SIZE AND SHAPE-SORTING OF COASTAL SANDS IN THE EASTERN PART OF THE GERMAN BIGHT (NORTH SEA)[1]

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ABSTRACT

Veenstra, H.J. 1984 Size and shape-sorting of coastal sands in the eastern part of the German Bight (North Sea)–Geol. Mijnbouw 63: 047-054.

Size analyses of sand samples taken from the islands and sand flats in the eastern part of the German Bight indicate that each island shows a separate grain size population. This rules out important longshore sand transport from island to island. Comparison with sediment maps of the adjacent seafloor suggests that the islands were formed by wave action. On the other hand rollability analysis reveals that the percentages of angular grains in the samples increase towards the north. It is held that this increasing angularity reflects the shape sorting of the sediments of the seafloor. The spit of Skallingen shows a drecreasing angularity of the sand grains towards its end, probably caused by prevailing influence of shape selection by coastal erosion over longshore transport.
In most cases the dune sands contain more angular grains than the beach sands.

INTRODUCTION

Along the eastern margin of the German Bight there are a number of islands and sand flats, the latter between Alte Mellum and Amrum (Fig. 1). In the southern part of the area samples have been collected in August 1978. In August 1979 collecting was done from Amrum till Blåvands Huk.

The aim of the present study was to check whether the existing ideas about sediment transport could be supported by an investigation of the variations in size and shape of the grains in the sand samples.

WIND, TIDES, WAVES AND CURRENTS

Erosion and deposition on beaches differs from place to place and is dependant upon such variables as: 1. direction of prevailing winds, 2. storm activity, 3. grain size of the sediments, 4. wave-climate, 5. offshore topography and 6. tidal height and tidal currents. The prevailing wind direction in the German Bight is from the southwest. Force 7 is reached during about 40 days per annum. In the case of Beaufort 4 the wave height is about 1 m and in the case of Beaufort 7 a wave height up to 3m is generated. In the area parallel to the coast the depth is less than 20 m up to a distance of 40 km. The mean tidal range for the different islands is given in Table I. It is clearly visible that there is no correlation between grain size and tidal range.

Under normal weather conditions the tidal currents amount to 0.8-1.5 knots (0.4-0.75 m/s) at most. In deep channels a velocity of 2.5-2.8 knots (1.25-1.4 m/s) can be reached. The residual current in the eastern part of the German Bight forms an anti-clockwise whirl north of Heligoland. Along the coast this residual current has a velocity of 1 knot (0.5 m/s) at most, and it runs from south to north (NEUMANN & MEIER, 1964).

PREVIOUS STUDIES

Data on the migration of the islands, sand flats and spits are numerous: on Alte Mellum in POPPEN (1912), on Scharhörn and Grosser Knechtsand in HOMEIER (1969), on Duhner Watt near Cuxhaven in GELLERT (1952), on Trischen and Blauortsand in WIELAND (1972), on Tertius in GÖHREN (1975), on St Peter-Ording in LANDESVERMESSUNGSAMT SCHLESWIG-HOLSTEIN (1966), on Amrum in GRIPP (1968), on Sylt in ZAUSIG

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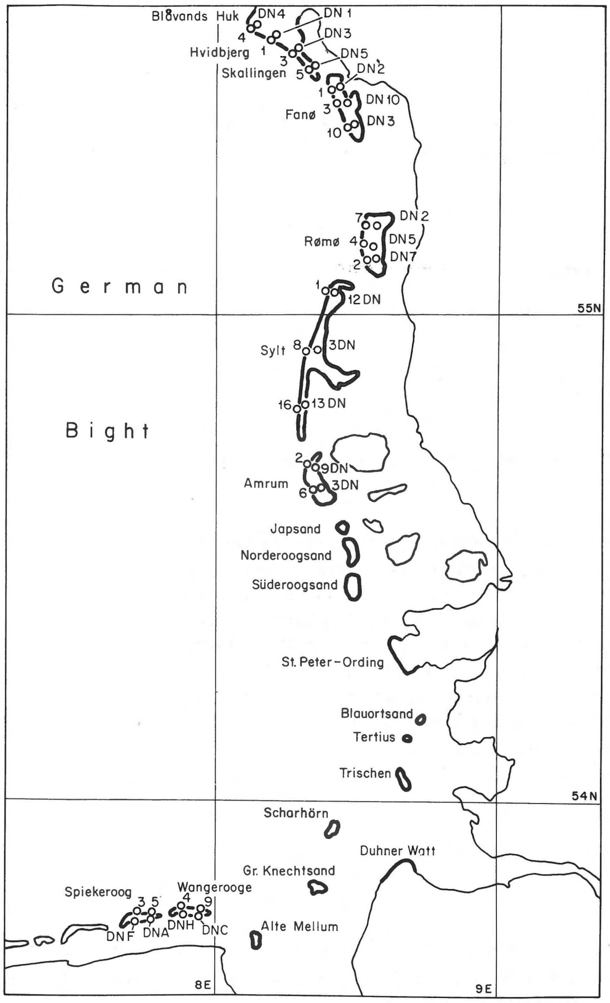


