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# BEACH EROSION AT KLIM, DENMARK. A TEN-YEAR RECORD.

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## ABSTRACT

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A 120,000 $m^2$ area, stretching over 850 m of coast at Klim in Northern Jutland, Denmark, was surveyed three times a year from 1968 to 1978, except in 1973 and 1974. Although there are considerable variations, the coastline retreated at an average of 5.0 m per year. The retreat was at its minimum in the central part of the area, where for a period German blockhouses served as breakwaters. In the same period erosion on the downdrift side of the blockhouses increased. Changes in height varied from −5.5 m in the northwestern part of the area where dunes were eroded, to +1.8 m in the southeastern part where new dunes were being built up. The greatest changes in profiles were measured in 1971—1972 and 1975—1976. They were both consequences of storm surges.

A comparison of the 1968 and 1978 surveys shows that 137,500 $m^3$ were eroded during these ten years, and that 6000 $m^3$ were deposited.

## INTRODUCTION

Changes in beach profiles constitute an important aspect of the variability of the coastal environment. Many investigations of the backward and forward movement of the coastline are based on comparisons of old and new maps and of aerial photos. Since there is usually a lack of actual measurements, these comparisons necessarily depend on the accuracy of the maps (for a good examination see Carr, 1962). A common feature, too, is that such investigations can only show the changes as moment-situations separated by a rather long series of years.

No standard set of terms exists for describing beach-profile features. However, certain features are sufficiently common in their occurrence to be recognized on most beaches and have been given names which are in general use. Figure 1 (Inman, 1971) shows the definition of some important morphological beach features. The present study is primarily concerned with three of these features which are basic parts of the beach profile: the berm and beach face, the terrace, and the bar. Movement or change in these three

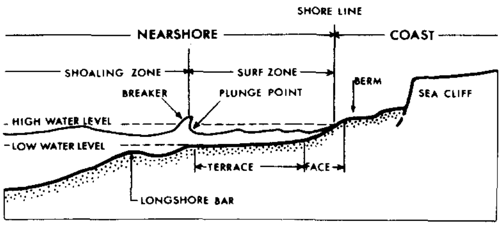



Fig. 1. Beach profile showing characteristic features.

features accounts for most of the changes in beach-profile configuration and is consequently most significant in describing profile changes.

This paper describes some long-term changes in beach profiles at Klim in Northern Jutland. Short-term variations, which have also been studied, will be described in a later paper.

## REGIONAL SETTING

The investigation area is an 850 m stretch of coast situated at Klim, north-west of Fjerritslev in Northern Jutland (Fig. 2). The tidal range in the area amounts to only 0.3 m, while variations in water level caused by meteorological conditions are from +2.5 m to −0.6 m above DNN (Danish Ordnance Datum). Southwesterly winds give the largest positive deviations whereas easterly winds give the largest negative deviations. Winds also create


Fig. 2. Locational map.

coastal currents. East-going currents prevail for about three quarters of the year. Current velocity in calm weather is about 1—1.5 knots. Southwesterly gales give the highest velocity, about 3 knots (Søkortarkivet = Royal Hydrographic Office, 1962). As a consequence of the prevailing westerly winds the net sediment transport along the coast is towards the east. In general the coastal configuration of Northern Jutland limits the fetch available for wind-generated waves from the south and the east. The wave-climates are, therefore, dominated from the west through to the northwest, superimposed upon Atlantic swell of much longer period and wave length. Mean wave height is less than 1 m for 76% the year. Maximum recorded wave height at Hanstholm Harbour is 9 m (winds from WNW, 20 m $s^{-1}$) (Harbourmaster, personal communication, 1979).

An important aspect in this study lies in the fact that up to 1974 this area, and other stretches of coast in the neighbourhood, were subjected to sand and gravel mining. Since then mining on the beach itself has been prohibited by law, but excavation continues in the area immediately behind it. Mean particle size is 0.45 mm on the beach and 1.75 mm in the swash zone.

## METHODS

A system of bearing marks with a mutual interval of 1 km has been established along the west coast of Jutland by the Danish Department of Coastal Engineering (Vandbygningsvæsenet). These marks form an excellent basis for surveys of beach profiles. With starting points at bearing mark 2590 H (UTM 32 E: 6332870.30 m, N 510340.85 m) and bearing mark 2600 H (UTM 32: E 6332881.65 m, N 509229.43 m) (numbers in brackets give the UTM co-ordinates) a base line was established in 1968 with a length of 1000 m. The base line runs almost parallel to the coastline.

