DIRECTIONAL TRENDS IN DUTCH COVERSANDS

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SUMMARY

The article presents a general survey of the coversands in The Netherlands and northern Belgium. About 50 samples were taken mainly in a N-S run and in 15 localities oriented cores were taken with plexiglas tubes. Of all the samples a grain-size analysis was made by sieving and all the sieve fractions were tested for rollability, a functional shape parameter.

After impregnation, the cores were inspected with X-rays and the directions of the oblique bedding planes measured. Of selected parts thin-sections were cut and the grain orientation was measured under a microscope.

The directional features of foreset dips and fabric anisotropy both pointed towards transport from mainly northern directions. Also the grain-size and shape-sorting studies revealed a N-S trend. This trend, however, was not continuous but showed a repetition south of the rivers Rhine and Meuse.

The coversands showed strong receiving shape characteristics and the coarser grains are of low sphericity. Although the influence of local sources is probable, the impression was gained that the main source of the Dutch coversands must be looked for in the region north and northwest to Holland, in the present North Sea. This fits well with the former observation of the pronounced sphericity of the sands in this area, which is explained as a lag characteristic obtained during the blowing out of the coversands.

I. INTRODUCTION

In large areas of Holland, northern Belgium and western Germany the topmost Pleistocene (Würmian) deposits usually consist of evenly bedded sands with a thickness of 0.5-4 metres and in exceptional cases even more than 10 metres. These sands are of eolian origin and are called coversands, because they cover the older Pleistocene deposits.

According to van der Hammen et al. (1967) at least six coversand deposits occur on top of each other. Generally speaking the coversands are restricted to the cold stadials of the Würm Glaciation. The following stratigraphy is proposed by van der Hammen et al.:

	Late Dryas	Younger coversand II
Late Glacial	Early Dryas	Younger coversand I
Upper Pleniglacial		Older coversand II
		Older coversand I
Middle Pleniglacial		
Lower Pleniglacial		Loamy coversand
Early Glacial		Coarse coversand

Formerly the coversands were thought to be Lower Terrace deposits of the Rhine. In 1930 Dewers in Germany demonstrated their eolian origin. In The Netherlands Edelman, Crommelin, van der Hammen, Maarleveld, Vink and many others have contributed to a better understanding of the coversand deposits. Snowdrifts should have transported sand and formed dunes and extensive horizontal sand beds (Edelman, 1947).

To determine the direction of the prevailing wind the following observations have been used:

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1) orientation of parabolic dunes and ridges
2) asymmetric cover on hills
3) dip of the sand layers
4) mineral components and their origin.

Numerous observations by various authors have led to the conclusion that the Older coversands and the Younger coversand I were deposited by NW winds, but the Younger coversand II by SW winds. Studies that support this hypothesis have been made in the SE part of The Netherlands (van der Sluijs and Maarleveld, 1963), in the central part of The Netherlands (Maarleveld and van der Schans, 1961), in the E part of The Netherlands (van den Akker, Knibbe and Maarleveld, 1964), in the N part of The Netherlands (Cnossen and Heijink, 1965), in Germany (Müller, 1955; Liedtke, 1958), in Poland (Dylik and Dylikowa, 1960), and in Belgium (Gullentops, 1957; de Ploey, 1961).

Only few authors have paid attention to the structures in the coversand. Measurements of the dip of sandlayers have been carried out by Chmielewska and Chmielewski (1960) in Poland and by Maarleveld and van der Schans (1961) near Ede (central part of The Netherlands). The latter authors carried out eleven measurements that proved that Older coversand II possessed a dip towards the south, whereas Younger coversand I had a dip towards the southeast.

The investigations by the present writers in 1970 were carried out to compare grain size and rollability of Younger coversands with other sands of the same area. Moreover the orientation of sand layers and grains has been used to find the wind direction of these coversands. About 50 samples and 15 cores were taken from north to south in The Netherlands and Belgium (fig. 1).

If a genetic relation between coversands and the loess deposits in the SE Netherlands and Belgium exists, it may be expected that the grain size of the samples diminishes towards the south.

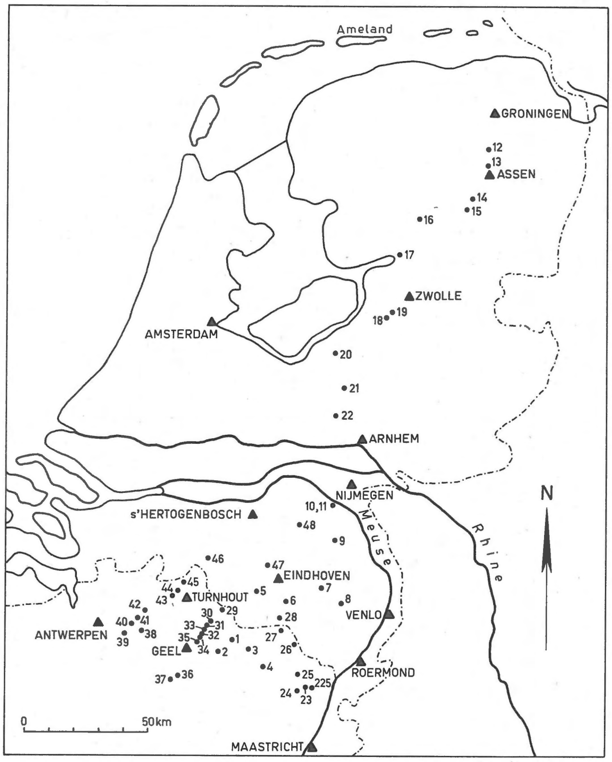


Fig. 1
Sample-location map.