Fig. 1
Sample location map

(1939) and VOLLBRECHT (1973), on Rømø and Fanø in MEESENBURG (1970) and finally on Skallingen till Blåvands Huk in TOUGAARD & MEESENBURG (1974).

From maps and sea charts of the last four centuries it appears that Alte Mellum and Grosser Knechtsand are migrating southeastward, Trischen, Tertius and Blauortsand eastward, and that during the past 100 years a large quantity of sand has been piled up off St. Peter. The sand flats Süderoogsand, Norderoogsand and Japsand are moving eastward, as well as the islands Amrum, Sylt, Rømø and Fanø. Especially Amrum and Sylt are liable to severe coastal erosion, whereas on Rømø and Fanø the beaches are now prograding.

At the moment Skallingen is slowly migrating landward, but in 1870 the spit was situated more landward than at present and in 1910 more seaward. The Hvidbjerg coast between Blåvands Huk and Skallingen is subject to erosion, and a series of groynes has been constructed.

Numerous data exist especially about the displacement of Trischen (inhabited till 1942) and about the coastal erosion of Sylt. The sands of Alte Mellum, Sylt and Skallingen have been extensively studied by various investigators, whereas a sedimentological map of the sea floor of the German Bight has been published recently (LUDWIG & FIGGE, 1979). DEPUYDT (1972) studied beach- and dune sands of various localities between Blanc Nez (France) and The Skaw (Skagen, Denmark). He collected on Amrum 2, on Sylt 2, on Rømø 3, on Fanø 4, on Skallingen 3 and from the Hvidbjerg coast between Skallingen and Blåvands Huk 6 samples. Owing to this limited collection no conclusions about sediment transport in the German Bight could be drawn.

GRAIN SIZE

The movement of the silt and fine sand in the tidal flats is well known (e.g. GÖHREN, 1975), but only few data exist about the sand movement in the study area, as the direction of transport in most cases has been inferred from the displacement of the sands flats (e.g. WIELAND, 1972) or the presence of megaripples (e.g. ULRICH, 1973).

There is no mainland source of sand, as the mainland along the German Bight consists of clayey sediments, whereas the few rivers in the area do not bring sand to the sea.

In the present study the median diameter, sorting coefficient and $CaCO_3$-content of about 100 samples were determined (Table I). The sieving was carried out at 1/4 phi intervals. The $CaCO_3$ content was measured by a sensitive Ca-electrode connected with a pH-meter.

The average $CaCO_3$ content varies between 0.1 and 1.0%, with the exception of the LW-samples of Fanø, which contain 1.8% $CaCO_3$. The $CaCO_3$ is mostly of organic origin: shell hash, foraminifera and echinid spines. The variations in $CaCO_3$ content are caused by the varying quantities of organisms.

It appears that in all cases the variation in grain-size is smaller for the dunes than for the beaches. Especially the dune sands of each island form a more or less separate population with small variations in grain-size and $CaCO_3$ content. The same conclusions were drawn from the West Frisian Islands (The Netherlands) studied by VEENSTRA & WINKELMOLEN (1976) and from the East Frisian Islands (Germany) studied by VEENSTRA (1982).

The beach sands of adjoining islands differ considerably in size; this contradicts a strong longshore drift, which would transport the sand from island to island.

