THE ORIGIN AND DESTRUCTION OF BEACH RIDGES

by

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Summary

During the Fall of 1945 the author measured daily the micro-topography of a beach profile at Zandvoort, the Netherlands. The daily changes and the movements of the beach ridges have been determined. Several beach ridges came into being and were destroyed during storms. The structure of the deposits has been studied.

Introduction

The surfaces of layers and laminae represent former planes of deposition or erosion. They formed once the surface of the land or the bottom of water covered areas. The study of the micro-topography of the surfaces of deposits in recent environments will lead to a better understanding of the origin of the structure of deposits in different environments.

In 1945 the author's attention was drawn by the rapid horizontal movement of ridges on the foreshore at Zandvoort in the Netherlands (figure 1). The micro-topography of the beach has been measured at regular intervals, first at each low tide, later-on only at times when interesting changes had occurred.

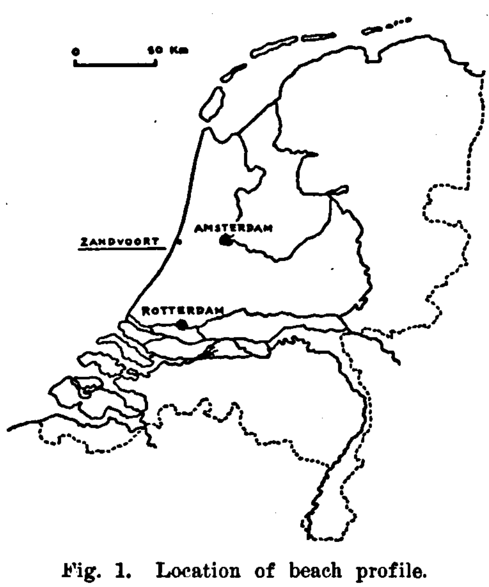


Fig. 1. Location of beach profile.

Terminology

Figure 2 illustrates the various terms used in this paper. Some confusion exists about the terms beach ridge, berm and double berm. J. A. STEERS (1948) and J. H. C. MARTENS (1939) clearly describe the ridges occurring on beaches. The Interim Report of the Beach Erosion Board of the U. S. Corps of Engineers (1933) does not show the typical ridge as it occurs on the Dutch beaches. The term berm is given to the horizontal or slightly landward sloping backshore. SHEPARD (1950) uses the term berm "for the highest part of the backshore and adds "double berm" for the more seaward part of the backshore when a second scarp is present. SHEPARD mentions that the double berms are due to aggradation and that "these double berms start developing during neap tides and are pushed landward during the succeeding spring tides".

The term "double berm" is thus equal to that of beach ridge as used by STEERS and MARTENS. The use of the word double berm for a terrace-like

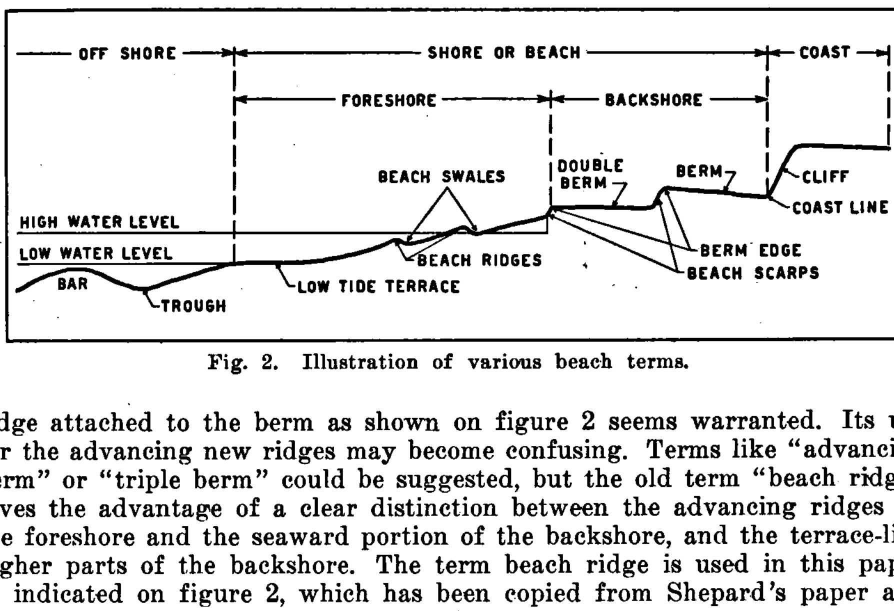


Fig. 2. Illustration of various beach terms.

ridge attached to the berm as shown on figure 2 seems warranted. Its use for the advancing new ridges may become confusing. Terms like "advancing berm" or "triple berm" could be suggested, but the old term "beach ridge" gives the advantage of a clear distinction between the advancing ridges on the foreshore and the seaward portion of the backshore, and the terrace-like higher parts of the backshore. The term beach ridge is used in this paper as indicated on figure 2, which has been copied from Shepard's paper and modified to show the beach ridges and swales.