Along the base line a system of orthogonal lines with a mutual interval of 50 m was established. In this way the range lines cut the contour lines almost at right angles. This system was found adequate since the topography of the beach is rather uniform. The base line was permanently marked so that the whole system could be re-established every year.

Surveys of the beach profile were made in two parts: (1) on the backshore and upper foreshore down to wading depths standard surveying techniques were used, starting from bench marks on the base line; (2) the offshore part of the profile seaward of the breakers was measured with echo sounder in a rubber boat (Fig. 3). By doing the surveys in calm weather, overlap of the two parts of the survey was achieved. For the land surveys of the backshore and foreshore precision levels (Wild model NAK 2 and Zeiss model NI 2), surveyor's rods and steel tapes were used. Elevations were measured to 0.01 ± 0.005 m. Distances between survey marks were measured to 0.02 ± 0.01 m while spot height locations were determined by tacheometry to 0.1 ± 0.05 m by using flags to mark the marks on the range. Spot heights were measured at 10 m intervals except where pronounced changes in slope

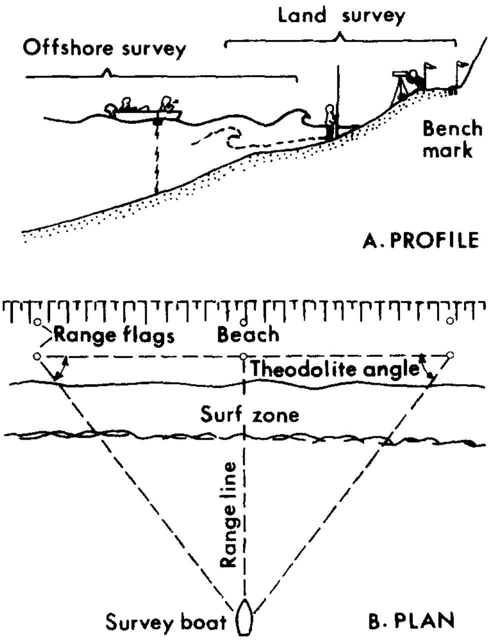



Fig. 3. Survey procedure.

occurred. Where the topography between range lines was complicated, the levellings were supplemented by using a plane-table, (Wild model RKI).

The offshore part of the survey was measured with an Elac Echograph model Superior-Laz 17, and measurements were calibrated for temperature and salinity. Boat positions were determined by a system of range and horizontal angles similar to that employed by Inman and Rusnak (1956), but modified for greater accuracy. Each range line was marked by two flags for approximate alignment, and horizontal angles were determined by the use of two theodolites (Zeiss model TH 42) placed on other ranges (Fig. 3).

Horizontal angles were measured to coincide with time marks on the echograph. The three stations were in contact by walkie-talkies. The distance on the range line was then calculated from the angles and plotted with the appropriate sounding.

All elevations are connected to the Danish Geodetical Institute's levellings and thus are referred to the same datum, DNN (Danish Ordnance Datum).

Levelling was carried out at least three times a year (June, July and August). In the results we have chosen to use the June data because they differ only little from the results from July and August. Maps at 1:1000 were drawn by interpolation between the range lines. By covering the maps with a grid-net of 50 × 50 m it is possible to determine the changes in volume in each grid from one year to another. This is done by reading the height at 30 points in the grid at mutual distances of 5 m. The average height in the grid is then multiplied by the area to get the volume. Change in water level was read every hour on a tide staff in survey periods. Additional information on change in water level was obtained from the nearest harbour in Hanstholm, 38 km to the west of the survey area. Information on wave conditions was also obtained from Hanstholm. Waves were measured 900 m NW of Hanstholm at a waterdepth of 19 m.

