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RECENT BEACH EVOLUTION ALONG THE BELGIAN NORTH SEA COAST.

by Guy DE MOOR (*)

SAMENVATTING. - Sinds enkele decennia wordt de Belgische kust op verschillende plaatsen getroffen door intense erosie. Deze omvat strandverlaging en terugwijken van de duinvoet. De auteur beschrijft eerst het verloop van het verschijnsel in de zone Bredene - De Haan. Op basis van korte duur evolutie van transversale mobiliteit en standbudget opgenomen door opeenvolgende strandprofielen in het representatief station Klemskerke KP 38 gedurende de periode 1976-1979, brengt hij naar voor dat het hier gaat om een erosieve fase uit een cyclisch, repetitief en alternerend verschijnsel, een littorale megaprotuberans. Historische argumenten voor het karakter van het verschijnsel worden naar voor gebracht.

RESUME. - Au cours des dernieres décennies, divers endroits de la côte belge ont été touchés par une intense érosion. Le démaigrissement des plages atteintes comprend un abaissement de l'estran et un recul de l'arrière-plage et du front dunaire. L'auteur décrit le déroulement du phénomène dans la zone Bredene - De Haan. Se basant sur l'évolution à courte échéance de la mobilité et du bilan sédimentaire transversaux, établis à l'aide de profils de plages successifs dressés dans la station représentative Klemskerke KP 38 au cours de la période 1976-1979, il avance qu'il s'agit d'une phase érosive appartenant à un phénomène cyclique, répétitif et alternant, une mégaprotubérance côtière. La nature du phénomène est mis en évidence à l'aide d'arguments historiques.

SUMMARY. - Since a few decades different zones along the open, sandy macrotidal Belgian coast show a residual erosional beach evolution. Classic coastal defense structures have only proved to be usefull by impeding further retreat of the dunefoot. Lowering of the beach itself still goes on.

Carrying out beach profiles, the author describes the course of the phenomenon in the Bredene - De Haan zone. Using successive beach profilings at the representative station Klemskerke KP 38 during the period 1976-1979, he studies the short run evolution of transversal sand mobility and beach budget and puts foreward that the erosional attack belongs to a cyclic, repetitive and alternating coastal megaprotuberance. Evidence for its nature is given by historical arguments.

(*) Laboratorium voor Fysische Aardrijkskunde, Geologisch Instituut, Rijksuniversiteit Gent, Krijgslaan 271, B-9000 GENT.

INTRODUCTION

The Belgian North Sea coast is an open (fig. 1), sandy, macrotidal one. The tides are semi-diurnal and show quite an important height difference between spring and neap tides.

The shore comprises a typical runnel and ridge beach with its different micromorphological zones. It is swept by the tides during more or less lasting time spans according to the dozen rule. The back-beach is standing against a dune belt. In front of the beach itself extends a shallow and relatively wide near shore zone whose bottom shows a mildered continuation of the runnel and ridge structure. More offshore it is preceded by a first row of shore-parallel running banks, considered as flood parabols (as flood currents are mainly NE directed) and a second row of banks which run obliquely to the shore and have been considered as eb parabols (J. VAN VEEN, 1936).

Width, generalised slope (table 1) and microrelief as well as sediment characteristics of the beaches are slightly changing along this 65 km long coast. These geographical variations however are less important than the changes those characteristics are subject to due to seasonal factors (fig. 1), to the evolution of the beach microrelief itself and to the changes in wave characteristics and tidal amplitude.

Except three narrow zones between Koksijde and Nieuwpoort, between Klemskerke and Wenduine and east of Knokke-Zoute, most of this coast shows classical defense structures such as groyns and sea walls, a single breakwater heading at Zeebrugge and till 1978, the single artificial nourishment beach extending between Heyst and Knokke was the only one.

BEACH EROSION PHENOMENA

During the last decades several coastal sections are known to have been hit by a more or less strong erosional attack, lasting at least tens of years, growing gradually in intensity and in extension up to affect several kilometers of coastal length and occasionally being activated by heavy storms.

Those erosional protuberances, as shown by a three year lasting beach profiling at Klemskerke (station KP 38), comprise a long run residual lowering of the beach (fig. 2), a back cutting of the back beach, a direct spring tide wave attack on the dunefoot and, at least in zones laking longshore sea walls, a retreat of the dune front itself (fig. 3). Meanwhile groyns and seawalls are laid bare.

Starting beneath the neap low water line and despite short periods of accretion corresponding to intermittent stockpilling, residual beach lowering gradually progresses in a landward direction hitting successively the ridges and runnels as well as the terraced zone. Back cutting of the back beach leads to undercutting of the dune foot, formation of an undercutting cliff and, due to oversteepening, to mass movements along the dune slope. Those down moved dune sands first extend over the terraced zone and help to stabilise temporarly the flexion line. Very soon however they are removed from the upper beach, which at that moment shows characteristic blackflow ripples, and despite recycling in the fore beach zone by wave action, by tidal movements, by runnel mechanisms and other less important processes, they disappear in a mainly seaward direction as there is no indication of any long run residual duneward nor longshore eolian accretion. During the lowering, ridges and runnels change somewhat in shape and dimension, mainly by passing waves of recycled sands, but they keep a certain transversal localisation stability.

Such erosional phenomena attack as well zones with as without defense structures and moreover construction of defense structures or nourishments seem not to alter their evolution.