II. TECHNIQUES

Short plexiglas tubes with a diameter of 4.5 cm and a wall thickness of 0.1 cm have been used to collect oriented cores of coversands.

In most cases a small hole was dug and the tube was driven vertically into the ground with a rubber hammer. To protect the brittle plastic tube a removable brass cap was fitted on the tube. In this way cores up to 30 cm could be obtained.

The cores were immediately sealed with gypsum on both ends to prevent disturbance of the sediment during transport. The orientation was measured with a compass and a nail was bedded in the gypsum at the top end of the tube to mark the north. Orientation and location number were also indicated on the tube.

The cores were dried in the laboratory. Small holes were drilled through the gypsum and the cores were impregnated with an epoxy-resin solution in gasoil (Havenaar and Meijs, 1963). In this way, the sand is consolidated but loses only 10% of its porosity. This technique is especially suited for the X-ray procedure described below, since a complete impregnation would diminish the contrast on the X-ray pictures.

The impregnated cores were put into a core rotator (fig. 2), built on top of an aluminium compensatory filter (Baker and Friedman, 1969). For the X-ray inspection, a large medical

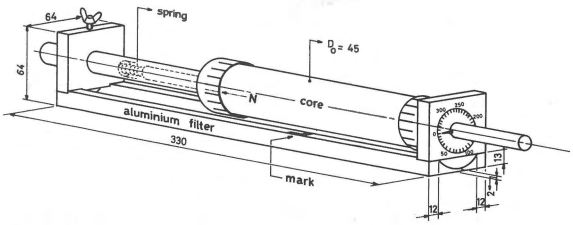


Fig. 2
Core rotator for X-ray inspection.

apparatus was used, which was provided with a picture amplifier. The oriented cores were rotated till the various foresets became sharp on the screen. The position of the needle on the dial gives then the direction of the dip of the bedding plane. The amount of dip can be easily measured with a protractor on the screen. On the edge of the aluminium filter a mark is cut out. This makes it possible to recognize the position of the cores, also on the photographs (fig. 3).

After the X-ray inspection, the plexiglas is removed from the cores and tangential slabs and thin-sections can be made from selected parts. These tangential slabs can be used for additional X-ray absorption photographs. A few examples are shown in fig. 4.

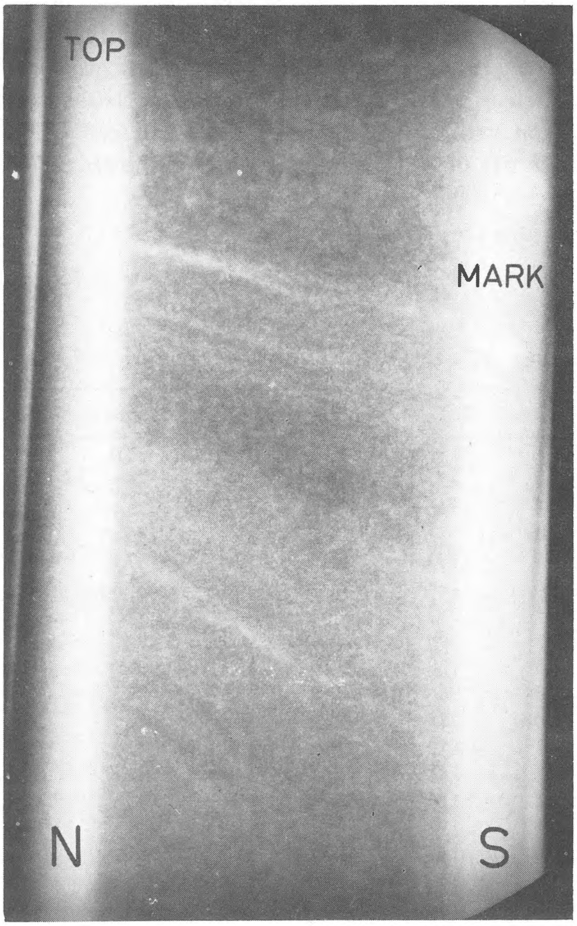


Fig. 3
Example of X-ray absorption photograph of a core (13).

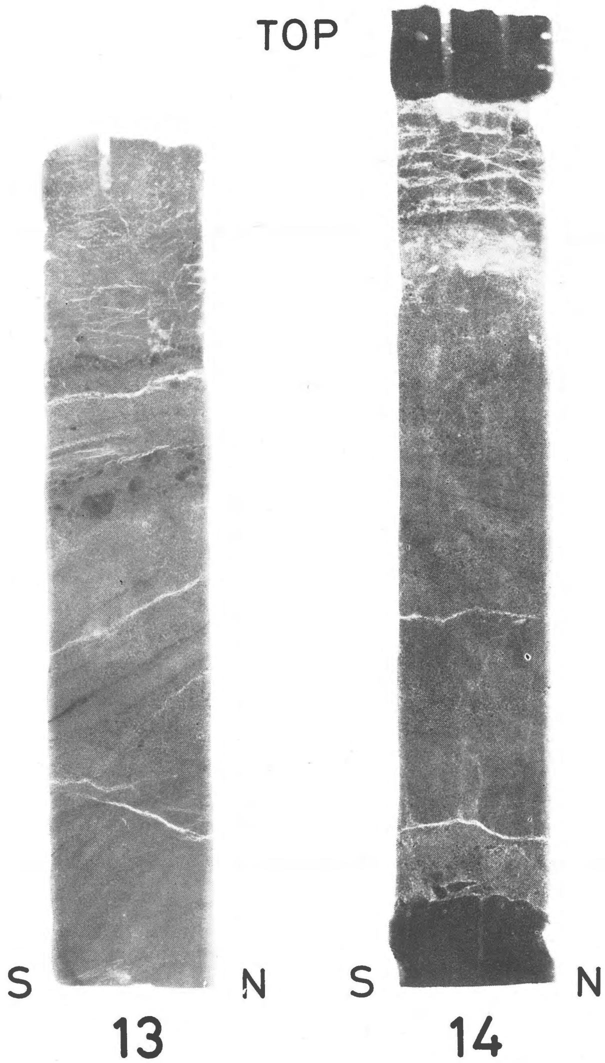


Fig. 4
X-ray photographs of tangential slabs (13 and 14).

