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An Artificial Longshore Bar at the West Coast of the Island of Sylt/German Bight—First Experiences

K. Ahrendt and R. Köster

Geologisch-Paläontologisches Institut
und Museum der Christian-Albrechts-Universität
Olshausenstrasse 40
24118 Kiel, Germany

ABSTRACT

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A section of the beach at the west coast of the island Sylt near Kampen, which was particularly endangered by coastal erosion, was protected by means of an artificial longshore bar in 1990. Three years later a significant improvement in the coastal structure can be recognized. A high and wide longshore bar has developed and leeward, the beach has widened as well. The longshore sediment transport rate was reduced to $C_a = 0.3345 * C_0^{0.8676}$ and the mobility (duration) of the sand decreased (increased). The position, height and length of artificial longshore bars must agree with local, natural conditions.

ADDITIONAL INDEX WORDS: *Coastal protection, artificial longshore bar, morphodynamics, littoral drift.*

INTRODUCTION

Sylt (Figure 1) is geologically composed of loose sediments with a central core of boulder clay and kaoline sand. Adjacent spits form the northern and southern part of the island. It is not protected by offshore sand deposits and is extremely exposed to the incident waves of the North Sea. Therefore Sylt is exceptional among the North-Frisian Islands.

The exposed west coast is characterized by a high energy input due to waves and currents. The mean tidal range is approximately 2.0 m in the south and 1.8 m in the north of the island. The wave climate has been recorded by a waverider and a wave direction buoy since 1986 by the Franzius-Institut of the university in Hannover. Since 1989 a gauge placed at the −10 m bathymetric line delivers continuous current, wave and wind data. Studies of the wave climate between 1987–1989 show wave periods between 3 and 5 seconds (Figure 2) with mean significant wave height between 0.5 m and 1.5 m (Figure 3). During storm periods wave heights up to 6 m are observed. The mean wave direction is normal to the shoreline, W to NW (Figure 4).

Since 1870 data about the rate of coastal erosion have been recorded (Figure 1). Since the middle of the 20th century, an increase in the rate of erosion is detectable. The reasons for this phenomenon are not yet known. According to KÖSTER (1974), the western edge of the Pliocene/Pleistocene outcropping of the island at the beginning of the postglacial transgression (8,000 b.p.) was about 10 km west of the recent shoreline. This would imply an average retreat of the coastline of 1.25 m/year. The same average yearly rate of erosion can be calculated from the data measured between 1870 and 1984. Therefore, one may conclude that the acceleration of coastal erosion since 1952 is only a short-term feature.

Figure 5 shows the duration of storm surges above 2 m msl at three different locations (List/Sylt; Wittdün/Amrum; Wyk/Föhr). A significant increase in duration is recognizable since the middle of this century. This increase correlates with the increase in coastal erosion rates since 1952. The question whether an increased energy input due to longer durations of storm surges is responsible for higher erosion rates has not yet been completely solved.

Several "hard" coastal protection measures in the past could not stop the coastal erosion (Table 1). "Soft" measures such as nourishment, since 1972 have gradually reduced the coastal retreat.

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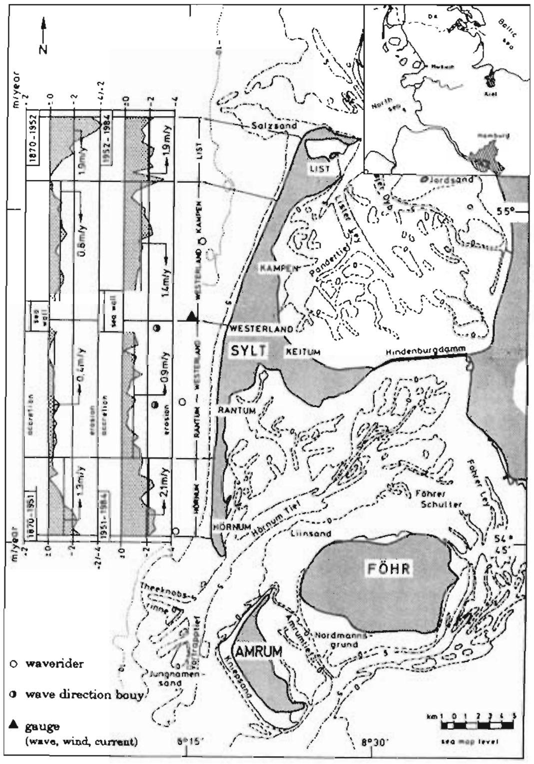

Figure 1. Study site and coastal erosion rates. (Modified from ALW, 1985).

Longshore bars run along almost the entire length of the west coast of Sylt. (LAMPRECHT, 1955; VOLLBRECHT, 1957; KÖSTER, 1974, 1979; FIGGE, 1976; MOUTZOURIS, 1985; AHRENDT, 1989, 1994b). Great quantities of material that have eroded from the morainal cliffs are contained within these bars. On the one hand, the bars serve as a breakwater and protection from erosion of the underlying seafloor and, on the other hand, as a location where sediment exchange with the beach (at least in the upper few decimeters) can occur. Natural features, such as the area of erosion seaward of Kampen, also influences the development of the bar system.

During the genesis of the island, sensitive dynamic equilibrium was developed between longshore bars, rip channels, troughs, ridge and runnels and the beach. The crest of the main longshore bar is located normally between −3.5 m and −2.5 m msl and is interrupted by rip channels. The distances between the rip channels spacing at the west coast of Sylt vary between 700 m and 140 m (Figure 6). Rip channels and troughs reach temporary a depth of −7 m msl. The distance from bar to shoreline is 300 m to 500 m (Figure 7). For more details about the morpholgy and morphodynamics see AHRENDT (1994b). A very sophisticated description of bar morphodynamics at sandy coasts is given in Journal of Coastal Research SI 15.

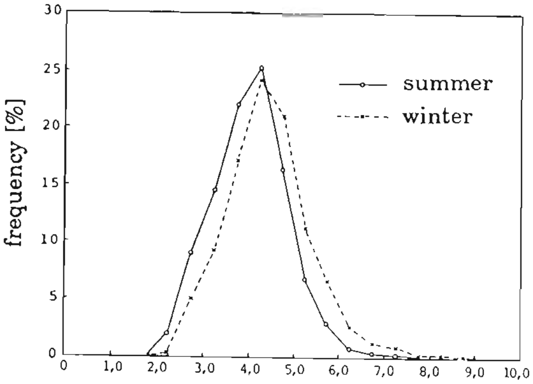

Figure 2. Wave period. (after SCHADE, 1991).