Method of measurement

A simple method of measurement of the profiles could be used. At the beach the horizon is a level point. The top of a tripod was used as fixed point on the beach. The relative height of a point of the beach was measured by looking along a calibrated pole placed at that point towards the horizon and noting the height above the beach at which a line over the top of the tripod to the horizon crossed the pole. Spots at a distance of 20 m from the tripod could be determined with an accuracy of 0.5 cm.

The tripod was replaced after measuring each 20 m of the profile. Its height with respect to the already measured section was determined carefully.

Points at intervals of 2 or 5 m along the section were determined. When steep slopes occurred more observations were made.

The top of an iron well at the foot of the dunes was used as zero point for all measurements. The height of this zero point above sealevel was determined by the Department of Rebuilding (Wederopbouw) at Zandvoort. The zero point of the profiles on the figures 4—7 is 296 cm above N. A. P. (mean sealevel).

Grain size of the beach sands

The size frequency distributions of the beach sands along the Dutch coast have been studied by the author (DOEGLAS, 1950). The size frequency distributions of samples in the surrounding of the profile described are shown in figure 3. The medians vary between 190 and 230 microns, the largest

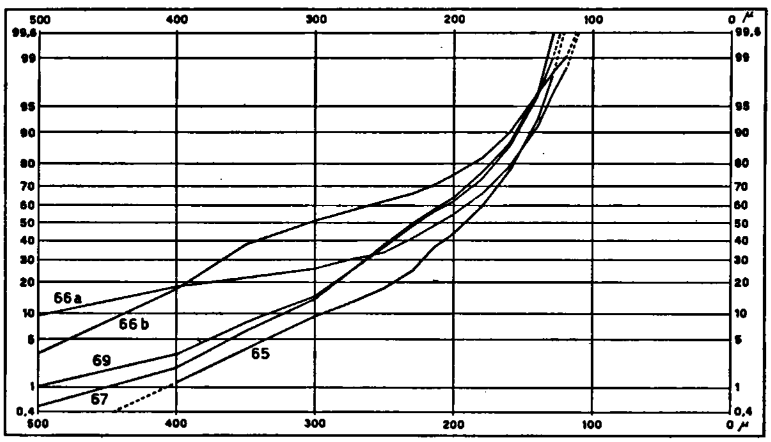


Fig. 3. Size frequency distributions of beach sands at Zandvoort. Numbers indicate kilometer poles.

quartile (Q_3) between 230 and 270 and the smallest quartile (Q_1) between 160 and 190 microns. The smallest grains have a diameter of 125 microns. Log So (geometric) is about 0,08 and the log Sk (geom.) —0,015. The content of calcium carbonate varies strongly. The average is 6 %. The main component of the sand is quartz.

Meteorological data

The meteorological conditions during the period of investigation are given in table I. These data have been obtained from the meteorological station at Castricum, 8 miles north of Zandvoort.

Waves and tides

Wave heights and periods have not been determined. Methods for an accurate measurement were not available. The height of the surf has been estimated. During east winds the surf height did not become higher than 0.5 m. During the stormy days estimation was difficult. The horizon could

TABLE I.

