ICES 1989 C.M.1989/C:43
Hydrography Committee

VOLUMETRIC ANALYSIS OF RESIDUAL SEDIMENT MIGRATIONS ON CONTINENTAL SHELF SAND BANKS IN THE SOUTHERN BIGHT (NORTH SEA)

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ABSTRACT

Sediment transport results in erosion and deposition and therefore in changes of form, location and volume of sea-bottom structures, especially sand banks. These changes can be studied over several time intervals. Residual sedimentdynamics concern net sediment migrations over longer periods as resulting from succesive short time direction and intensity varying displacements. In an environment with high sediment migration variations, residual sedimentdynamics can be approached by geomorphological techniques.

The paper analyses the residual sedimentdynamics on the Flemish Banks over the period 1983-1988 on ground of a monitoring of volumetric changes of sand banks along fixed reference profiles. The monitoring departs from sequential detailed bathymetric profiling along the reference tracks, high precision navigation and positioning and profile normalisation to make successive data comparable, using appropriated software equipment. Sequential profiling at a 1 mile distance alllows bank covering over one tidal cycle.

It presents numerical and cartographic data about evolution trends in the sedimentdynamics along the Flemish Banks over the period 1983-1988.

1 INTRODUCTION

Assessment of residual sediment dynamics on a shelf sandbank can be based on two main approaches : the analysis of the residual sediment transport paths in relation to the bank stability and maintenance, and the monitoring of the volumetric evolution of the bank in a number of test sites in order to evaluate the real effect of the sediment mobility pattern and to express numerically and graphically the short term evolution trends.

In 1984 a sand mobility model has been published for the Kwintebank, one of the Flemish Banks on the Belgian Continental Platform (De Moor, 1984). It shows the residual sediment transport paths in 1982. It was based on the cartography of types and geometric characteristics of bedforms such as sand waves and megaripples, as deduced from side-scan sonar registrations, and diagnostic for the direction of the residual bed load transportation.

That sand mobility model put forward that maintenance of the Kwintebank results from a residual sand supply from two opposite directions towards the bank's main axis. the western steeper side, In the Kwinte swale, dominated by the western steep side of the Kwinte bank, nett movement of megaripples is seaward due to a residual flood current. In the Negenvaam swale, along the eastern slightly dipping side of the bank, nett movements of megaripples is landward, due to a residual ebb current.

In these swales the bedforms are transversal to the bank axis, but on the bank flanks they are deviated partly because of friction, so that they become almost parallel to the bank axis and climb up the bank, providing a sediment uppiling on the bank top. There the sediment is reworked by wave activity and by tidal currents, especially as peak tidal currents overtopping the bank are slightly oblique to the axis.

In the period 1983-88 the chronologic and geographic constancy of the model has been tested by sequential side scan sonar registrations on the Kwintebank and by extending the registrations over adjacent banks (see Lankneus ,e.a. 1989).

This article pays special attention to the short term volumetric evolution trends on the Kwintebank between 1983 and 1988.

2 THE KWINTEBANK AND ITS DYNAMIC ENVIRONMENT

The Kwintebank is a shelf sandbank in relatively shallow water, having a length of 25 km, a width between 1 and 3 km, and a relative elevation varying between 10 and 20 m (fig. 1). The mean water depth varies from 6 m in the central part to more than 10 m on the northern and southern edges. Having a SSW-NNE direction, the bank runs oblique to the coastline. There is a distinct kink in the length profile at the transition between the northern and central part. The bank shows a distinct and constant transversal dissymmetry with a steep western slope dominating the Kwinte swale. This swale reaches greater depths than the Negenvaam swale situated at the eastern side, and which presents a shallow threshold at its landward end. The steep side proved not to be a residual progradation side (De Moor, 1983). The sandbank shows transversal and longitudinal superficial grain size variations : the bottom sediment being coarser on the off shore part and on the western steep slope (De Moor, 1984, 1985^{a}; Lankneus ,e.a., 1989). Different types of bedforms occur on the bank itself. Sandwaves, up to 8 m elevation and running more or less parallel to the bank axis occur on the bank top, especially on the northern and southern edges. Hence a threefold longitudinal partition of the bank is obvious. Megaripple fields occur on the bank top and bank flanks, with opposite progradation sides on both bank flanks. Megaripple fields on sandwave backs very often stretch under a direction oblique to the sandwave crests, suggesting transport by a different tidal current component and possibly grain size differentiation as well. In between the sandwaves, temporarily bank longitudinal scouring channels have been observed (De Moor, 1986), suggesting important but discontinuous longitudinal sand transfers.