STUDY SITE

Problems related to coastal erosion were especially severe in the "Red Cliff" section of the coastline near Kampen (Figure 8). This area is different from others on the island of Sylt as far as sedimentologic and morphologic structures are concerned. At most places in this area the Pleistocene boulder clay, which is normally covered with a thin layer of sandy material, is at the surface. Unfortunately, a longshore bar which is stable on a long-term basis was not developed in the past and so the shoreline was not protected by a wave-energy dissipating longshore-bar (Figure 9). The substantial retreat of the cliff required coastal protection in addition to beach nourishment.

Results

From July to September 1990 an artificial longshore bar made of plastic tubes filled with sand (geotextiles) was established off the coast of the endangered section. This bar closed a 300 m wide gap in the now existing longshore bar. This gap seems to be the result of sediment deficit as op-

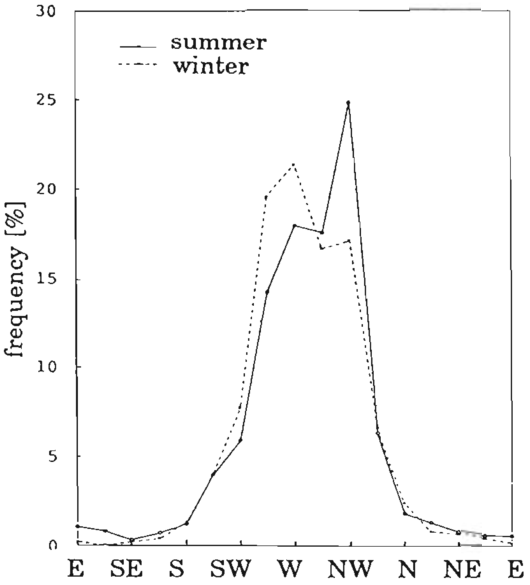

Figure 3. Wave height. (after SCHADE, 1991).

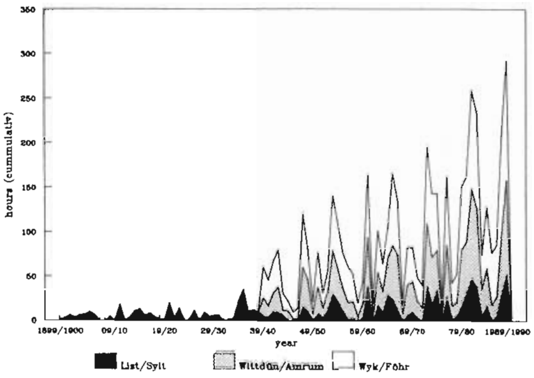

Figure 4. Wave direction. (after SCHADE, 1991).

posed to rip currents. A real rip channel is situated north of the area shown in Figure 10. It was not planned to build a detached submerged breakwater but to initiate the development of a longshore bar. Thus the bags were placed on the landward side of the adjacent longshore bars to create the requirements for the development of a gently seaward slope. It was expected that the wave-energy would dissipate on the wide and gentle seaward slope of the longshore bar.

The artificial bar is 320 m long, and its crest lies about −3 m msl, which is similar to adjacent bar structures. The dimensions of the bags were 6 m × 3 m × 0.8 m. Each bag was filled with 10 m^3 of sand, which is about 80% of their volume. They were piled up in 1 to 3 layers according to the water depth. The first layer consists of three, the second of two and the third of one line of bags. Four hundred-sixteen bags were used. The result was a longshore bar which was 18 m wide at the base and 6 m wide at top. Every single bag was put lengthwise normal to the coastline (Figure 11).

After the artificial bar was completed divers from the University of Kiel made observation with an underwater video camera. They found that the southern section of the bar was compact while the northernmost 100 m showed gaps which were up to 20 m wide. In the spring of 1991, the artificial bar was completely covered with relatively fine sediment (mean grain diameter 2.2–2.5 ϕ, 0.176–0.217 mm). Before the construction, the seafloor sediment had been covered with a thin (no more than a few decimeters) but coarser sand layer (mean grain diameter 1.2–1.8 ϕ, 0.287–0.434 mm). The natural longshore bars in this area mainly consist of fine sediment, whereas bars to the south are basically built of medium sand (mean grain diameter 1.4–1.8 ϕ, 0.287–0.379 mm). Most likely the initial fine sand cover on the geotextile bar originates from the partial erosion of material from a beach nourishment, which was undertaken at the same time south of the bar.

In the autumn of 1991 (Figures 13, 15), the southern part of the bar was still completely covered with sand. Only in the northern section the bags were not covered. In the spring of 1992, the whole bar was again completely covered with sand. The slope gently rises from the seafloor to the crest of the longshore bar and falls abruptly to the landward trough. The main accretion zone was landward of the bar. In the winter of 1992/1993 and in the spring of 1993 and summer 1994, the nearshore zone was again depth sounded. Although the data have not yet been completely evaluated, it is obvious that the cross-shore-profile has not changed fundamentally. Landward of the artificial bar, the beach was much wider than in adjacent areas (Figure 16). Today all evidence seems to indicate that a dynamic equilibrium between bar and beach has been established. At the

Table 1. *Coastal protection measures at Sylt (changed and extended after* PARTENSCKY* et al., *1988*