Wind direction and velocity, in meters/second at 2 p. m.[1]			Mean wind velocity in meters/second
October 1945			
10	SSW	7.6	5.4
11	NE	3.7	3.4
12	SW	1.5	0.8
13	NNW	3.1	2.5
14	NW	4.0	3.6
15	NNW	4.4	3.6
16	W	4.5	3.2
17	NNE	4.0	2.1
18	ENE	3.3	1.6
19	E	3.7	2.7
20	S	3.5	2.7
21	SSE	4.0	3.1
22	SW	6.3	5.2
23	SW	10.8	7.7
24	SW	10.1	8.8
25	SSW	10.3	9.7
26	WSW	14.7	13.3
27	WNW	7.7	8.0
28	ESE	4.9	3.7
29	S	4.8	3.2
30	SW	3.5	1.6
31	NE	1.6	2.4
November 1945			
1	ENE	4.8	4.3
2	SSE	1.4	1.2
3	SW	3.0	2.1
4	E	4.4	3.6
5	ESE	2.8	2.6
6	NNW	1.8	1.2
7	WNW	2.1	2.0
8	NW	10.2	8.5
9	NE	6.7	6.7
10	ENE	5.8	5.4
11	NNE	5.6	4.8
12	NE	4.0	2.4
13	ENE	2.8	2.4
14	E	2.5	2.2
15	S	0.7	1.0
16	ESE	2.7	2.4
17	ESE	6.1	5.0
18	NE	4.7	4.4
19	E	3.7	3.4
20	E	0.3	1.1
21	ESE	2.5	2.3
22	E	3.7	3.1
23	ESE	4.5	4.0
24	E	3.2	2.8
25	WNW	0.8	1.3
26	NE	5.9	4.7
27	NW	3.0	3.7

[1] all data for Castricum.

not be seen due to clouds and the spray of water caused by wave action. During the periods of strong erosion of the beach the inner surf waves were more than 2 m high.

The difference between low and high tide is about 1.50 m. The highest level reached by the swash is given on the profile of the figures 4—7. With offshore wind the swash did run up to 100 cm above mean sealevel. On the days with stormwinds from the west the swash reached 2.60 m above mean sealevel.

Spring tide occurred on October 24 and November 21, and neap tide on November 7.

Measurement of the profile

The profiles of the beach at kilometer pole 67 are illustrated in the figures 4—7.

Figure 4 shows the changes on October 19, 20 and 21. On the 19th and 20th measurements were made at each low tide. On the 21st and following days only one observation could be made as the low tide was late in the afternoon.

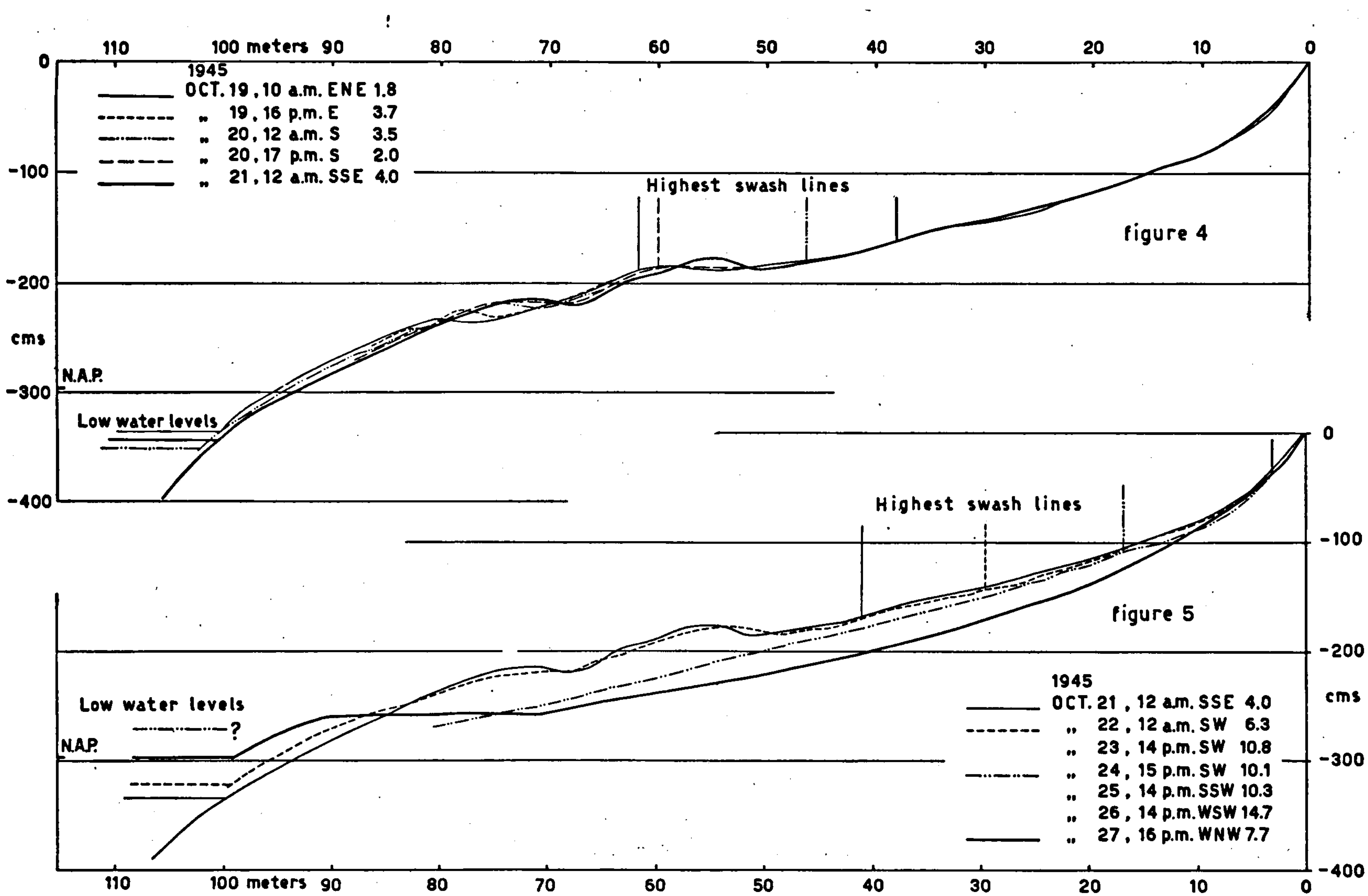
The wind changed from eastnortheast to east and south on the 21st. Wind velocity was small, 1.8—4.0 m/sec. Only small surf waves about 20 cm high occurred and the mean water level was lower than normal, except on October 21. On the 19th the upper ridge was not covered by water and, therefore, did not change. The top of the lower ridge, however, moved 240 cm landward and grew 9 cm higher. During the night (19-20 October) both ridges moved landward. The crest of the upper one moved 100 cm without increase in height, that of the lower ridge moved 380 cm and heightened 6 cm. The high tide in the afternoon of the 20th moved the lower ridge about 90 cm landward with only a slight increase of height. The ridge flattened and grew broader. The shape of the upper one changed little. Forward movement did not take place and the height did not alter.