The grain-size of the samples is shown in Fig. 2. It appears that large areas have a more or less uniform grain-size distribution, that is distinct from adjacent areas. One area is the Trischen-Tertius-Blauortsand region, another the Süder oogsand-Norderoogsand region, which has a coarser size (Table I).

In most cases the dune sands demonstrate a smaller statistic standard deviation than the beach samples. The beach and dune sands of Sylt form the coarsest sands of the whole area,

Table I
Median diameter, Trask sorting and $CaCO_3$, content of all samples.

Locality	LW-samples				HW-samples				DN-samples				mean tidal range
	Nos	Md	So	$CaCO_3$	Nos	Md	So	$CaCO_3$	Nos	Md	So	$CaCO_3$	m
Hvidbjerg	5	185±7	1.18	1.0	5	183±11	1.15	1.0	5	169±7	1.14	0.5	1.5
Skallingen	6	199±63	1.31	0.5	6	184±7	1.13	0.3	6	194±20	1.18	0.2	1.5
Fanø	10	149±15	1.30	1.8	10	149±21	1.12	1.0	11	154±23	1.13	0.6	1.4
Rømø	9	245±191	133	0.3	9	179±121	1.19	0.3	8	163±15	1.18	0.1	1.6
Sylt	16	522±206	1.25	0.4	16	463±184	1.31	0.2	17	413±94	1.30	0.2	1.7-2.0
Amrum	10	218±15	1.16	0.2	10	212±11	1.15	0.2	10	221±13	1.16	0.4	2.2
Norderoogsand	8	202±18	1.20	0.7	8	200±13	1.18	0.6	–	–	–	–	2.4
Süderoogsand	7	211±8	1.15	0.4	7	209±7	1.15	0.4	–	–	–	–	2.6
St. Peter-Ording	6	196±43	1.22	0.7	6	195±23	1.23	0.6	–	–	–	–	2.8
Blauortsand	4	172±15	1.20	0.2	4	188±12	1.10	0.3	–	–	–	–	3.2
Tertius	5	165±10	1.14	0.9	5	169±7	0.7	1.13	–	–	–	–	3.1
Trischen	6	157±122	1.20	0.3	6	184±9	1.15	0.2	–	–	–	–	3.1
Duhner Watt	4	167±25	1.19	1.0	4	148±14	1.17	0.9	–	–	–	–	2.9
Grosser Knechtsand	–	–	–	–	6	158±17	1.20	0.5	–	–	–	–	2.7
Alte Mellum	6	192±27	1.23	0.2	4	185±15	1.22	0.1	–	–	–	–	3.0

followed in coarseness by the sands of Amrum. In the coarser sand fractions many grains of flint, granite and feldspar can be identified by microscope, which points to a glacial origin (BÄSEMANN, 1979).

In the area between Amrum and Grosser Knechtsand the sand movement is strongly influenced by residual currents, which run northward north of St. Peter and southward south of St. Peter (GÖHREN, 1979). As Sylt and Amrum possess a boulder clay core that extends towards the sea floor, it is not surprising that their sands are coarser than those of the other islands and sand flats, where no Pleistocene crops out. The sands of Rømø (Denmark) are much finer than the sands of Sylt, but coarser than the sands of Fanø. The sands of Skallingen spit are somewhat coarser than the sands of the Hvidbjerg coast.

From the grain-size distribution it follows that there is a close relation between the sands of the islands and flats and the sediments of the adjacent sea floor. Recently LUDWIG & FIGGE (1979) published maps of median size and sorting of the sediments of the sea floor of the German Bight. If one takes their data from localities 5 km off the coast, the similarity with the values, obtained in the present study, is striking (Fig. 3). From the size distribution in the study area it can be construed that the sands of the islands and flats have been transported at right angles to the coast by the uprush of the breaking waves, as there is no indication of significant longitudinal transport from island to island. This is in accordance with the construction of the East Frisian Islands (VEENSTRA, 1982).