III. GRAIN SIZE

The coversands of The Netherlands often show a distinct grain-size maximum ranging from 105-210 micron, but maxima between 210 and 420 micron and between 50 and 105 micron also occur. From table I it appears that the samples collected possess, with only a few exceptions, a median grain size between 105 and 210 micron.

The majority of the samples has been taken in small sand pits, but in some cases an auger has been used. Most samples were collected at about 50 cm below surface and represent Younger coversands.

The southernmost coversand samples in Belgium showed a high glauconite content. Obviously older marine deposits have acted as a source. Therefore, samples from neighbouring Tertiary outcrops have been collected also. Sample 225A, collected on top of marine Diestian deposits, probably represents a coastal dune facies according to the structure of the sediment. It is possible that the samples 2 and 32A belong to the same white sands (fig. 5).

The marine Diestian sands (36,37,38,39) possess a greenish colour due to their glauconite content, but they are analogous in size distribution to the Würmian coversands. A Poederlian sample (40), consisting of marine sand with numerous shell fragments, showed a bimodal grain-size distribution quite different from the other curves.

In The Netherlands also a few samples were collected, that did not belong to coversands. Sample 10A consists of cross-bedded fluvial sand, whereas sample 11 is a fine sand interbedded in these fluvial sands. However, it appears that as far as the grain size is concerned sample 11 could represent a coversand. The same applies to the preglacial sands 16X and 20A, which show the same grain-size distribution as the re[illegible] coversands. The samples 19 and 20B represent coarse coversand, whereas sample 28A forms an example of fine coversand.

Considering the results of the grain-size analyses and comparing these with the thickness of the coversand deposits (M a r é c h a l and M a a r l e v e l d, 1955) the following hypothesis can be set up. The deposition of coversands took place separately in two areas. The first area comprises uniform coversands with a small thickness in the northern part of The Netherlands, followed by finer (21,22) and occasionally thick bedded coversands in the central part of The Netherlands. This area consists of low hills and ridges, that are chiefly built up of preglacial fluvial sands, pushed upwards by the land ice of the penultimate glaciation and covered during the Würmian by coversands. At the southern edge of this area a small zone of loess of the same age as the coversands is present (V i n k, 1949).

Southward of this loess zone the Dutch coversands (45,46,47,48) show hardly any difference in grain size with those (13,14,15,16) of the northern part of The Netherlands. Farther southward in the hilly region of northern Belgium the coversands become finer once again (30,31,33,41,44), till coversand and loess of the E-W running European loess belt merge into one another (see also fig. 10B).

If the above relationship between the coversands and loess exists, one has to assume prevailing northwesterly winds. The two areas with diminution in grain size can be explained by the difference in composition of the source material of the coversands according to C r o m m e l i n (1964) and M a a r l e v e l d (1968). However, it seems more logical that the finer sand was blown farther and caught in a region with low hills, whereas the material with a grain size of 10-50 micron has been deposited in the lee-side of hills.

TABLE 1

Sample	Median	Sample	Median	Sample	Median
1	159μ	20A	151μ	33B	154μ
2	252	20B	250	34	144
3	146	21	151	35	147
4	151	22	119	36	138
5	152	225A	190	37A	130
6	154	225B	206	37B	144
7	141	23A	105	37C	162
8	140	23B	198	38	151
9	136	23C	173	39A	109
10	266	24	136	39B	122
10A	233	25	158	40	138
11	171	26	115	41	144
12	158	27	146	42	168
13	175	28A	53	43	147
14	171	28B	167	44	154
15	162	29	143	45	127
16	142	30	134	46	200
16X	152	31	137	47	142
17	184	32A	144	48	157
18	190	32B	146		
19	261	33A	143		

