EXCHANGE OF SEDIMENT BETWEEN BEACHES AND BARS AFTER A BEACH NOURISHMENT

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Abstract - Shortly after the completion of the middle section of a 14 km long dyke protecting a lowland (Kiel Outer Fjord / Baltic Sea) erosion processes increased in the nearshore sandy area. That's why several episodes of beach nourishment were carried out along with a sedimentological research program to determine the incorporation of artificially supplied material into the natural sediment cycle and to estimate the response of the nearshore environment due to such a measure. Considering these aspects sedimentological mapping and an experiment with a tracer (luminophores) were conducted. It could be seen that fine sand which mainly builds up the nearshore bars and which was the main component of the fill material was completely removed after one year and the former conditions developed again. Additionally it became obvious that during storm conditions sediment transport from the beach towards the offshore occurs in very narrow tracks with different velocities for single grain size spectra.

Keywords: Nearshore sandy environments, offshore bars, sediment transport, rip current, artificial tracer, beach nourishment, coastal monitoring.

Résumé - On sait que le succès d'une opération de rechargement des plages dépend en grande partie de la taille des matériaux mis en place. L'auteur expose la méthode utilisée pour arriver à une meilleure compréhension des mécanismes de l'évolution après le rechargement dès lors qu'une grande partie du matériel s'est échappé vers la mer moins d'un an après l'opération. Le suivi ,qui repose sur l'utilisation de traceurs, sur des prélèvements d'échantillons de sable et leur tamisage systématique, montre que les sables les plus fins fuient en grand nombre selon des directions très localisées correspondant à l'existence de courants d'arrachement lors des tempêtes. Par temps calme, les barres qui existent dans les petits fonds (la Baltique n'a qu'un très faible marnage) se reconstituent mais du fait de la taille des sables, le bilan est actuellement négatif. Ceci explique le caractère nécessairement répétitif des rechargements.

Mots-clés - érosion marine, côte et avant-côte, barres et sillons pré-littoraux, courants d'arrachement, rechargement de plage, protection de la côte, suivi de la côte.

INTRODUCTION

Answers about the temporal and spatial displacement of the sediment along sandy coastlines have become more significant nowadays since beach nourishment and beach replenishment have been favoured as the most propitious solution for the coastal erosion and the best for the environment (DIXON & PILKEY 1991, PILKEY 1990, SCHWARTZ & BIRD 1990). It is also important to consider economic aspects because the stability of artificial beaches which depends on the sediment movement in nearshore areas determines the number of sometimes expensive repetitions of nourishment.

It is well known that an exchange of sediment between the beach and the bar/trough zone of nearshore sandy environments still exists (BRYANT 1986, SCHWARZER 1989, SHORT 1984, WRIGHT et al 1986). Nevertheless, up to now only a few reliable scientific findings have documented the way this exchange of sediment happens which finally determines the changes in the nearshore morphology and thus deals with the question of where and how fast different grain size spectra move (INGLE 1966, KNOTH & NUMMEDAL (1977)).

In order to study this exchange, sedimentological mappings was repeated in successive short periods (several months) accompanied by a tracer experiment (luminophores). They were conducted in correlation with beach nourishment along a beach and nearshore environment of the tideless Baltic Sea (Fig. 1).