Year	Groynes	Seawalls/Longshore Bars	Nourishments
1867	Kampen: 3 light pile groynes		
1872	Westerland: 3 stone groynes		
1873	List: 5 pile groynes		
1875	Wenningstedt: 3 pile groynes		
1878/87	4 km S to 7 km S Westerland: 30 stone groynes and 70 pile groynes		
1889/90	Rastum to List: 17 stone groynes and 70 pile groynes, extension of another 12 groynes		
1907		Westerland: iron and Concrete seawall, 1 = 67 m	
1912		Extension of seawall north, 1 = 507	
1913	Westerland: iron & concrete pile		
1916		Light footrest for wall	
1921/22		Restoration with footrest, 1 = 125 m	
1922/23		Footrest, reinforcement	
1923/24	Restoration of pile/stone groynes in Westerland	Extension to south, 1 = 90 m	
1924/25	3 iron & concrete groynes in Westerland	Extension to south, 1 = 142 m	
1927	Bulkhead Westerland/Wenningstedt		
1928	2 bulkheads Westerland/Wenningstedt		
1929/30	130 bulkhead groynes, Westerland to Ellenborges, south side Ellenborges, east of Hörnum	1935/36 bulkhead in Westerlands 1937 revetment in Westerland, 1= 360 m 1938 revetment Ellenborges, 1= 2240 m	
1940		Reinforcement footrest Westerland	
1946		Exchange of north wall deckwork, 1= 140 m	
1947	36 concrete pile groynes Westerland to Wenningstedt		
1953		Restoration footrest, revetment Westerland	
1954		Extension revetment north, 1= 200 m	
1956		Reinforcement footrest, Westerland	
1957/58	3 flat groynes		
1961		Footrest Westerland with 580 Tetrapods	
1962/63	3 flat groynes Westerland	Tetrapodes longshore S of seawall, 1 = 420 m Tetrapodes longshore S of wall, 1 = 300 m	
1966/67	3 flat groynes Westerland	Extension Tetrapodes longshore	
1968		Tetrapodes longshore Hörnum, 1 = 1000 m	
1969		Tetrapods cross-shore Hörnum, 1 = 230 m	
1972			Wester., 1= 300 m, 1.0 Mio m^3
1978			Westerland, 1 = 900, 1.0 Mio m^3
1983			Hörn., 1 = 1000 m, 0.63 Mio m^3
1984			Wester./Kampen, 1= 1500 m, 1.1 Mio m^3 Rant., 1 = 1400 m, 0.33 Mio m^3
1985			Wenning./Kampen, 1= 4600 m, 1.97 Mio m^3
1986			Hörnum, 1 = 3200 m, 1.6 Mio m^3
1987			Rant., 1= 3000 m, 1.0 Mio m^3 Kampen., 1 = 600 m, 0.3 m^3
1988			Wester., 1 = 2000 m, 1.0 Mio m^3 List, 1 = 3000 m, 1.2 Mio m^3
1989			Rantum, 1= 4000 m, 2.0 Mio m^3
1990		Artificial longshore bar in Kampen, 1 = 320 m plastic tubes filled with sand	Hörnum, Wester., Kampen,, 1= 5000 m, 3.45 Mio m^3
1991			Wenning., Hörnum,, 1= 4500 m, 2.0 Mio m^3
1992			Kampen/Klapp., 1 = 5500 m, 2.0 Mio m^3

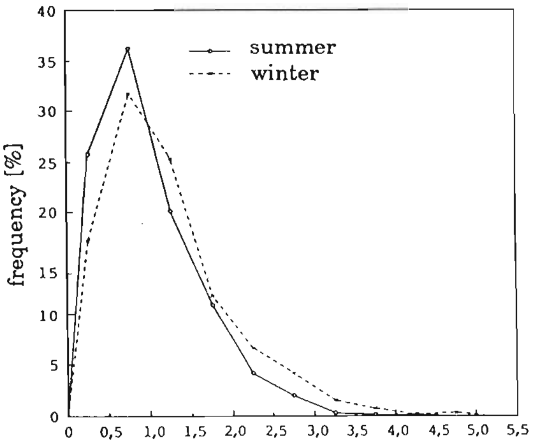

Figure 5. Cumulative yearly duration of three tidal gauges of storm surges above 3 m msl.

north end of the longshore bar a new rip channel has been established (Figure 14).

Numerical Computations

By means of numerical modeling the rate of sediment transport before and after the measure was calculated. This model, which proved to be useful for the west coast of Sylt (AHRENDT, 1994a,b), is based on ENGELUND and FREDSØE (1976), FREDSØE (1984), FREDSØE *et al.* (1985), DEIGAARD *et al.* (1986a,b; 1989). This paper only refers to the results. The theoretical background was published in the cited literature. The calculation of the sediment transport rate is based on recorded field data (bathymetric profiles, wave parameters (H_{zrms}, T_z, angle), sediment parameters and sea-level data).

Numerous calculations were made with a verified model using the measured hydrological and mophological data. Without a significant long-

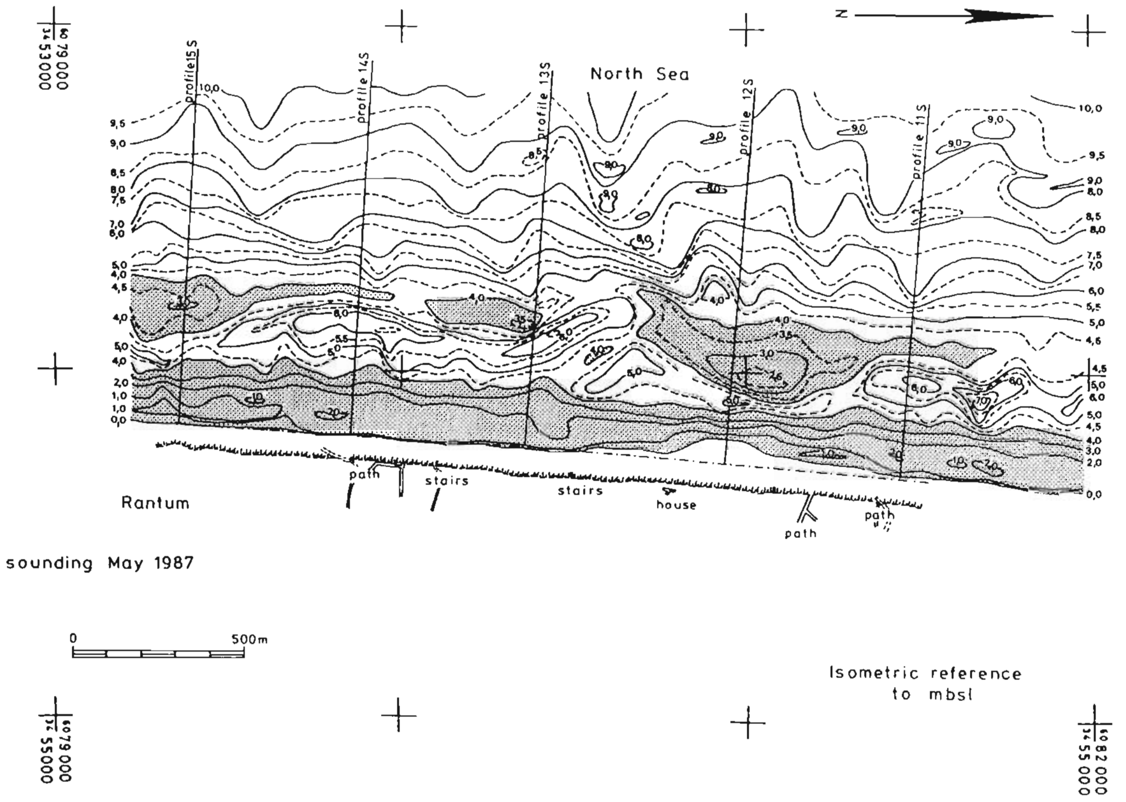

Figure 6. Depth contour map (site Rantum) with a well developed longshore bar.