## RESULTS

### *Receding of the coastline*

If we define the intersection between DNN and the rangelines as the transit between water and land, Table I and Fig. 4 show the distance from the water line to the base line as measured on each of the range lines. It can be seen from Table I that the distance is subjected to great variations from one year to another. However, the general tendency from 1968 to 1978 is a retreat of the coastline amounting to 50 m or 5.0 m/year. The retreat was specially marked from 1971 to 1972 (14 m) and from 1968 to 1969 (25 m). The retreat was small from 1969 to 1970 (5 m). The coastline moved forward from 1972 to 1975 (2 m), from 1977 to 1978 (4 m), and from 1970 to 1971 (5 m). On examining the distances along the individual range lines we can see that the eastern part of the area has been subjected to the greatest retreat (up to 93 m on range line no. 745). In the western part of the area the retreat was

TABLE I

Distances from DNN on the rangeline to the baseline in m from 1968—1978.

| year<br>Rangeline | '68 | 69 | 70 | 71 | 72 | 75 | 76 | 77 | 78 |
|---|---|---|---|---|---|---|---|---|---|
| 45 | 87 | | 85 | 82 | 70 | 76 | 52 | 50 | 50 |
| 95 | 101 | 94 | 98 | 93 | 73 | 90 | 44 | 54 | 65 |
| 145 | 113 | 102 | 105 | 94 | 84 | 87 | 63 | 66 | 69 |
| 195 | 130 | 112 | 110 | 103 | 87 | 87 | 66 | 73 | 83 |
| 245 | 131 | 120 | 120 | 125 | 98 | 92 | 67 | 78 | 78 |
| 295 | 133 | 133 | 135 | 132 | 100 | 100 | 86 | 90 | 82 |
| 345 | 144 | 135 | 135 | 140 | 115 | 111 | 90 | 84 | 93 |
| 395 | 130 | 130 | 124 | 136 | 122 | 111 | 97 | 85 | 102 |
| 445 | 135 | 127 | 118 | 127 | 116 | 113 | 97 | 95 | 112 |
| 495 | 145 | 140 | 114 | 117 | 110 | 125 | 116 | 88 | 117 |
| 545 | 150 | | 110 | 114 | 120 | 120 | 106 | 105 | 111 |
| 595 | 155 | | 115 | 127 | 113 | 114 | 105 | 94 | 105 |
| 645 | 164 | | 123 | 132 | 113 | 111 | 116 | 109 | 102 |
| 695 | 182 | | 129 | 127 | 125 | 123 | 122 | 117 | 100 |
| 745 | 195 | | | 133 | 113 | 127 | 133 | 114 | 102 |
| 795 | 194 | | | 133 | 119 | 135 | 150 | 122 | 109 |
| 845 | 194 | | | 138 | 137 | 126 | 175 | 111 | 116 |
| Average | 146 | (121) | (116) | 121 | 107 | 109 | 99 | 90 | 94 |

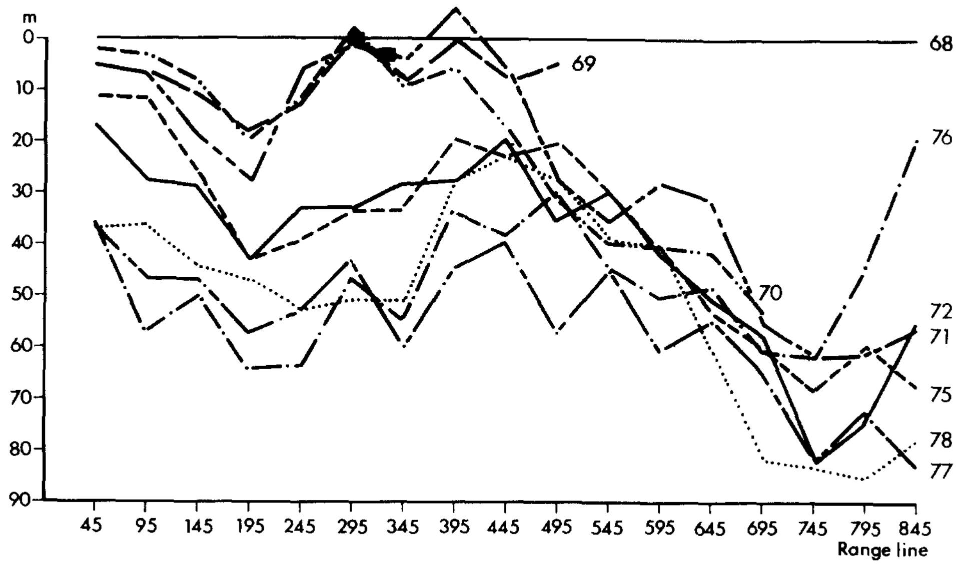



Fig. 4. Position of the shoreline from 1969 to 1978 relative to the 1968 shore. The latter is represented as a straight line. ▪ German blockhouses.

more modest, down to as little as 36 m (range line no. 95). The retreat in the central part of the area has been as little as 23 m (range line no. 445). A careful examination of Table I also shows that in any one year the coast can move back in some parts and forward in others.