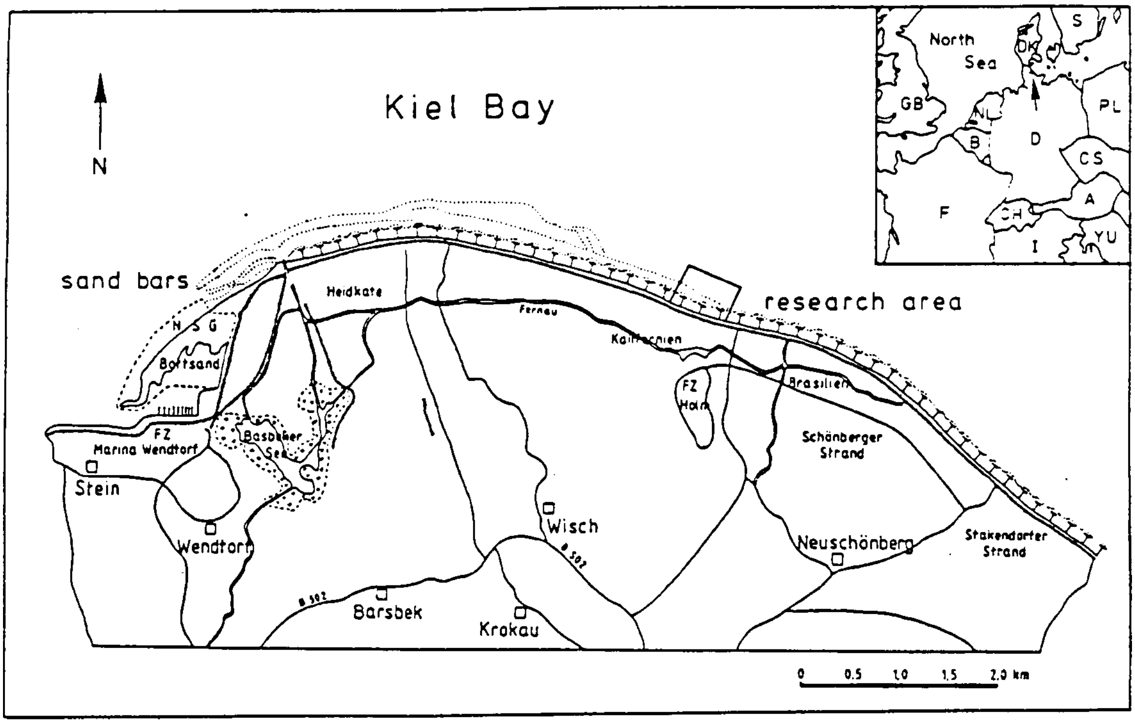

Fig. 1: Research area

STUDY AREA

In the "Probstei" area, lying in the eastern part of Kiel Fjord, a 14 km long dyke together with T - groin system (Fig 1) was constructed in several phases between 1975 - 1990. This measure was necessary to protect a lowland lying behind against floods.

KÖSTER (1979) derived sedimentological and morphological tendencies for the development of this region. He postulates an erosional front in the area B 21 - B 23 which is slowly moving westward. One reason for this assumption is the collision of two different bar systems in the central part of this area (B 22 / B 23, Fig. 1). One, consisting of two bars which are different in their median diameter, passes in from the east and ends at B 22 / B 23. In comparison with the inner bar the outer bar is formed by finer material (median < 0.18 mm). The rising up over the seabottom of both of these bars is only a few decimetres.

The other bar system begins at B 21 / B 22 and extends to the west by simultaneously increasing in the number of bars. In comparison to the easterly system the median grain size of the outer bar is coarser (median > 0.200 mm) than of the inner bar (median < 0.200 mm). The rising up of the western bars above the seabottom is more than one meter. They are better developed than the eastern ones.

Settlements and summer houses developed very close to the coastline were forced to build the new dyke in some places on top of the prior beach and foreward into the area with the existing erosional front. This was a risk because of the well-known long term negative sedimentary balance in this central part. Subsequently, the formerly existing sandbar system disappeared during only a few months over a distance of nearly one kilometer. Additionally, in groin fields wider than 200 m the beach was totally eroded so that one year after the dyke had been finished several episodes of beach nourishment became necessary. A first one was carried out in spring 1987 between B 22 - B 30 (192.400 m^3), a second one in late summer 1989 again between B 22 - B 30 (121.600 m^3), and a third one in late summer 1990 between B 39 and the end of the dyke (206.800 m^3).

RESEARCH-METHODS

To get detailled knowledge about the incorporation of the artificially-supplied material into the natural sediment cycle and about the changes of the sediment composition and distribution due to different weather conditions during the annual season-cycles, the first beach nourishment was accompanied by a sedimentological research program. A sequence of four samplings between April 1987 and May 1988 was calculated in such a way to map the conditions before (spring 1987) and immedediately after the beach nourishment (June 1987). Additional spatial sampling was done to measure the development of the distribution of the flushed material in the nearshore environment were carried out in October 1987 and in May 1988. 280 samples were taken in each sample cycle in the whole research area which was 1.6 Km long (B 20 - B 29) and 0.5 km in width.

