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ACOUSTIC TELEDETECTION OF SHELF BEDFORMS AND THEIR MEANING FOR THE SEDIMENT DYNAMICS

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ABSTRACT

Different surveys were made of the Flemish Banks from 1982 to 1988 using side-scan sonar and echosounder. The maintenance of the Flemish Banks is explained by a sediment dynamic model which uses megaripples rather than sandwaves as residual sand transport indicators. The model presents a continuity in time as all mayor transport paths could be recognized on the different recordings. Nevertheless differences in the distribution and geometry of bedforms occur specifically in the deeper northern and southern edges of the banks where reversals of the asymmetry of megaripples were detected. The characteristics of the detected bedforms on the central shallower parts of the banks remain similar through time. Longitudinal transport of sand parallel to the bank axis can occur temporarily on the bank summit in one or two opposing directions.

1 INTRODUCTION

The Flemish Banks (fig. 1) are a complex of large off-shore tidal sandbanks, reaching lengths of tens of kilometres, widths up to a few kilometres and relative elevations up to 20 metres. The banks (Kwintebank, Buiten Ratel and Oost Dyck) are separated by swales (from east to west: Negenvaam, Kwinte, Buiten Ratel swale and Oost Dyck swale) with maximum depths of about 30 m below MLLWS. The banks have a SW-NE orientation and present an elongated plan form with several gentle or well pronounced longitudinal articulations. They are subject to strong rotating tidal currents reaching peak velocities of 2.5 kilometres and present a flood dominance. The banks show a overall morphography dominated by a transverse asymmetry (De Moor, 1986) which is a typical feature for tidal sand ridges.

The purpose of this research is to elaborate a model capable of explaining some of the factors responsible for the maintenance of the Flemish Banks. To achieve this objective a detailed evaluation was undertaken of the paths along which sand is moving residually through the area. The study was based on the identification of the asymmetry and strike of the bedforms by the use of side-scan sonar (De Moor and Lanckneus, 1989). The side-scan sonar registrations allow to develop a plan view of the relief on the sea-floor and to detect its texture (Flemming, 1976).

2 SURVEYS

Detailed surveys were made of the Flemish Banks using echosounder and side-scan sonar during several campaigns. We will discuss here the interpretations of the registrations recorded in three periods: May 1983, November 1986 and November 1987.

Bathymetric profiles of the sea-bottom were recorded with a Deso XX echosounder. Side-scan sonar operations were performed with a Klein two-channel side-scan recorder. The recordings of 1983 were made with a 100 kHz transducer whereas a 500 kHz transducer with higher resolution could be used for the 1986 and 1987 campaigns. During the operations a slant range of 100 m was continuously used. Event marks were spaced one minute away. A ship speed of 4.5 knots was maintained during the operations. The fish was towed on starboard and lowered approximately five metres under the water surface.

The position of the ship together with other navigation parameters such as absolute ship speed above the bottom and bearing were recorded every 30 seconds by computer and stored in a data file. During the 1983 and 1986 campaigns positioning was performed with the help of the hyperbolic electronic systems Decca and Toran while navigation was done by Decca. Syledis was used for navigation and positioning during the 1987 survey. The survey tracks correspond with loxodroms each defined by two reference points fixed along a red Decca lane.

3 PROCESSING OF THE SONOGRAPHS

The resulting sonograph does not represent an isometric map of the sea-bed and various distorting factors have to be accounted for when reproducing sonograph mosaics in map form (Flemming, 1982). For this reason all features visible on the phonograph were re-drawn with the true scale on maps on a scale 1/10.000. The asymmetry of the megaripples was determined with the help of the side-scan sonar registrations and the height of the sandwaves was deduced from the bathymetric profiles. The interval of occurrence of megaripples was used as a classification criterion. Furthermore a distinction was made between megaripples with continuous crests and megaripples with discontinuous crests (Rheineck and Singh, 1980). The used symbols for the classification of the bedforms are visualized in figure 2.

Figure 3 shows an example of detailed cartography by computer plotting obtained by digitizing the bedforms.

4 KWINTEBANK MODEL BASED ON RECORDINGS OF 1986

Let us consider in a first stage the side-scan sonar registrations of the Kwintebank recorded in November 1986. Two important types of bedforms will be discussed here: sandwaves and megaripples as ripples are to small to be detected with the sonar (transverse resolution when using a slant range of 100 metres: 0.50 metres).