In the night between October 20 and 21 both ridges moved rapidly landward due to a higher water level caused by the approaching spring tide. The lower one moved 100 cm, the upper 300 cm landward with an increase in height of respectively 2 and 9 cm. In the afternoon of October 21 the wind changed from south to southwest (velocity 6.0 m/sec) on the morning of the 22nd. Two tides elapsed before the next observation which took place on the 22nd at 12 a.m. (figure 5). Only the upper ridge had moved 120 cm landward. Both features, however, had flattened out. The height of the lower ridge decreased with 6 cm and the upper one with 1 cm.

The backshore surface had been eroded by the wind and became 4 cm lower.

On October 23 the southwest wind increased to 10.8 m/sec. The surf was high (estimated upon 2.00 m). The horizon was not clear and measurements were not made. The storm continued untill the 27th. Wind velocity increased to 14.7 m/sec on the 26th. The wind direction varied between westsouthwest and south.

In the afternoon of the 24th the profile could be measured with difficulty and is not very accurate due to the strong wind. The ridges were entirely absent and the beach was respectively 32 and 29 cm lower at the spots where they had occurred. Three days later (27th) the lower part of the



Figs. 4 and 5. Beach profiles between October 19 and 27, 1945.

beach was entirely flat and nearly horizontal. A low tide terrace had been formed. Figure 5 shows that the spot where the upper ridge occurred (80 m from zero point) was again 19 cm lower. The seaward part of the low tide terrace was 11 cm higher than on the 24th. This gave the impression that a new ridge was building up (the measurements of the 24th, however, were not accurate).

No survey was made on the 28th. On October 29 a small ridge had been formed at the outer edge of the flat beach. This ridge enlarged and moved rapidly landward during the following days. On October 31 it was already 46 cm high (figure 6). The steep landward edge moved 800 cm and increased 17 cm in height between November 1 and 7. Neap tide occurred on November 7. The suggestion given by SHEPARD (1950) that the addition of sand to the berm occurs during advancing spring tides, when sand ridges are moved landward due to rising tide levels, is only partially true. New ridges are also added during neap tides when wind and wave conditions are favorable.