All samples for mapping the seabottom surface were taken with a grab except in positions directly around the groins. This sampling was done by scuba divers. In the laboratory the material was sieved in 1/4 Phi° steps. By keeping the same sample grid and the same number of samples during all the four sample cycles it was possible to compare the results of the different mappings.

To measure the integration of the flushed material under storm conditions an experiment with luminophores was carried out: 50 Kg of tracer material which was of the same grain size distribution as the washed up material (Fig. 2) was buried in a small ditch 10 m long, 35 cm below the surface but 30 cm above NN on the dry beach some meters away from the shoreline (0.00 m NN). During a storm event two months later (end of November 1987) a very large part of this beach section was eroded so that approximately half of the tracer material was transported away from the beach.

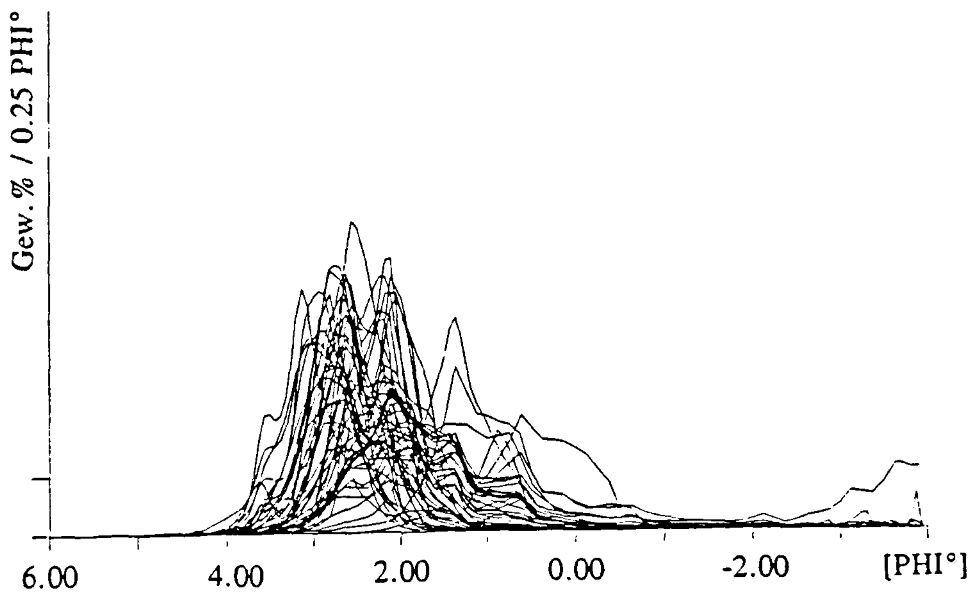

Fig. 2: Grain-size distributions of the flushed material

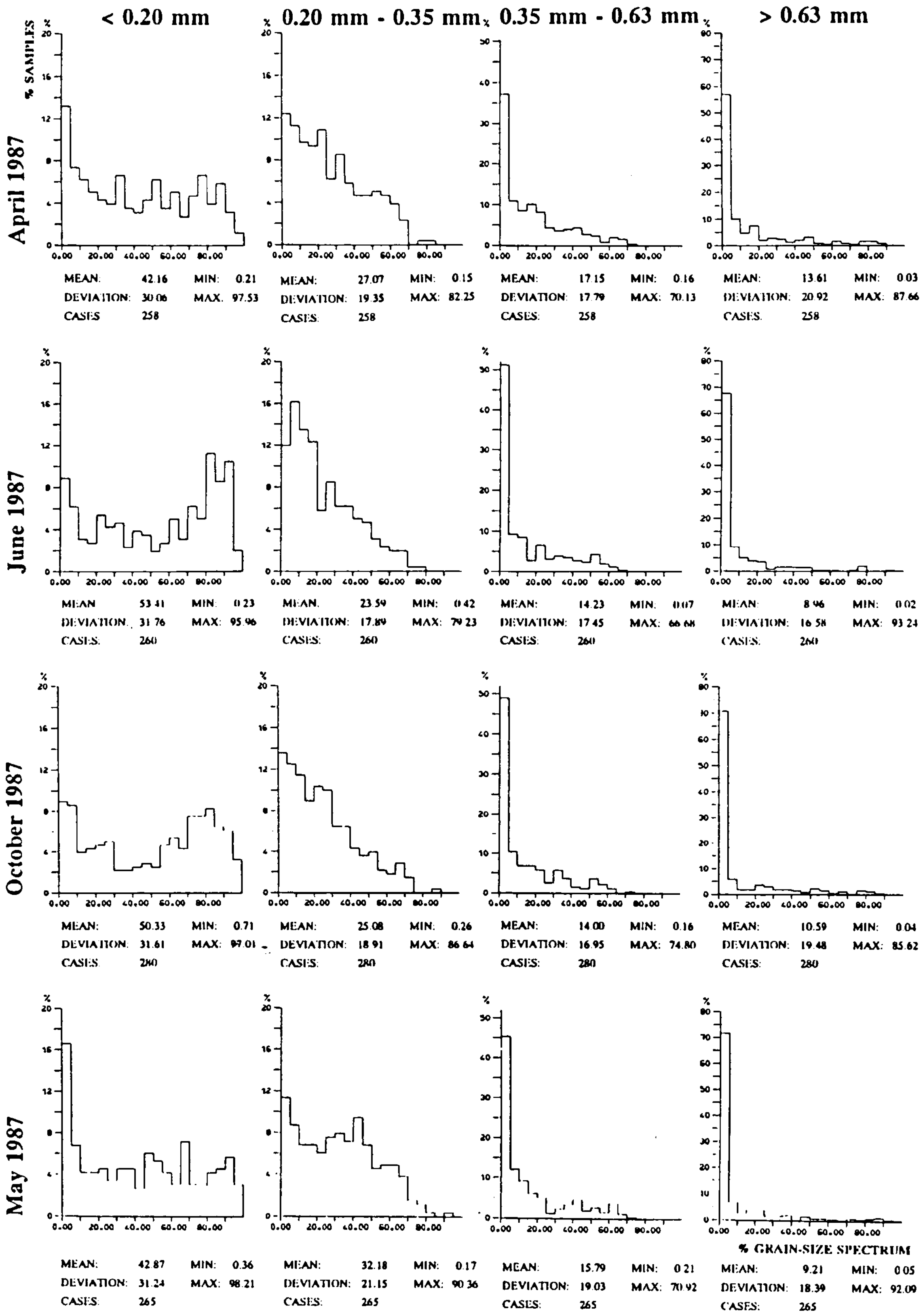

Fig. 3: Development of the beach nourishment by histogram representations

Immediately after the storm divers took samples from the nearshore area in a very rigid spatial sample grid (Fig. 4 a. 5) several times. Afterwards these samples were also sieved in 1/4 Phi steps and then fractionwise analyzed for tracers particles. Thus it was possible to determine both migration paths of different grain size fractions and of the whole sediment.