SHAPE SORTING

The shape of the sand grains can be measured with the rollability apparatus built by WINKELMOLEN (1969). The term 'rollability' only refers to the behaviour of the grains during the measurement in the rollability apparatus, which is an inclined rotating tube. Rollability is a physical shape parameter, which correlates well with the shape effect on the terminal fall velocity of grains settling in water. Therefore, a high rollability value means a low surface/weight ratio and high settling velocities. Low rollability on the contrary means a high susceptibility to the drag forces of the transporting medium. Under lag conditions, well-rollable grains are concentrated.

As quartz grains are rather equidimensional, this means that well-rounded quartz grains correlate with a high rollability and angular quartz grains with a low rollability. Mica flakes also possess a low rollability. The measurements are performed on 1/4 phi sieve fractions. The absolute measurements have been converted to relative rollability values. The relative rollability of a size interval of a sample is expressed as a percentage deviation of the arithmetic mean of the rollability values of that sieve interval in the study area. The results can be related then to selection during transport and deposition, since the influence of the shape characteristics of the source material is largely excluded. As zero level the average relative rollability was used of a large number of samples from the Dutch tidal area, consisting of samples of beaches, dunes, tidal flats and shallow offshore. Zero level for each size fraction is different. The same zero levels have been used in the studies of the West Frisian Islands (VEENSTRA & WINKELMOLEN, 1976) and the East Frisian Islands (VEENSTRA, 1982). Therefore, comparison of the sand of the various islands is possible. It appeared that the East Frisian Islands do not differ much in size and rollability from the West Frisian Islands, as both series of islands are situated W-E and the forces of wind, waves, tides and currents are analogous. In contrast the North Frisian islands in the eastern part of the German Bight are situated north-south and differ considerably in rollability from the Frisian Islands mentioned above.

The results of the rollability analysis are the following: Spiekeroog and Wangerooge (East Frisian Islands) possess