The hydrodynamics around the Kwintebank are characterised by semidiurnal tides of megatidal range and with a distinct difference between neap and spring tidal range. Near to the coast, situated at about 25 km, mean tidal range reaches 4,5 m. The tidal movement presents a distinct elliptic current rose with SW-NE axis : general direction of floodpeak currents being SW-NE, of ebb peak currents NE-SW. There is a distinct velocity and duration dissymmetry of ebb and flood peak currents. Surface peak currents velocity reaches up to 2,0 kts. Maximal wave direction frequencies are from SW and from N. Longest fetch is from the North.

The anti-clockwise rotation of the tidal currents with their gradually changing velocity between a slack minimum and two different peak maxima is very important for the whole pattern of direct sand transport and sediment sorting.

Since 1978 the Kwintebank, especially its northern part, has been subject to a sand dredging at an estimated mean rate of about 400.000 m^{3}/year.

3 METHODOLOGY

3.1 Field observations

In order to monitor the volumetric changes of the Kwintebank during the period 1983-88, sequential bathymetric profiles have been sailed at 10 kts with a mean interval of 3 months along fixed reference lines, used as test sites, and situated at about 1 mile from each other.

These reference tracks correspond to loxodroms between fixed begin- and end points situated upon red Decca lines (5B network). They run approximately transversally to the bank. Eleven reference lines have continuously been used.

Navigation and positioning have been based on Decca and Toran up to 1987 and on Syledis since 1988. Toran but especially Syledis provide an accurate, high frequency, and geographically reliable positioning. Position, ground velocity components, bottom course and ships heading have been registered simultaneously every 30 seconds by the ship's HP1000 computer using the ODAS acquisition programme (M.U.M.M.). After transfer to the HP600A laboratory computer these data have been used for detailed track plotting, allowing a control of the accuracy of the tracks and opening a way for elimination of the data along inaccurately sailed tracks.

3.2 Corrections of bathymetric registrations

Raw bathymetric registrations were taken by an Hydrographic Deso XX echo-sounder after adaptation for sound velocity and ships draught. These registrations have been digitized and corrected partly by means of tidal reduction, (using the Van Cauwenberghe method (1972) and tidal curves simultaneously registered in 3 Belgian coastal stations); partly by corrections for ship's velocity variations; partly by scale uniformization, etc... After correction nett bathymetric profiles have been plot in relation to a zero datum level (corresponding to the local MLLSS). Figures 2,3 and 4 provide examples of corrected bathymetric profiles on the Kwintebank. They illustrate the great variations in morphology and sand stock of the three bank parts.

3.3 Volumetric calculations

For each of the bathymetric profiles a bank base has to be defined. It corresponds to the horizontal plane crossing the highest of both the base concavities of the bank along the corresponding reference line at the start datum of the monitoring. The introduction of additional reference levels, situated at different fixed depths beneath the zero datum level, allow to calculate the area of the cross section above these levels as well as between two successive such levels.

To introduce the volumetric concept, unit volumes have been defined. They correspond to the volume of a transversal bank cross section having 1 m width.

Different types of such bank unit volumes can be defined :

- the total bank unit volume above the reference level just above to the bank base
- the full unit volume of a slice between two reference levels, the two most important being the base slice and the top slice. The base slice is comprised between the two lowest reference levels above the bank base; the top slice between both the highest reference levels crossing the bank.

Such unit-volumes have been calculated per reference line and per registration datum.

The resulting comparable unit-volumes show important variations. These are due to different reasons : natural sediment transport, navigation errors, tidal reduction errors, etc...., and possibly sand dredging as well. Matching of successive profiles along a same reference line by superposition is used to eliminate unreliable unit-volumes. Superposition is based on coincidence of fixed reference points along each of the reference transversals. Moreover the corresponding sailed tracks are compared with the reference lines. Figure 5 shows an example of such matching by superposition of comparable nett bathymetric profiles.

After such eliminations reliable unit-volumes for successive days along a same reference transversal still show important variations as indicated by the volumetric time series on fig. 6 and 7. They are due to residual sediment transportation related to an important short term sediment dynamism or to human impact. As on beaches, here as well short term sediment mobility seems to be much more important than residual sediment dynamics over longer periods. This is due to the impact of rapid variations in the directions an intensities of the hydrodynamic factors.