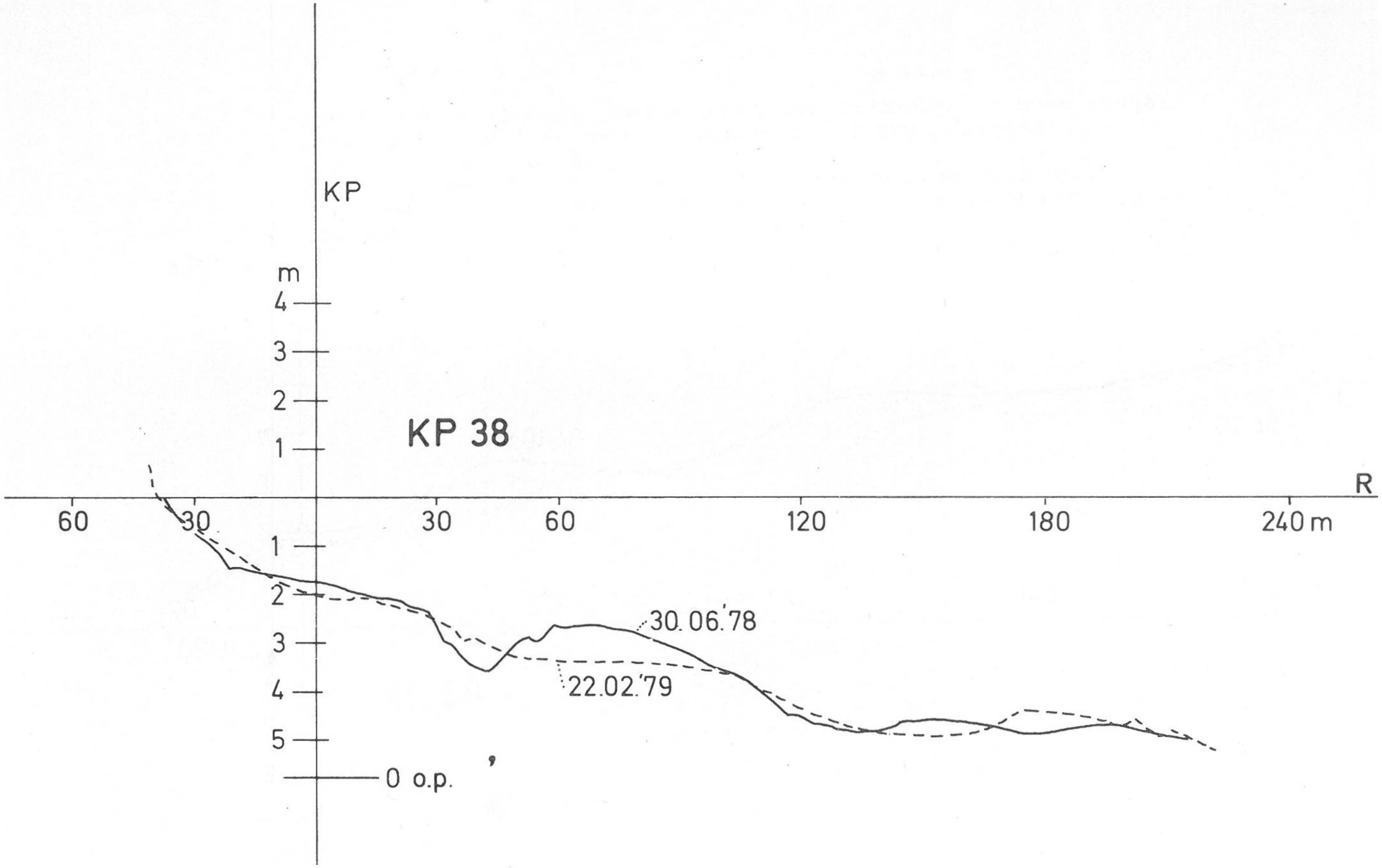

Fig. 1 - Station KP 38 (Klemskerke)
Transversal profiles of the natural beach.
Micromorphological difference between summer and winter beach.