4.1 Sandwaves

The term sandwaves is used to refer to bedforms which are sufficiently large to have megaripples superimposed on them. Such bedforms are typical for shallow-marine tidal environments.

On the Kwintebank sandwaves have a length of several hundreds of metres, a width of several tens of metres and a height varying between 1 and 7 metres. The wavelengths of the sandwaves vary between 70 and 200 metres and are correlated with the heights of the corresponding bedforms (Dalrymple, 1984). The sandwave crestlines display in plan view a good lateral continuity and vary from nearly straight to weakly sinuous.

The sandwaves occur in well-defined fields on the flanks and summit of the bank. They lack almost completely in the adjacent channels Kwinte and Negenvaam. No sandwaves occur in the central part of the Kwintebank.

The strike of the crestlines of the sandwaves vary in the northern part of the bank between N 10° W and N 5° W. In the crest area of the central and southern parts the strike of the sandwaves is nearly parallel with the bank axis.

The majority of the sandwaves are asymmetric. The sandwaves on the northern, deepest part of the Kwintebank have their steep slope dipping to the east. Towards the south where the bank becomes more defined and shallower the steep slope of the sandwaves dips generally towards the east on the western flank and towards the west on the eastern flank. This is however not a general rule as exceptions are present on both flanks. Symmetric sandwaves occur as well between both types of asymmetric structures. The northern edge of the central part displays exclusively symmetric sandwaves.

4.2 Megaripples

Smaller bedforms commonly named megaripples occur on the sandbanks where they can mantle the stoss and/or the steep slopes of sandwaves and in the adjacent swales where they can be found in fields covering the flat sea-bottom.

The strike of the megaripples in the swales is dominantly NW-SE. The steep slope of the megaripples is dipping in opposite directions on both sides of the Kwintebank. In the Kwinte the megaripples dip to the north-east while in the Negenvaam the megaripples dip to the south-west. On both sides of the banks the megaripples are deflected towards the crestline of the bank. Their steep slope is directed towards the bank summit.

No structures were detected with the side-scan sonar in some central parts of the Kwinte. This absence of bedforms could be related with outcropping of patches of tertiary clay substratum or occurrence of gravel pavements.

4.3 Sediment dynamic model

The geometric characteristics of the bedforms give a valuable insight into the residual sediment dynamics in this area, because of their relationship with the residual current directions. Analysis of the residual sediment transport paths can be made using sandwaves (Caston, 1972) or megaripples (McCave and Langhorne, 1982).

When we examine sandwaves and the superimposed megaripples on the Kwintebank we see that megaripples are usually oriented at an oblique angle to the sandwaves with a divergence varying between 20 and 40°. This could be interpreted as an indication that both bedform types are the result of two temporally distinct tide events in which the large sandwaves are produced by the peak currents whereas currents later in the same cycle form the smaller bedforms.

However if we compare on the Kwintebank the orientations of the two types of bedforms with the directions of peak tidal currents (N 74° E for the flood peak near the southern edge of the Kwintebank) it is clear that megaripples (strike of N 18° W) are almost perpendicular to the direction of the peak tidal current.

Dalrymple (1984) explains the oblique orientation of the sandwaves relative to the dominant current as a result of a slower or faster migration of certain portions of the crestline.

Side-scan sonar pictures recorded during several periods of the tidal cycle clearly show that on the Kwintebank megaripples can maintain their identity over long periods. However reversal of the asymmetry of megaripples is mentioned to occur with each reversal of the tidal currents (Knight, 1977).

As there is a clear evidence that megaripples are a product of the peak currents and as they can maintain their asymmetry over a long period we will base our following analysis on megaripples rather than on sandwaves.

In the eastern part of the Kwinte the residual sand transport is directed seaward and commanded by flood currents coming from the south-west. In the western part of the Negenvaam the residual sand transport is directed landward and thus commanded by ebb currents coming from the north-east. Adjacent to the Kwintebank, however, the megaripples are deflected towards the crestline of the bank.

So the Kwintebank receives sand from both adjacent channels in opposite directions, provoking a sand uppiling towards the central parts (figure 4). This convergence of sand streams at the crest will provide material for the growth of the bank. Vertical growth is probably limited by wave and storm action (Van Veen, 1936; Caston, 1972).