3.4 Regression analysis of volumetric data

To define the volumetric evolution of the bank or bank slices along fixed reference lines regression analysis has been applied upon time series of unit volumetric data per reference transversal. Examples of such time series are given in fig. 6 and 7.

That analysis provides a value for the mean annual change of the absolute unit volume of the considered type (A in $m^3/m/y$ for the considered reference line). As these data are insufficiently suited for a good evaluation of the bank morfodynamics themselves, and do not allow to compare morphological effects of volumetric changes between different reference lines, due to the great variations in total unit-volume, they are normalized in relation to a reference unit volume B and expressed in a mean annual change to the relative unit volume (R in %/y). The reference volume B is the initial unit volume corresponding to the volume to be read on the linear trend line at the date of the first of the considered time series.

3.5 Cartographic representation

The trends for A and R represent the residual evolution along different transversal reference lines across the bank. They have been introduced in a cartographic representation. That cartographic representation opens a way to a numerical and geographical evaluation of the presently existing trends in the residual sediment dynamism and morphodynamism.

Fig. 8 provides a generalised flow chart of the successive main steps.

4.RESULTS

The maps (fig.10 to 15) show the unit-volumetric evolution trends for the different reference transversals used as test sites for the Kwintebank over the period 1983-88.

4.1 Total bank evolution

Mean annual change of the absolute total bank unit volume along the successive reference lines is shown in fig. 9.

Sediment losses are most important on the south side of the northern part (rG23) near to the kink in the length profile of the bank. They are as well important on the southern bank part, along the reference line rG17. Most important gains are situated just south of the northern part, along reference line rG22 and in the southern part of the bank (around rG18 and rG16).

As the available sand stock at these test sites is quite different, the impact of these gains and losses upon the morphology of the bank and upon the sand reserve is quite different. That impact is given by the mean annual change of the relative total bank unit volumes along the reference lines (fig 10.). Diminishing of the total bank only occurs at its northern edge around the reference line rH02. Rather important enlargement only occurs on the southern edge of the bank.

4.2 Evolution at the bank base

Evolution at the bank base is shown by the mean annual change of the absolute unit volume of the basal slice along the successive reference lines (fig. 11)

The bank base shows quite important losses at the northern edge(around rH02) as well as around reference line rG17 on the southern part of the bank. Important gains on the bank base are only observed nearto the southern edge (rG16). Else in the northern part the bank base unit volume remains stable while the bank base in the central part shows some losses.

The impact of this residual sediment budget upon the bank morphology is shown by the mean annual change of the relative unit volume of the full basal slice along the reference lines. The map (fig. 12) distinctly illustrates the break down of the bank base at its northern edge and the growth on the extreme southern part.

4.3 Evolution of the bank top.

Evolution of the bank top slice, which not allways corresponds to the very bank top itself, is shown by the mean annual change of the absolute unit volume of the full bank top slice along the reference lines (fig. 13). On the northern part of the kwintebank, especially around reference line rG23, the bank top shows a general sediment loss, which is particulary important along reference line rH01. Sand dredging could be one of the factors for this loss. On the central part the bank top shows little gains, in the southern part however quite important sediment gains.

The impact of this budget is particulary important for the bank top morphodynamism, and, as the available sand volume in this top slice is generally low, for the available sand stock as well. This impact is shown on fig. 14. The break down of the bank top is quite important over the whole northern part. Mean annual losses there reach 10%. Bank top growth on the contrary is important on the southern part. In the central part some break down and growth alternate from place to place.

5.CONCLUSION

Thanks to the use of highly accurate Syledis navigation and positioning, to Deso XX bathymetric registration, to different correction procedures, to computer facilities and to the development of original software programmes, it has been possible to obtain an acceptable numerical evaluation of residual sediment dynamics along reference lines on a shelf sandbank by means of a basic geomorphological technique adapted to off shore conditions.

The method of sequential unit-volumetric measurements along reference lines has been preferred to the construction of volume difference maps based on sequentional hydrographic charting because of the fact that, despite analogy of fundamental technological problems, this method opens a possibility to cover a complete bank with a relatively high resolution within one tidal cycle.

Total sand mobility and morphological changes are quite varying along the shelf bank. On the Kwintebank most important residual losses occur at its northern edge and the short term evolution seems to trend in that way. Morphological break down of the Kwintebank top is most significant at its northern part. Impact of sand dredging is questionable. Growth of the bank is most considerable on its southern edge, suggesting a possible longitudinal shifting.

