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SIZE, SHAPE AND ORIGIN OF THE SANDS OF THE EAST FRISIAN ISLANDS (NORTH SEA, GERMANY)[1]

H. J. VEENSTRA[2]

ABSTRACT

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Beach and dune quartz sands of the East Frisian Islands (Germany) demonstrate an irregular tendency of coarsening eastwards. The sands contain flint, feldspar and igneous fragments. The sediments of the offshore probably determine grain-size of the sands: the coarse fractions are derived from reworked Pleistocene sands at Borkum Rough and Wangerooge Ground.

On each island the dune sands form one population in size and shape. By means of rollability analyses it appears that the dune sands are more angular than their source, the beach sands.

INTRODUCTION

Study of the sands of the West Frisian Islands (the Netherlands) revealed a diminution in grain size towards the east (VEENSTRA & WINKELMOLEN, 1976). This holds true for samples collected at the LW-mark, at the HW-mark, or at the dune foot of foredunes or inner dunes. It appeared that the sands of each island differed in size from the sands of the neighbouring islands. Moreover, investigations of the sand transport in the tidal inlets between the islands indicated that the influence of longshore transport is not so important as thought half a century ago. Most of the sand is trapped in the tidal deltas and migrates along a circular path in the inlets (BRUUN & GERRITSEN, 1959; WINKELMOLEN & VEENSTRA, 1974).

A correlation between tidal range and coastal morphology has been found in the German Bight (HAYES, 1975). It needed investigation to establish whether a relation between tidal range and grain size did exist. Sand samples have been collected on all islands and sand banks of the German Bight This article deals with the East Frisian Islands (Germany) (Fig. 1), that form the continuation of the West Frisian Islands (The Netherlands).

[1] Manuscript received: 1980-12-30.
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[2] Geological Institute, Rijksuniversiteit Groningen, Melkweg 1, 9718 EP Groningen, The Netherlands.

METHODS

It is widely known that the grain size of beach sands strongly varies, even on a small stretch of beach. The grain size is dependent on the location of the sample in the ridge and runnel systems of the beach. Also differences in size, density, sorting and shape will be found between samples from the LW-mark and samples from the HW-mark (MILLER & ZEIGLER, 1958).

To compensate for size variations, sand laminae were collected at the LW- and the HW-mark at the same time. The dune samples were taken at the base of the foredunes and inner dunes of the islands. The samples weighed about 100 g.

A comparison of the sand of various beaches makes sense only, if the sampling has been carried out in the course of a few days and in a period without strong winds.

In each sample the $CaCO_3$-content has been determined with a Ph-meter with Ca-electrode. After mechanical sieving in each sample the median diameter and the sorting coefficients have been calculated.

OBSERVATIONS

The samples have been collected between 11 and 22 July 1977, a period of quiet weather. The beach samples are spaced at 1 km intervals, the dune samples have a random distribution over the islands (Fig. 1).