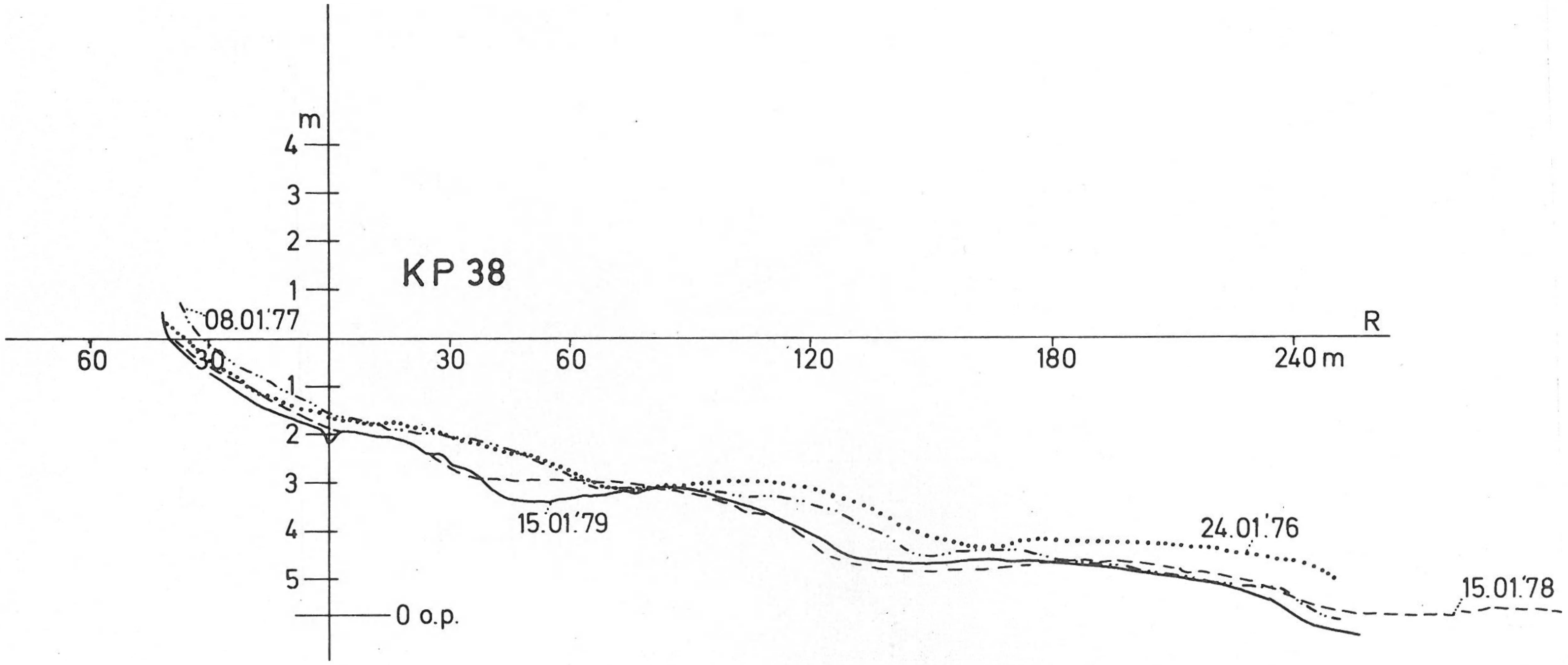

Fig. 2 - Station KP 38 (Klemskerke)
Transversal profiles of the natural beach.
Residual evolution during the period january 1976-january 1979.
General lowering of the beach, progressing gradually away from the low water mark.
Retreat of the wave exposed parts of the beach ridges.
The terraced zone is less altered due to supply of dune sands.

