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SMALL-SCALE DEPOSITIONAL STRUCTURES OF SURFACE SEDIMENTS OF THE FLEMISH BANKS

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ABSTRACT

The depositional structures of 37 undisturbed boxcore samples from the Flemish Banks are analysed and interpreted. The inference of that study is, together with published data on hydrodynamics, bed morphology, and grain-size characteristics, incorporated into a preliminary, qualitative model of sediment dynamics on the Flemish Banks.

1. INTRODUCTION

In its recent offshore sediments, as well as in its geological sedimentary record, Belgium contains remarkable examples of shallow-marine clastic tidal sands. The recent sandbanks have sometimes served as a guide for the interpretation of ancient sediments. The aim of our study is to provide material for the comparison of sedimentary structures from both kinds of deposits. Another aim is to establish and map areal differences in sedimentary structures, because we expect a significant interdependence between the structure of the surface sediments on the one hand and hydrodynamics and sea-bed morphology on the other hand.

As our area of interest, we chose the Flemish Banks, more particularly the Oost Dijk and Buiten Ratel (fig. 1). They are nice representatives of long, linear banks, and quite some studies have already been carried out on their morphology, sediment dynamics, and large-scale internal structures (Van Veen, 1936; Houbolt, 1968; Van Cauwenberghe, 1971; V.N.D. Caston, 1972; Bastin, 1974; Gullentops et al., 1977; Kenyon et al., 1981; Lanckneus, 1984; De Moor, 1985, 1986; De Moor & Lanckneus, 1988; Vlaeminck et al., 1985, 1989; BMM, 1988).

Tidal flow and surface wave measurements are carried out by the Ministry of Public Works, Coastal Service. Peak spring surface tidal cur-

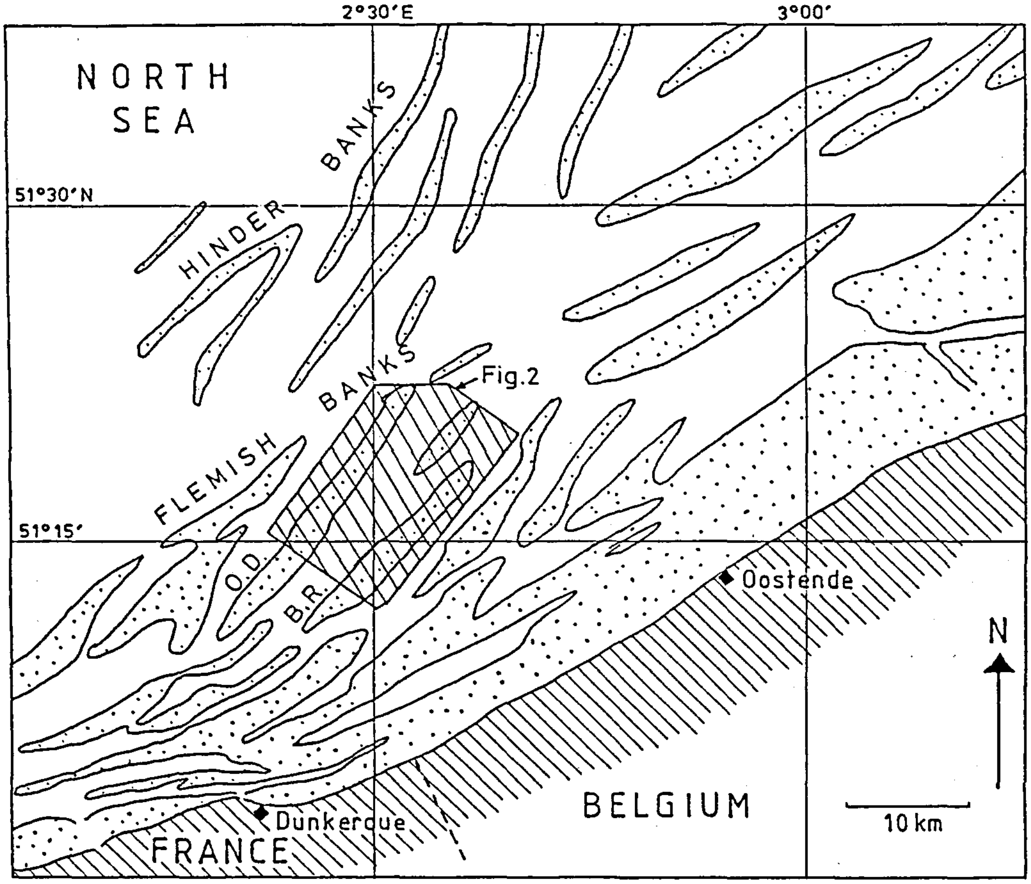

Fig. 1. Localization map. O.D. = Oost Dijk; B.R. = Buiten Ratel.