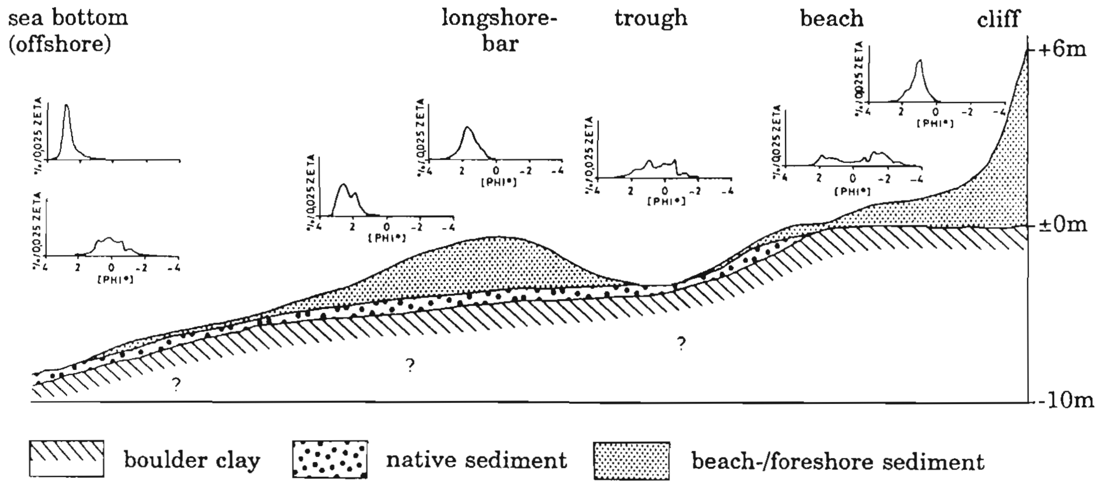

Figure 7. Mean cross-shore profile (site Rantum).

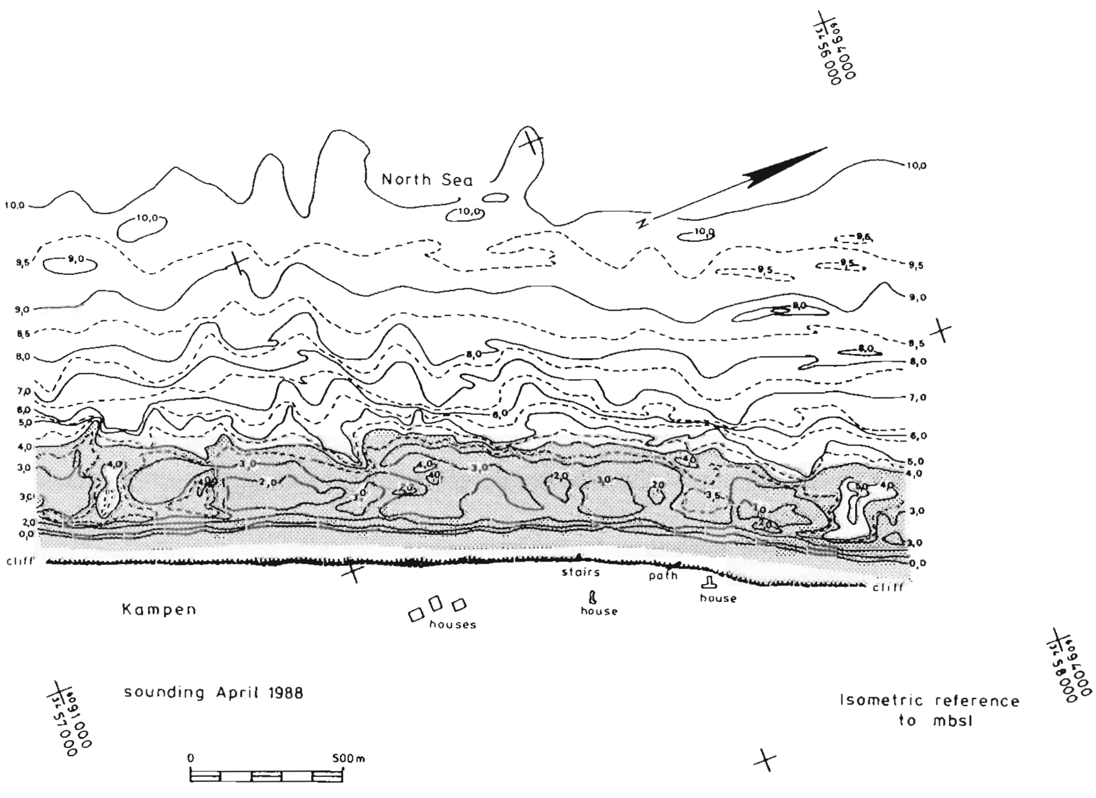

Figure 8. Depth contour map of the study site Kampen, note that there is no well developed longshore bar.

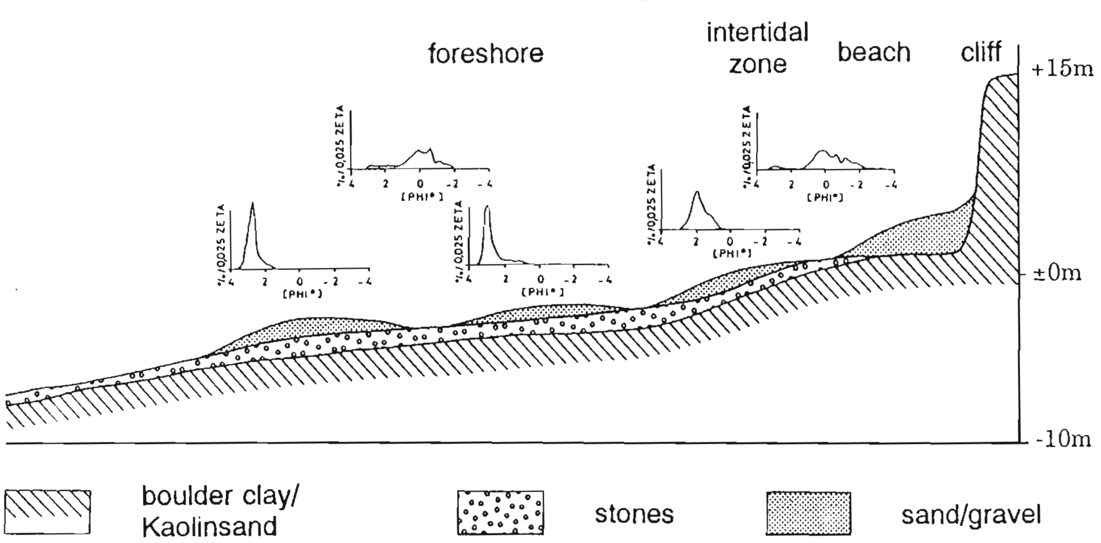

Figure 9. Cross-shore profil site Kampen.