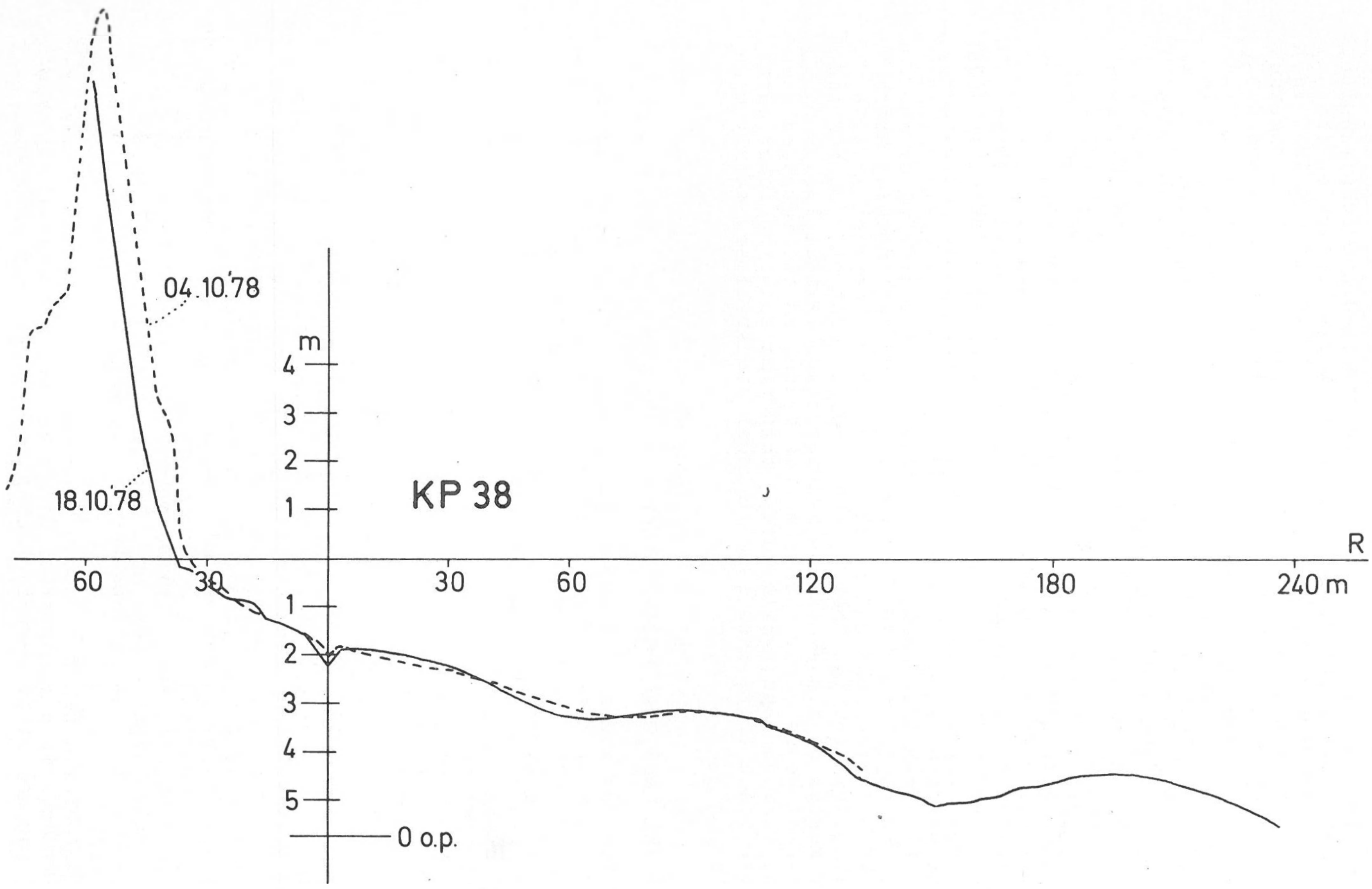

Fig. 3 - Station KP 38 (Klemskerke)
Transversal beach and dune front profile.
Retreat of the dune front during a 12 days lasting spring tide cycle.

Since 1935 a 10 km long stretch east of Heyst is under strong attack and despite extension of defense structures and two sand nourishments (1958, 1978), remains so. Since 1960 the Koksijde beach has been hit by a rather mild erosion phase. On the other hand the beach west of De Panne is under such heavy attack that since 1976 a 3 km long sea wall had to be constructed and even rebuilt.

Most spectacular however is the nowadays erosion on the beach between Bredene en De Haan. There it started around 1955 in the westernmost Bredene section and despite construction of numerous groyns up to 300 m of lenght, increased in strength and extended still more eastwards. At the profiling station KP 38 at Klemskerke-Vosseslag, erosional effects for the first time became visible in 1970, increasing gradually in intensity, and reaching a dramatic level since the heavy storms of 1 January 1976 and 24 December 1976. Computation of the beach budget over three successive years since 24 January 1976 gives a quantitative assessment of the beach losses at the station, considered as representative for the beach (table 2). In the period 1970-1979 the residual retreat of the dune foot there reached about 40 m. At several places along the Bredene-Klemskerke section the dune front was up to be breached.

This evolution forced the administration to provide the Bredene-Klemskerke section with a defense structure. Indeed in 1978 a 2,5 km long Longard defense structure has been fitted, forming an artificial beach by sand nourishment and a rectangular, sand filled plastic tube armament. Weekly transversal beach profiling of the artificial beach (station KP 37) and of the adjacent natural beach (station KP 38) since the end of the beach nourishment on 26.9.78 distinctly proved that on both beaches erosion went on. During the first six months of the evolution however, the heaviest losses on the artificial beach occured on the back beach, on the terraced zone and in the flexion zone, while during that time span the lower parts of the fore beach there knew some residual stockpilling, mainly upon the ridges.

NATURE OF THE EROSIONAL PROTUBERANCE

Besides a description of the nowadays erosional protuberance, a first aim of this study was to get more insight into its course as well as in its possible long run (time span of at least tens of years) evolution, using therefore short run (time span of several successive years) observations of changes in the residual sand movement and in the residual sand budget of the beach over different and increasing time spans.

Sand movement over quite short periods proved to reach very high values but to be extremely variable as well, and to show successively opposite or varying directions. Hence the beach budget shows successively losses and gains. Over more or less longer time spans however, they result in only small residual changes of the beach morphology and of the total sand volume of the beach. As the sand movement is due to different more or less cyclic factors, acting more or less simultaneously, one of the problems is to determine the number and the lenghts of the elementary time spans.

Any beach can be considered as an autonomous system of sand motions commanded by mechanisms of erosion, transport, deposition, recycling and redistribution acting under various driving forces (such as wave action, swell, tidal movements, water oozings, etc...). Hence each micromorphological unit has its own morphological and sediment mobilities and its own budget, as well as the beach as a whole itself.

Moreover a beach is not a mere closed system, as it may exchange sediments in a transversal direction as well with its backing dune belt (or any other feature such a rocky cliff) as with its forelying nearshore zone. It may however also have exchanges in a longshore way with adjacent beaches or beach sections, even indirectly. Hence not only transversal movements and budgets as well as longshore ones have to be taken in account.

Studying the evolution of the beach as a whole, only residual changes in the total sand volume of the beach during the considered period are meaningfull. Hence, not the internal but the external budget and the overall sand motion will be the main concern. Moreover an important prerequisite will be a functional definition of the beach limits.

A balanced sandy beach knows a dynamic equilibrium as the sediment is not at all at rest. Such a beach can be affected by more or less important internal sand movements and micromorphological changes and even show balanced exchanges with the adjacent zones. Nevertheless it shows a total residual volumetric stability within its limits but it doesn't correspond to any sedimentologic nor morphologic internal immobility.

A balanced beach is a stable one if neither the beach, neither its adjacent zones show residual losses nor gains in their external budget over the considered period. An instable balanced beach doesn't show volumetric changes as well, but its external budget is balanced by equal residual input on one side and output on the other one. The beach is a zone of transit. It can prograde or retreat. An unbalanced beach has a positive or negative external budget, eventually in combination with a more or less important transit function.

Global mobility is the total amount of sand moved on the beach, within its limits and within a definite time span. It corresponds to the summation of the absolute values of the total volumetric gains and losses within those time and beach limits.