RESULTS

It is well known from former investigations (KACHHOLZ 1982, KÖSTER 1979) that specific grain size spectra are suitable for characterizing sedimentological/ morphological units in this nearshore area. For example the fine sand (< 0.20 mm) characterizes the bar zone while the coarser material (> 0.35 mm) is the main component of areas consisting mostly of residual sediment - troughs between the bars and the abrasion platform seaward of the bars - which results from underlying boulder clay.

Because of keeping the same sample grid during all four sample cycles it became possible to observe the sedimentological development of the seabottom by changes in the weight percentage of specific grain size spectra. Fig. 3 shows the development of the four spectra < 0.20 mm, 0.20 mm - 0.35 mm, 0.35 mm - 0.63 mm and > 0.63 mm during the four sample cycles. Each histogramm contains the samples taken during each sample cycle. The different number in the "cases" of the four sample cycles results in the fact that sometimes the grab was empty or contained only a few bigger stones (not useable for sieve analysis).

On the x-axis the percentage of the grain size spectra devided into 5 % classes is shown; the y-axis gives the percentage of samples. For example: in April 1987 4 % of all samples contained 80 - 85 % of material < 0.20 mm whereas in June 1987 after the beach nourishment 13 % of all samples contained 80 -85 % of material < 0.20 mm).