rent speeds may attain values of 1.4 m/s. Bedform distribution and strike patterns (V.N.D. Caston, 1972; De Moor & Lanckneus, 1988; Vlaeminck et al., 1985, 1989) are in agreement with the picture of normal (fair-weather) flow around sandbanks, that has gradually been refined (Van Veen, 1936; Off, 1963; Houbolt, 1968; Caston & Stride, 1970; V.N.D. Caston, 1972; McCave, 1979; G.F. Caston, 1981; McCave & Langhorne, 1982; Stride, 1982; Venn & D'Olier, 1983; Howarth & Huthnance, 1984) and may be summarized as follows. The long axes of the Flemish Banks are nearly 20° oblique with respect to the regional, coast-parallel tidal flow direction. This angle deviation is however diminished for local flow in the channels between the banks, i.e. the tidal flow is here deflected, so that it has a direction more parallel to the banks. The flood flows towards the NE; it is the regional dominant flow. It governs the bed-load transport in the long SE half of the inter-bank channels; part of the flow is deflected over the steeper NW flank of the banks, so that it crosses the bank at angles of 45° maximally. The opposite picture applies to the ebb current, whose influence is concentrated on the NW half of the channels and the mild SE flanks of the banks. The zone where flood- and ebb-dominated bed-load transport areas meet, coincides with the NW-edge of the relatively flat top plane of the sandbanks (*sandwave convergence line*, Vlaeminck et al., 1985, 1989).

2. SEDIMENT SAMPLES

The samples of the surface sediment were taken using a small reineck boxcorer (Reineck, 1958, 1963). Our apparatus returns undisturbed samples of 11x17 cm area and measuring as high as 20 cm. The box containing the sample was left quiet for some minutes, so that the water could leach out, and was frozen afterwards. In the laboratory, the box-shaped sample was unfrozen in an embedment of plaster. A side of the plaster block was then cut away, so that a lacquer peel could be made. Actually, of each sample, lacquer peels were made from two orthogonal sides.

The position of the sampling stations is shown in fig. 2. This map is an extract from the morphological map of Vlaeminck et al. (1989). The samples are mainly located on two cross-profiles, situated in the middle of the Oost Dijk and Buiten Ratel. Some stations were sampled twice.

3. CLASSIFICATION OF THE SEDIMENTARY FACIES

Although the number of samples (37) is rather limited, the results of the structure analysis were very consistent. Sedimentary structures are compared on the basis of their different morphological features, as they would appear in an outcrop, c.q. lacquer peel. Each type of characteristics is called a sedimentary facies. From our samples, we recognized 3 main facies, that could be further subdivided into 8 subfacies. The main facies include undisturbed structures (cross-bedding and horizontal bedding) and disturbed structures.

3.1. Megaripple cross-bedding (X)

The sand is arranged in cross-beds of 3-10 cm thickness; the bottomsets are thin (< 1 cm). The bed planes are parallel. The foreset slopes vary from 25 to 35° (steeper in coarse sand). A few times, topsets were