The significance of the symmetrical sand waves is not very clear. Mc Cave (1971) showed that they can occur in an area of zero net transport. McCave and Langhorne (1982) suggest that symmetric sandwaves are a "conduit" for sand moving parallel with sandwave crests. The side-scan sonar registrations, recorded in November 1986, display some minor fields of megaripples extending across the symmetrical sandwaves.

5 KWINTEBANK MODEL BASED ON RECORDINGS OF 1987

We can compare now the recordings of 1986 with registrations of the same area one year later (November 1987).

We have to be careful in comparing two recordings as problems of accuracy and repeatability are encountered when using shipborne survey techniques. During the campaigns of 1987 positioning and navigation were performed with the Syledis system which has a positional accuracy of a few metres. Despite the fact that during the 1986 campaign Decca was used for navigation, positioning with the more accurate Toran allows to compare both registrations.

Hence comparison of both campaigns makes it possible to deduce some interesting features.

5.1 Sandwaves

The sandwave fields observed on the bank in 1986 are present on the recordings of 1987, although differences occur in their localisation. Moreover height and asymmetry of the sandwaves themselves are subject to changes. We intend to study their adaptation to the system of tidal currents and changing weather conditions which must have an impact on the bedform morphology.

This is not a surprising fact as results of a study on the dynamics of sandwaves by Langhorne (1982) showed the existence of crest oscillation with successive flood and ebb tides. He also stressed the importance of wind stress and surface wave activity capable to interrupt the normal tidal dynamic trends.

All structures are slightly oblique to the bank crest and their strike varies between N 10° W and N 10° E.

Worth mentioning is the complete absence of symmetric sandwaves over the whole bank.

5.2 Megaripples

Megaripple fields similar to those of 1986 are observed on both flanks of the Kwintebank and in the adjacent swales. The strike of the megaripples in the swales is perpendicular to the bank axis and on the slopes of the bank the structures turn off to climb the bank with their steep slope oriented towards the bank summit.

However on the summit of the bank distinctive megaripple fields occur with a strike perpendicular to the crest of the bank.

On the northern edge of the bank all megaripples have their steep side dipping towards the south-west.

On the southern part of the summit two distinct ribbons of megaripples with steep slopes dipping in opposite directions occur one next to the other. On the western side of this southern part the steep slope of the megaripples dips to the north-east, on the eastern part to the south-west.

5.3 Sediment dynamic model 1987

The general model from 1986 is still valid. The Kwintebank is fed by sand coming from both swales in opposite directions (fig. 5). However, clear evidence exists now which stresses the importance of longitudinal transport of sand on the bank summit. This transport is dominantly south-westwards in the deeper northern parts of the bank. In the central and southern parts sand is processed longitudinally along two paths, one to the north-east and one to the south-west. The megaripple fields are limited in some cases to the steep slope of the sandwaves, in other cases they mantle the stoss slope or both slopes of the sandwaves.

Moreover the occasional presence of distinct longitudinal erosional trough furrows between sandwaves points as well towards a vigourous longitudinal sand transport (De Moor, 1985).

So we see that longitudinal transport on the bank summit is not restricted to symmetric sandwaves, as observed by McCave and Langhorne (1982) but that sand can travel perpendicular to the crest of asymmetric sandwaves between the sandwaves or on one or both slopes of the sandwaves.

6 KWINTEBANK MODEL BASED ON RECORDINGS OF 1983

We compare now our previous results with phonographs of the same area recorded in 1983.

6.1 Sandwaves

The sandwave fields, observed in 1986 and 1987, have not changed significantly in comparison with the registrations of 1983. The strike of the sandwaves seems to be a quite stable feature as here as well their orientation vary between N 10° W and N 10° E. The steep slope of the sandwaves on the northern Kwintebank dips dominantly to the north-east. No sandwaves occur on the central part of the bank, as it was the case on the other recordings. The presence of symmetric sandwaves is almost exclusively restricted to the southern extremity of the bank.

6.2 Megaripples

The megaripples in both adjacent swales dip in opposite directions although they are restricted in the Negenvaam to the central part of the bank. Almost all the structures on the summit of the bank are dipping to the north-east.

6.3 Sediment dynamic model 1983

The Kwintebank receives sand from both adjacent swales in opposite directions although the contribution from the Negenvaam is now limited to the central part of the flank (fig. 6).