The main component of the material artificially supplied to the nearshore area consisted mostly of fine sand (2.00 Phi - 3.00 Phi, Fig. 2). This fraction is known as very mobile for this area (KÖSTER 1979, SCHWARZER 1989) and therefore the beach nourishment was consumed very fast as Fig 3. shows.

The amount of fine sand in the single samples increased immediately after the beach nourishment - a lot of samples comprised more than 80 % < 0.20 mm -but in May 1988 the same conditions as before the beach nourishment appeared. The behavoir of the other fractions was just the opposite.

The success of a beach nourishment does not only depend on the time the washed up material remains within the nourished field but it is also of importance to know in which way the different fractions of the supplied material become distributed within the nearshore area under changing hydrodynamic conditions.

By the tracer experiment a direct sediment exchange perpendicular to the shore between the beach and the bar was not recognized but the luminophores migrated in the trough lying between the beach and the bar in the main transport direction parallel to the shore until they were carried out seaward by a rip current and deposited in a fan directly in front of the rip current structure. The migration paths were the same for all grain size fractions; differences occured in regard to the transport velocity and the transport distance between the grain size fractions (fig. 4). The fraction 0.15 mm -0.18 mm moved farthest distance from the release profile inside the research area. Similar experiments in neighbouring areas have confirmed that these grain size spectra are the most mobile material for the entire Probstei area (SCHWARZER 1989).

Sediment transport into the bar system from the seaward direction is possible. Transport across the bars and farther in direction to the beach has never been recognized during the storm conditions and shortly afterwards.

The distribution of spatial migration paths and the concentration of tracers at some