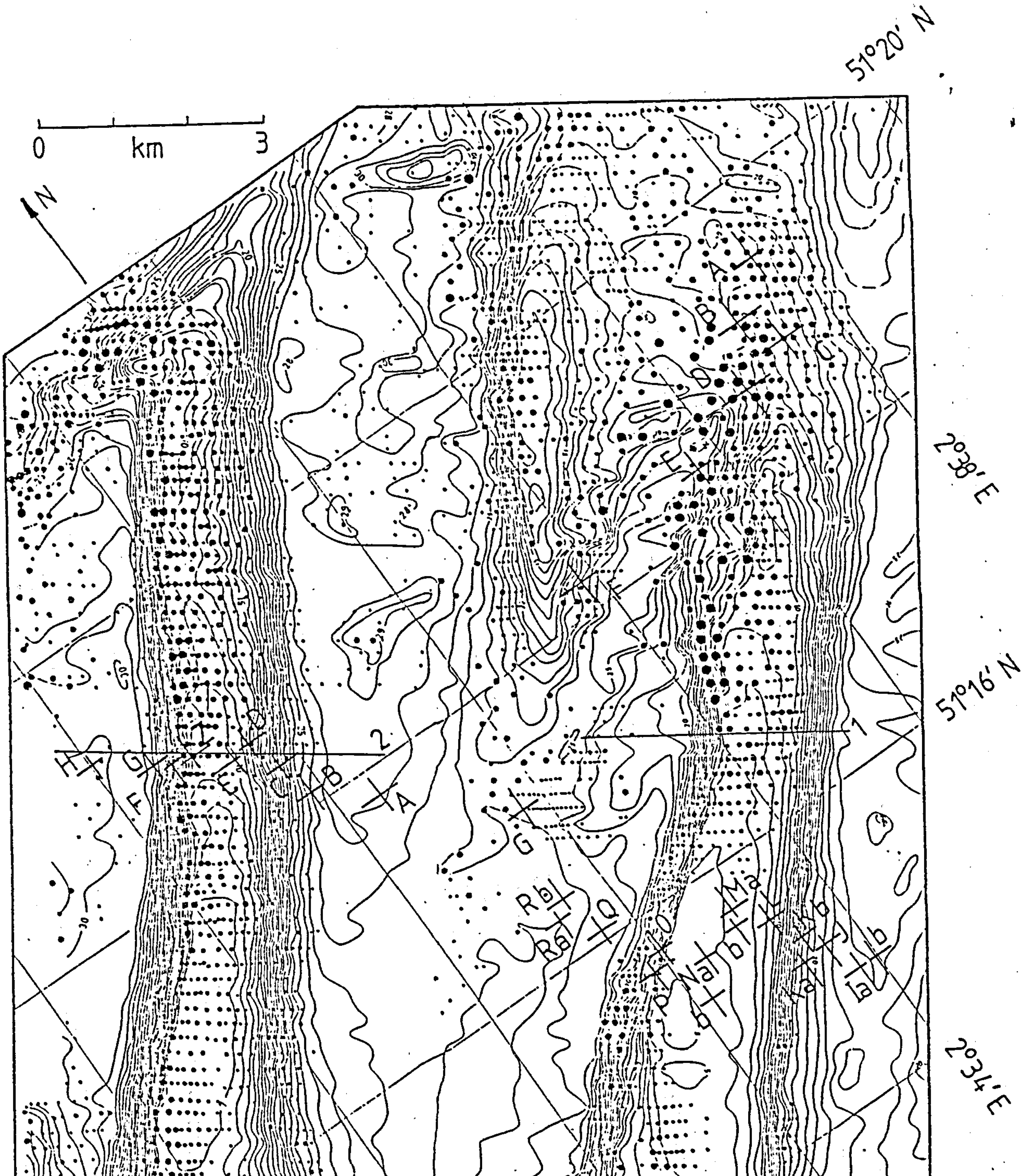

Fig. 2. Position of the samples. Left : Oost Dijk (samples A-H, I); right : Buiten Ratel (samples A-G, H, I-R). 2 : side-scan sonar profile of fig. 5. Isobath interval : 1 m. Dots represent large bedforms (0.5 m minimal height).

observed. The foreset laminae are only 1 or 2 mm thick. They can be recognized mainly by grain-size differences and layering of tiny shell fragments.

The subdivision depends on a visual appreciation of the grain size in relation with the lamination. Subfacies Xvc, Xc, and Xm contain mostly foresets of very coarse, coarse, and medium-sized sand, respectively. Subfacies Xh is also cross-bedded, in spite of its homogeneous appearance. That characteristic is due to the excellent sorting of the sand and the lack of flat shell fragments. Fig. 3 is an example of structure type Xvc.

3.2. Horizontal bedding (H)

The sand is horizontally layered. Subfacies Hl consists of moderately sorted, fine to medium sand, arranged in 2-3 mm thick laminae. Subfacies Hg consists of fine to medium gravel (2-10 mm), and whole and broken shell valves. The base may be pure gravel, but the grain size fines upwards so that layers of medium to fine sand are intercalated.