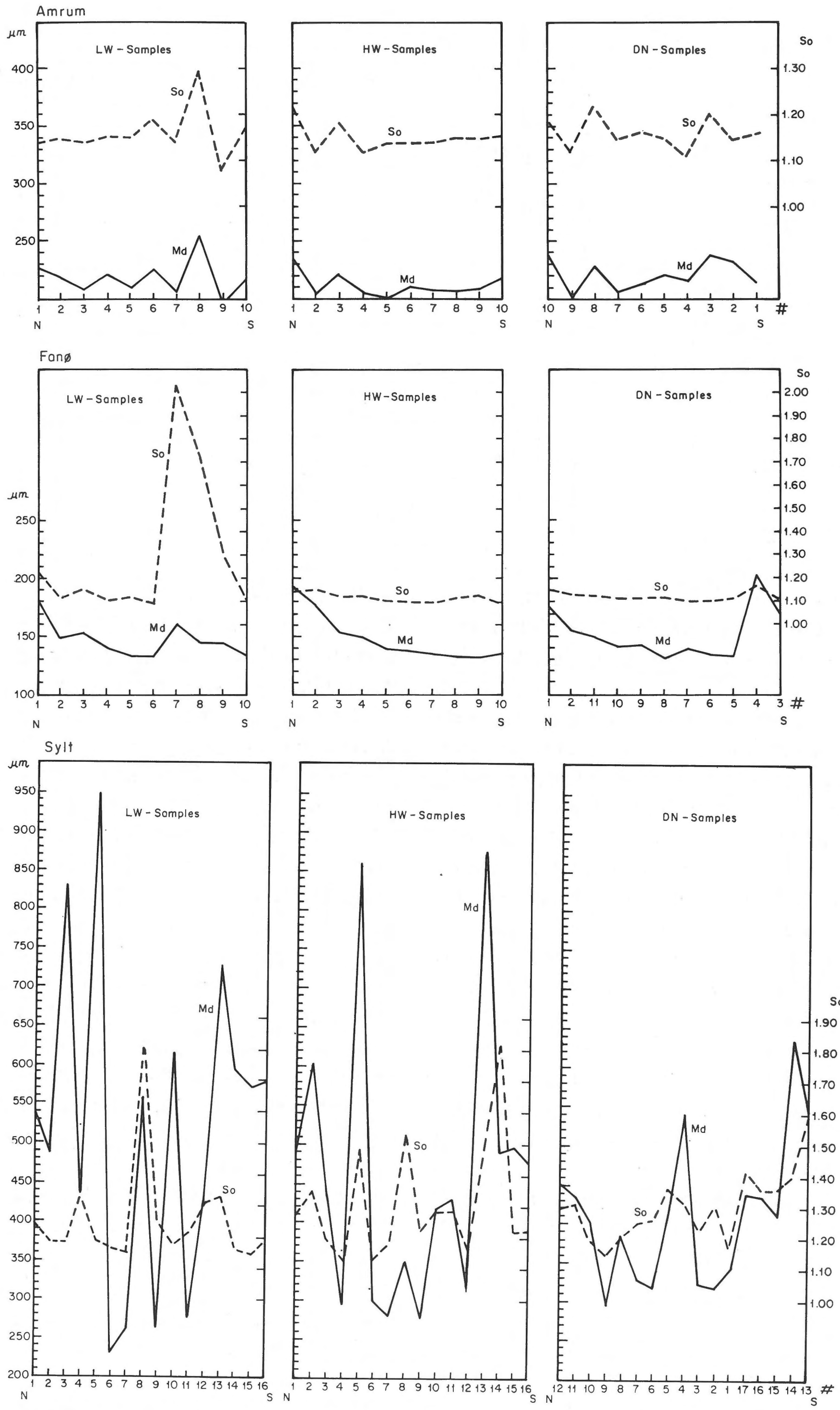


Fig. 2a
Median diameter and sorting of samples from Amrun, Fanø and Sylt.

more rollable sand in comparison than the localities of the present study (Fig. 4). The sands of Sylt are more angular than those of Amrum. The coarse fractions of the sands of Rømø are more angular than those on Sylt, but the fine fractions of Rømø are rounder than those on Sylt. The sands of Fanø are more angular than the sands of Rømø. The sands of Skallingen peninsula are better rounded than those of Fanø and also better rounded than the sands of the Hvidbjerg coast. The general picture is that the sands from Amrum towards Blåvands Huk become more angular. It might be possible that longshore currents have affected the sediments of the sea floor and indirectly also the sands of the islands and flats.

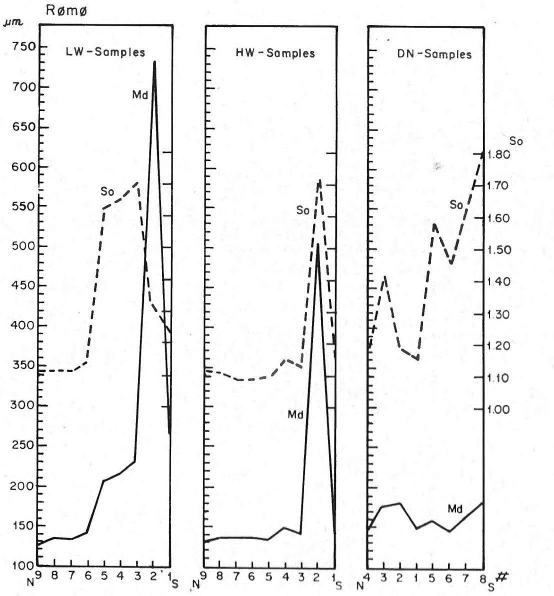


Fig. 2b Median diameter and sorting of samples from Rømø

Certainly longshore currents influence the sediments off Sylt and Amrum, as testified by a pattern of megaripples with W-E crests on the sea floor (KÖSTER, 1974; ULRICH, 1973).

The relative rollability of most size fractions of the samples under discussion is far more negative than in the size fractions of the East Frisian Islands. This implies that the LW–and HW beach samples and the dune samples of the present study contain more angular or platy grains than the samples of the East Frisian Islands.

On Amrum and Rømø the dune sands were more angular than the sands of the HW-line and the LW-line. The same relation was found in the East Frisian Islands. On Sylt the HW sands were more rollable, i.e. better rounded, than the LW samples. The fine fractions of the dune sands of Sylt were always more angular than those of the beach sands. On Fanø the dune sands in most cases are the more angular ones and also HW-samples occur that are better rounded than the adjoining LW-samples. At Skallingen the HW-samples form the more rollable ones, but at the Hvidbjerg coast the HW-samples are the more angular ones in some cases.