This volumetric approach distinctly shows that a sediment dynamic model of the bank cannot be based merely on the analysis of residual sediment transport paths. Moreover it suggests that complicated processes, probably bound to the hydrodynamism, are conditionning the sediment dynamism. It suggests that beside transversal sand uppiling, longitudinal residual displacement could be important as well, as already inferred from morphological arguments.

The evolution trends detected here from a 6 years observation period, are not likely to continue over a long time. This is shown by the fact that, using quadratic regression analysis instead of a linear one, some of the reference transversals already show maximal and minimal trend curves, indicating a reversal in the residual sediment dynamism during the period 1983-88 (fig.15).

Comparative analysis of half bank volumetric evolution trends could be of great help for a better understanding of the evolution of the bank's position, the transversal dissymmetry, the kink phenomenon and the related dissymmetry inversion (De Moor 1986) that affects many shelf banks.

6 ACKNOWLEDGEMENTS

The authors thank the Belgian Ministry for Sience policy for its grant, the belgian Management Unit Mathematical Model North Sea for its continuous support and the commanding officers and the entire crew of the Belgica for their help during the campaigns

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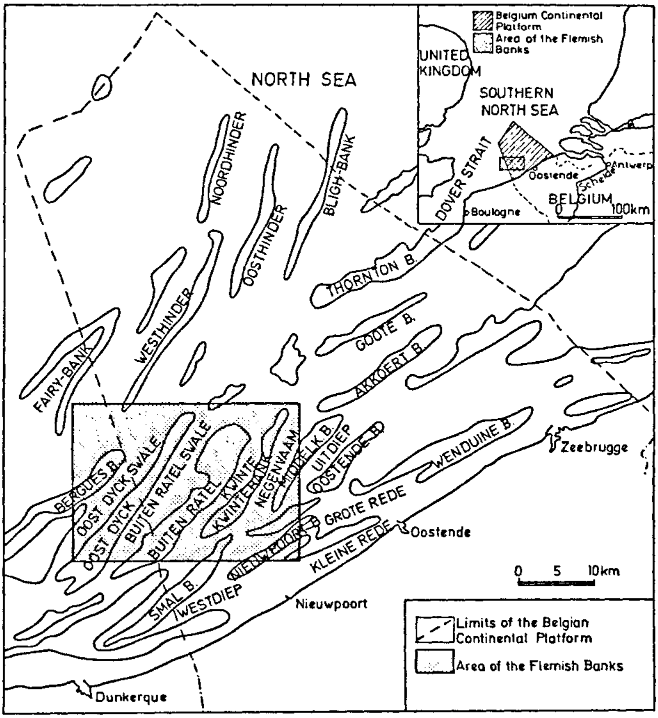
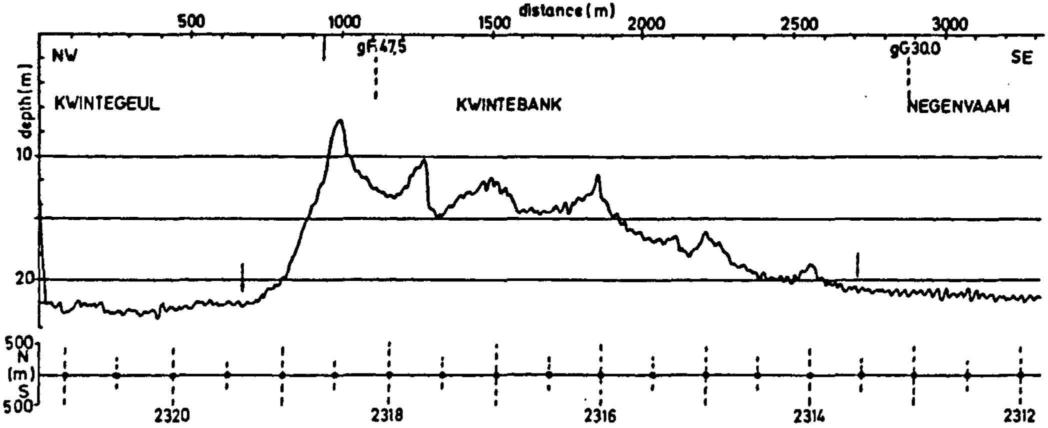


Fig. 1. Location of the Kwintebank.