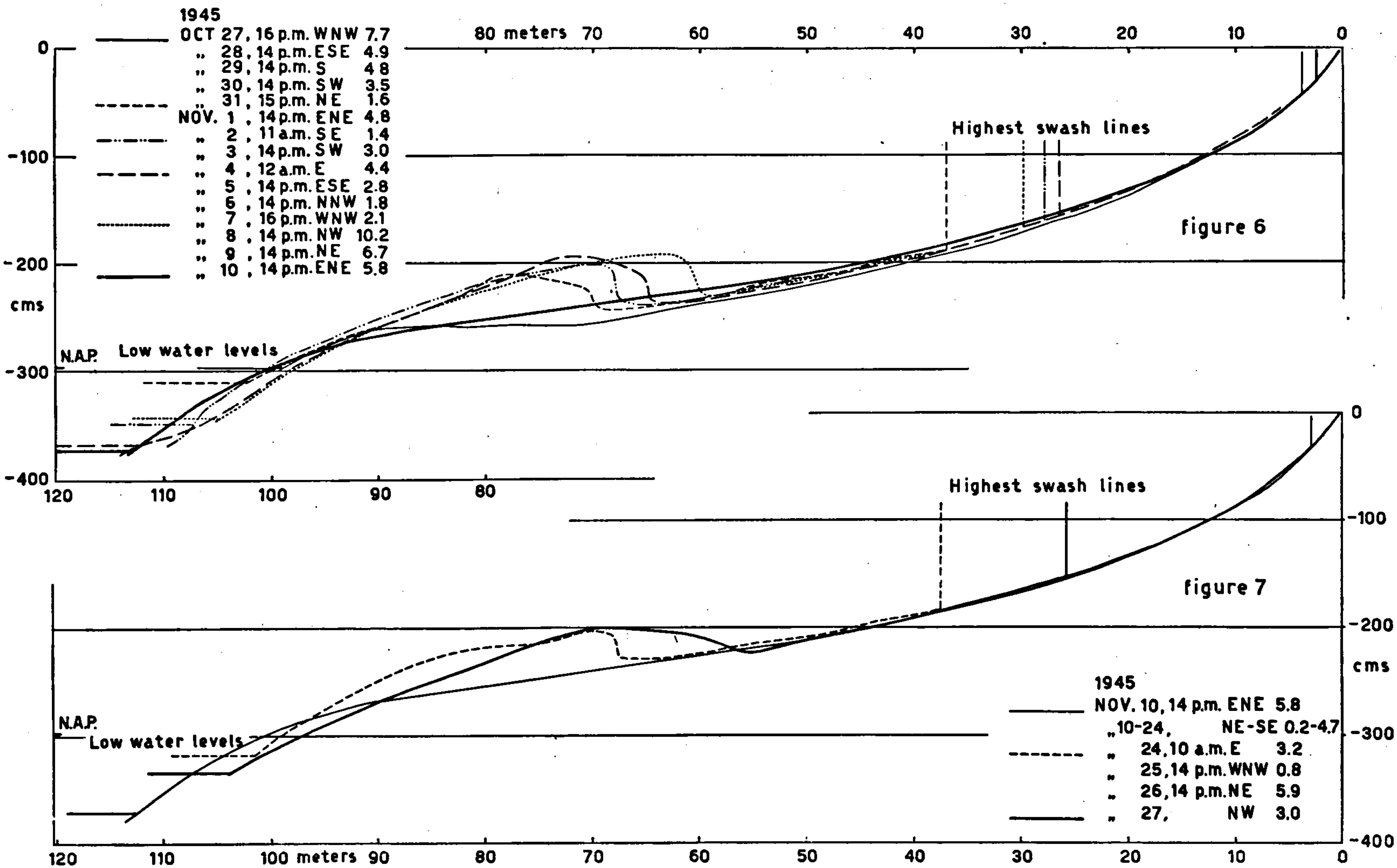
On November 8 the northwest wind suddenly increased to 10.2 m/sec and changed to eastnortheast. The ridge disappeared entirely, lowering the beach at this point 37 cm. The area between the ridge and 30 m landward increased 4 cm in height. Part of the ridge material had been spread landward, the rest seaward.

The following 14 days the wind remained continuously seaward (NNE—ESE) and was not strong (table I). No measurements were made during this interval. Observations showed only minor changes daily. The total change can be observed in figure 7. The last measurement was made on November 27th. The landward side of the ridge moved in 3 days 900 cm. The height hardly varied. The landward edge was less steep, probably due to the stronger wind, on November 26.

The variations of the beach ridges shown in the figures 4—7 occurred equally over a distance of more than 500 m. At both ends of the ridges shallow transverse gullies (rip channels) existed which drained the swale behind the ridge at low tide. Other ridges occurred over a long stretch along the beach. About 3 km north of Zandvoort they pinched out. The beach there was broader and flatter. Towards the south, however, the ridges succeeded each other for more than 4 km. Due to mine fields observations further south could not be made.

