mean direction in the same quadrant and only two of them (N7 and N11) are bad fits with the Von Mises distribution. The multi-sample test, in this case based on ten fabrics, accepts equality of mean direction though not of concentration parameter.

Fabrics N1–N6 are from the lower aeolian unit which is characterised by the alternation of finer and coarser grained, horizontal thin beds. In the upper aeolian unit, which contains the fabrics N7–N12, low-angle inclined bedding is associated with large sets whose bases are sharply bounded by undulating or scoop-shaped deflation surfaces. Predominance of westerly winds in the depositional process could be deduced from the attitudes of these dipping layers (Schwan, 1987). All of the fabrics, save N7, are from underneath the paleosol of Allerød Interstadial age that occurs in aeolian unit A2. Since their mean directions, without exception, are in the NW/SE quadrants the conditions at site Nordlohne corroborate the already quoted views of Maarleveld (1960).

Experimental sediment. For fabric data see Table 1. All three samples fitted a Von Mises distribution and, therefore, were included in the multi-sample test which accepted equality of both mean direction

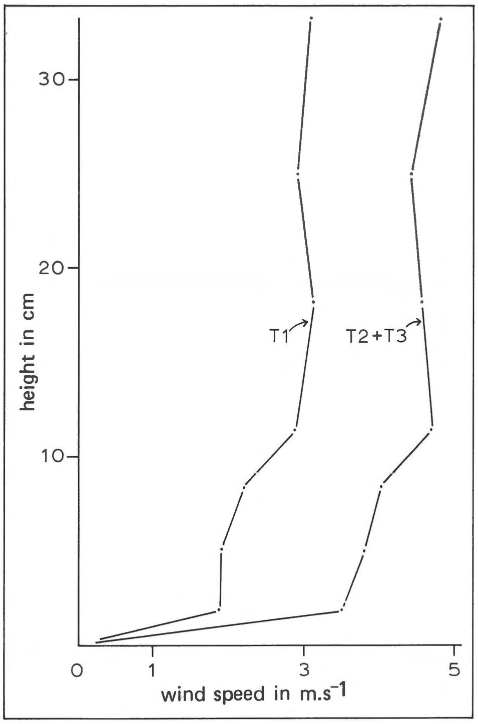

Fig. 5. Wind speeds during deposition of experimental fabric samples T1–T3. Dots mark heights of Pitot tubes above tunnel floor.

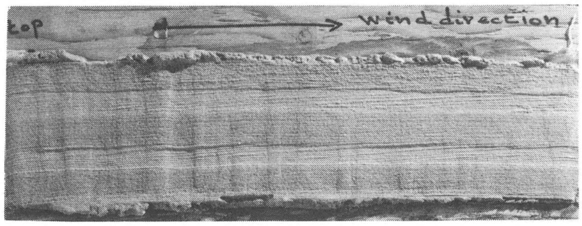

Fig. 6. Lacquer peel of experimental accretion deposit. Alternation of coarser-grained and finer-grained sets marks changes in wind velocity. Climbing translatent stratification is distinct in finer-grained sets but the angle of climb approaches zero in coarser-grained units. Thickness of peel is 12 cm.

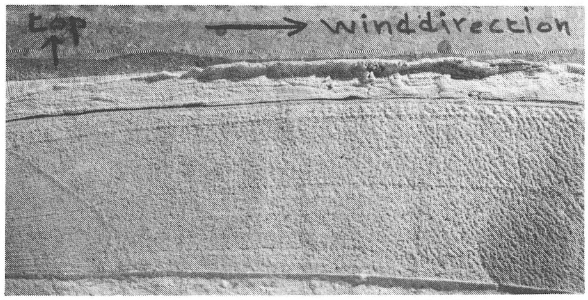

Fig. 7. Laquer peel of experimental grainfall deposit. Grainfall deposit in middle part of peel and incipient climbing – adhesion – ripple structures in its right–hand part. The grainfall deposit with mean grain–size of 230μm is the fallout residue of a parent sand with mean grain-size of 128 μm. Mean thickness of peel (excluding hand-laid cover and substrate) is 12.5 cm.

and concentration parameter. The former result is not surprising since the walls of the wind tunnel force the airstream in a steady direction. Homogeneity of concentration parameter, on the other hand, is more of an unexpected outcome since the three fabrics T1–T3 correspond to strata of unlike origin. In the next section, however, it will be explained that particle alignment by wind is presumed to be both instantaneous and independent of depositional process.