This is specially the case from 1975 to 1976. The retreat was great in the western part (46 m on range line no. 95), whereas the eastern part moved forward (up to 49 m on range line no. 795). In the eastern part the coastline propagated because a part of the sand eroded from the dunes in January 1976 still remained in the swash zone. Only when this natural beach nourisment was removed the next winter, could the normal retreat go on.

Figure 4 shows that from 1968 to 1970 the German blockhouses served as break-waters, resulting in little erosion on range lines no. 295—395. On the other hand, in the same period the beach on the downdrift side of the blockhouse was far more eroded than the updrift side.

*Changes in height*

Figure 5 shows the total changes in height during 1968—1978 at points spaced 50 m apart. Not all changes can be shown on this rather coarse grid. Thus the greatest changes are some 150–200 m from the base line between range lines 795 and 845. Here changes in height from 1968 to 1978 exceed 5.5 m. A former dune in this grid square is now eroded and the elevation is down to −0.5 metres (Fig. 6).

Figure 6 shows that in the western part of the area erosion has reached the base line. Thus the base line has been cut down from 1000 m in 1968 to 845

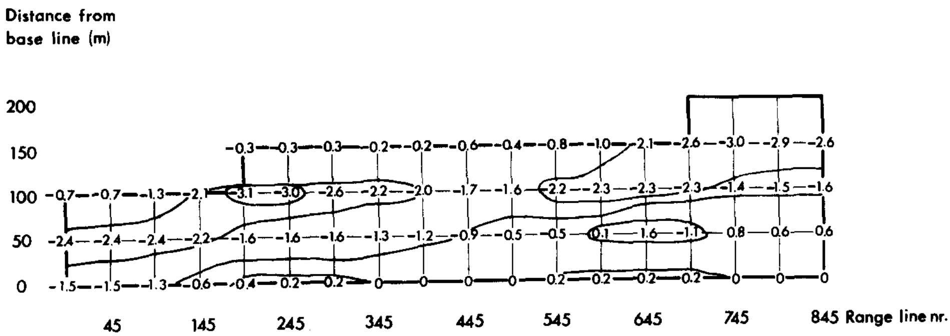



Fig. 5. Net changes in elevation 1968—1978, in metres, at the 50 m-grid intersections. Isopach lines have been interpolated. (Deposition is positive, erosion is negative).

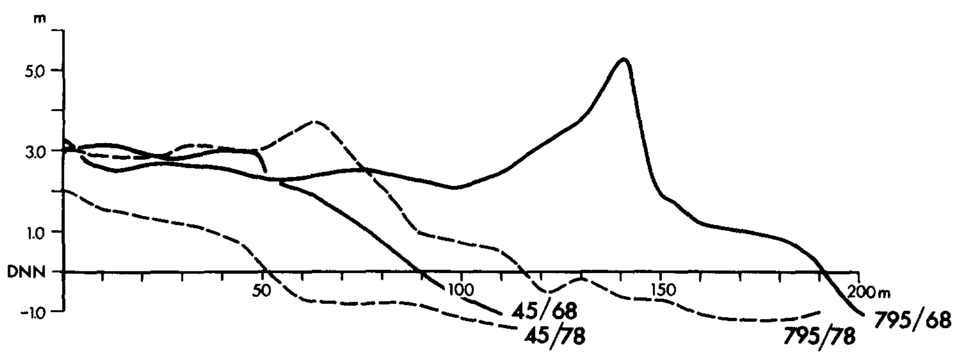



Fig. 6. Profiles from the western (45/68 — 45/78) and eastern (795/68 — 795/78) parts of the survey area. Erosion has reached the base line in the west.

m in 1978. It is interesting to note that the 1978 soundings in the western part outside the 1 m depth curve do not differ by more than 0.3 m from the 1968 survey (Fig. 6).

One has to point out that the actual changes have been greater than the 10-year totals suggest. A comparison of maps from 1968 and 1977, for example, shows greater differences, indicating that there was considerable accumulation from 1977 to 1978. In the southeastern part of the survey area there has been an accumulation of up to 1.6 m. New dunes are here being built up, especially after the floods of 21st January 1976.