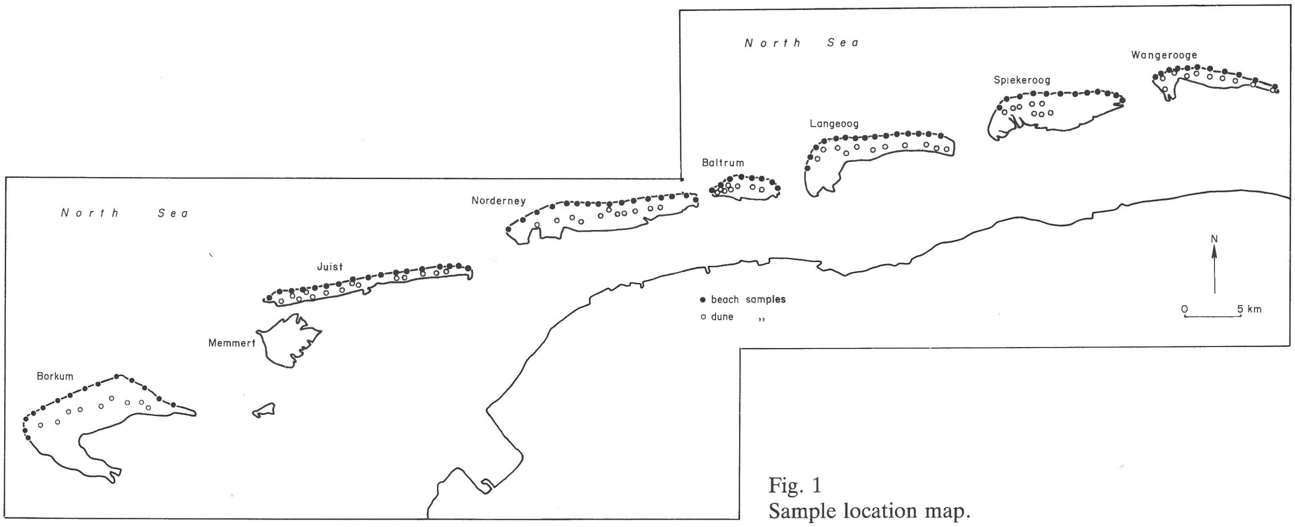

Fig. 1
Sample location map.

Grain size

Low water samples – The average median grain size of the samples collected at the LW-mark points to some eastward coarsening of the lower part of the foreshore of the island beaches. The LW-samples of Juist and Norderney are coarser than those of Borkum, and the LW-samples of Langeoog, Spiekeroog and Wangerooge are coarser than the samples of Baltrum. However, the samples of Langeoog-Wangerooge seem somewhat finer than the samples from Juist-Norderney (Fig. 2). As can be seen in Table I, the standard deviation of the LW-samples is large, which is caused by the variation in grain size of the samples, due to migrating ridge and runnel systems on the foreshore.

The average Trask sorting values vary between 1.16 on Borkum and 1.32 on Baltrum, which means that the sands at the low water line are well-sorted. The average $CaCO_3$ content of the LW-samples varies between 0.5 and 1.1%, which mainly depends on the quantity of shell fragments in the samples.

High water samples – With the exception of Borkum the HW-samples show an eastward coarsening (Fig. 3), whereas the average median is lower than in the LW-samples (Table I). The standard deviation of the medians is lower in the HW-samples than in the LW-samples due to a smaller variation in size distribution. The same trend has been found on the West Frisian Islands (VEENSTRA & WINKELMOLEN, 1976). The sorting of the HW-samples varies between 1.13 on Juist and 1.20 on Baltrum, which is well-sorted and better than the sorting of the LW-samples. The average $CaCO_3$ content of the HW-samples varies between 0.4 and 1.8%, which mainly depends on the amount of shell hash in the samples.

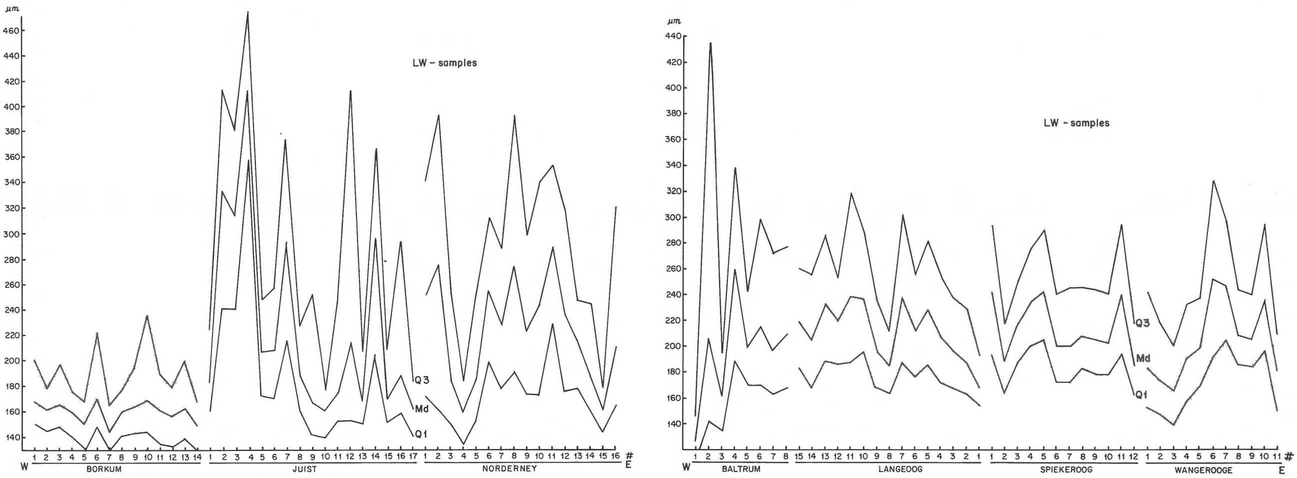

Fig. 2
Size parameters of LW-samples of the East Frisian Islands.

