## CHAPTER 50

# Dynamics and Morphology of Sand Banks in the Surf Zone of Outer Tidal Flats

by

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### 1. Abstract

Extended sand banks ranging up to some hundred acres with a crest height in the MHW-level are typical structures of the outer tidal flats of the south-eastern North Sea coast (Fig. 1).

Primary forms grow up in the surf zone at the sea-side tidal flat border. They are formed like bars and migrate towards the coast with a surprisingly high velocity, up to 150 m/year.

The movement is caused by strong erosion on the sea-side slope - which is shaped beach-like - and deposition at the steeper land-side (lee-side) slope.

It was found that surf action at the bar is linked with strong unidirectional currents across the crest, up to 100 cm/s. The currents are most likely generated by wave set-up in front of the bank and by wind-drift water motion.

The migration velocity of the sand banks decreases with increasing distance from the tidal flat border. This

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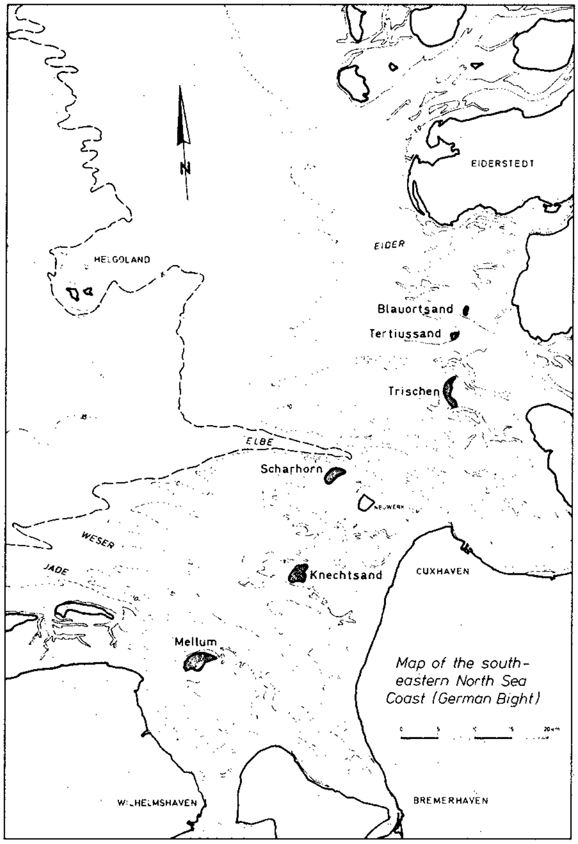


Fig. 1

effect seems to be most important when generation of new banks continues. It leads to "overtaking" and "interaction" of the single structures, thiswise growing together and building up the large sand banks as described above and gives an explanation of the development of large offshore sand banks and dune islands on tidal flats.

## 2. Sand Banks on the Outer Tidal Flats of the South-Eastern North-Sea Coast

Extended tidal flats cover the south-eastern North Sea coast from DEN HELDER, Netherlands to ESBJERG, Denmark. A chain of dune islands and large sand banks streches along the sea-side rim of this tidal flat region, the latter ones concentrating in the German Bight (Fig. 1).

Fig. 2
Aerial view of "Scharhörn", a sand bank in the tidal flats of the Elbe Estuary (German Bight, North-Sea)

Fig. 2 gives a look from a birds eye on the sand bank of Scharhörn in the Elbe Estuary, a typical structure of that kind. The bank or plate has an extension of more then 4 $km^2$, this area lying just a few cm above mean high water. Because of this height the plate cannot be generated by tidal currents. The sand on the top is coarser than the sand in the surrounding flats. That is the reason for the bright surface compared with the darker shining flats around, which are wet and partly muddy. The tidal range is about 3 m in this coastal region; the extended flats around the islands submerge during high tide and are then covered by a water layer of about 1.5 m.