Evidence for longitudinal transport is present on the summit of the bank; the movement of the sediment however is confined towards the north-east as no southwards dipping structures are encountered.

Transport of sand from the south-west to the north-east is dominant. Sediment is passing obliquely over the bank in the southern and northern edges of the Kwintebank.

This image contrasts with the picture obtained in 1987 which displayed in the northern part a dominant flux of sand towards the south-west. The model from 1986 seems to represent a situation between those two extremities as the sediment is moving in the two directions.

Earlier workers have postulated a circulation of sand around a bank (Houbolt, 1968; Caston, 1972). They supposed as well a net movement over the crest from the gentle to the steeper slope where accretion occurs. However we suppose that the steep slope of the Kwintebank (5-7%) is not a depositional surface but an erosional slope (De Moor, 1985a; Vlaeminck et al., 1985). Subbottom profiler registrations prove that on the Kwintebank erosion occurs mainly on the steep western slope by the action of the strong flood currents (De Moor, 1985b; De Moor et al., 1989). The gentler eastern flank,with a mean slope of 2.5 to 3 %, shows residual accumulation as indicated by the internal structure.

7 SEDIMENT SAMPLE DATA ON THE KWINTEBANK

One hundred samples were taken on the Kwintebank with a Van Veen bottom sampler (Lanckneus, 1989) to study the grain size characteristics of a single sandbank. The mean value of the quartz sand fraction was calculated, according to Folk and Ward. The classification of the samples in four groups was performed by a cluster analysis using Ward's method (Ward, 1963). The samples belonging to a same cluster were grouped together in a class represented by a particular symbol (figure 7).

Several features are clearly shown. The surface of the Kwintebank does not present uniform grain-size characteristics. On the bank the sediments coarsen towards the north-east edge and the western slope consists of coarser sand than the eastern one.

8 MODEL FOR THE FLEMISH BANKS - CONCLUSIONS

Finally we can verify if the model developed for the Kwintebank is valid as well for the remaining Flemish Banks.

Side-scan sonar registrations on the whole of the Flemish Banks prove that the model is applicable to the Buiten Ratel, the Oost Dyck and to the intermediate swales (fig. 8).

Each bank receives sand from both adjacent channels. Residual flood currents from the south-west command the residual sand transport on the western flanks, while residual ebb currents from the north-east are responsible for the sand transport on the eastern flank. As a result sand is moving in each swale along two opposite directions.

This causes a sand uppiling on the bank summit which is the main mechanism in the maintenance process of the banks.

Vertical growth of the bank is balanced by wave and storm action and by vigourous longitudinal transport. On the summits sand can travel in opposite directions along parallel ribbons. The width of those ribbons and the importance of this transport can vary significantly from part to part. The transport of the sediment can be exclusively to the north (for example on the southern Buiten Ratel, 1987), exclusively to the south (northern Buiten Ratel, 1987) or can be divided along two channels of similar importance (southern Kwintebank, 1987).

Although our proposed model of residual sand transport is valid for each period of registration we observe that the directions of residual sand fluxes can change significantly through time. In November 1983 the direction of residual sand transport was oriented towards the north-east whereas residual flow towards the south-west was restricted to narrow and small areas. In November 1987 the sonographs displayed an opposite image: the dominant transport of residual sand was towards the south-west whereas movement of residual sand towards the north-east was severly limited. The situation of November 1986 seems to represent an intermediate situation as transport of residual sand is more or less of equal importance towards the north-east and the south-west.

9 ACKNOWLEDGEMENTS

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Figure 1 Situation of the Flemish Banks in the Southern Bight.