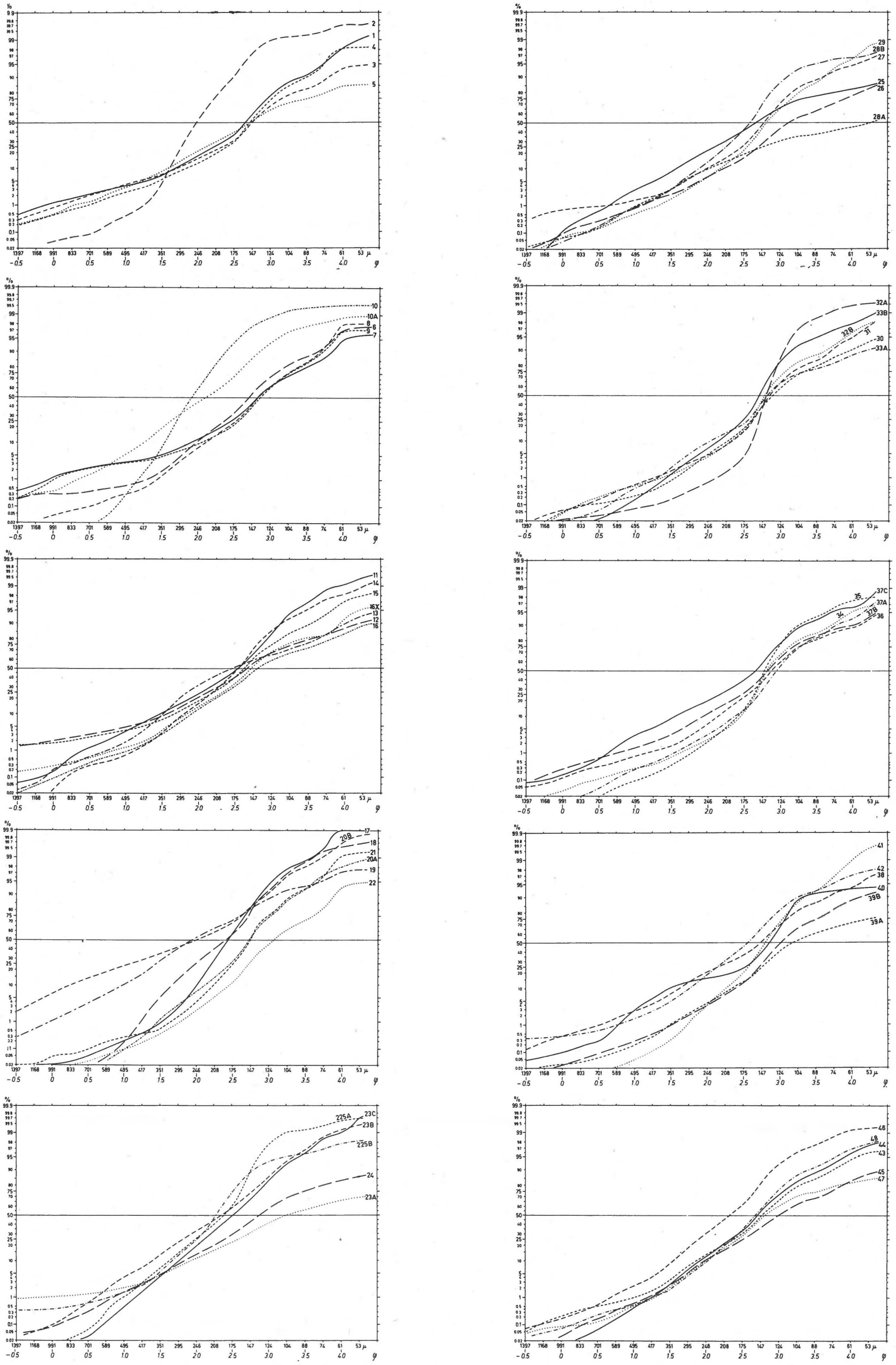


Fig. 5
Cumulative grain-size curves.

IV. STRUCTURES

In the outcrop, most coversands give a very homogeneous impression which makes directional measurements in the field impossible. However, of the 15 cores that have been taken 13 showed distinct oblique bedding during the X-ray inspection. In several cores horizontal bedding was present also. This horizontal bedding is in most cases expressed as a distinct difference in grain size, whereas such differences are much less clear in the oblique bedding planes.

The dip of the oblique bedding varied mostly between 10 and 30 degrees, only in two instances larger dips were found. In some cases the dip direction was consistent within the whole core interval. Within other cores the directions varied. The cores 14 and 20 showed dips in nearly opposite directions.

The measured directions are plotted in fig. 6. Although the significance of the 18 measurements presented cannot be rated high, the picture suggests a predominance of southern and eastern directions. In between SW and NW only one measurement is present.

It is not allowed to translate the dip directions directly into wind directions, since in desert environments foreset bedding often is obliquely to the wind direction. This question will be discussed in the next chapter.

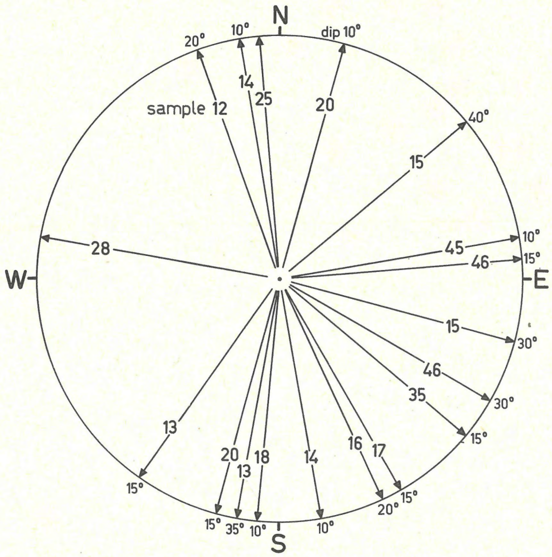


Fig. 6
Directions and amount of dip of oblique bedding planes.

V. GRAIN ORIENTATION

From 7 core samples, 38 thin-sections have been prepared, of which the grain orientation was measured under a microscope. Where the X-ray pictures revealed oblique bedding, the sections were cut parallel to these oblique bedding planes. When no structures could be seen, the thin-sections have been taken horizontally. In each thin-section, 150-200 grain long-axis directions were measured and plotted as rose diagrams, from which the direction of preferred grain orientation was determined visually.

Since not much work has been published on grain orientation in eolian deposits, the interpretation remains difficult. There are a few general rules, however. The grains are transported with their long axis normal to the transport direction. Only when they come to rest, they can be pivoted around the point of largest bottom friction. This will in general result in a roughly wind-parallel orientation.