We discover a tiny dune island at the north-western edge of the plate on the aerial photo indicating that sand transport by wind occurs. But there is no opportunity for growing up large dunes, and Scharhörn like the other plates in the vicinity (Mellum, Knechtsand, Trischen) cannot be compared with the well known large dune islands along the Dutch and German North Sea coast, to the west of the area plotted in Fig. 1.

## 3. Morphology of the Sand Bank of Scharhörn

The morphology of the sand banks in the German Bight has been studied by several authors (Ref. 4 to 10). The morphologic behaviour of Scharhörn, which is typical, shall be described in this paper, using the results of recent investigations.

Scharhörn as well as the other big sand banks are exposed to erosion at their sea-side shores. Due to surf action at their western flanks and deposition on the opposite sides the banks migrate slowly towards the east. Nevertheless we find high plates in most of these areas in the oldest charts, indicating that they are more or less stable though they are migrating, a fact which will be explained later.

The migration of Scharhörn is demonstrated in Fig. 3. Here the MHW-contour of the west and north-west shore is plotted in 4 different periods, beginning more then 100 years ago. The origin of the oldest survey is dubious and between 1868 and 1930 no surveys are available, so that we don't know what actually happened in that time. The average velocity of displacement is about 15 m/year, but it is decreasing in the last years, and it will be demonstrated that the migration will stop and even reverse temporaryly in the very near future.

On the aerial foto (Fig. 2) a smaller bank in front of the large plate is to be seen, having obviously a similar crest height and the same coarse sand on top (Fig. 4). This bank looks like a bar or a sand wave. It is several km long and several 100 m broad. A more or less sharp crest seperates the sea-side and the lee-side slope of the bar, the crest height being only a few cm below MHW. The sea-side slope is flatter than the lee-side one and is beach-shaped. The surface of the sea-side slope is doubtlessly formed by breaking waves.

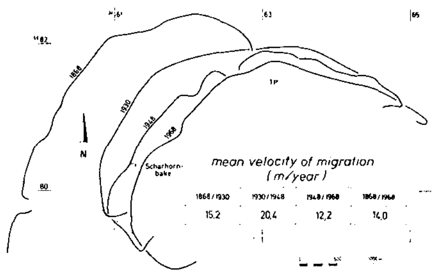


Fig. 3
Displacement of the MHW-contour of Scharhörn

The generation of this particular bar has been investigated by a series of consecutive levellings (Fig. 5) and aerial fotos (Fig. 6). Primary small accumulations of sand were observed in 1948 at the tidal flat border. They grew up to two sand waves, which began to migrate coastwards with a considerable speed. The plots in Fig. 5 and 6 give an impression of this displacement. It seems evident