3.3. Disturbed bedding, due to bioturbation (B)

The original horizontal and cross-bedding is partly or completely de-

Fig. 3. Lacquer peel of sample BR E. Facies Xvc. t : tidal reactivation plane, covered with small-ripple lamination. Scale is 10 cm.

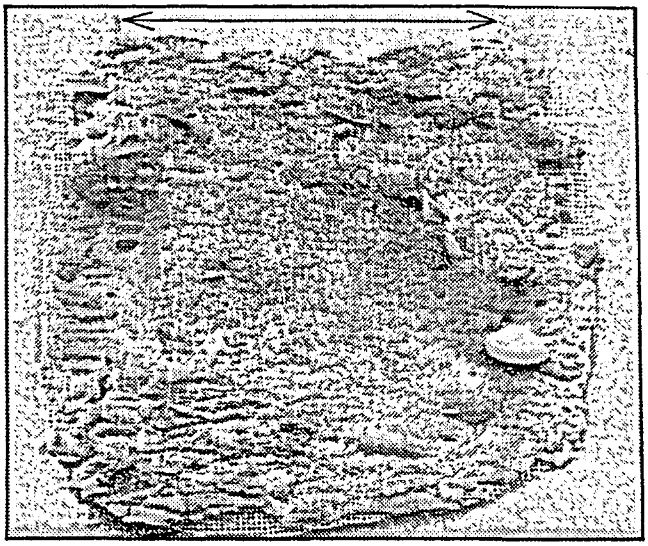

Fig. 4. Lacquer peel of sample BR J. Facies Bg. Some original, horizontal lamination Hl has been preserved to the left. Scale is 10 cm.

stroyed due to the action of organisms that live in the sediment. Subfacies Bg consists of fine, medium, and coarse gravel and whole and broken shell valves, in a matrix of fine to medium sand. Dwelling tubes of *Polychaeta* worms are recognizable, as well as feeding traces of sea urchins (*Echinocardium cordatum*). Subfacies Bh is completely homogenized, fine to medium sand.

Here again, small vertical dwelling tubes (2 mm thick, 1-2 cm long) of *Polychaeta* are preserved throughout the sample. Moreover, many spines of sea urchins are found distributed over the sample. Fig. 4 shows a lacquer peel of facies Bg, with some horizontal lamination preserved burrows to the left.

4. INTERPRETATION OF THE SEDIMENTARY STRUCTURES

Cross-bedding of the scale of our facies X is often found in sand sediments; it is produced by the migration of megaripples. Exceptionally, the bedding planes were covered by oppositely laminated small ripples; once, we found remnants of a single mud drape on these ripples. Such a bedding surface is called a *tidal reactivation plane* (de Mowbray & Visser, 1984) or a *pause plane* (Boersma & Terwindt, 1981). This is formed during the opposite flow stage of the tide; the mud settles out during the slack-water stage of the turning of the tide. It typifies nearly-symmetrical tides, a fact that is also supported by the herringbone cross-bedding that was often found in other samples.

The undisturbed cross-bedding shows the megaripples that produce it are actively migrating during each tide. When the bottom shear stresses are high enough to move fine gravel into megaripples (Xvc an Xc), it may be concluded that the finer sand fractions are gradually being winnowed out. The good sorting of facies Xm, and especially of Xh, proves a continuous reworking of the sediment by the same force, i.e. the tide. The lack of coarse grains makes areas characterized by this facies, a destination area of medium sand, winnowed out of facies Xc and Xvc.

The horizontal lamination Hl is directly produced by wave action. The fining-upwards layering of facies Hg is explained as a (small-scale) storm sequence : sand is removed from the gravel base during highly turbulent water flow, probably occasioned by storm waves; it gradually settles out from suspension afterwards.

Samples showing some part of wave- and storm-related facies Hl and Hg are extremely exceptional and all of them were associated with some bioturbation. Our samples were mostly taken during fine-weather periods. The presence of storm structures may then be interpreted as preserved storm structures, in areas that are not affected by the daily tidal flow.