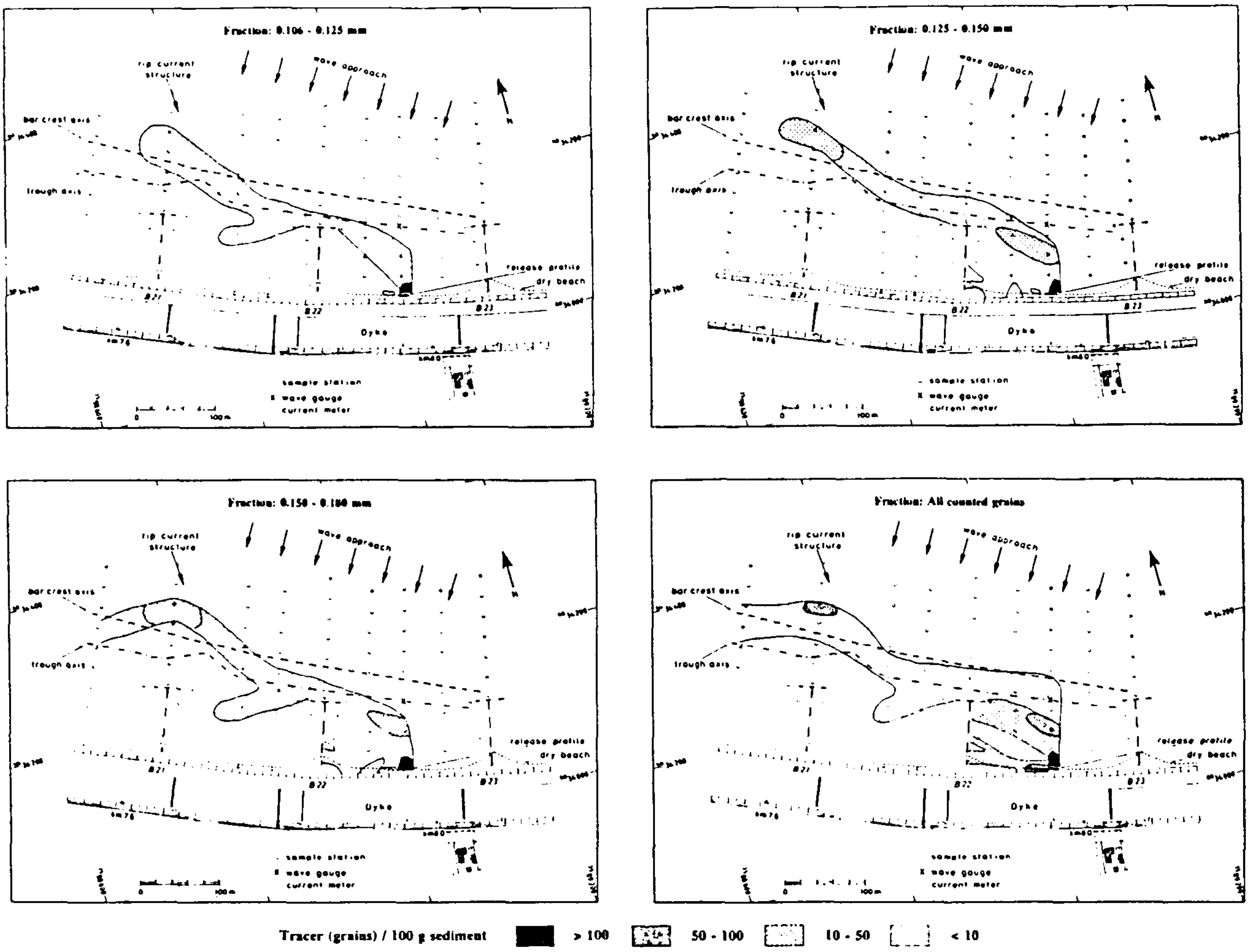

Fig. 4: Aerial tracer distribution of different grain-size spectra

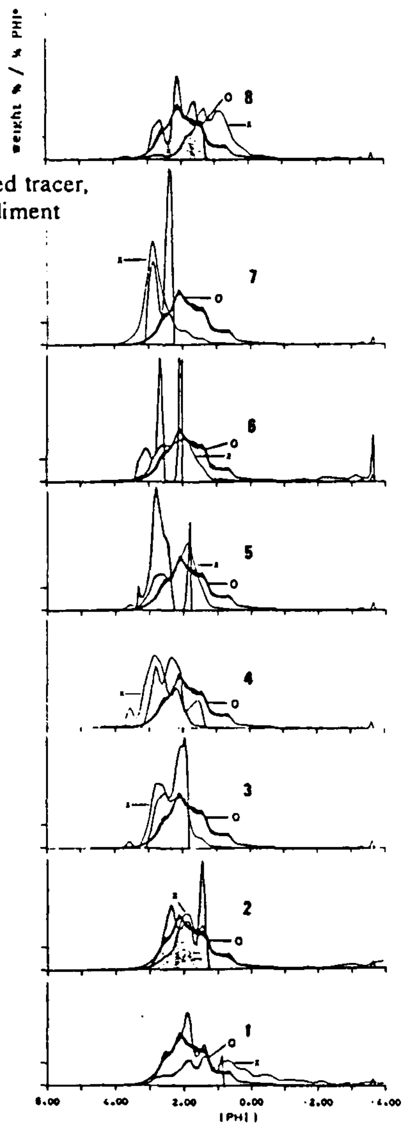

Fig. 6: Grain-size distributions of injected tracer, tarnsported tracer and autochthonous sediment