Global beach budget corresponds to the algebraic summation of the total volumetric gains and losses within the considered time and beach limits.

Computation of volumetric gains and losses over a definite period has not been based on a direct measurement of the moving sediment during that time span, but on an indirect one by considering the residual hypsographic effects of the sand movement over that period and along a beach profile in a station considered as representative for the studied beach section. Total volumetric gains and losses both have been obtained by summation of elementary gains and losses occuring in between any two successive levelling stations along the same profile and during the time span between two successive transversal beach profilings taken at the beginning and at the end of the considered period. They have been calculated for a constant beach length of 1 m (length unit L_1) along the profile. The equidistancy of the levelling stations always was 3 m. The global values have been calculated for a unit beach width (E_1) limited by the spring tide high water mark and by the neap tide low water mark. Regularly however profiling has been extended over the foredune zone and as far as the spring tide low water mark.

Evolution of the sand motion has been based on mobilities and beach budgets computed over time spans of different lengths as well as over time spans of increasing lengths.

The representative station for the natural beach was situated at Klemskerke-Vosseslag (KP 38). Beach profiling started on 24 January 1976 and after an initial period of irregular levellings, continued since June 1978 mainly by weekly profilings, allowing mobility and budget computation for daily cycles, weekly cycles, full spring cycles as well as for longer time spans.

Longshore mobility and budget have not been taken in account. Indeed, qualitative observations allow to put forward that, due to the huge variability in their orientations and to to and fro motions, longshore displacements, although quite important, showed only very few impact upon the residual morphologic evolution, at least within the considered time spans and beach lengths. For the same reason no distinction has been made according to the origin of the sand motion.

Losses by eolian transport at the advantage of the back beach or of the dune belt have not been accounted for, the residual effect of long shore displacements there being of quite little importance, but especially because of the quick recycling of any transversal gain in these zones due to their erosional retreat.

Mobility and budget values are thus transversal, residual, global and unitary ones and they refer only to the considered time spans.

Moreover, in order to get a better comparison and appreciation of the highly variable values obtained over different time spans, not only their total values (M, B) for any period, but also their mean daily values ($\overline{M}$, $\overline{B}$) for these time spans have been computed.

The $\overline{B}$/P diagram (fig. 4) shows the relationship between mean daily values for the beach budget at the station KP 38 and the length of the corresponding time spans. Mean daily losses and gains have been drawn separately and all time spans taken over the considered period (1976-1979) have been referred to a single starting moment t_b and without taking in account their relative time position. In this case single values as well as different frequencies of gains and of losses for any single time span are of little importance as they are automatically eliminated by the mean daily values of the next larger time span. Important however are the extreme gain or loss values for each increasing time span. Hence the distribution may best be fitted by two enveloping curves, both being oblique, asymmetric hyperbolic envelopes on half-logarithmic paper and the residual effect studied by their characteristics.

For the studied beach and period the diagram shows a distinct decrease of the global mean daily gains and losses with increasing time spans. It also illustrates that within the considered maximum time spans extreme mean daily losses are always higher than their gain counterparts so that the residual evolution is an erosional one. Most important however is that the losses hyperbolic envelope, despite its larger distance to the budget balance line, is faster approaching that line than the gains one. Hence there will be a time span t_e at the end of which (and at least if trends and conditions may be considered as constant) both, loss and gain envelopes will reach equal values and the beach at that moment be a balanced one, just before starting another morphological evolution stage characterised not by residual erosion, but by residual aggradation. A symmetric hyperbolic envelope set would correspond to a long run balanced beach, showing a decreasing beach budget but without any distinct indication about the mobility.

The diagram suggests that the nowadays erosional effects of the coastal processes will change in a residual aggradation within a time span t_e. According to the characteristics of the envelopes and to the relative position of their crossing points, different types of successive morphologic evolution phases can be considered.

However, as the nowadays beach erosion not always existed, it has to have been preceded by an accumulative one. Hence another set of oblique asymmetric hyperbolic envelopes may be fitted, forming more or less the mirror image of the one expressing the today's evolution (fig. 5). The time span - t_e' corresponds another dynamic equilibrium between losses and gains and to the transition of a period of decreasing residual aggradation into one of increasing residual erosion under increasing mobility. This time span - t_e' itself ought to be preceded by a time span + t_e'' corresponding to the beginning of the last accumulative phase.

Elaboration of the equations of the hyperbolic envelopes and their asymptotes could open a way to a prognosis about the course