Grain orientation can also result from gravity forces, e.g. when the grains are deposited on the lee slope of ripples. The grains roll downslope with their long axis parallel to the strike of the slope, but as soon as they got stuck, the centre of gravity will try to come as low as possible in respect to the point of largest friction with the slope. This will result in a

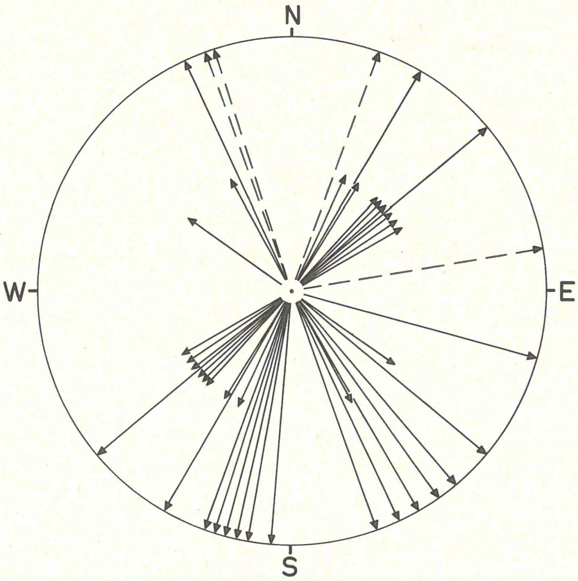


Fig. 7
Wind directions deduced from the grain orientation in combination with the oblique bedding.

long-axis orientation roughly parallel with the dip of the slope.

Also a combination of both is possible, i.e. when grains come to rest on a slope under the shearing influence of wind. The dip-parallel orientation is then deviated in the downwind direction.

In all these cases, the directions of the long axes of the grains are symmetrically distributed around the orienting force direction or around the component of the acting forces.

Beside this depositional grain orientation, also post-depositional reorientation may happen. In general, reorientation occurs when a grain packing is subjected to shearing movements. The long axes then tend to become reoriented normal to the shearing movement. When such a post-depositional reorientation is superimposed on an already existing fabric, the resulting long axis pattern will in general be asymmetric.

We noticed quite a number of such asymmetric rose diagrams. There can be many reasons for this. E.g. cryoturbatic phenomena (which are known from the coversands) can cause flow and shearing movements. Also sliding of thin sheets during or shortly after the depostition is quite normal on the lee side of eolian deposits. Furthermore asymmetric patterns can be obtained when different laminae with different orientations are counted within one thin-section.

For this investigation the asymmetric rose diagrams have been discarded for the interpretation.

Based on the above stated principles, the observed grain-orientation directions have been interpreted in terms of most probable wind directions, which are shown in fig. 7. Only in the cases of grain orientation combined with the oblique bedding, an unique wind direction can be inferred. In the horizontal sections, it cannot be decided if the wind has blown from a certain direction or the opposite one. Since there was no time left to study also the imbrication in vertical sections, such directions are indicated in fig. 7 as a line through the centre with a double arrow.

The homogeneous looking cores in general showed consistent orientation throughout the core. Others showed distinctly divergent directions in different levels. X-ray inspection (see fig. 4) revealed that these cores consisted of several thin layers, differing in grain size and sorting.

In general, the wind directions inferred from the long-axis fabric agree very well with those obtained from the dip directions of the oblique laminations (compare fig. 6). In a statistical way, this had to be expected. However, individual cases show that oblique bedding can make an angle with the wind direction. This is the case e.g. with seif dunes and in the periferal parts of barchans.

The evidence presented suggests that several wind directions played a part in the final deposition of the coversands. NW and NE directions seem to have been dominant, E and SE very rare. It is dangerous, however, to try to locate the source of the coversands in this way. During heavy storms with bulk sand transport, the traction carpet is saturated and no erosion or deposition takes place as a rule. Only exchange between transported load and bottom sediment is possible.

Such strong winds, therefore, can possibly have left little directional evidence in the sediment. Contrary, the impression is gained that moderately gentle and variegated winds are responsible for the final morphological appearance of the Dutch coversands.

VI. SHAPE SORTING

Of all the samples, $\frac{1}{4}$ phi-sieve fractions have been prepared from which a functional shape parameter, the "rollability" was measured (Winkelmolen, 1969). The absolute values, so obtained, were transformed into relative rollability values. This was achieved by expressing them as percentual deviation (+ or –) from the average values, obtained in a former investigation of Dutch coastal and shallow off-shore sands. A positive relative rollability value means that the grains are more spherical and better "rollable" than the average Dutch coastal sands, a negative value means a high surface/weight ratio and hence a high susceptibility for the drag forces of the transporting medium, especially for suspended and saltation transport.

The first thing that became clear at once was, that the Dutch coversands are nearly completely in the negative rollability values. This is especially true for the coarser grain sizes. Only the very fine grains of about 100 micron are approaching the average rollability values of the Dutch coastal sands. This was not amazing, since former investigations and experiments made it clear that the wind preferentially picks up the least rollable material and leaves, especially for the coarser sizes, the spherical grains selectively behind. This can also be seen from a comparison of recent beach sands with the adjoining dunes (W i n - k e l m o l e n, 1969).

The best method to judge the depositional character of a sandy deposit is to plot the relative rollability values against the grain sizes of a sample. The so obtained diagram is called the Shape Distribution Character of a sample. Receiving deposits are characterized by low relative rollability values for the coarsest grain sizes present and increasingly higher values for the finer sizes.

The opposite is true for lag deposits, from which the spherical larger grains were selectively left behind and this less and less so for increasingly finer grains.

The Dutch coversands showed invariably a pronounced receiving character. In this respect, they are very similar to the recent coastal dunes in Holland. It would take too much place to demonstrate all the curves here. Instead, composite curves have been constructed, in which groups of samples have been averaged.