*Changes in profiles*

Figure 7 shows the annually measured profiles during 1968 to 1978 at bearing mark 2590 R. A line suggests the profile from 1963 as it can be estimated from a 1:25,000 map. The "coordinated point" behind the dune crest of 1963 was placed on the German blockhouse which can be seen on

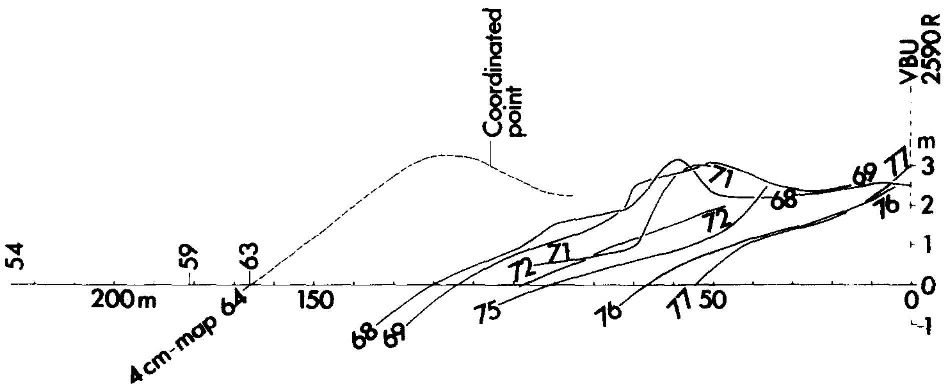
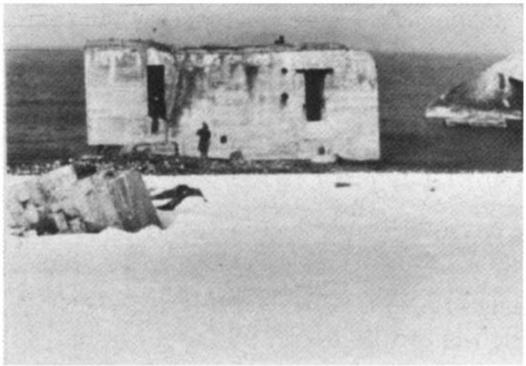



Fig. 7. Annual profiles 1968—1972 and 1975—1977. The position of waterline in 1954 and 1959 is taken from air photographs. The 1963 profile is derived from the 1:25,000 map.

Fig. 8A, B and C. The lables "1954" and "1959" in Fig. 6 refer to the location of the shoreline read from air photographs. It can be seen that the shoreline has retreated by 170 m in the last 24 years, i.e. with an average rate of 7 m/year.

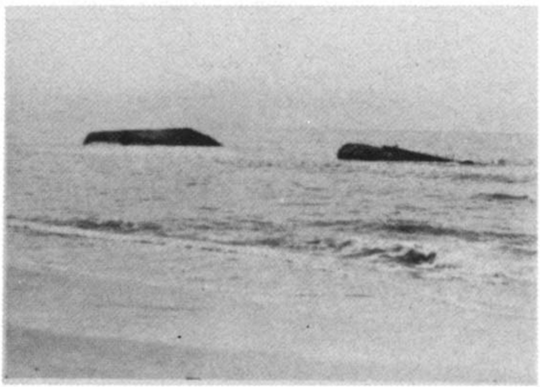
The greatest changes in profiles were measured in the years 1971—1972 and 1975—1976, when there were specially great storm surges (Fig. 9). On the night between 20th and 21st January 1976 the dunes were eroded back for a distance of 40 m. A little ice-cream shop behind the dunes, 150 m to the south of the base line on range line 345, disappeared that night. It is worth noting that the profiles in the survey area following those two storm surges assumed the same form as that measured in the Netherlands after the



A

Fig. 8A. Explanation on p. 291.

B



C

**Fig. 8. Three views of two German blockhouses, which were originally built into dunes. A. Spring 1970. B. Summer 1972. C. Summer 1978.**

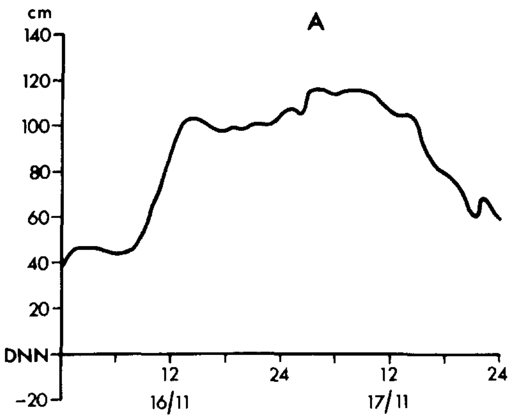
storm surge of 1953. According to Van de Graff (1977) this so-called storm profile can be empirically defined by the relationship:

$$z = 0.415\ (x + 4.5)^{0.5} - 0.88$$

where $z$ = depth below the maximum water level during the storm surge ($m$), and $x$ = distance from the intersection of the beach profile and the maximum water level ($m$), see Fig. 10.