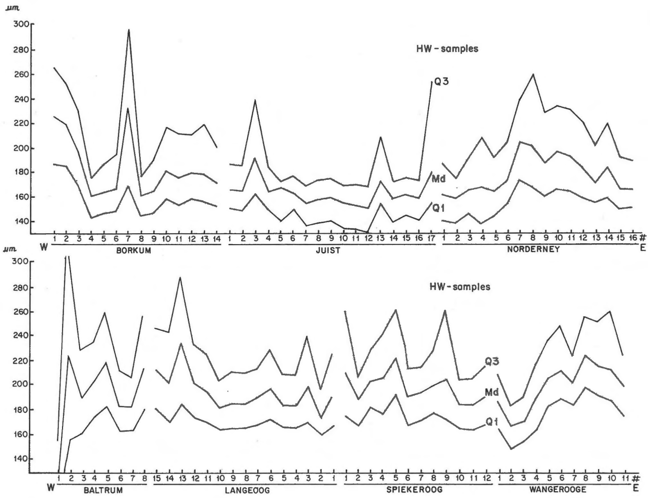

Fig. 3
Size parameters of HW-samples of the East Frisian Islands.

Dune samples – It appears that the average median grain size of the dune sands does not differ much from the median of the HW-samples. The same has been found on the West Frisian Islands. The general trend is a coarsening eastward, with the exception of Baltrum (Fig. 4), which has finer sand than its neighbours (Table I). The dune sands are well-sorted. The standard deviation of the medians is smaller than those of the beach samples, which suggests a rather homogeneous composition of the islands. The average $CaCO_3$ content varies between 0.02% on Spiekeroog and 1.1% on Juist. In most cases the dune samples have a lower $CaCO_3$ content than the beach samples, due to decalcification.

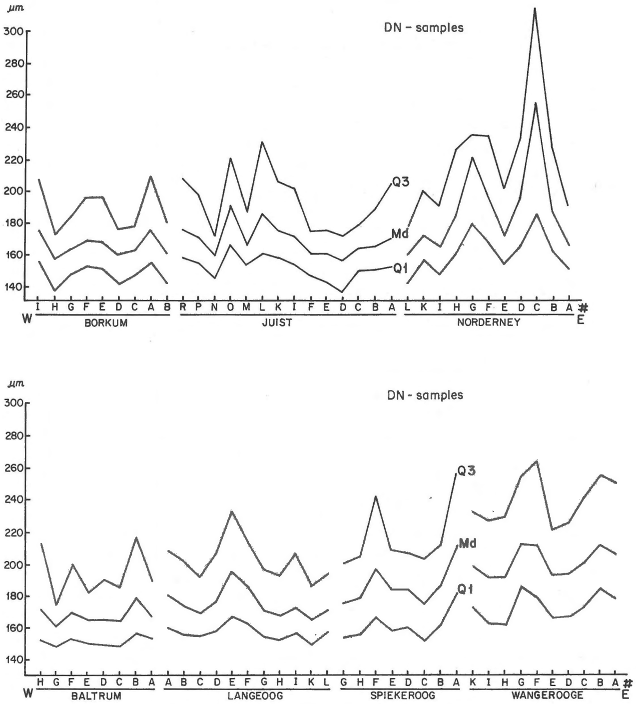

Fig. 4
Size parameters of DN-samples of the East Frisian Islands.

Table I
Number of samples, average median size and sorting, and average $CaCO_3$ content of all samples.

Island	LW-samples	HW-samples	DN-samples	Tidal Range (m)
BORKUM				
No.	14	14	9	
Md (µm)	160 ± 8	184 ± 24	166 ± 6	2.3
So	1.16	1.16	1.13	
$CaCO_3$%	0.6	0.4	0.2	
JUIST				
No.	17	17	14	
Md (µm)	226 ± 75	164 ± 10	171 ± 9	2.3
So	1.26	1.13	1.13	
$CaCO_3$%	1.1	0.9	1.1	
NORDERNEY				
No.	16	16	11	
Md (µm)	224 ± 40	179 ± 16	190 ± 28	2.4
So	1.31	1.17	1.17	
$CaCO_3$%	1.1	1.3	0.6	
BALTRUM				
No.	8	8	8	
Md (µm)	198 ± 39	192 ± 29	169 ± 6	2.4
So	1.32	1.20	1.13	
$CaCO_3$%	1.0	0.7	0.4	
LANGEOOG				
No.	15	15	11	
Md (µm)	212 ± 22	191 ±15	176 ± 9	2.6
So	1.20	1.15	1.13	
$CaCO_3$%	1.1	1.8	0.1	
SPIEKEROOG				
No.	12	12	8	
Md (µm)	214 ± 20	195 ± 12	187 ± 12	2.7
So	1.18	1.15	1.16	
$CaCO_3$%	0.5	0.6	0.02	
WANGEROOGE				
No.	11	11	10	
Md (µm)	204 ± 30	194 ± 18	201 ± 8	2.8
So	1.21	1.14	1.18	
$CaCO_3$%	0.6	0.4	0.1	