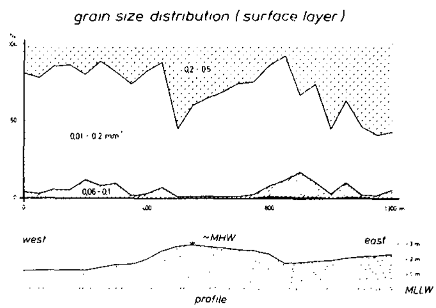


Fig. 4
Grain size distribution in a profile across the bar in front of Scharhörn

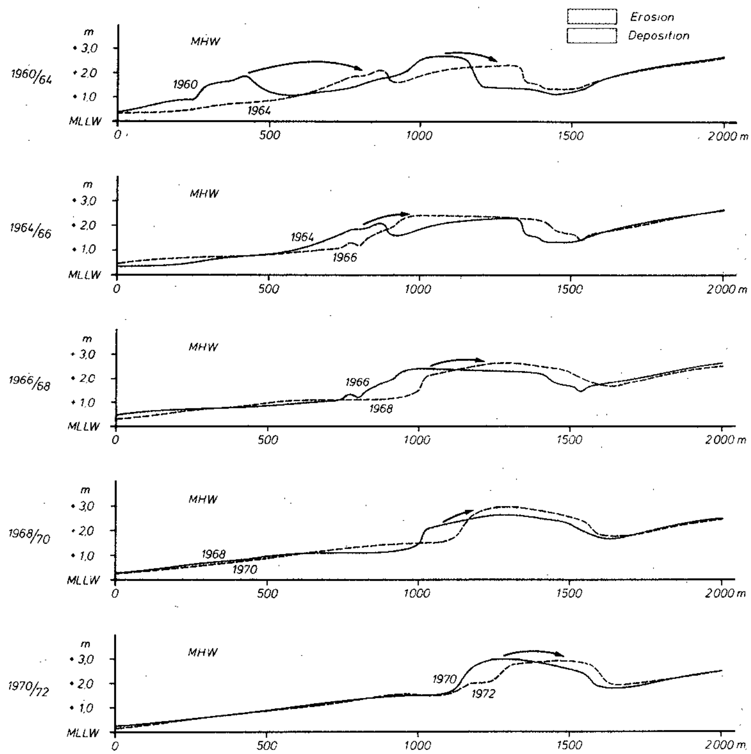


Fig. 5

Displacement of the bars in front of Scharhörn, indicated by a comparison of consecutive profiles

(especially from a comparison of the consecutive profiles) that sand is eroded on the sea-side slope, pushed across the crest and deposited on the lee-side.

The two bars - observed in 1957 - traveled with different velocities, the more exposed one (bank I) faster than the second (bank II). This led to an "overtaking" of the single structures, thiswise growing together and obviously diminishing the movement after that event. The maximum displacement exceeded about 150 m/year, a surprisingly high value for a surf influenced coastal structure.

It can be expected that the migration continues and the bar "touches" the large plate of Scharhörn. Then this one will get a supply of new sand and a rough comparison of consecutive charts indeed will give an impression of "returning a step" in the eastward displacement.

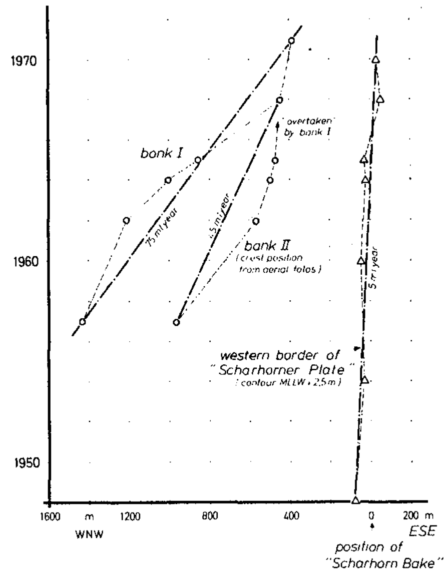


Fig. 6

Displacement of the sand bank of Scharhörn and of the small banks (migrating bars) in front of it

## 4. Current Observations

It can be concluded from the morphologic study that neither normal tidal currents nor the common longshore currents of the breaker zone can be predominant forces for the sand movement in the region of the tidal flat sand banks. In order to investigate the acting forces and to confirm the presumed principle of sand movement across the bar (Fig. 7), an array of 4 current meters was set up in summer 1973. The positions are plotted in Fig. 8. Fig. 9 shows a station with the recording current meter as it was used (a type which has been developed in Germany especially for research in shallow waters and tidal flats). The measuring level is about 40 cm above bottom.

The records of the 4 meters which were taken over several months' contain a couple of wind-influenced tides and - fortunately - 3 storm surges which occured at the German North-Sea coast during the fall of that year.

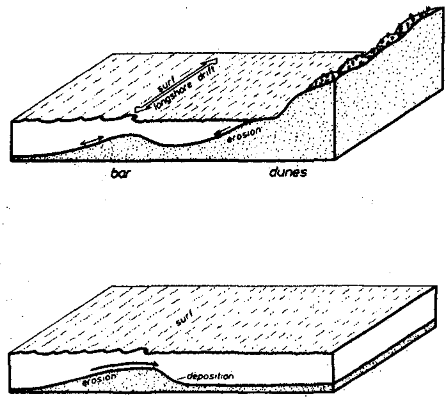


Fig. 7
Main sediment transport at a common surf beach and a migrating bar in a tidal flat

The measurements confirm in principle what is known from former investigations (Ref. 2), that high velocities, up to 100 cm/s, prevail in the tidal flats during storm tides, whereas at normal (calm wind) tides current velocities seldom exceed 40 cm/s.