*Changes in volume*

By comparing the volume in each 50 × 50 m grid net from one year to another changes in volume can be determined. Figure 11 shows these changes from 1968 to 1978. Most of the area has suffered a loss of material. The greatest loss, $11.0 \times 10^3$ $m^3/2500\ m^2$, is found at the extreme eastern end of the area, 100–150 m seawards of the base line. Here there were dunes in 1968 with heights of up to 5.5 m above BNN. The average height in 1978



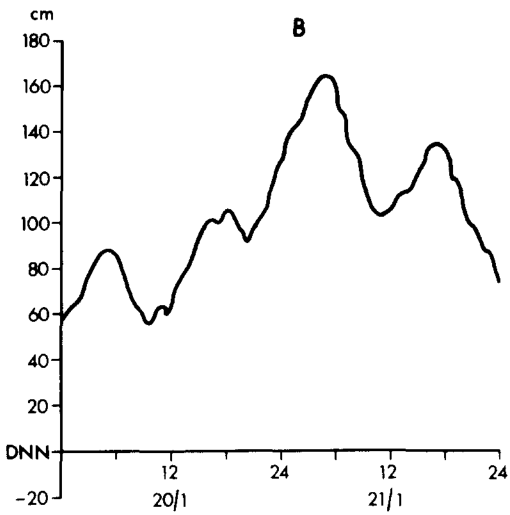




Fig. 9. Hydrographs from November 1971 (A) and January 1976 (B).

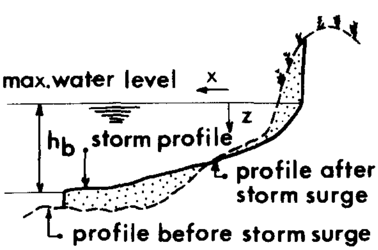



Fig. 10. Typical changes on a beach during a storm (after Van de Graff, 1977).

TABLE II

Changes in volume 1968—1978. Accumulation is positive, erosion negative

| | | Annual change, above mean sea level only | | | | | | Total change including area below mean sea level 1968—1978 |
|---|---|---|---|---|---|---|---|---|
| | | 1968—1971[a] | 1971—1972 | 1972—1975[b] | 1975—1976 | 1976—1977 | 1977—1978 | |
| Erosion | ($m^3$) | −26,430 | −20,174 | −2075 | −30,886 | −9347 | −3087 | −137,593 |
| Accumulation | ($m^3$) | 3478 | 4307 | 10,444 | 2426 | 5137 | 10658 | 5906 |
| Net change | ($m^3$) | −22,952 | −15,867 | +8369 | −28,420 | −4210 | +7571 | −131,687 |

[a]The surveys of 1969 and 1970 were not complete.
[b]No surveys in 1973 and 1974.

is —0.5 m. Further inland in the same area there was again of up to $1.8 \times 10^3$ $m^3/2500\ m^2$. Here, starting with the floods of 1976, new dunes are being built up.

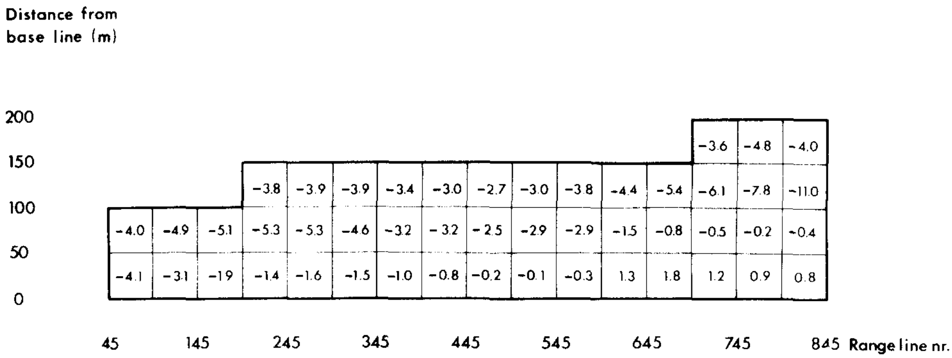



Fig. 11. Net volumetric change 1968—1978 for the grid squares, measured in 1000 $m^3/2500\ m^2$. (Deposition is positive, erosion is negative).