Shape

With the method developed by WINKELMOLEN (1969, 1971) the rollability, which is controlled by the shape of the grains, was determined in all samples. In figure 5 the results of three samples (LW, HW, DN) are shown for each island.

The zero level in the rollability graphs is the same level as the one used in the West Frisian Islands (WINKELMOLEN & VEENSTRA, 1974, 1980; VEENSTRA & WINKELMOLEN, 1976). There is a tendency for the LW-samples to show a higher positive rollability than the HW-samples. Contrary to the beach samples, the dune samples have a definite negative rollability.

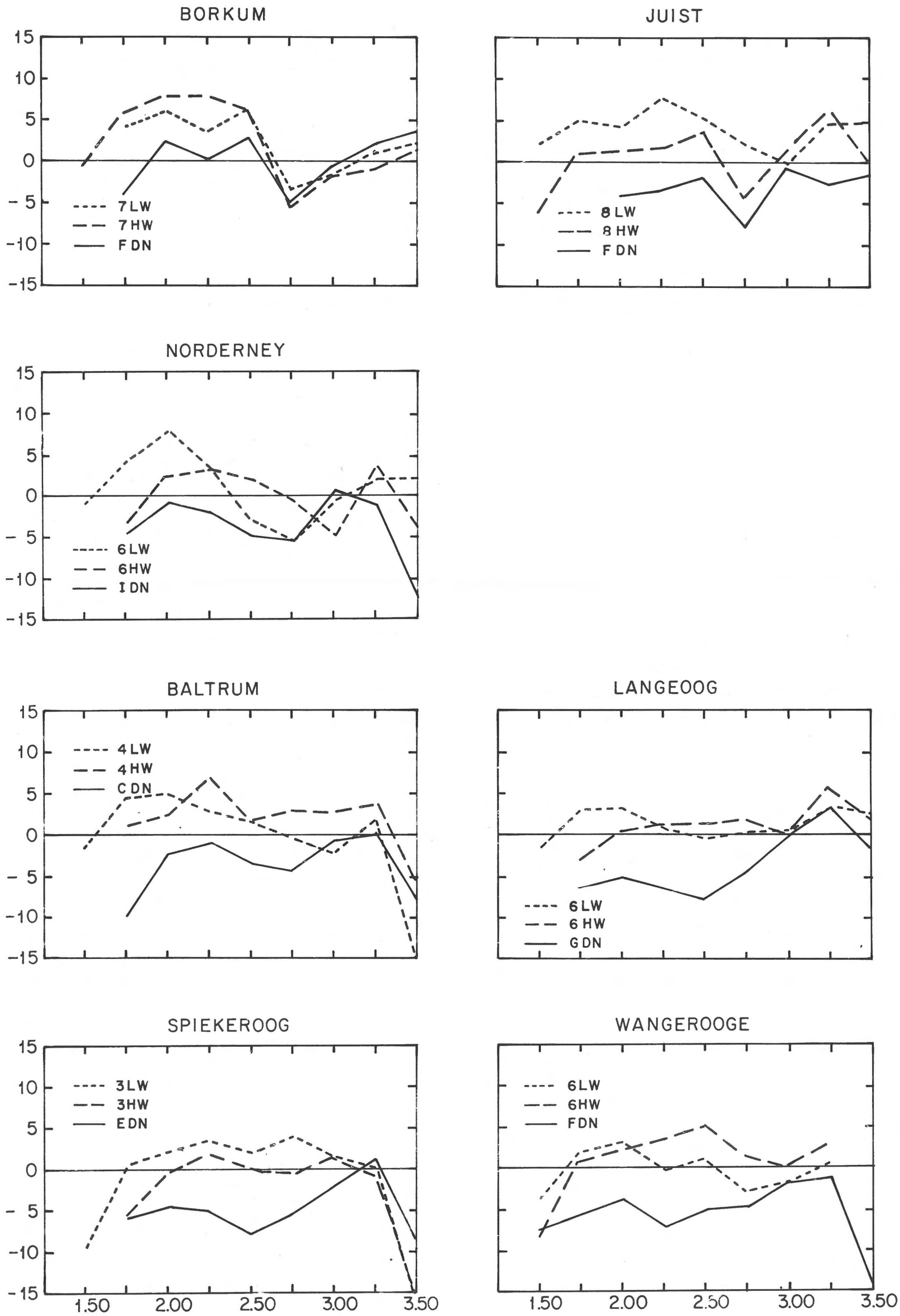

Fig. 5
Comparison of rollability diagrams of three samples (LW, HW, DN) per island. Above zero level positive rollability, which means rollable grains. Below zero level negative rollability, which means angular or tabular grains. Scale on the left marks relative rollability, scale at the base phi-values.

Composition

The sieve fractions of the samples have been searched by microscope for characteristic grains. All sands are chiefly quartz sands. Especially in the fractions 355-710 µm flint, feldspar and igneous rock fragments were found in the beach samples. Many dune samples also contained flint and feldspar fragments. The sands of all the islands contain these fragments but even for Borkum and Juist, which have the largest admixture, they never exceed 0.5%.

DISCUSSION

How can the coarsening of the sands of the islands in an easterly direction be explained? Three possibilities will be dicussed here.

(1) The East Frisian Islands are the remnants of a spit. As spits generally show fining towards their end, the hypothetical spit should by connected with the mainland at its eastern part. The Weser and Elbe should have supplied the sand, although no Holocene river sands are known in the area. The hypothesis is rejected, because about 12 old Holocene inlets of over 20 m depth are found under the islands (SINDOWSKI, 1973).