WINKELMOLEN & VEENSTRA (1980) observed a greater rollability of HW-samples compared with LW-samples, especially in the fine sand fractions. It could be caused by the backwash, which transports fine and angular sand grains easier than coarse and rounded grains. Another explanation is that angular grains are preferentially carried off as a consequence of strong coastal erosion.

Angular and flaky grains are predominantly selected by the wind. According to KUHLMAN (1960) wind force 7 (i.e. 15 m/s) can transport grains with a diameter of 400 µm in suspension. During storm even coarser grains can be transported. This explains that on Sylt many dunes contain >20% material with a grain-size >700 µm, a composition that is also found on the adjacent beaches.

Along the Hvidbjerg coast and the Skallingen peninsula the longshore drift is towards the SE, as aerial photographs demonstrate. During the past century the spit of Skallingen did not grow in length. One would expect a decrease in rollability towards the end of the spit of Skallingen due to shape selection by the current, but it appears that from Blåvands Huk till Skallingen the rollability increases in all the samples, which is contrary to the direction of the beach drift. The explanation is, that although more angular and platy grains are transported by the beach drift towards the end of Skallingen, this effect is overshadowed by coastal erosion which carries the majority of the angular grains seaward. The same phenomenon has been observed by WINKELMOLEN (1978) on Spurn Head, a spit on the British East coast.

CONCLUSIONS

The size analysis of the sand samples shows that each island has its own separate sand population, which does not indicate an important longshore sand transport from island to island. Comparison with sediment maps of the adjacent seafloor suggests that the islands were built by the waves. Shape sorting reveals that the percentage angular grains in the samples increases towards the north. It is held that this reflects the roundness distribution of the sands of the seafloor, produced by current action.

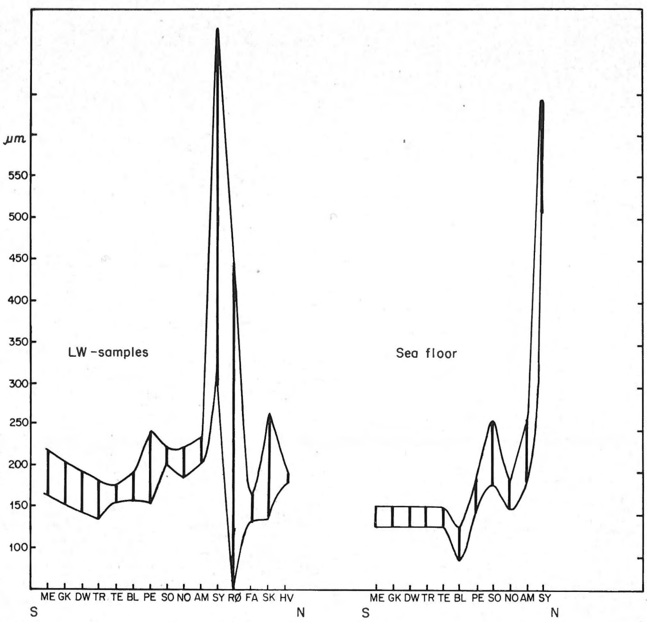


Fig. 3
Correlation between median diameters in sieve fractions of sands from the seafloor (right graph, Ludwig & Figge, 1979) and average median diameter with standard deviation (left graph, this study). ME–Alte Mellum, GK–Grosser Knechtsand, DW–Duhner Watt, TR–Trischen, TE–Tertius, BL–Blauortsand, PE–St. Peter-Ording, SO–Süderoogsand, NO–Norderoogsand, Am–Amrum, SY–Sylt, RØ–Rømø, FA–Fanø–, SK–Skallingen, HV–Hvidbjerg.