Fig. 2. Nett bathymetric profile across the northern part of the Kwintebank

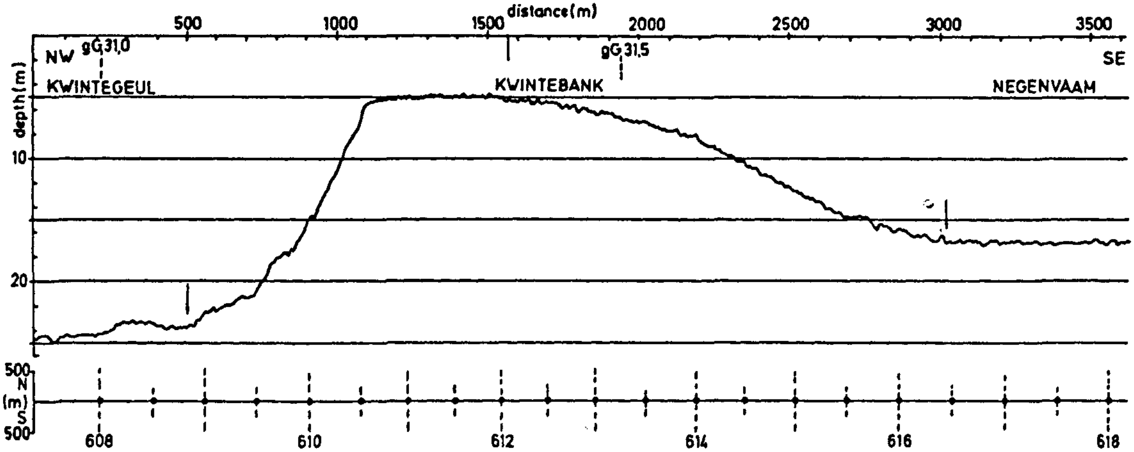


KWINTE BANK **Reference line: rG22.00**

Registration: 20/02/89 with: Atlas Deso XX

Scale: distance: 1/10.000 Depth: 1/250

Fig. 3. Nett bathymetric profile across the central part of the Kwintbank

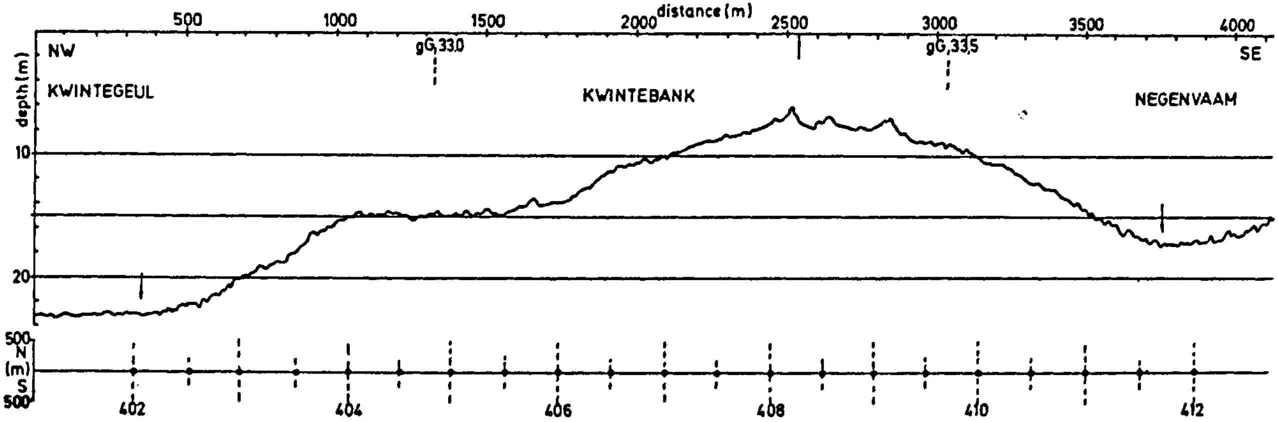


KWINTE BANK **Reference line: rG19.00**

Registration: 21/02/89 with: Atlas Deso XX

Scale: distance: 1/10.000 Depth: 1/250

Fig. 4. Nett bathymetric profile across the southern part of the Kwintebank