(2) There has been a winnowing eastwards of the sands, caused by longshore currents and dispersal of the fines seaward by tidal currents. This process is known from the English east coast (MCCAVE, 1978), where tidal currents of 3.5 knots are known. As the longshore currents along the islands are not very strong, generally less than 0.25 knots, and the force of the tidal currents does not surpass 1.5 knots at springtide, this hypothesis is discarded also. Moreover, no good correlation has been found between the tidal range, which is steadily rising eastwards, and the grain size of the samples, which is irregularly increasing eastwards (Table I).

(3) The sands of the East Frisian Islands are derived from the sediments of the seafloor. Thus coarse offshore sediments of the seafloor give rise to coarse beach sands and fine offshore sediments to fine beach sands. As will be described below, there are many arguments in favour of this theory.

Composition of heavy mineral placers along the German beaches (LAMCKE, 1938) revealed that the longshore sand transport from W to E along the East Frisian Islands was not very important and that the main supply of sand came from the seafloor. From the position of the East Frisian Islands in historical times SINDOWSKI (1963) drew the same conclusion.

The composition and quantity of the heavy mineral fraction showed an abrupt change at Baltrum (WASMUND, 1938; LÜTTIG, 1974). East of Baltrum the heavy fractions contain more ilmenite than garnet, but westwards more garnet. This is in accordance with the present grain size study, in which at Baltrum the sands are finer than should be expected from the general trend, which is a coarsening eastwards.