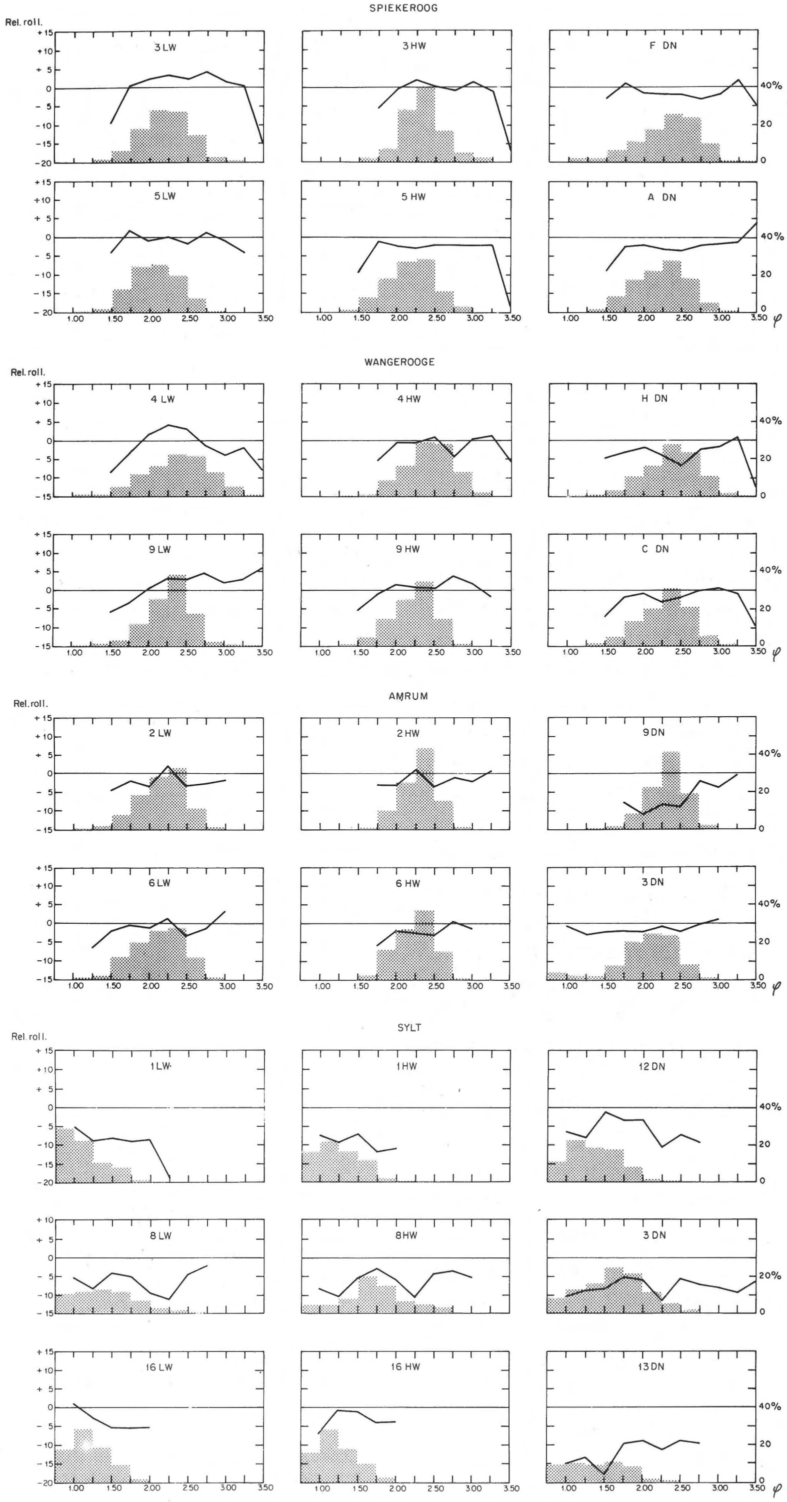
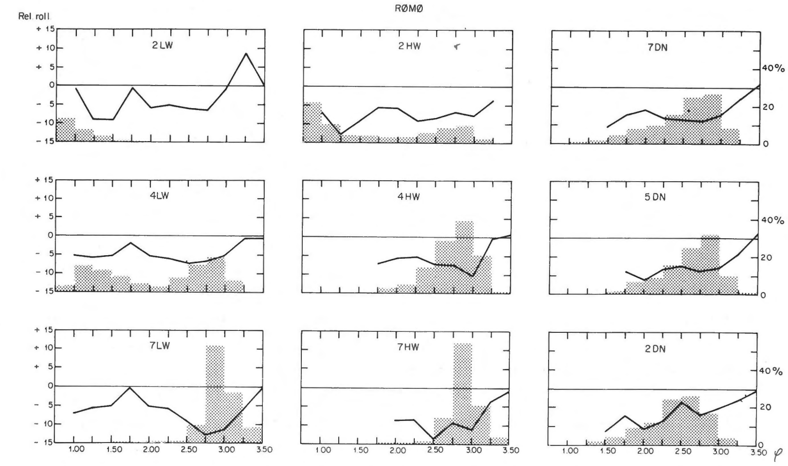