In Fig. 8 the maximum velocities at mean tide and during the 4 storm tides are plotted. The latter exceed 80 to 100 cm/s and are obviously directed perpendicular to the bar and also to the big bank of Scharhörn. The currents in front of the bar and in the trough behing it are of similar magnitude but they are directed towards north-east in a more longshore pattern

Fig. 10 enables a comparison of a 12 days' record of station 12 (top of the bar) and 13 (in front of the bar). It is a period of continuous strong winds blowing coastwards. Due to the prevailing winds currents are almost unidirectional - perpendicular to the shoreline. During the storm tides maximum velocities at both positions are almost equal, averaged over the whole period howerer they are higher on the bar than in front of it (and also behind it).

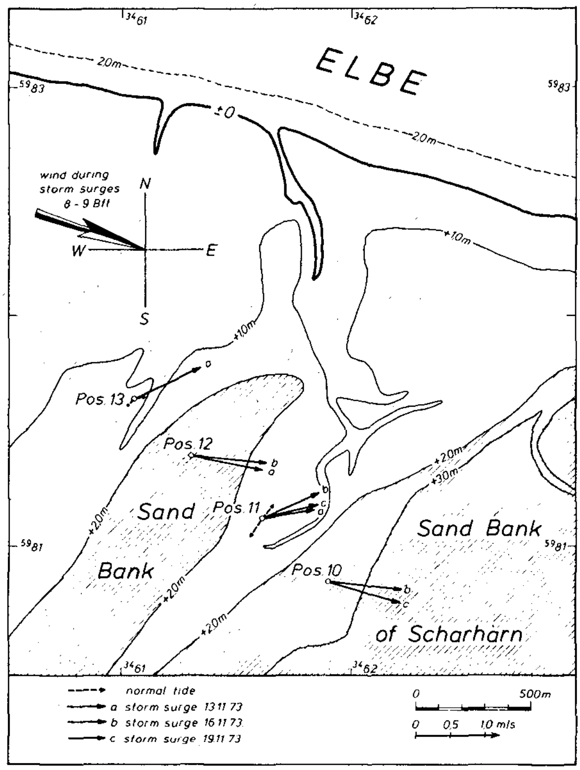


Fig. 8

Maximum current velocities (0.4 m above bottom) at Scharhörn during storm surges in Nov. 1973 and at normal tides

There is no theory available to satisfyingly describe this current pattern which must be generated by wind sheer stress, wave set-up and inclinations of the water level due to the displacement of the tidal wave and to the coastal topography.

5. Conclusions

Fig. 9

Recording current meter on a tidal flat station at low water

Putting all these observations together, which could be proved and completed by investigations on other sites, a satisfactory hypothesis on the generation and stability of the extended sand banks along the sea-side rim of the tidal flats in the German Bight can be established. Generation can be explained by the effect of single small sand bars formed in the surf zone of the tidal flat border, migrating and growing together due to their decreasing travelling velocity when they get shelter by approaching new ones. The sand movement in this system is mainly generated by strong unidirectional currents perpendicular to the bar axis. Sand on the sea-side slope of the bar is stirred up by breaker action and pushed across the crest to be deposited behind it in a zone of relative calmness. Fig. 11 gives a schematic sketch of this morphologic principle. (It must be noted in this context that in the south-eastern North Sea winds from south-west to north-west are prevailing and only these directions generate wind set-up in the German Bight which is necessary to permit that "overflow" of the banks and bars).