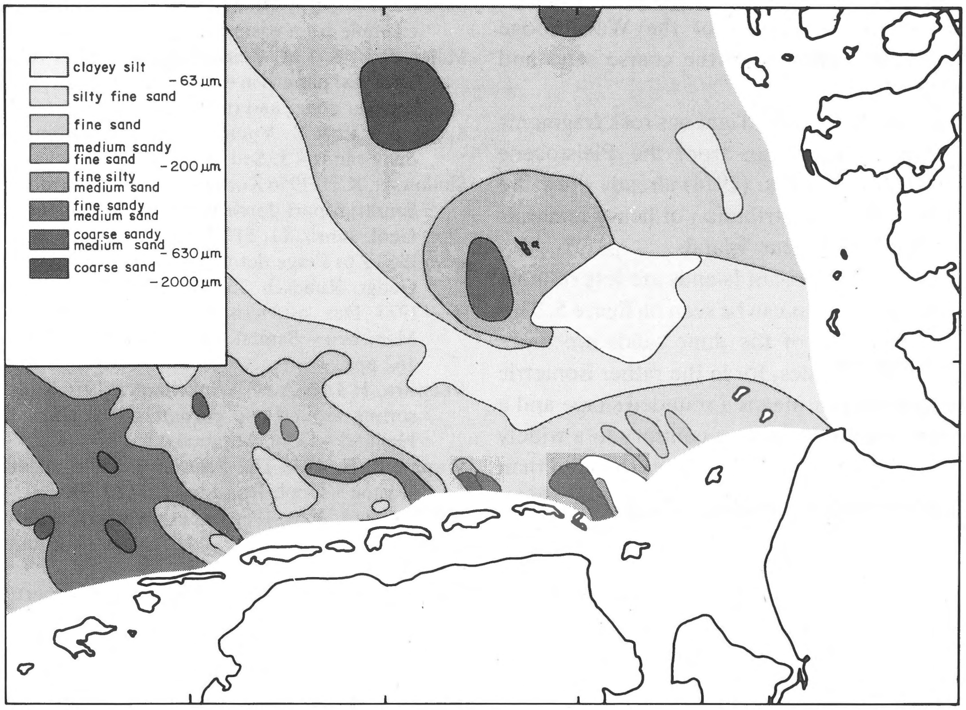

Fig. 6
Bottom chart of the German Bight (mainly after Gadow & Schäfer, 1973).

The beaches of the western parts of Juist, Baltrum, Langeoog and Spiekeroog are coarser than the eastern parts of the beaches of the same islands, whereas the western part of the beach of Wangerooge is finer than its eastern part. The sediment distribution map by GADOW & SCHÄFER shows a patch-like sediment distribution in the shallow offshore (Fig. 6). Coarse and medium sand patches are situated northwest of Juist, north of Langeoog, north of Spiekeroog and northeast of Wangerooge. It is held that the coarse sediment patches control the size distribution of the adjoining beaches.

The grain size of the seafloor sediments in the Southern Bight of the North Sea drops from medium sand (250-500 μm) off the Zeeland coast to fine sand (125-250 μm) off the NW part of the Netherlands (JARKE, 1956). On the other hand the beach sands of the Dutch west coast have a median grain size of 250 μm, whereas the median of the West Frisian Islands is generally between 160 and 200 μm. No doubt a relation exists between the grain sizes of the beaches and the source, the adjoining seafloor. As already shown by JARKE (1956) there is a gradual fining eastwards of the seafloor in the central part of the German Bight.

EISMA (1968) has given numerous size analyses of the shallow seafloor off the Dutch coast from Hoek van Holland to Ameland, whereas GADOW & SCHÄFER (1973) published numerous size analyses and a sedimentological map of the southern part of the German Bight between Borkum and the Elbe Estuary (Fig. 6). From their map it can be seen that there are two large areas with coarse sand off the East Frisian Islands: the Borkum Rough north of Borkum and the Wangerooge Ground north of Langeoog, Spiekeroog and Wangerooge. These areas consist of eroded Pleistocene boulder clay. The coarse sediments of the Wangerooge Ground are nearer to the coast than the coarse sand and gravel of the Borkum Rough.

The occurence of flint, feldspar and igneous rock fragments in the samples supports an origin from the Pleistocene sediments that lie off-shore. LÜTTIG (1974) already drew the same conclusion based on the distribution of heavy minerals on the seafloor off the East Frisian Islands.

The dune sands of all East Frisian Islands are less rollable than their source, the beaches, as can be seen on figure 5. This means that the quartz grains of the dune sands are more angular than those of the beaches, for in the rather isometric quartz grains a high roundness means a rounded shape and a low roundness an angular grain. This is contrary to a widely held opinion, that dune sands should be better rounded than the accompanying beach sands (SHEPARD & YOUNG, 1961). WINKELMOLEN (1969) already drew attention to this. He found that dune sands are more angular than beach sands. This should also be expected, as angular grains are easier picked up by the wind. The conclusions of SINDOWSKI (1956, 1973), who studied about 50 dune samples per island of Langeoog, Spiekeroog and Wangerooge, and could distinguish 4 dune types on each island with regard to grain size and roundness, can not be sustained. The dune sand samples in the present study were collected at random and number between 8 on Baltrum to 14 samples on Juist. The majority of the dune samples were taken from inner dunes, but foredunes were sampled as well. The median grain-size of the dune samples of each island has a small standard deviation. The rollability graphs of the dunes of an island do not show significant differences.

The conclusion is that the dunes are formed at present in the same way, i.e. under the same wind force, the same wind direction, and with the same density of vegetation as prevailed in the past centuries.

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