The absolute change from 1968 to 1978 was 143,500 $m^3$, with 137,500 $m^3$ eroded and 6000 $m^3$ deposited (Table II). It can be seen from Table II that these 10-year changes disguise the fact that in some years accumulation exceeds erosion. If one looks at 1977—1978, for instance, total erosion amounted to 3087 $m^3$, while accumulation came to 10,658 $m^3$ (net accumulation 7571 $m^3$).

Some of the sediments have been removed by the local sand- and gravel-mining firm, but they claim that mining only took place in June 1974, and that only a few hundred $m^3$ were taken. Our own evidence suggests that the total during the 10-year period was considerably greater, but mining can at best explain only a very small fraction of the total sediment loss.

## DISCUSSION

One of the aims of the present study was to examine what influence coastal sand and gravel mining has on the sediment budget. We had intended to compare the amount removed by mining with the annual volume changes. However, since meaningful data on the mining are not available, no firm conclusions can be derived from such a comparison.

We have therefore had to rely entirely on the survey data. From 1954 to 1968 there was an average coastal retreat of 7.5 m/year, which is more than the average of 5.0 m during the last ten years. This could mean that the retreat has slowed down after the gravel mining on the beach was stopped in 1974. If, on the other hand, we compare the average advance of 0.7 m from 1972 to 1975 with the average retreat of 5 m from 1975 to 1978, we could get the impression that matters have been even worse since 1974. We must therefore conclude that sand mining has not played a major role in the sediment budget. The decisive role in the net sediment loss in this area has been played by storm surges. By far the greatest loss was experienced during the flood of November 1971 and January 1976. The volumetric loss in 1976 was 1½ times as great as that of 1971 although the average linear retreat during 1975—1976 was only 10 m against 14 m in 1971—1972. During the storm surge in 1971 most of the sediment was taken from the berm and beach face. During the storm surge of 1976, on the other hand, the water level was so high that most of the loss came from the dunes.

Even on beaches without significant long-term changes there may be considerable short-term variations. Such variations can be either seasonal (Fox and Davis, 1978) or connected with specific events (Nielsen and Nielsen, 1978). In all such cases the sand lost during storms is returned to the beaches during the post-storm recovery. It is customary to express all volumetric changes, whether short-term or long-term, in terms of $m^3$ per linear metre of beach (Kana, 1977; Harray and Healy, 1978). We found an average loss of sand of 16.2 $m^3$ per metre of beach per year. Fully 49% of this total came from the dunes. Thus, it is extremely important to specify whether the changes occur in the dunes (Van de Graff, 1977), are due to bluff recession (Komar and Rea, 1976) or take place on the beach itself.

Our results are based on a sampling interval of 50 m. Using a sampling interval of 1000 m, the Vandbygningsvæsen (Hansen, 1968) estimated coastal retreat in the same area for the period up to 1968 to be approximately 0.5 m/year, that is, only one-tenth of our results. Perhaps the erosional rate is subject to major cyclic variations, such as those recognized by De Moor (1979) in the Bredene-De Haan zone in Belgium (De Moor, 1979).

Another, more likely explanation is that the difference is a direct result of the chosen sample intervals. For example, Hayden et al. (1979) found that measurements taken on a given stretch of coast during a given period varied widely according to the equidistance of the sampling.

It might therefore be more relevant to compare our data with the Vandbygningsvæsen profile which lies within our area. Table I shows that along-the-coast variations vastly exceed the annual averages. Thus individual profiles can rapidly prograde at a time of major degradation. Komar (1978) also found appreciable longshore variations in the nature of beach profiles some 300—600 m from one another. Hayden et al. (1979) found that U.S. mid-Atlantic coast shorelines were characterized by a series of along-the-coast periodicities in shoreline dynamics. Nielsen and Nielsen (1978), using a very high-resolution sampling interval (4 m), also found that individual profiles can be misleading in that the oblique onshore movement of a convex bar can produce apparent prograding or degrading by appearing and disappearing on a single range line. We can thus conclude that the above comparison with the Vandbygningsvæsen data is unjustified, and, more generally, that in coastal studies no conclusions should ever be based on a single profile.

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