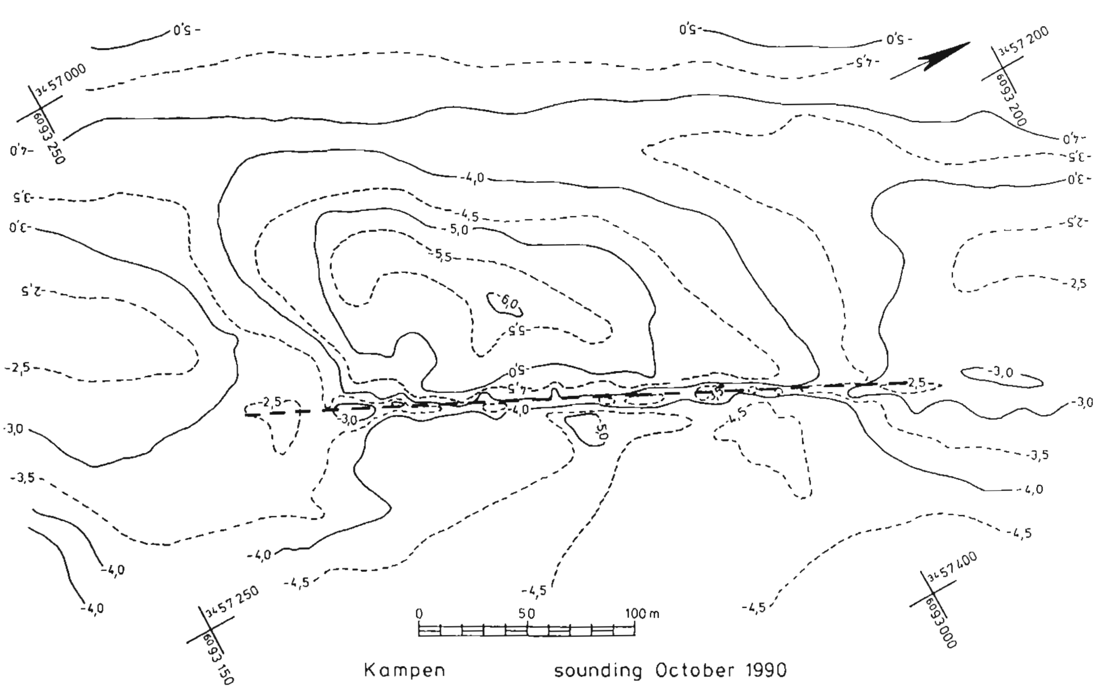

Figure 10. Depth contour map Kampen with an artificial longshore bar (— — —).

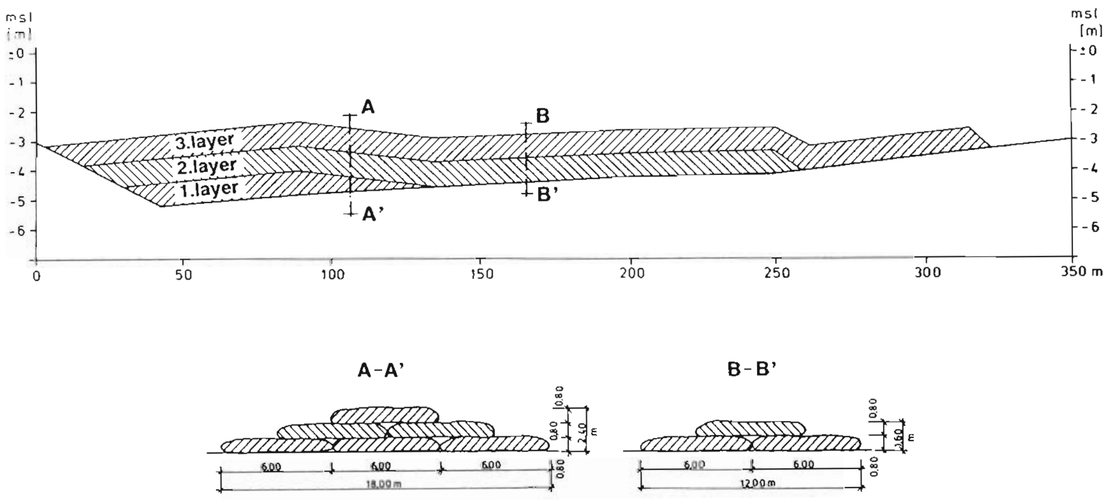

Figure 11. Scheme of the artificial longshore bar.

shore bar, most waves reach the foreshore unbroken. The waves break close to the beach and release their concentrated energy onto the foreshore and the beach (Figure 17). Therefore the conversion of wave energy takes place in a spatially restricted area and reaches a maximum of 0.028 m³/sec/m (Figure 17). With the development of a longshore bar the area of wave energy conversion moves from the nearshore zone towards the longshore bar (Figure 18). Moreover, the main sediment transport rate decreases and reaches a maximum of 0.002 m³/sec/m in a 250 m wide strip at the seaward slope of the bar (Figure 18). The transport in the nearshore zone is dramatically reduced. This consists in lower sediment transport rate around the profile, because the wave energy dissipates in a wide region. The total longshore sediment transport rate over the profile goes down from 0.517 m³/sec to 0.161 m³/sec.