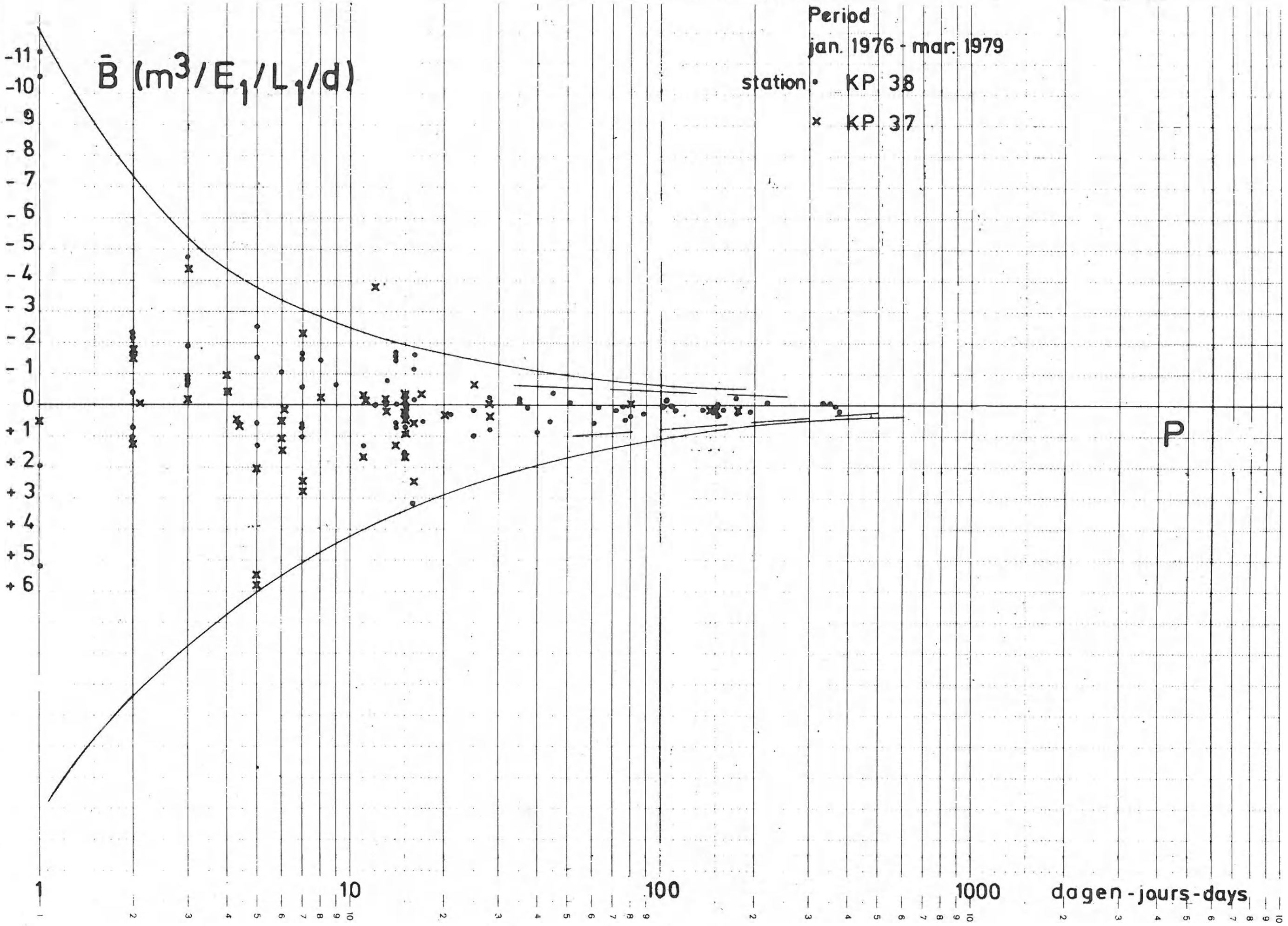

Fig. 4 Mean daily transversal beach budget $\overline{B}$ versus increasing time span P.