The changes of the cross sections of the rip channels were small. One time they got deeper, another time more shallow or they disappeared entirely. These variations are due to changes in the position and shape of the beach ridge and the swale landward of it. When the swale is filled, the outflow of water decreases. This lessens the erosion in the gully. The direction and strength of the wind, the height of the tide and waves are secondary influences.

During the growth and movement of the ridges the slope of the outer foreshore increases and the low water line moves landward. The width of the beach becomes smaller. After strong erosion during strong on-shore wind the beach gets lower and wider.



Figs. 6 and 7. Beach profiles between October 27 and November 27, 1945.

Amounts of sand transported during aggradation and erosion

Table II gives an insight of the quantities of sand transported during aggradation and erosion. The data have been calculated from the profiles for a strip, with a width of one meter, perpendicularly to the coast.

The quantity of sand building up a new ridge is generally larger than the amount eroded from the foreshore. A supply of sand from the bottom of the trough between the coast and the first sub-marine bar, from the first sub-marine bar itself and further seaward is necessary.

TABLE II. QUANTITIES OF SAND DEPOSITED OR ERODED AND WIDTH OF BEACH.

Date	Quantity of sand supplied (+) or eroded (—) in cubic meters				Width of beach from zero point to mean sea-level in meters
	Outer foreshore above low water	Ridges	Backshore	Total	
October					
19	n. d.	n. d.	n. d.	n. d.	95.5
20	n. d.	n. d.	n. d.	n. d.	94.1
21	— 2.74	+ 1.33	—	— 1.4	93.0
22	+ 0.15	— 0.15	— 1.80	— 1.8	95.3
24[1]	?	— 14.4	—	— 14.4	?
27[1]	+ 4.8	— 10.8	—	— 6.0	98.2
31	+ 0.4	+ 7.0	—	+ 7.4	98.6
November					
2[2]	n. d.	n. d.	n. d.	n. d.	100.0
4	n. d.	n. d.	n. d.	n. d.	97.5
7	— 1.4	+ 6.8	—	+ 5.4	97.2
10[1]	+ 4.8	— 9.2	+ 2.0	— 2.4	99.8
24	+ 0.3	+ 8.0	—	+ 8.3	98.2
27	—	+ 3.6	—	+ 3.6	96.1

[1] Days with strong on-shore wind.
[2] New supply of sand on foreshore.
n. d. = not determined.

When the beach is eroded more sand is moved from the backshore than is laid down on the foreshore. The first sub-marine trough deepens during strong west wind. Sand thus is transported to deeper water.

The strong erosion of the bottom of the first sub-marine trough proves that long-shore currents occur in the trough and that sand must be transported in the same direction. The distance along the shore, however, is not large. The water flows out to the sea through channels which cross the bars. The currents in these channels (rip currents) are very strong. The direction of the currents in the sub-marine trough depends on the bottom topography, the direction of the wind, the tidal currents and the height and period of the waves (SHEPARD, EMERY and LAFOND, 1941). During aggradation the sand probably is transported towards the beach by landward movement of the sub-marine bars and not by long-shore currents through the troughs.

The width of the beach varies rapidly (table II). Between October 21 and November 2 a difference of 7 m was measured at mean sealevel.

During the landward movement of the beach ridge the swale on its landward side sometimes is deepened due to erosion of the upper beach by water running back to the sea. In other cases the depression is being filled with fine sand transported by the swash. Ripple marks are common and have their axes mainly normal to the coast line. At the end of the ridges deep holes may be formed by swift seaward currents.

After rapid forward movement of the ridge its landward edge is steep (about 38°). The crest is then at the landward side. Sometimes, however, the top occurs in the middle of even more seaward, e.g. October 31, November 4 and 24. This is due to the presence of a new layer of sand moving landward over the front slope of the ridge. This could be clearly observed on November 24 (figure 7) at a point 74 m from zero point. The day before November 24 a strong east to eastsoutheast wind occurred. On November 2 a new top layer covered the slope of the ridge seaward of point 76 m. On November 4 this layer with a thickness of about 7 cm had moved landward and formed the top of the ridge. On November 1 a rather strong eastnortheast wind probably caused the extra supply of sand. Just before the measurements started on October 19, strong east winds occurred forming the outer ridge. A similar increase in height of the front slope occurred on October 22.