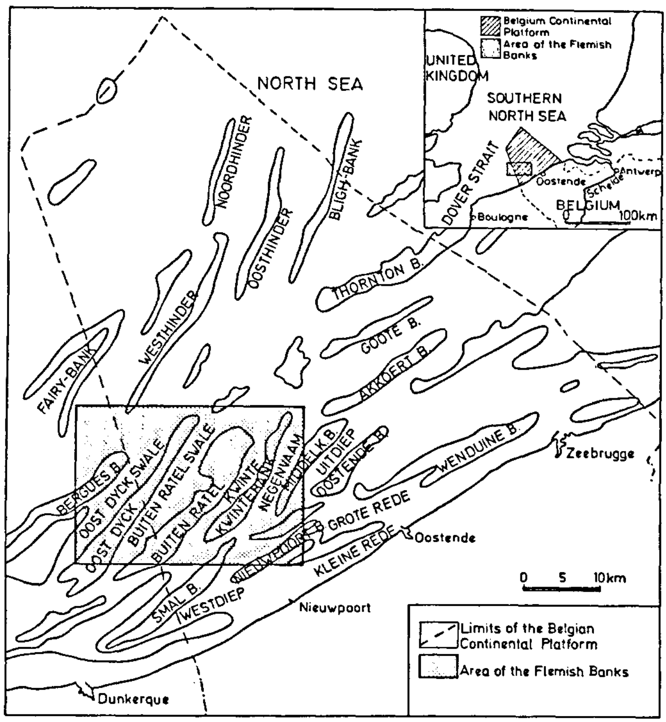


Figure 2 Symbols used for the classification of sandwaves and megaripples.

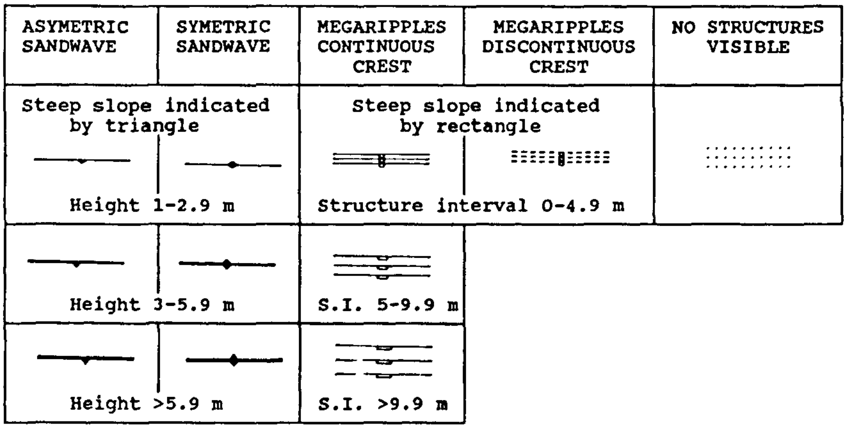
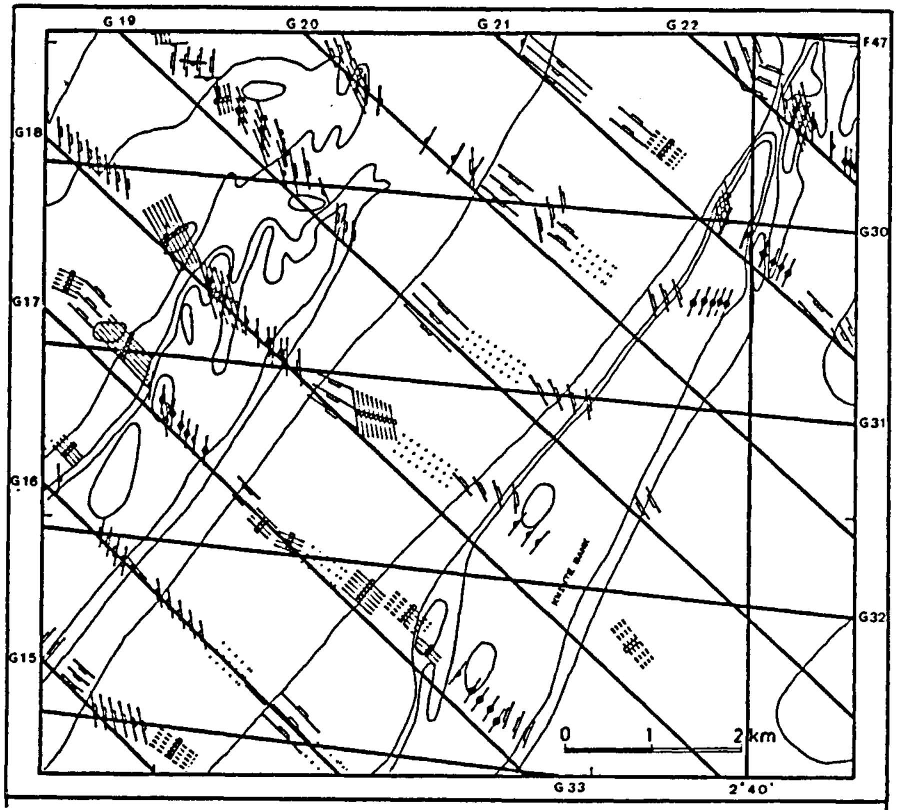
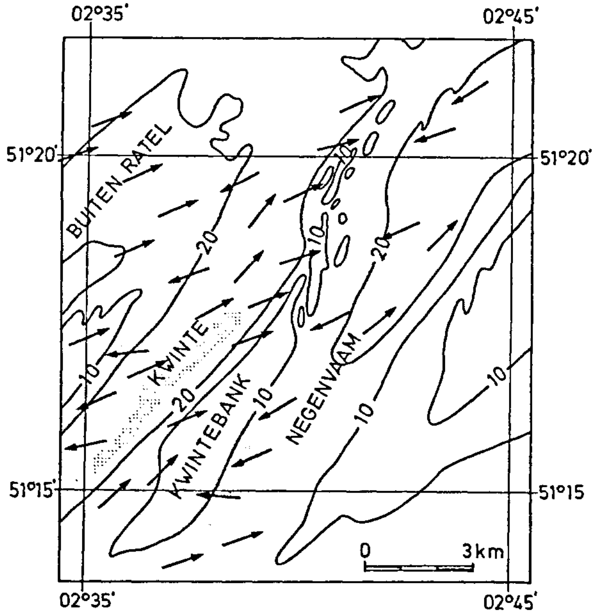