Fig. 8 shows the Shape Distribution Character (S.D.C.) of the coversands. Curve A is the average of the samples north of Zwolle, curve B represents the samples in between Zwolle and Arnhem, curve C are the samples south of the great rivers and north of the line Antwerpen-Venlo, while curve D are the coversand samples south of this line. It should be noted that the individual variations from these group averages are only small.

Although all the curves of fig. 8 are typically receiving in character, this is least so for the northernmost samples. The more to the south the samples have been taken, the more pronounced their receiving character, i.e. the steeper the curves. As yet the loess south of the coversands has not been investigated. It is to be expected that this loess will show the continuation of the trend. Indications of this can be found in the literature; e.g. S m a l l e y and P e r r y (1970) mention the extreme angularity of the coarsest components of the loess.

In fig. 9 the grain-size distributions of some typical eolian sands are plotted as histograms. Fig. A, B and C are typical coversand patterns. Fig. D is an average dune sand of the Dutch west coast while E is a dune sand from the isle of Ameland in the north. Fig. F is a Sahara-desert sand from south Algeria and G is a sand from the Kalahari desert. This Kalahari sand is bimodal and the coarsest mode will probably represent the bottom-creep population.

The most conspicuous feature of fig. 9 is the role

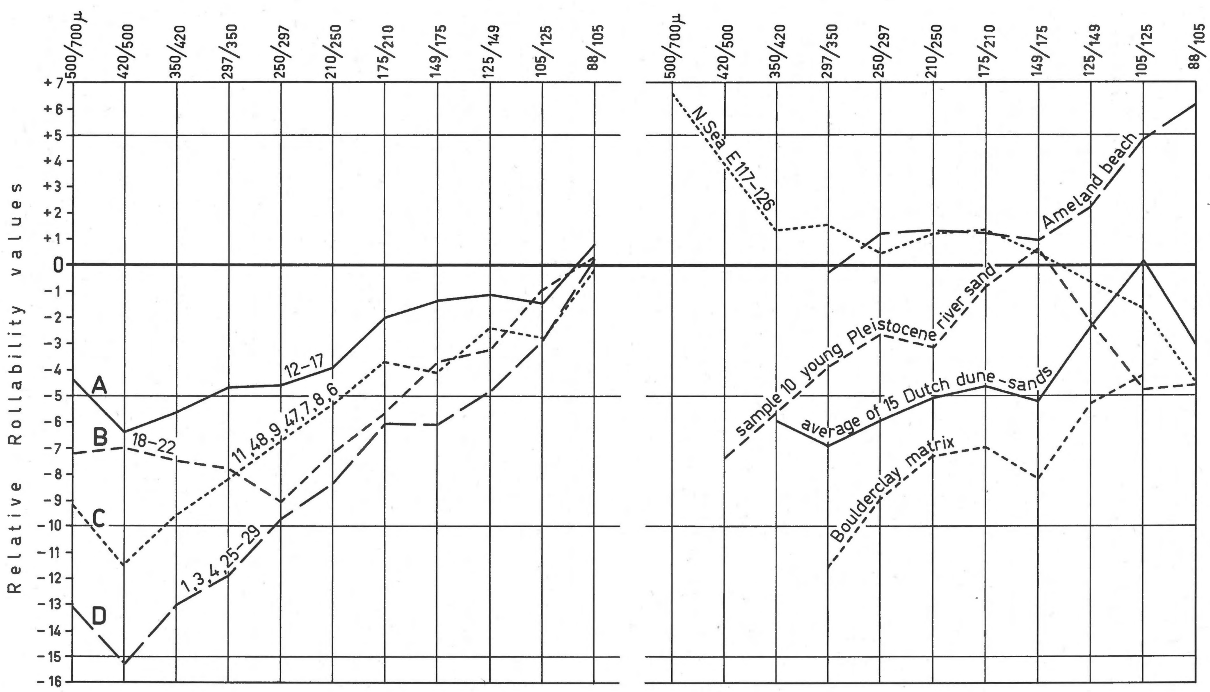


Fig. 8
Shape Distribution Character. A,B,C and D are curves of the coversands. On the right, other S.D.C. are shown for comparison.

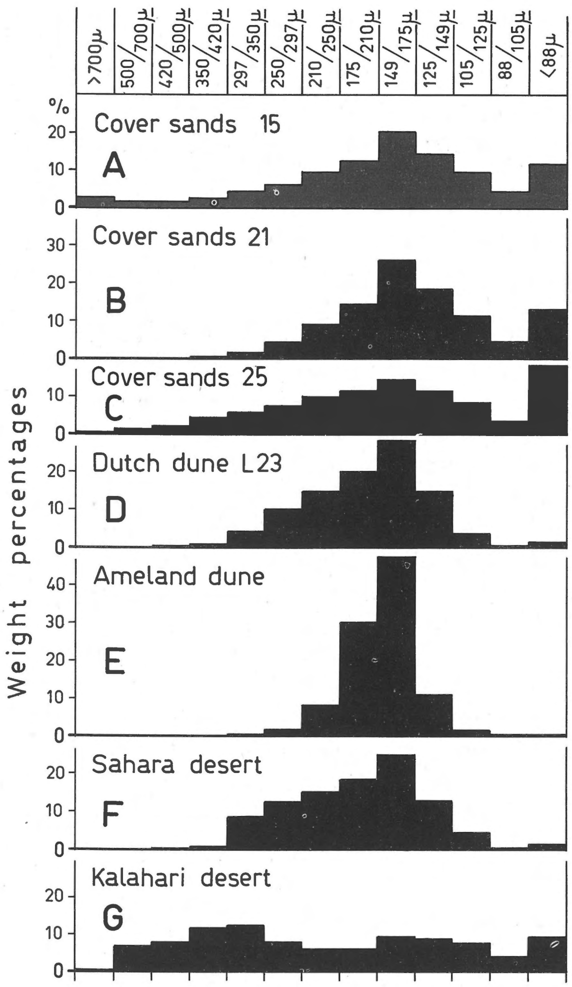


Fig. 9
Histograms of typical eolian sand.

of the 149-175 micron sieve fraction. In nearly all eolian sands so far investigated, this sieve fraction formed the mode of the grain-size distribution and often the 149-175 micron fraction with its two neighbours form much more than 50% of the sediment. This appeared to be rather independent from the source material of the sediments.