+ = losses - = gains

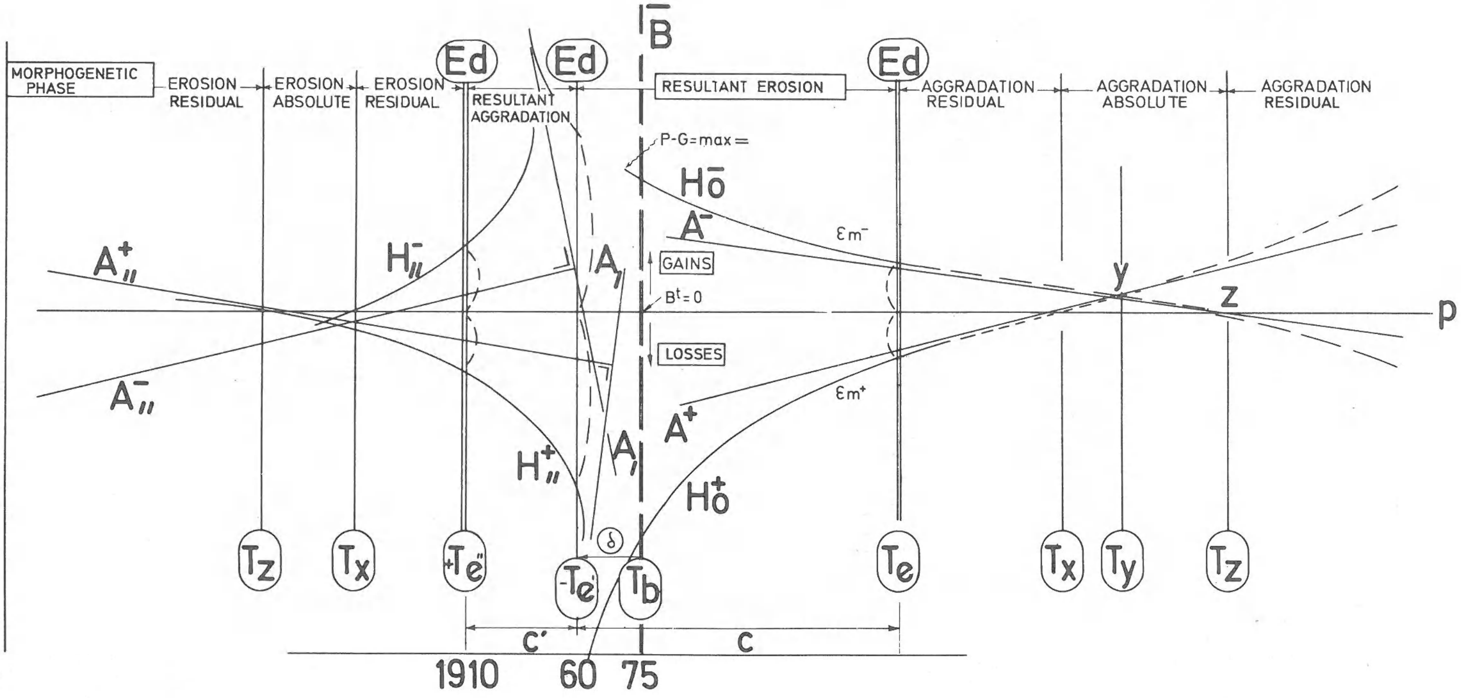

Fig. 5

Cyclicity of the coastal megaprotuberance of the mobility and of the beach budget and the ensuing evolution of the beach erosion process. The shortage of data, especially the rather short maximal time spans, however still impede a full statistical-mathematical treatment of the distribution and its envelopes.

Nevertheless it has been possible to provide evidence that the nowadays beach erosion in the Klemskerke section belongs to a chronolically cyclic, geographically repetitive and morpho-sedimentologically alternative phenomenon. At about 250 m NE of the profiling station KP 38 the retreat of the dune foot laid bare from below the dune ridge an old defense structure consisting of a longshore sea wall with forelying short groyns. It has never been seen since at least 1930. This structure is indicated on a detailed map dating from 1912* . It also shows a drawing of the construction of the concrete structure so that both have to be considered as being of about the same date**. Older people from Klemskerke itself testified that the structure dates from about 1910. Moreover an old burried wooden milestone, dug into tidal flat, podzolised dune sands and dune depression deposits of Dunkerquian 1-2 age has been laid bare near the station ensuing the retreat of the dunefoot. It is clear that the concrete structure witnesses of a former period of beach erosion in this Klemskerke section. The erosion reached such an intensity that it forced the administration to the fitting of a defense structure which however was shortly thereafter burried by dune progradation related to an accumulation phase of the coastal mega-protuberance phenomenon. As the dune foot prograded as well over the structure as over adjacent sections without defense structures, there is no reason to make the structure responsible for the accumulation and progradation.

BEACH EROSION ORIGIN

During the period of most intense erosion of the Knokke beach in 1950-1955 many hypothesis have been put forward to explain the origin and the mechanism : approach of the passes and migration of the beach sand into them; change of the direction of tidal or wind currents; lowering of the offshore banks and the nearshore ridges, allowing the waves to reach the shore with a higher energy, increasing the beach gradient, the frequency of plunging breakers and of destructive waves as well as the importance of the undertow; influence of the Zeebrugge breakwater upon the longshore currents; part of the dregging of harbour access passes; lack of maintenance of the defense structures due to the war; meteorological or tidal variations; soil movements due to setting of the peaty sublayer; etc... All those opinions however got no evidence and even the part of the defense structures has never been distinctly settled.

In the Klemskerke section most of these causes are even out of question. On the contrary, the off shore banks, the nearshore ridges and even the forebeach ridges are known to present passes or shallow transversal depressions*** moving slowly to and fro in a longshore direction. There is also evidence for vertical variations in the banks height. Moreover it is well known that at least on medium and small scale the travelling energy fronts don't reach the shore uniformely, even if they are travelling parallelly to the shore, but by means of medium and small scale linguiform protuberances.

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* "Plan général de la côte" - Ministère de l'Agriculture et des Travaux publics. Administration des Ponts et Chaussées. Service spécial de la côte. - Bruges, 20 mai 1912 - Ostende (sign. ill.). Bruges (sign. ill.), Nieuport (sign. Allaert).
Map put at our disposal by C. VAN CAUWENBERGHE, Director of the Coastal Hydrographical Service.

** According to Ir. BLOMME (Coastal Hydrographical Service at Oostende).

*** "Saddles", reaching hundreds of meter longshore length and unlike transversal forebeach channels.

Table 1a

Characteristics of the beach between spring tide high water mark and spring tide low water mark at different stations along the Belgian coast

K. P.	Localisation	Date	Mean slope	Transversal width (m)
3	De Panne	9.8.1978	1,3 %	510
12	Oostduinkerke	9.8.1978	1,5	480
37 (°)	Klemskerke	19.8.1978	2,7	260
37 (°°)	Klemskerke	26.9.1978	2,0	360
42	Vlissegem (Wenduine)	28.9.1978	2,1	310
38	Klemskerke	5.8.1978	2,0	340
51	Zeebrugge	6.8.1978	1,7	320
65	Knokke-Zwin	24.7.1978	2,4	200

K. P.	Kilometer-marker
(°)	before nourishment
(°°)	after nourishment and comprising a back-beach of about 45 m width

Table 2

Evolution of the transversal mobility (M) and the transversal Beach Budget (B) at the station KP 38 at Klemskerke over different time spans P