The bioturbation of facies Bg and Bh is attributed mainly to the action of relatively large animals, such as sea urchins, that live a few centimetres below the water-sediment interface. The presence of dwelling tubes of *Polychaeta* species proves that the sea bottom here has been stable for some time. Indeed, the construction of such tubes takes at least several weeks. It follows that areas, containing bioturbated facies, are not affected by tidally induced near-bottom sediment transport. The lack of mud layers, however, shows the tidal flow is still high enough to prevent the settling of the fine suspension. Some animals are capable of filtering out that fine suspension; mud was found incorporated in the mucus-reinforced walls of some dwelling tubes. The presence of fine dwelling tubes throughout the vertical dimension of samples of facies Bh, testifies that here a slow aggradation takes place, for these burrows are made by species that live near the very surface. That continuous, slow supply of fine sand can only be from out of suspension. The original structure of other, only partly bioturbated facies (mainly Bg) shows horizontal as well as cross-bedding.

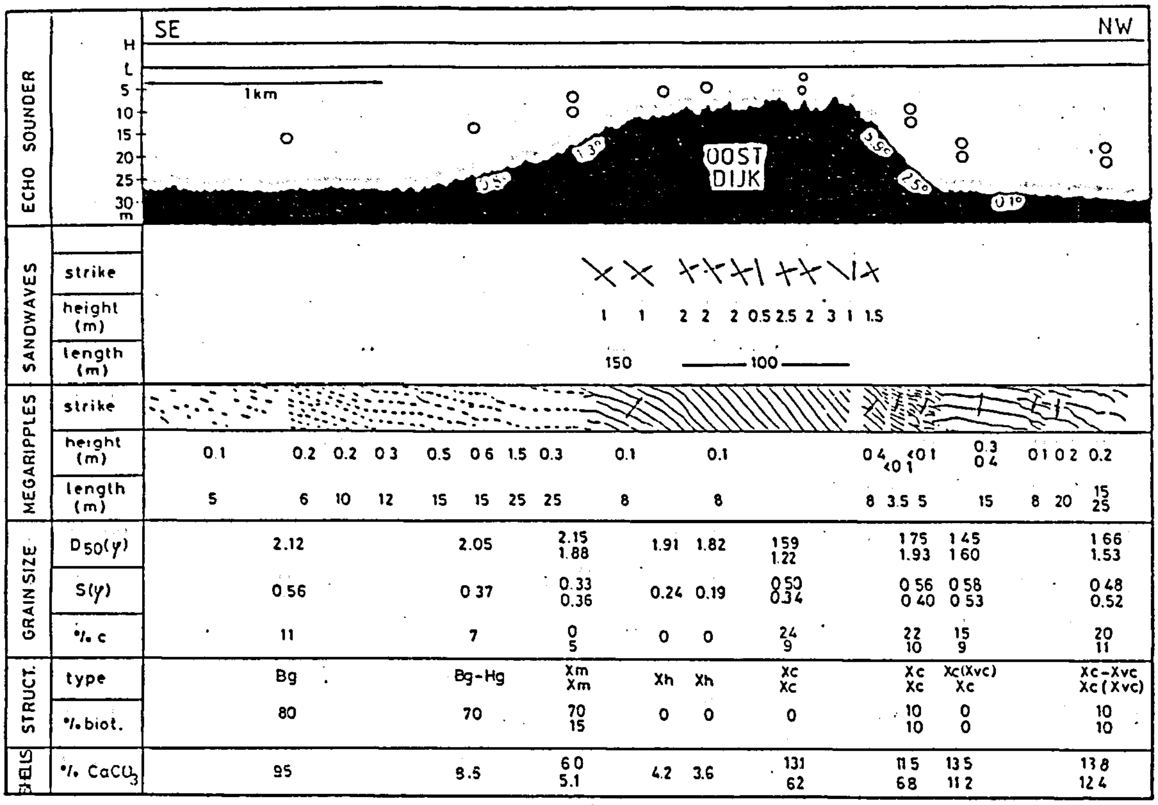

Fig. 5. Combined cross-section of the Oost Dijk (position : see 2 in fig. 2). From top to bottom : echo sounder profile (with slope angles and indication of samples); sandwaves; megaipples (arrow = orientation of lee side; no arrow = symmetrical megaripples; dashed lines = moribund megaripples); grain size (D_{50} = median grain; S = sorting; %c = percentage of coarse sub-population); sedimentary structure; weight percentage of shell fragments.