From a comparison of the dunes with the adjoining beaches in The Netherlands (Winkelmolen, 1969) it became clear that, although strong western storms are common, grains of over 400 micron are extremely rare in the dunes, though they are abundant on the beach. Apparently, only the finer grains are really suited to be transported by wind over larger distances. The histograms suggest that especially the grains smaller than 250 micron are easily transported and that the grains between 200 and 100 micron form the bulk of the saltation load moving close to the surface. Grains smaller than 100 microns can be lifted to higher levels and be dispersed further and come to rest outside the typical desert areas.

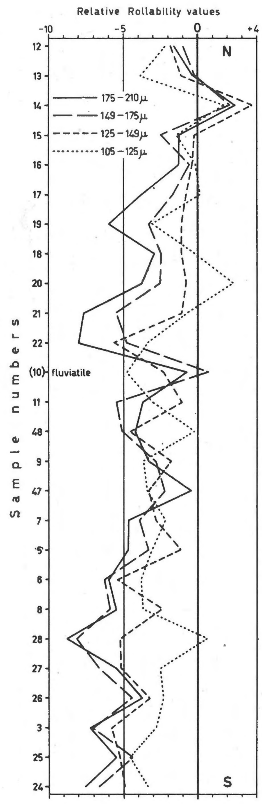
Selection by wind, therefore, will be mainly visible in these modal fractions. As soon as a saltation carpet is installed and the capacity of the transporting medium is reached (see also Bagnold, 1941) no more material can be picked up from the bottom, but exchange of grains between the saltation load and the bottom sediment remains possible. Grains of low susceptibility will be selectively dropped and exchanged for grains of higher susceptibility and hence lower rollability from the surface. The farther off-wind, therefore, the richer the saltation carpet will become in grains of low rollability for a given grain size.

In order to find the transport trend in the coversands, a diagram was plotted from the relative rollability values of these modal sieve fractions in the NS-direction (fig. 10A).

From sample 12 (south of Groningen) to sample 22 (north of Arnhem) there is a clear trend of decreasing rollability towards the south. This trend is clearest for the 175-210 micron fraction and less pronounced the finer the grains are.

South of the rivers Rhine and Meuse, the same trend is visible again. However, there is a distinct jump back to higher rollability values just south of the rivers. This jump cannot be explained by the wind-transport mechanism alone. Contrary, when only this transport mechanism would have been responsible, much lower rollability values should have to be expected south of the rivers. In the first place, the northern winds are forced over the hilly ice-pushed area just north of the rivers, causing increased resistance and therefore a drop-out of the least stable grains. But, moreover, it is very difficult for a saltation carpet to by-pass a river or even a moist zone. Only grains of very high susceptibility and low weight might succeed to pass such a barrier.

A possibility to explain the sharp break in the NS-trend is, that the river systems supplied a new source of loose material for the winds. In this respect it is interesting to note that sample 10, which is a Late Pleistocene fluviatile sand, has a completely different rollability characteristic (see curve 10, fig. 8). In fig. 10A the relative rollability values of the



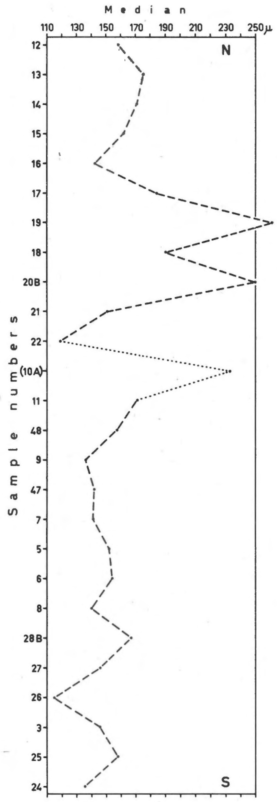


Fig. 10A
Relative rollability values of the dominant size fractions of coversand samples in a N-S-section.

Fig. 10B
Median grain-size values of same sample localities.

NOTE:
The samples used for the grain-size analysis are not the same as for the shape studies. For the grain-size determination, samples of approximately 200 grams were collected, whereas for the rollability studies, samples of only 25 grams were taken, where possible of one influx lamina only. In general, fine-grained laminae were selected for the shape studies.

concerning sieve fractions of sample 10 are included in the diagram. It is evident that, if the winds could pick up sufficient material of the rollability characteristics of sample 10, then the jump south of the rivers can be explained very satisfactorily.

Coversands south of the Belgian border show locally a high glauconite content (4-7% in some cases). Fig. 10A shows that these southernmost samples also deviate slightly in the general rollability trend, i.e. they possess a higher rollability then should fit with the general trend. With a magnetic separator, the glauconite was separated from the samples and tested for rollability. It appeared that the glauconite showed the same Shape Distribution Character as the quartz fraction. This means that the glauconite has gone through the same selection processes. It is clear that local older formations as e.g. the Diestian sands acted here as an additional source for the southernmost coversands.