Stability of the thiswise produced "large banks" despite of continuous erosion at their sea-side shores can be explained by the sand supply from approaching new migrating bars. This process is of cause not continuous and periodic, so that the large sand banks are suffering long-range variations of position and magnitude. There are indeed not enough long-term surveys available to

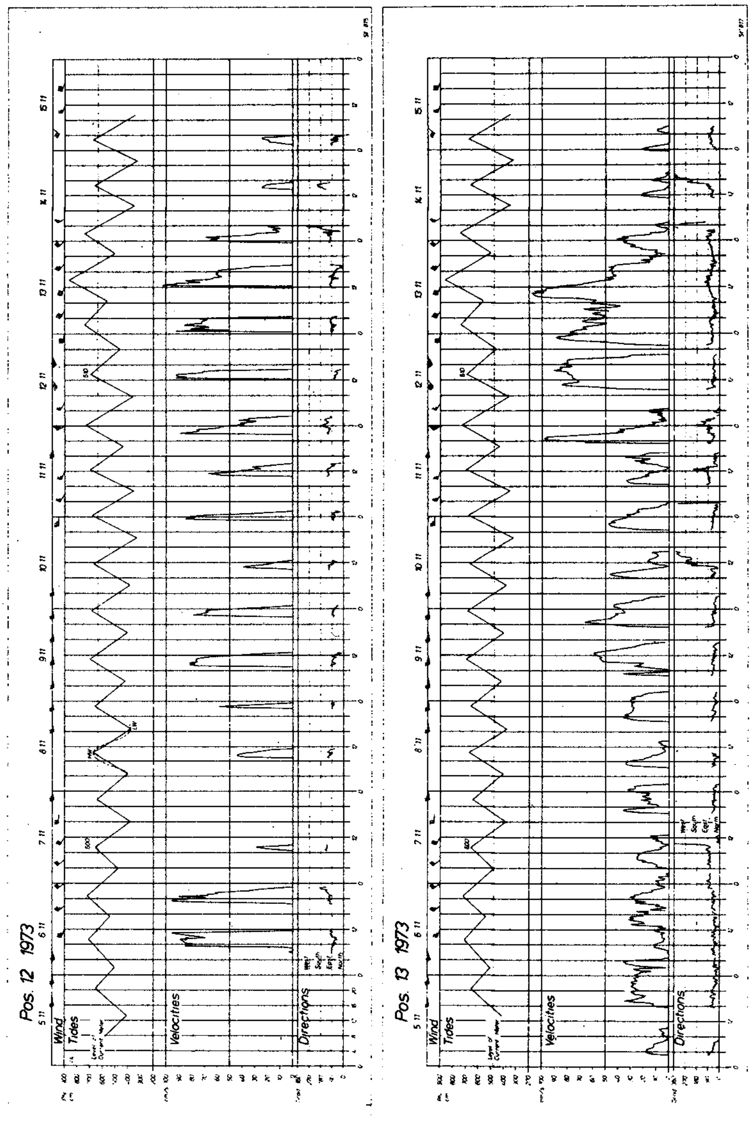

Fig. 10

Records of current meters on top (Pos. 12) and in front (Pos. 13) of the bar of Scharhörn satisfyingly investigate these morphologic processes. But the fact that we find descriptions or drawings of large banks already in navigational manuals and sea charts of the middle age at almost the same sites proves that a long-term sand supply from sea must exist counter-balancing the losses of material which all sand banks in this region are suffering on their sea-side shores.

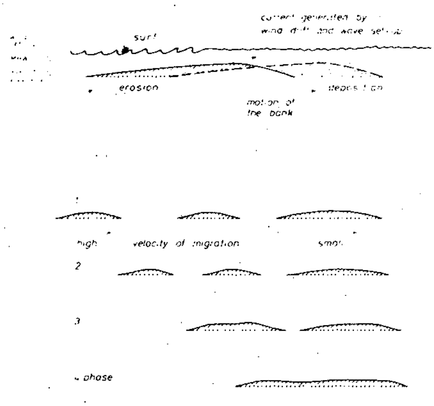


Fig. 11
Principle of generation of a large sand bank from small migrating bars in a tidal flat


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