Time span P	total mobility	daily mean	total budget	daily mean
	($m3/E_1/L_1$)	($m3/E_1/L_1/d$)	($m3/E_1/L_1$)	($m3/E_1/L_1/d$)
24.1.76/08.1.77	49,1	0,140	- 25,5	- 0,051
08.1.77/15.1.78	83,4	0,224	- 79,0	- 0,212
15.1.78/15.1.78	34,8	0,095	- 2,6	- 0,007
24.1.76/15.1.79	109,6	0,101	-109,1	- 0,101

d	per day
E_1	per length unit (1 m)
L_1	per width unit (distance between STHW mark and NTLW mark (= 230 m at station KP 38)
+	gain
-	loss

Table I b Granulometric characteristics of the beach sand at Klemskerke

Localisation and date	Fraction	Percentages (weight) for samples (1) taken at a distance (m) seaward (-) or landward (+) of the NTHW mark											
	(6)	+60	+30	+15	0	-15	-30	-45	-60	-90	-120	-150	-180
K.P. 38 26.9.78	a			18,3		15,3	12,3	17,5	16,5	15,3			
	b			67,2		64,5	63,7	61,1	60,0	66,8			
	c			8,9		16,7	16,0	15,5	13,4	12,0			
	d			3,4		1,8	2,9	1,7	4,5	2,0			
	e			0,6		0,7	3,3	1,4	4,1	1,0			
K.P. 38 20.12.78	a	(3) 31,1	18,9	7,5	7,6	5,1	3,8	7,8	9,4	8,2	9,0	16,8	13,4
	b	56,3	63,6	65,5	65,1	57,1	44,9	49,8	53,1	54,8	55,0	68,3	57,3
	c	8,9	13,7	15,0	21,0	31,1	33,4	23,6	20,8	26,1	16,9	6,5	13,7
	d	1,1	0,7	7,1	3,1	4,5	7,1	7,2	6,4	6,0	5,7	2,6	5,5
	e	0,3	0,2	4,2	1,8	1,8	8,6	8,7	6,9	3,6	7,6	3,8	7,2
K.P. 37 (7) 26.9.78	a	(4) 19,3	7,1		12,3	4,8			16,5				
	b	36,8	23,1		41,7	16,2			48,8				
	c	18,6	17,8		25,5	41,2			23,3				
	d	13,2	18,6		15,6	26,0			5,7				
	e	10,2	22,5		5,0	8,4			3,7				
K. P. 37 10.12.78	a	(5) 6,9	9,0	9,5	20,7	5,1	2,9	4,3	10,2	23,8	30,5	33,5	32,8
	b	25,5	46,0	72,3	26,2	38,0	22,8	30,3	35,4	57,1	45,6	53,1	52,0
	c	26,4	22,7	15,7	37,3	25,8	25,7	22,5	26,8	13,8	10,2	5,2	8
	d	11,2	6,2	1,8	13,4	10,7	17,5	19,5	8,0	1,7	0,2	2,3	1,2
	e	11,3	6,9	0,3	2,3	15,0	23,6	18,7	11,3	1,4	5,2	1,9	1,3

(1) Samples taken at a depth between 2 and 20 mm.
Analysis by sieving of 100 gr. samples during 20 minutes.

(2) NTHW : neap tide high water

(3) Dune sand

(4) Nourishment sand

(5) Nourishment sand reworked by wind

(6) Granulometric fractions : a = 125-177 μm ; b = 177-250 μm ; c = 250-297 μm ; d = 297-354 μm ; e = 354-500 μm.

(7) Sampling immediatly after nourishment. Fraction below 50 μm always below 1%, that above 500 μm always below 5%, without taking in account shell fragments larger than 2 mm.

Therefore temporary alignement of the lower zones of banks and ridges provokes coastal windows and opens the shore to local and temporary energy concentrations and to stronger wave and current attack, originating the erosional phases of the coastal megaprotuberances.

CONCLUSIONS

The intense beach erosion hitting the Belgian coast at different places is a natural phenomenon and it consists of the erosional phase of coastal megaprotuberances. There is evidence for its cyclic, repetitive and alternating nature.

To get a better insight in the phenomenon, in its genesis and evolution, to improve the detection method and to reach a possibility of mathematical treatment allowing prognosis of the evolution, more data about sand mobilities and global beach budgets however are needed as well on a chronological, on a geographical basis as on a genetic basis. We need budget data over shorter as well as over longer time spans, an increase of the computed values allowing more accurate $\overline{B}$/P diagram drawing, an enlargment of the beach width by systematic budget computation as far as the spring tide low water line. Mobility and budget computation has to be extended to the transversally adjacent zones. Longshore mobilities and budgets have to be taken inaccount. We need the detection of beaches in other stages of evolution.

Moreover mobility and budget computation and establishment of $\overline{B}$/P diagrams for other beaches open the way for a dynamic beach classification and for a better insight in the beach activity and evolution.

Finally we need more geologic evidence for the long run nature of the phenomenon especially by detailed study of the recent coastal evolution using sedimentological and stratigraphical as well as paleogeographical arguments. The regular pattern of the Dunkerquian transgression breaches* also asks for an interpretation. As to the origin of the phenomenon, more accurate data and comparative research is needed about the offshore and nearshore morphology and about the displacements and hypsographical changes of the offshore banks and nearshore ridges and their correlation with the beach erosion phases and zones.

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* cfr. fig. 3 in TAVERNIER, R. e. a. (1970).

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