Figure 19 shows the sediment transport rate from different H_{zrms}, T_z, incident wave angle, tide level with and without longshore bar. Profiles are from May 1990 before construction and from the autumn of 1992, two years after the construction. With increasing sediment transport rates, the reduction also increases. Noticeable reduction is observed above 0.025 m³/sec, at times with high energy-input. The reduction factor could be calculated by $C_a = C_0^y * b$ ($r = 0.91$) with

C_a = sediment transport rate with longshore bar [m**3/sec]

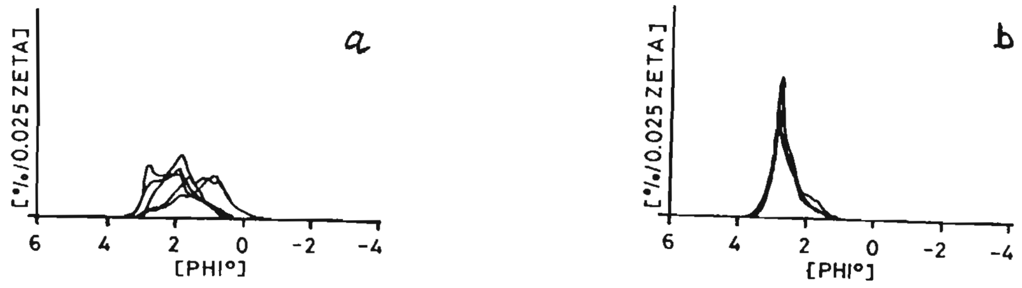

Figure 12. Grain-size distribution: (a) Before construction, (b) from artificial longshore bar.

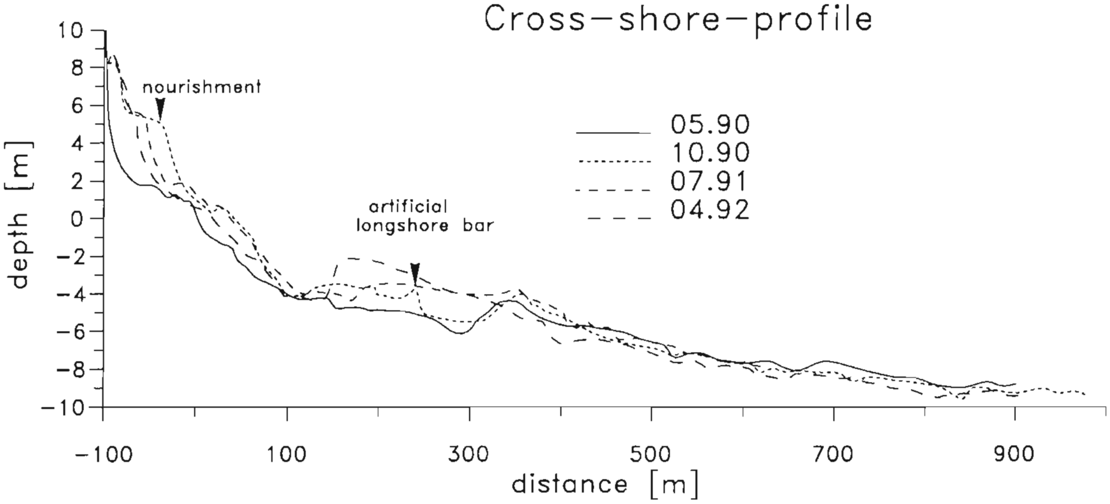

Figure 13. Cross-shore profile over the artificial longshore bar.

C_0 = sediment transport rate without longshore bar [m**3/sec]
y = 0.8676 empirical determined
b = 0.3345 empirical determined
r = coef. of determination, R-squared

DISCUSSION AND CONCLUSION

The extreme high range in morphodynamics at wave controlled sandy coasts induces various problems (see Short, 1979; Bruun, 1990; Larson and Kraus, 1992). Rigid buildings like the seawall in Westerland/Sylt and tetrapodes near Hörnum/Sylt cause well known negative effects such as lowering of the beach and lee erosion. Even breakwaters (see *Journal Coastal Research, SI No. 7*) might influence the littoral zone incalculably, if built into a dynamic equilibrium. Although the west coast of Sylt shows pseudo-stable littoral morphologic elements (longshore bars, rip chan-

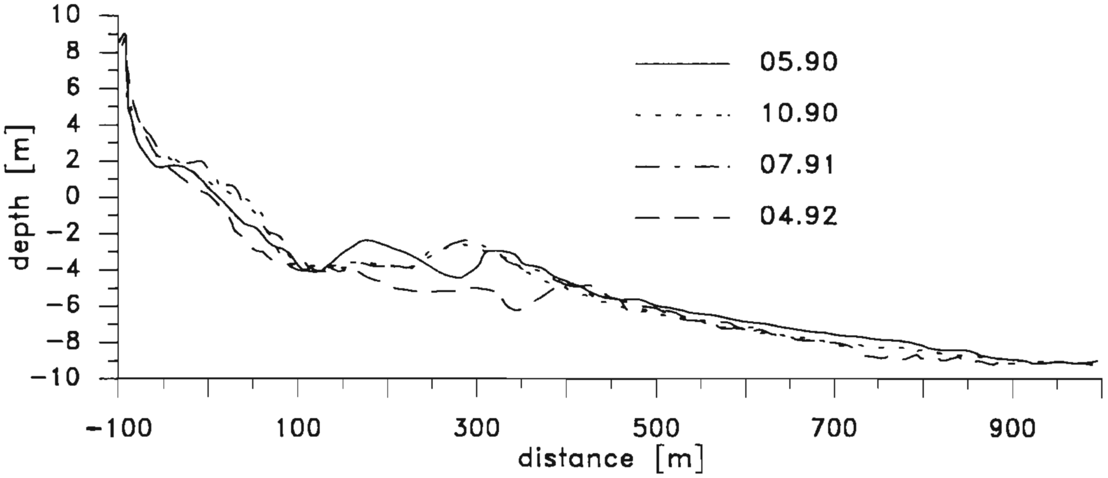

Figure 14. Cross-shore profile over the adjacent region north of the artificial longshore bar.