Fig. 4 (this and facing page)
Rollability diagrams of selected samples. Scale on the left marks relative rollability, scale at the base phi-values. Scale on the right marks weight percentage of the size histograms. Above zero level positive rollability, which means rollable grains. Below zero level negative rollability, which means angular or tabular grains.

RØMØ



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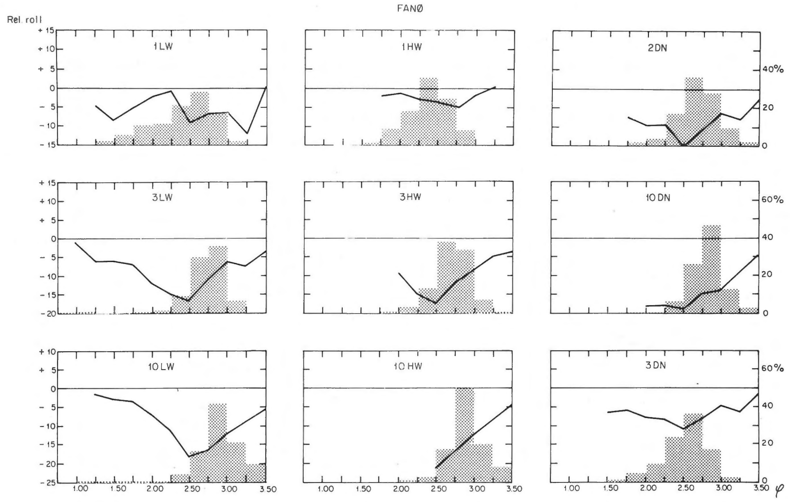
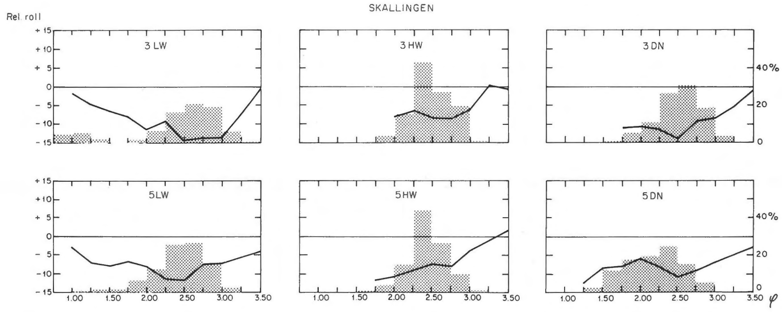


SKALLINGEN



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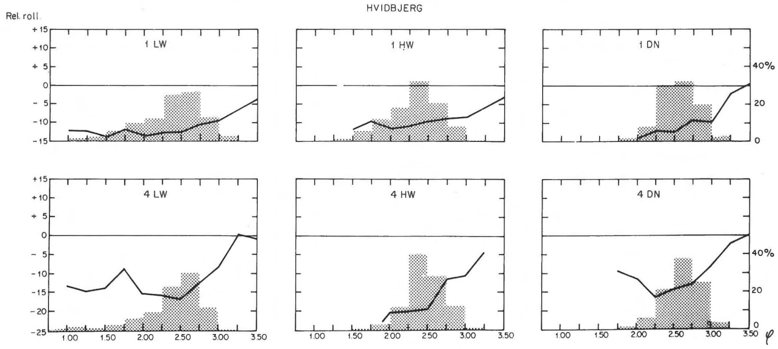

The spit of Skallingen shows a decreasing angularity of the sand grains towards its end, probably caused by predominant shape selection through erosion of the coastline.

The rollability analysis shows that the dune sands generally contain more angular grains than the adjacent beach sands, because angular grains are easier picked up by the wind than rounded grains of the same size.

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