The conclusion can be drawn that seaward wind always causes aggradation. The supply of sand must be mainly caused by the landward undercurrent which compensates the lowering of the sealevel due to the off-shore wind. Wind parallel to the coast and on-shore wind can cause aggradation and erosion. The erosion of long-shore wind is not very strong. A slight levelling of the ridges occurs but they are not destroyed. Weak on-shore wind and the swell cause a medium surf which still can cause aggradation. Strong on-shore wind, however, erodes the beach. With a wind velocity of 6 m/sec slight erosion occurred and with a velocity of 10 m/sec the beach became entirely levelled. The height of the surf only could be estimated. Erosions seems to occur at a surf height of more than 2 meters.

During northwest, west or southwest storm the beach is strongly eroded. The top-layer remaining after the storm, however, clearly shows the structure it had before the storm. Only the top 2—5 cm have been reworked. The best example was found on November 10 (figure 6). The bottom layers of the beach ridge which had been formed between October 27 and November 7 were still present. The position of the swale could be located again between 45 and 55 m from zero point due to the presence of ripple marks and fine sand 4 cm below the surface. At 60—70 m from zero point the steeply dipping layers (oblique lamination) of the ridge were found 2 cm below the surface in a 10 cm thick layer.

On October 24 oblique lamination was found between 52 and 60 m from zero point. Figure 8 illustrates the oblique lamination and the swale deposits observed in June at that locality.

Aggradation of the backshore could hardly be studied. During the period of October 19 to 22 the backshore slightly lowered due to wind erosion. The storm of October 23—27 eroded the backshore considerably as indicated on table II. Between October 28 and November 7 slight aggradation took place by water action. Accumulation of fine sand occurred in the swale. Windblown sand covered the dry backshore. Between November 8 and 10 a thin layer of sand was deposited by the swash on the entire backshore.

The wind is able to cause considerable variations. This has been observed at the end of the storm of October 27. The sand was blown into 15—20 cm high ridges which made an angle of 70° with the coastline and stood normal to the direction of the westnorthwest wind. Sand vanes parallel to the wind direction also occurred. These, however, were seldom thicker than 3 cm. The eolian deposits were destroyed during the next high tide.

The higher part of the beach at Zandvoort is never covered with ridges. These are only built up to a level slightly above normal high tide. No oblique lamination has been found between zero point and 45 m seaward of it. The laminae in this area are practically parallel with the surface. The marine layers formed during high water, die out toward the dunes. The thickness of the eolian layers increases toward the foot of the dunes and then decreases again. In sections parallel to the coast these laminae have an elongated, lenticular shape. Their thickness varies between a few millimeter and 20 cm.

During a long interval without strong on-shore wind the beach is being built up to the highest level of the swash. The swale landward of the ridge gets filled up with sand and finally a berm is formed.

A new ridge can be formed on the lower foreshore. When sufficient supply of sand is present and on-shore storms are scarce a broad berm could be built up in this way. Along the Dutch coast this phenomenon seldomly is observed. On October 23 (figure 7) a small berm had nearly been formed.

In the United States of America berms are commonly present along the coasts of southern California and the Northeast Atlantic Coast. When these berms are broad the sea is not able to remove all the sand, even during storms, and a low scarp is formed. In the Netherlands this seldomly happens. Generally the foot of the dunes is eroded during storms and a scarp is formed. The dunes are located on top of the berm.

Structure of beach deposits

The structure of the deposits of the fore- and backshore can easily be deducted from the profiles. Figure 6 illustrates four stages of the development of a beach ridge. The structure of the ridge of November 7 (dotted line) contains laminae parallel to the surface of the ridges of October 31, November 2 and 4. The ridge overlies the erosion surface of October 27. The landward bottom portion of the ridge exists of nearly horizontal laminae of the swale over which the bar progressed.

Landward of the ridge slightly seaward dipping, thin layers of the swale and the backshore die out toward the dunes. These beds are elongated lenticular and deposited by the swash or the wind. Erosion by the wind lowers the entire backshore parallel to its original surface, leaving a kind of desert pavement consisting of shells. The swale deposits clearly show the wavy surface of ripple marks.