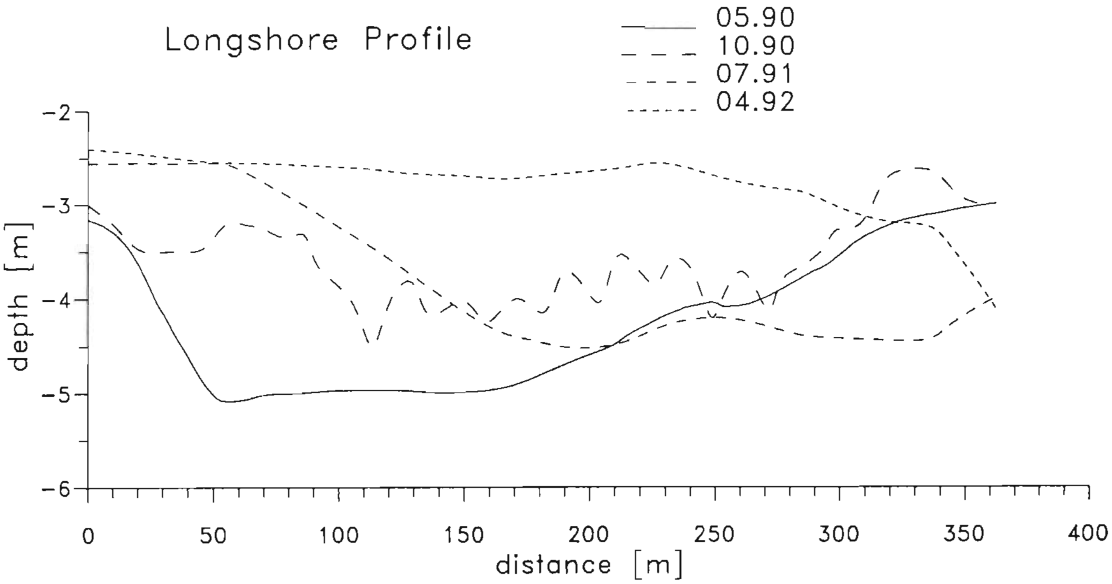

Figure 15. Longshore profile at the crest of the artificial bar.

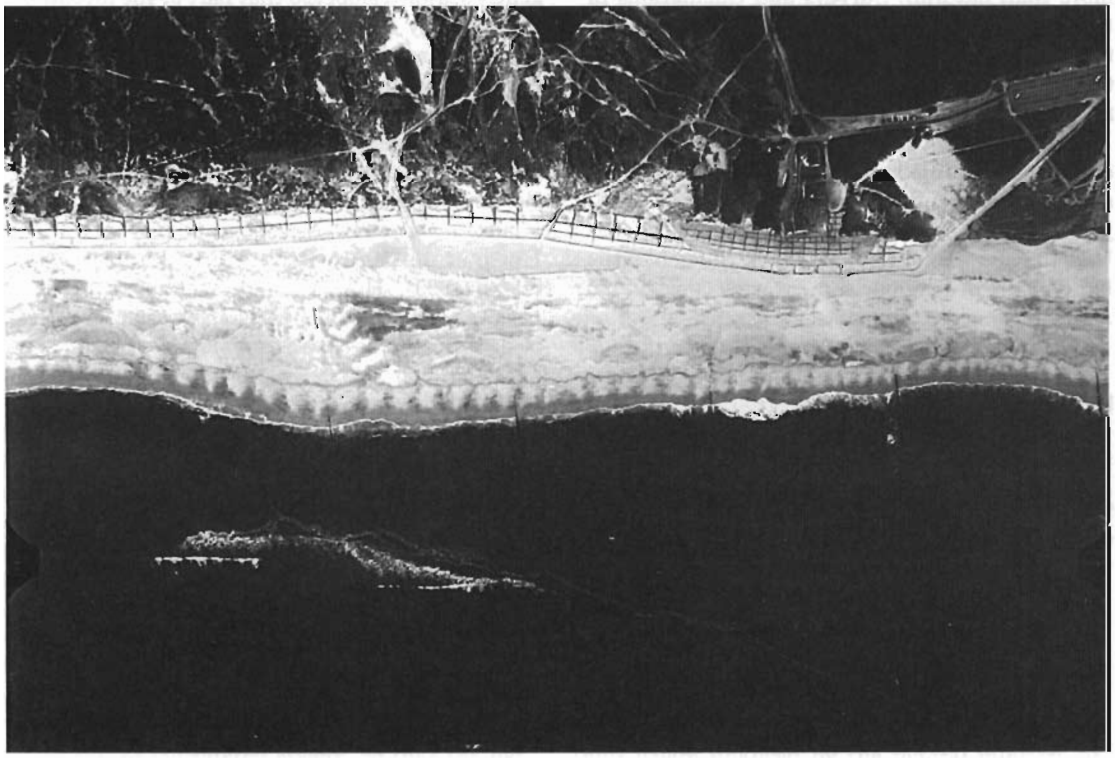

Fig. 16. Aerial photograph of the study site.

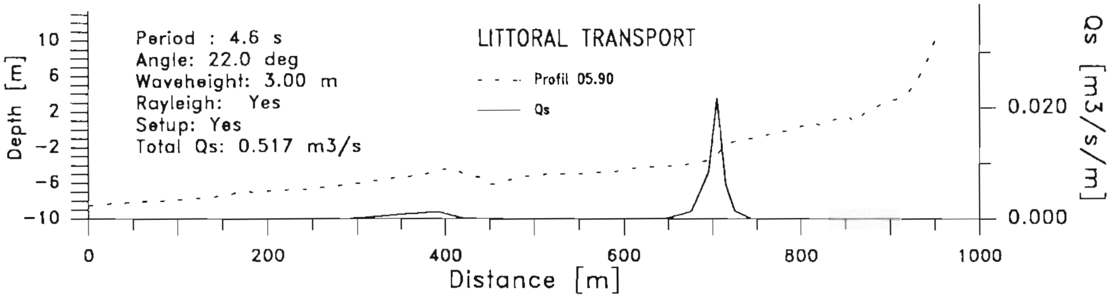

Figure 17. Sediment transport rate before construction during a small storm surge.

nels), AHRENDT (1993, 1994a,b) has proved that an excessive sediment transport does exist. At a coast which is undernourished by sand, the main goal is to keep the sand inside the morphodynamic system as long as possible. Therefore in addition to annual beach nourishments, the energy conversion has to be shifted from the nearshore and beach zone towards the seaward slope of the longshore bar without changing the natural cross-shore profile negatively (erosion on and outside the bar more than natural). Surveys and calculations in the study at Kampen show some success with the use of a geotextile bar which was above expectation. One decisive factor was probably the beach nourishment south of the study site in 1990.