Figure 3 Example of detailed cartography of the southern Kwintebank and central Buiten Ratel by computer plotting (sonographs recorded in Nocvember 1986).



<u>Figure 4</u> Sediment dynamic model developed for the Kwintebank based on recordings of November 1986. The arrows indicate the directions of residual sand transport.



DIRECTION OF RESIDUAL SAND TRANSPORT
(NOVEMBER 1986)

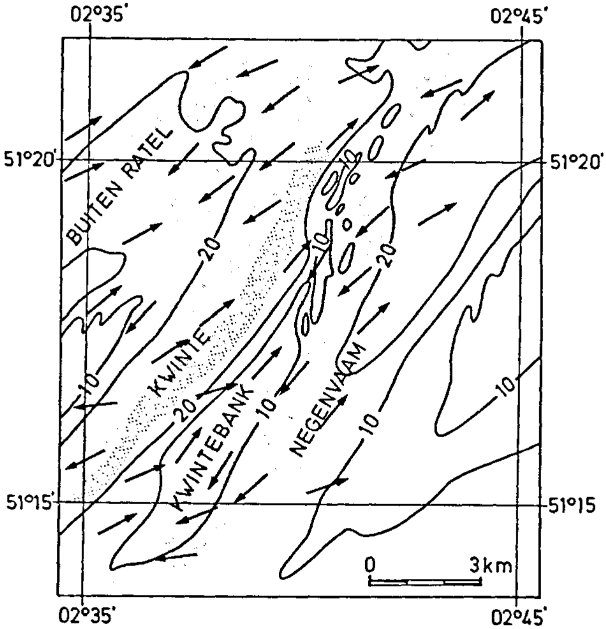
AREA WITHOUT VISIBLE STRUCTURES

AREA WITH MEGARIPPLES DIPPING TO THE SOUTH-WEST

AREA WITH MEGARIPPLES DIPPING TO THE NORTH-EAST

AREA WITHOUT DISTINCT STRUCTURES OR SITUATED OUTSIDE THE SURVEYED ZONE

Figure 5 Sediment dynamic model developed for the Kwintebank based on recordings of November 1987. The arrows indicate the directions of residual sand transport.