5. OCCURRENCE OF THE FACIES

There is some relationship between sediment structure and grain size, especially grain sorting. Cross-bedded facies are better sorted, particularly the facies Xm and Xh, that occur on the sandbank top. Bioturbated facies contain several grain-size populations; hence their poor sorting. This fact illustrates the complex depositional history of the bioturbated samples.

Fig. 5 is a combination, compiled for one cross-section of the Oost Dijk, of several characteristics relating sediment dynamics on a sandbank : morphology (depth; occurrence, height, spacing, and strike of both sandwaves and megaripples), grain-size parameters, and depositional facies of the surface sediment. The results for the Buiten Ratel cross section are very similar to this Oost Dijk one.

As to grain size, it may be seen that the mean grain fines along the profile, from NW to SE; it is remarkable that the sandbank top plane contains relatively coarse sand, while here the sorting is at its best.

The bedform morphology was derived from a side-scan sonar profile. Megaripples occur practically anywhere; however, their morphological characteristics vary with the place they take in in the overall topography. Megaripples of the sandbank top plane, steep NW side, and of the channel to the NW, appear as fresh, sharp-crested bedforms; their spacing is minimal on the steep sandbank side. Those of the channel to the SE and of the mild SE flank of the sandbank have vague crest lines and are therefore interpreted as "moribund" megaripples, i.e. the bedforms are not undergoing active sediment transport at the time the sonar profile was made. At that time, the weather had been fine for several weeks. It is interesting to note that sandwaves are restricted to the summit area of the sandbank.

Undisturbed, cross-bedded samples are invariably found in areas that contain sharp-crested megaripples. Coarse sand and fine gravel (%c) are found throughout the area, except in the central part of the top plane. There is a complete lack of bioturbation on the top plane of the sandbank. The most bioturbated structures are found in the channels and on the lower SE slopes of the sandbanks. The bioturbated samples containing coarse gravel are restricted to the channels.

6. A PRELIMINARY MODEL FOR SEDIMENT DYNAMICS ON THE FLEMISH BANKS

Our results regarding sandbank morphology and grain-size parameters agree very well with published data on the same subject. Our samples yielded furthermore structures clear enough for a consistent sedimentological interpretation. They allow to formulate a preliminary and qualitative model for fair-weather sediment dynamics around the Flemish Banks. Our model takes into account the hydrodynamics, described above, the published data on morphology and sediment parameters, as well as our interpretation of the structures of the surface sediment.

An essential point is the distinction between bed-load and suspension transport. Here, bed load is considered to be the part of the near-bed sediment transport, that causes the migration of the megaripples. That the transport of sand in suspension may be important near sandbanks, has been reported by divers, and is also witnessed by the structures of type Bg, Bh and Hg. It could also have been expected theoretically, since flow velocities are high enough, and settling of fine sand from suspension may especially be expected in the area downstream of the bank, because here, cross-bank flow should experience important flow line expansions. As the environment is tidal, it is clear that the area of suspension settling in the lee of the bank, alternates from SE to NW of the bank with flood and ebb.

In fig. 6, suspension and bed-load sediment transport have been pointed out separately, on two profiles, the northeastern of which represents the flood situation; the central profile stands for full ebb conditions. With the exception of the kink area of the bank, the arrows of the ebb and flood profile may be regarded as representative for the morphological facet (steep flank, top plane, ...) in which they are shown. The thickness of the arrows is qualitatively proportional to the amount of sediment transport during each half tidal cycle.

When the transport amounts and directions are compared (fig. 6), it is clear that sand transport is maximal in the sandbank crest area. This sandwave-covered area experiences nearly equal amounts of bed load during ebb and flood; this may be one of the reasons why sandwaves developed here.

The steep NW flank is eroded during the flood stage, and the amount of sediment received (partly from suspension) from the ebb is not enough to compensate for the erosion. The mild SE flank is an aggradational area, in agreement with the regional dominance of the flood.

All the deeper parts receive sand from suspension, but this fact is only documented by the sediment structure of samples from the central channels and mild SE slopes, since here bed-load sediment transport by the normal tidal flow is nearly inexisting.