VII. SOURCE AREA OF THE COVERSANDS

Some twenty years ago it was thought (Vink, 1949; Rutten, 1954) that the material of the Dutch coversands had been taken up by westerly gales from the dry North Sea floor, whereas the loess would have been transported by northerly winds from the sediments of the periglacial belt round the ice sheet. Later investigations (Maarleveld, 1960) indicated that the prevailing wind direction during the deposition of the various types of coversands changed from NW during the Pleniglacial to W-SW in the end of the Late Glacial.

Crommelin (1964) studied the heavy minerals of Younger coversands in The Netherlands. He could distinguish three groups, viz. in the northern, central and southern Netherlands. The difference between the central and southern region is very distinct. The area in which Rhine and Meuse run since the last glaciation forms the boundary. The conclusion was that the Younger coversands had local sources, i.e. they were not transported over long distances. According to Crommelin the coversands in the northern Netherlands could originate from boulder clay and fluvioglacial sediments, those in the central Netherlands from Middle Pleistocene Rhine deposits and those in the southern Netherlands from Lower and Middle Pleistocene Meuse deposits.

Maarleveld (1968) also carried out mineralogical investigations on coversands. Basing himself on a great number of mineral assemblages, he reached the conclusion that the main source of the coversand could have been dried up river beds. However, the shape sorting characteristics of the coversands clearly showed that the coversands have gone through severe selection processes. Since selection is a question of susceptibility, which means the ratio surface/weight forces, the density as well as the shape are involved equally in the selection processes. Beside on density, the heavy minerals are as well selected on their, often pronounced, mutual shape differences. It is therefore to be expected that the heavy-mineral associations in the coversands will differ considerably from the source areas and a complementary character is more probable than a resemblance.

Although boulder clays are suggested as a source for the coversands in the northern Netherlands, there are several objections against this. Boulder clays are very difficult to blow out and if so, they would soon be protected by a residual boulder cover.

Furthermore, the boulder clays are largely underlying the coversands, which excludes them therefore as a source.

The matrix of two boulder-clay samples south of Groningen has been investigated on shape characteristics. The average S.D.C. is shown in fig. 8. When this matrix material is inspected under a microscope, it appears that as far as shape is concerned, the grains show an extremely wide spectrum. Very round and spherical grains are present next to extremely angular and flaky material. If such material had been acting as a source for the coversands, which would have meant the lagging behind of the spherical grains, even lower rollabilities than the present low values would have resulted in a selective process. It is therefore improbable that the boulder clays supplied substantially to the coversand material.

All evidence collected in this investigation: the structures, the grain orientation, the grain-size trend and the trend in shape sorting, point in the direction of a northern source area for the Dutch coversands. Since these trends are present already in the northernmost coversands due south of Groningen, it is apparent that the source area must have been situated still further north, viz. in the present North Sea.

There are several more facts in favour of this hypothesis. In an earlier investigation (Winkelmolen, 1969) it was found that the more northern sands along the coast of Holland and in the off-shore area have a higher average rollability value than the more southern sands. This phenomenon could not be explained by the present hydrodynamic situation. The higher rollability values in the north have been tentatively explained then as a lag characteristic of Late Pleistocene processes.

In fig. 8, the Shape Distribution Character of northern off-shore North Sea sands is given. As can be seen, these sands have a pronounced lag character. Moreover, their relative rollabilities are for the coarser fractions well within the positive values.

When a deposit is split up by a selective process into two different populations, the deposit and its repository (see Kuenen, 1964; Winkelmolen, 1969), these should have complementary characteristics. The Shape Distribution Character of the North Sea samples now is indeed complementary to the character of the Dutch coversands. Moreover, the shape distribution in these northern North Sea sands cannot be logically explained by the present hydrodynamic situation in the North Sea. There is a residual current towards the north and when the sands should have been derived by the currents from more southern directions, a receiving character should have been the result. But, admittedly, also the Holocene transgressive phase could have been responsible for these lag characteristics.

To our opinion, the tentative explanation of the lag characteristics of the northern coastal and marine sands by the blowing out of the coversands is strongly supported by the results of the present investigation. Admittedly, local additional sources cannot be excluded and also the present investigation gives indications in this direction. However, it is the opinion of the present authors that the bulk of the coversand material must have been derived from the present North Sea area north of The Netherlands.

Also quantitative considerations do not oppose this proposition. A very rough estimation, based on maps by Woldstedt (1935) and Maréchal and Maarleveld (1955) is that the volume of the coversands in The Netherlands amounts to 6×10^{10} m^3, in northern Belgium 1.4×10^{10} m^3 and in northwestern Germany 3×10^{10} m^3, thus a total volume of about 10^{11} m^3. Assuming northwesterly winds a North Sea area of about 350 by 600 km (= 2×10^{11} m^2) could have supplied the material. This area is shallower than the present 40 m isobath and certainly was land during the end of the last glaciation. Even if half of the volume of the coversands had a local origin, than this would indicate that the sediments of the North Sea floor would have lost a layer of only 25 centimetres.

VIII. CONCLUDING REMARKS

The aim of the present investigation was to demonstrate that a combination of conventional and more advanced sedimentological methods can throw more light on problems connected with the deposition of Würmian coversands. The authors had not the intention to discuss extensively the stratigraphy, the source or the deposition of these eolian sediments. It must be kept in mind that our results are based on a limited number of samples.

The results obtained by the simple coring technique, combined with the X-ray inspection, show how quick progress can be made for a better understanding of directional features in coversands and other fine-grained deposits.

The shape studies proved to be an essential complement to the measurement of size and the study of composition. Nowhere, the different methods produced conflicting evidence.

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