The reason for the sand accumulation is not yet completely clarified. It is most likely that the availability of sand by beach nourishments in adjacent regions combined with the artificial bar lead to sand accumulation. Since the geotextile bar *and* the beach nourishment were constructed at the same time, one measure cannot be evaluated separately. The artificial bar differs remarkably from the adjacent bars. While the geotextile bar goes to −2.0 m msl and consists of fine sediments, the natural bars are smaller with crest elevating of −3 m to −2.5 m msl and they are built of coarser sediments. Therefore, there is an unexpected inverse correlation between the level of the crest and the grain size, since more exposed bars should consist of coarser sediments due to the higher energy input. The artificial bar has a gently seaward slope, so that part of the incoming wave energy is dissipated before it reaches the crest. The relative solid core of the geotextile bar is probably the main reason for its wide cross-section. Continued field studies and a natural reduction of available sand might give further information on that issue. Studies by SHORT (1979), BOWEN and INMAN (1969), DOLAN *et al.* (1979a,b), KIRBEY *et al.* (1981), SYMONDS and BOWEN (1984), HOWD *et al.* (1991), BOCZAR-KARAKIEWICZ *et al.* (1990, 1993), HOLMAN and SALLENGER (1993), LIPMANN *et al.* (1993) *etc.* show that low fre-

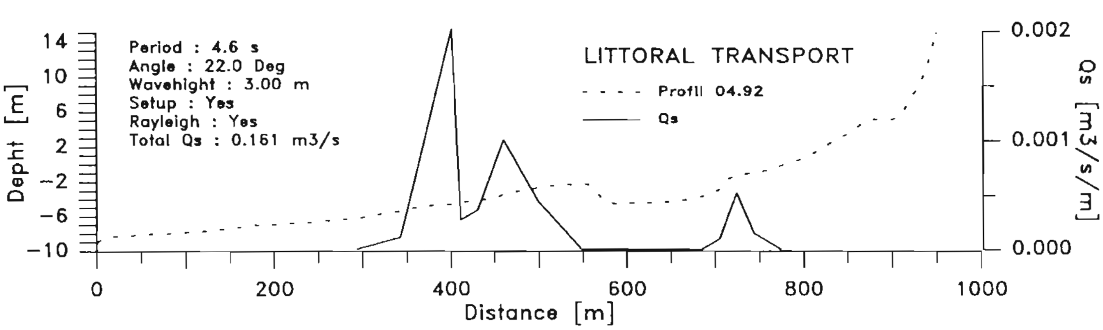

Figure 18. Sediment transport rate with an artificial longshore bar during a small storm surge.

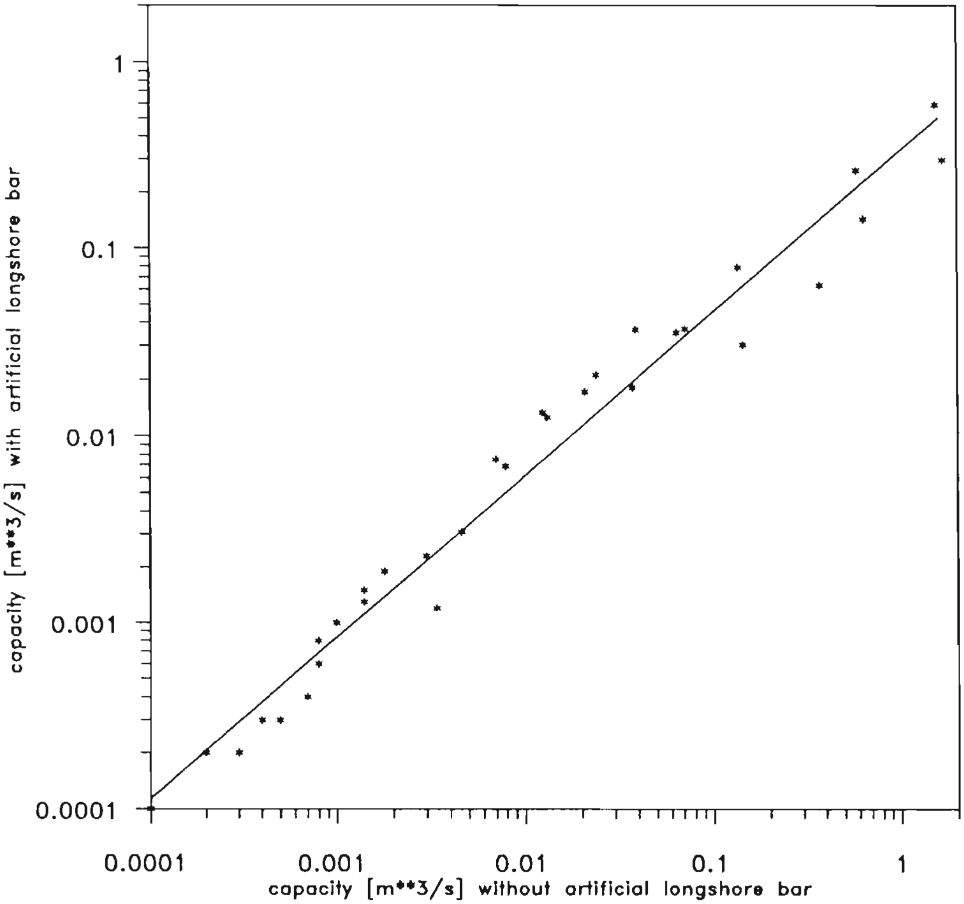

Figure 19. Scatterplot of sediment transport rates.

quently standing infragravity waves and/or edgewaves are responsible for the development of the longshore bar. Maybe the construction of the geotextile core of the longshore bar has contributed to a long-standing build-up so that, as an interaction, a sandy longshore bar could form. The single-bar beach model after WRIGHT and SHORT (1984), SUNAMURA (1988), Lippmann and HOLMAN (1990) or SHORT and AAGAARD (1993) as described in the cited literature could not be substantiated during an investigation of eight years by AHRENDT (1994b). After AHRENDT (1994b), the position of the longshore bar is relatively stable with changes in height. The response time of a bar system seems to be longer than the time over which wave condition can be considered steady, so that the bar is rarely in equilibrium. The position of the longshore bar at Sylt island seems to be the mean equilibrium profile whereby the centre of mass is stable. Therefore, the conditions for a stabilization of the longshore bar system by geotextiles are relatively good. Future coastal protection measures of this kind should fit into the local morphologic and dynamic environment. The artificial bar must not be constructed to block rip currents. Artificial bars should neither be built too high nor too long.

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□ ZUSAMMENFASSUNG □

Ein besonders durch Erosion gefährdeter Strandabschnitt an der Westküste von Sylt vor Kampen wurde 1990 durch ein geotextiles Riff geschützt. Drei Jahre nach der Baumaβnahme ist eine eindeutige Verbesserung der Küstenstruktur in diesem Bereich eingetreten. Es hat sich ein breites hohes Riff mit dahinterliegender Strandverbreiterung eingestellt. Die Sedimenttransportkapazität über das küstennormale Profil konnte durch diese Maβnahme auf $Q_a = c^{0.8676}*0.3345$ reduziert werden, welches die Verweildauer des Sandes erheblich erhöht. Maβnahmen dieser Art müssen den natürlichen morphologischen Rahmenbedingungen angepaβt sein, d. h., daβ Rifflänge,-position und- höhe die natürlichen Ausmaβe nicht überschreiten dürfen.