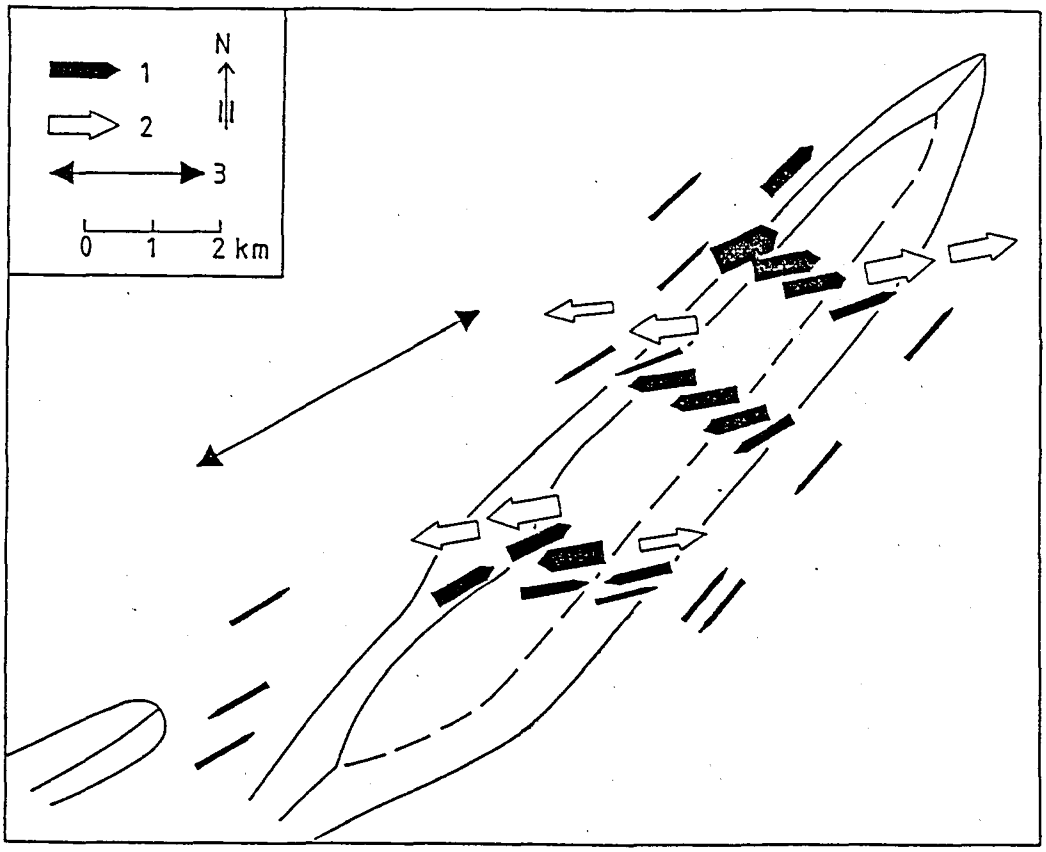

Fig. 6. Model of sediment dynamics. For explanation, refer to text. Key : 1. bed-load transport; 2. suspension transport; 3. regional direction of the tide.

7. CONCLUSION AND DISCUSSION

Our method of studying the surface sediment appears to be a valuable technique that appreciably contributes to the study of the sediment dynamics of the Flemish Banks. The sedimentary structures were clearly recognizable from the lacquer peels, and could be interpreted in the light of our sedimentological background.

There exists a close relationship between sedimentary facies of the surface sediment on the one hand, and small-scale bed morphology and grain-size characteristics on the other hand.

The inferences from our analysis allow the construction of a preliminary model for sediment dynamics in the Flemish Banks (fig. 6).

It must be stressed here, that our model only applies to fine-weather conditions. The model would generate a steady, southeasterly shift of the sandbanks, whereas such a resultant displacement is not supported by evidence from successive surveys of the area (Van Cauwenberghe, 1971; De Moor, 1985, 1986).

Our samples only suggest the influence of strong tides and storm wave action (gravel lags, bioturbated cross-bedding and horizontal lamination). It is however beyond doubt that, like in the Norfolk Banks (Stride, 1988), these high-energy processes strongly affect the shallow sandbanks. It may therefore reasonably be put forward, that their action partly or completely counterbalances the effect of the fair-weather processes.

8. ACKNOWLEDGMENTS

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