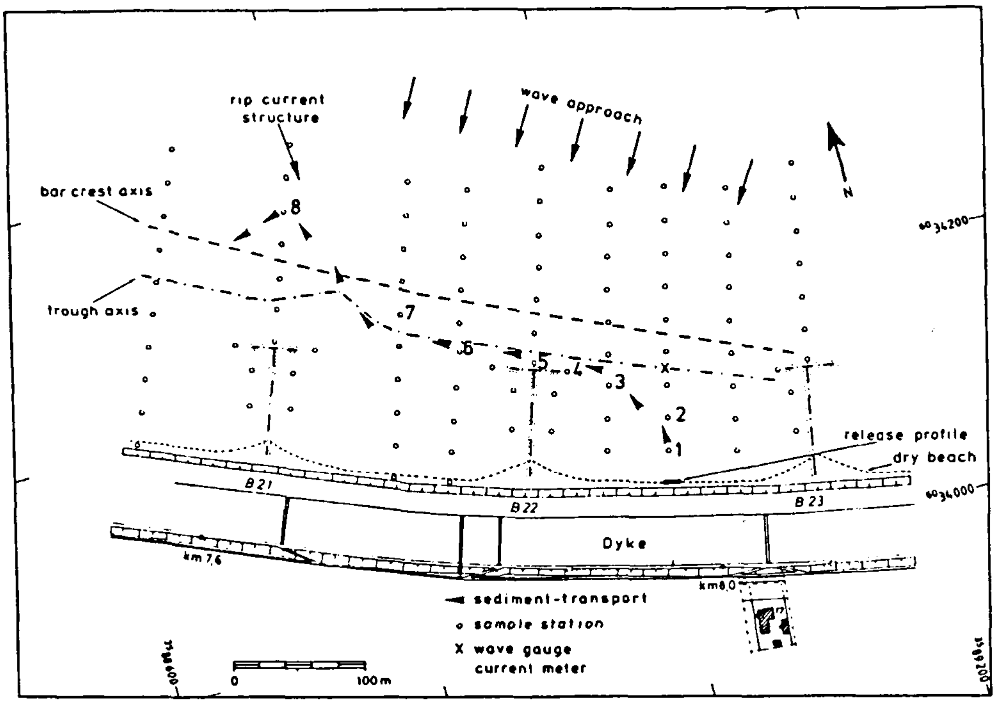

Fig. 5: Main transport path of the tracer

distinct points (fig. 4 a. 5) do not allow to be drawn conclusions whether the whole grain-size-spectrum of the tracer or only distinct fractions are selectively picked up and transported. To answer these questions the numbers of all found coloured grains of the samples were fractionwise multiplied by the weight of a single grain on the basis of the assumption that all grains were spherical with a density of 2.65 g/cm^3. In this way grain-size grain weight distributions are obtained from grain-size grain number distributions which then become comparable with the injected material as well as with the autochthonous sediment of each sample. Furthermore the registered coloured grains of all samples are summed up fractionwise so that a theoretical sample is gained in which all the transported tracers have been accumulated (fig. 6).

Seaward of the rip current the grain-size distribution of the tracer material is almost identical with the injected sediment (fig. 6, sample station 8). Only the coarse fractions show an insignificant deviation by a loss of material in the tracer distributions. Therefore it can be concluded that the whole spectrum of luminophores can be transported to the seaward side of the bars. From that accumulation area only the relatively "fine" material reaches the bars but now from the seaside direction. Although the supply of "coarse" sand into the rip current fan is small there is nevertheless an accumulation of these fractions because the fine sand is continuously led away.

The result of the analysis of the single samples taken along the way of transport from the beach through the trough into the rip current fan is shown in Fig 6. During the transport in which the whole sediment is in movement, there is a continuous diminishing of the grain sizes of the luminophores starting from the release profile (sample station 1) to the accumulation area in front of the rip current (sample station 8). Tracer and autochthonous sediment seldom show the same distribution curves, but a high degree in their modes which can be judged as an advanced state of equilibrium in respect to the fact that the tracer has been worked into the autochthonous sediment.

DISCUSSION

Rapid changes in the nearshore morphology under storm conditions have been investigated intensively during the last decade (SHORT 1985) but are mostly limited to a description of conditions because morphological and sedimentological measurements during high energy conditions are impossible. The way the sediment moves which in the end is responsible for the rebuilding of the morphology could be sucessfully shown by a tracer experiment. In the research area - which was known as an erosion area - artificially supplied material mostly consisting of fine sand was almost completely consumed after one year. One of the main reasons was the very high amount of fine components.

By a tracer experiment it became obvious that the transport of sediment is not spread over the whole sea bottom perpendicular to the shore but in very narrow tracks with different velocities for the single grain-size spectra. Rip currents play an important role in these processes.

The genesis and source of coarse grained layers found by HUNTER et al. (1979) and GREENWOOD & MITTLER (1985) in cores taken from sediment fans in front of rip currents, which they also assigned to storm conditions, can be explained in so far as material can result from beach erosion.

Immediately after the storm calmed down the rebuilding of the bar from the seaside direction began. This is important in so far as sediment which is eroded from the beach or derived from a beach nourishment is available to rebuild the nearshore morphology and therefore to balance the sediment budget.

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