Wind-tunnel experiments

The experimental fabric samples were produced in the wind tunnel of the Institute for Soil Fertility at Haren (Gr.), The Netherlands. The observation section of this suction tunnel with closed circuit had a length of 20 m and a cross section of 75 × 75 cm². Wind velocities could be measured with a vertical array of seven Pitot tubes.

Fabric samples T1 and T2 are from aeolian sand beds that accumulated by accretion at two different wind velocities (see Fig. 5). Accretion, a term originally proposed by Bagnold (1941), is alternatively referred to as tractional deposition (Hunter, 1977) or ripple deposition (Fryberger & Schenk, 1981). The internal structure of sediment so formed is shown in Fig. 6. Fabric sample T3 originates from a layer that was laid down by grainfall. In the tunnel, this process takes place when the airstream is oversaturated with grains and, consequently, drops it excess load at a short distance downwind of the sand feed. As can be seen in Fig. 7, paucity of structure is the main feature of the deposit under discussion.

In fabrics T1 and T2 there is a close correspondence between the orientation of the dominant mode and the direction of the sand-transporting

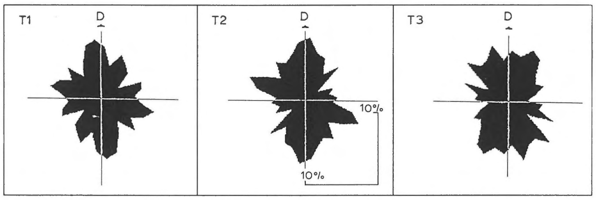

Fig. 8. Grain fabrics of experimental aeolian sands. T1 and T2 are fabrics of accretion deposits and T3 is a fabric of a grainfall deposit. D = Down-wind tunnel-axis direction.

wind (see Fig. 8). In both fabrics the two parameters differ by 5° only. This minor discrepancy can be accounted for by (i), the choice of the zero-direction of the grouped data and (ii), the fact that the airstream in the tunnel moves in a slightly meandering rather than in a straight path.

A subsidiary mode perpendicular to the wind direction is not present in fabrics T1 and T2. Their strenghts differ considerably (see Table 1) and it might be surmised that this feature has to do with the difference in velocity of the winds which deposited the two fabric samples (see Fig. 5). Fabric T3 has a mean direction that practically coincides with the wind direction and a higher than average $\bar{R}$-value of 0.1547. The fabric is from a fallout residue deposited 2 m downwind from the sand feed. Since the wind had a velocity of approximately 4.6 m/s (see Fig. 5), the constituent grains of the fabric remained in the air for only 0.4 s. This suggests that impartment of preferential particle orientation (Einregelung in German) takes place almost instantaneously once the grains have entered the airstream. From the similarity in strength of fabrics T2 and T3 it can be inferred that particle alignment by wind is virtually independent of depositional process (accretion v. grainfall). Generalised theories on the orientation of particles during sedimentation can be found in Jizba (1971) and Allen (1982).

Conclusions

1. The two-dimensional fabrics of 23 natural and 3 experimental aeolian sand-deposits have mean resultant lengths that range from 0.0389 to 0.2757. These generally low fabric strengths are thought to be an inherent characteristic of the investigated sediment type rather than a result of postdepositional disturbance.
2. On a statistical basis, the 26 fabric plots can be grouped into three types of distribution pattern. The first type, that comprises 16 samples, has a distinct unimodal preferential grain-orientation. In the second type, represented by 6 samples, unimodal preferential grain-orientation is either weakly developed or absent. In the third type, the distribution pattern is bimodal to polymodal.
3. The natural fabric samples were collected from three different exposures of Weichselian coversand. The hypothesis of within-site homogeneity of the samples had to be rejected at 5% level of significance for each of the three exposures.
4. Since chronostratigraphic information on the coversand exposures was available, it could be verified that the fabric data do not contradict the existing views on the paleodirection of the depositing wind. This applies to each of the three sites.
5. The wind-tunnel experiments suggest that (i), particle alignment by wind occurs almost instantaneously once the sand grains have entered the airstream and (ii), fabric strength does not depend on type of depositional process whether this be accretion or grainfall.

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