DIRECTION OF RESIDUAL SAND TRANSPORT
(NOVEMBER 1987)

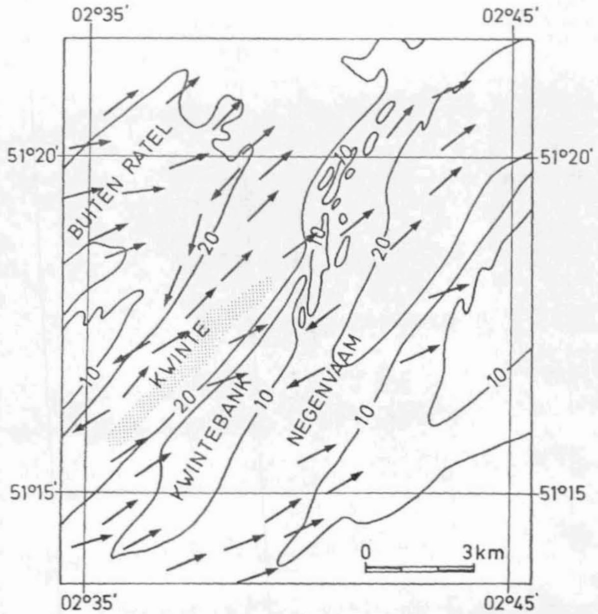
AREA WITHOUT VISIBLE STRUCTURES

AREA WITH MEGARIPPLES DIPPING TO THE SOUTH-WEST

AREA WITH MEGARIPPLES DIPPING TO THE NORTH-EAST

AREA WITHOUT DISTINCT STRUCTURES OR SITUATED OUTSIDE THE SURVEYED ZONE

<u>Figure 6</u> Sediment dynamic model developed for the Kwintebank based on recordings of May 1983. The arrow indicate the directions of residual sand transport.



DIRECTION OF RESIDUAL SAND TRANSPORT
(MAY 1983)

AREA WITHOUT VISIBLE STRUCTURES

AREA WITH MEGARIPPLES DIPPING TO THE SOUTH-WEST

AREA WITH MEGARIPPLES DIPPING TO THE NORTH-EAST

AREA WITHOUT DISTINCT STRUCTURES OR SITUATED OUTSIDE THE SURVEYED ZONE

Figure 7 Grain size distribution of the Kwintebank; mean values were calculated on decalcified samples. A cluster method was used for the classification of the samples in four groups.

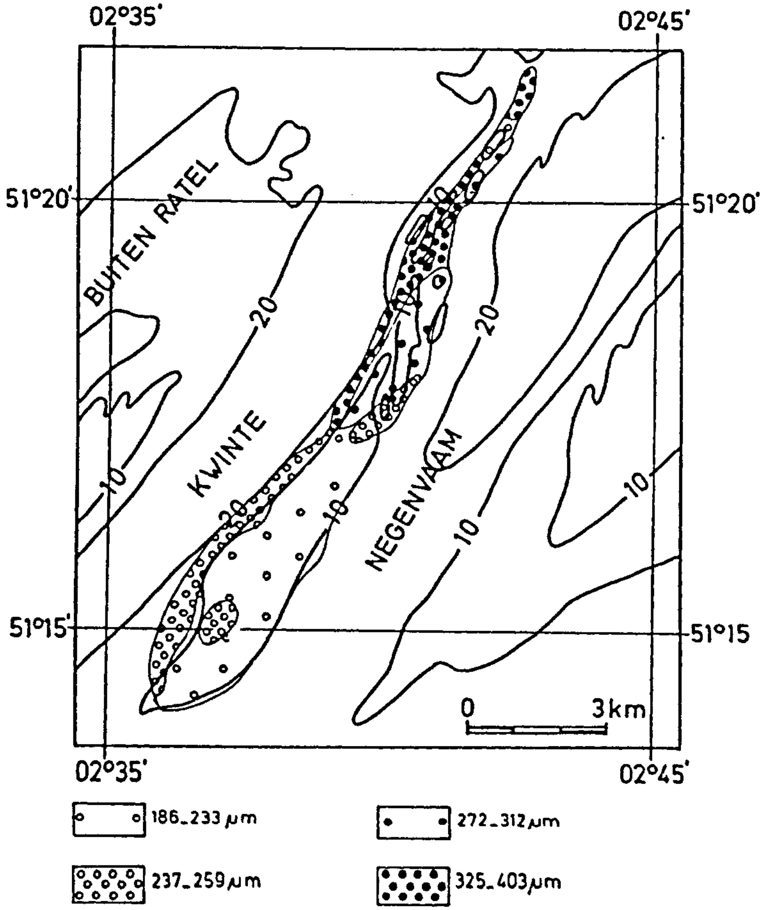


Figure 8 Sediment dynamic model for the Flemish Banks based on recordings of November 1986. The arrows indicate the directions of residual sand transport.