After the strong erosion during the storm of November 8—10, the top part of the ridge had been destroyed. Below the erosion surface the bottom portion of the ridge, however, remained. The oblique lamination of the bottom part of the ridge and the ripple marks of the swale could be observed in a

50 cm deep ditch, dug normal to the coast-line across the entire beach. Figure 8 shows the lamination of the bottom part of an eroded ridge with oblique lamination (central part of photograph) gradually merging into the undulating swale deposits to the right. The top layer of 2—5 cm thickness covering the remnant of the ridge and the swale has horizontal lamination. This is due to the small surf wave which is formed at the beach caused by the interaction of the swash and backwash. The water of the backwash runs in seaward direction under the advancing swash. The strong turbulence of the 5—20 cm high rolling wave reworks a few centimeter thick top layer. During ebbtide the entire surface of the beach between the high and low water level is reworked in this way. At the same time the swash leaves a 2—5 cm thick layer with fine lamination parallel to the surface on the landward side of the rolling wave. All former surfaces of a beach have such a thin parallel laminated layer. The layers below the ridge and swale of figure 8 belong to those top layers. When ridges are entirely destroyed after storm oblique lamination may be absent from beach deposits.

The grain size of the foreshore varies considerably. Layers with whole and broken shells alternate with coarse and fine sand layers. The oblique laminations of the ridges generally are coarser, the swale deposits consist of fine sand, sometimes with very small amounts of clay. The lowest foreshore shows the greatest variation.

In 100 cm deep pits on the backshore only lamination parallel to the surface has been found. The ridges do not reach the backshore. Laminae show a scattered distribution of shells and shell fragments. The deposits, however, are better sorted than those of the foreshore.

Dip of the deposits

The main planes of deposition are those formed during erosion. The lower foreshore laminations at Zandvoort had a seaward dip of about 1:20 (2° 52′). After a storm even 1:17 or 3° 22′ had been measured. The higher part of the foreshore on which the ridges occur had a seaward dip of 1:35 to 1:56 (1° 38′ to 1° 00′). The slope of the backshore varied between 1:30 and 1:25.

Fig. 8. Structure of beach deposits at Zandvoort. The sea is to the left. In central part oblique laminations of bottom part of ridge merging to the right into swale deposits. Note parallel lamination of top layer covering all deposits. Bottom layers, nearly horizontally bedded, have been formed during erosion. Length of profile 430 cm.

Conclusion.

The study shows that continuous microtopographic measurements of the surface of areas with active deposition and erosion will give a clear insight in the structure of the deposits. Measurements with longer time intervals (Shepard, 1950; Thompson, 1937; Wentholt, 1912) indicate the general tendency but are insufficient for an understanding of the different kinds of laminations. Beach deposits are only a minute part of sedimentary layers. The study, therefore, has a limited value. Similar continuous measurements of off-shore, fluviatile, deltaic and aeolian deposits will lead to a better understanding of the various structures in these deposits.

The present study shows that the laminations of deposits on the backshore differ from those of the foreshore. The backshore deposits have a horizontal or slightly seaward dipping, parallel lamination. The foreshore may have oblique lamination, steeply dipping landward in profiles normal to the coast and horizontal parallel lamination in sections parallel to the coastline. This parallel lamination is only interrupted by a few rip channels with oblique lamination in sections parallel to the coast. The oblique laminations on the foreshore, however, are generally destroyed by erosion during storms. Parallel lamination and bedding, parallel with the surface of eroded beaches and slightly concave upward, is left.

When oblique lamination in sections normal to the coastline is present, these oblique laminations overlie swale deposits with ripple marks. The axes of these ripple marks are mainly perpendicular to the coastline as they are formed by currents running behind the ridges and parallel to the coast. The direction of these currents depends mainly on the location of the rip channels. The main directions of transport on a beach are normal to the coastline in the beach ridges and the top layers of erosion surfaces. Layers below the ridges are deposits of swales in which longshore transport takes place. The backshore deposits have been deposited by the swash during spring tides and storms in the highest swales or by wind. The transport direction of the wind may vary. The material of the deposits of spring tides and storms will have been transported nearly normal to the coastline. Those of the highest swales will have had only low beach ridges on their seaward side and, therefore, will have undergone little long-shore transportation. The highest swales will contain deposits swept over the low beach ridge by the swash during spring tides nearly normal to the coastline or brought by the wind from various directions. These highest swale deposits form the highest, nearly horizontal, or slightly landward or seaward sloping part of the backshore, called berm.

The upper one to two meters of recent beaches will show more variation in structure than the older and deeper part. The latter consists more of deposits formed during erosion, except when strong aggradation or submergence occurs.

Shepard (1950) ascribes the aggradation and erosion of beaches mainly to wave height and period, long-shore currents, rip currents, slope, grain size and availability of sand. The direction of the wind is hardly mentioned. The influence of off- and on-shore winds on the level of seawater near the coast and the resulting undercurrents in land- and seaward directions are also of importance, especially on the beach itself.

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