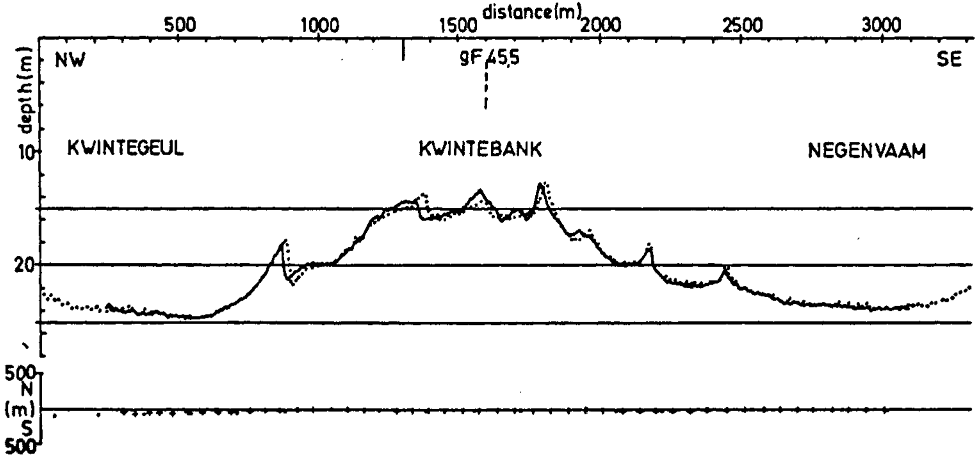


KWINTE BANK **Reference line: rG16.00**

Registration: 21/02/89 with: Atlas Deso XX

Scale: distance: 1/10.000   Depth: 1/250

Fig. 5. Visual comparison of succesive nett bathymetric profiles by superposition.

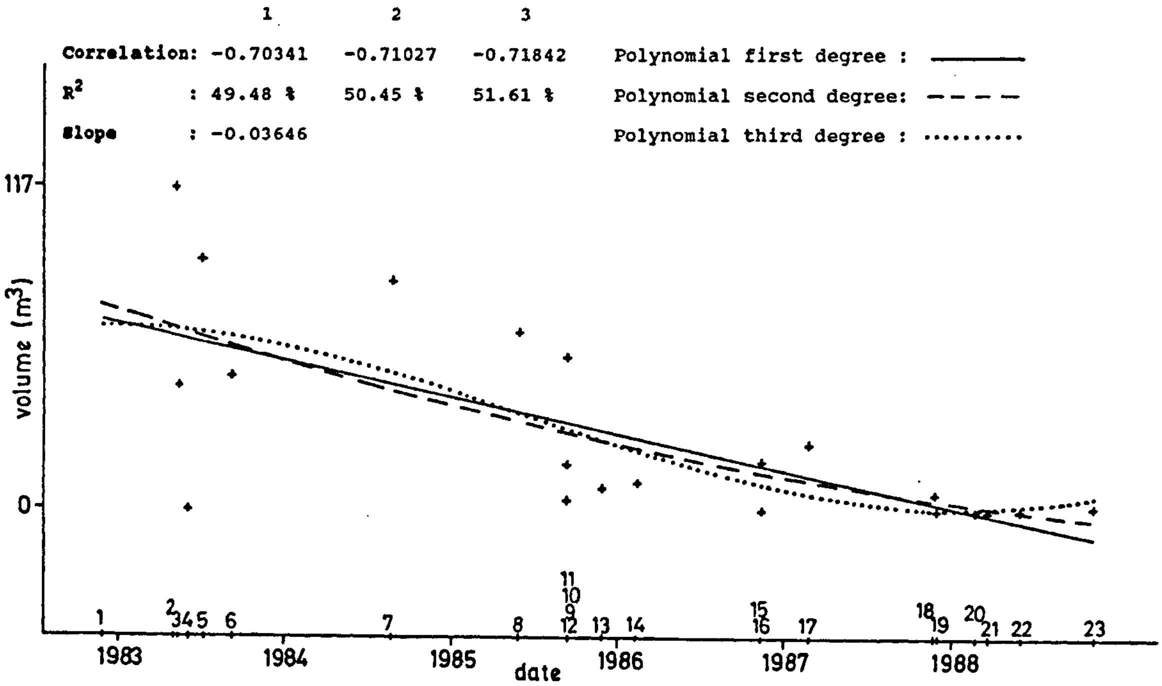


KWINTE BANK **Reference line: rH01.00**

Registration: 30/11/87 with: Atlas Deso XX (——)

Registration: 22/02/88 with: Atlas Deso XX (······)

Fig. 6. Unit-volumetric time series with regression lines.
Kwintebank total unit-volume along reference line rH01.

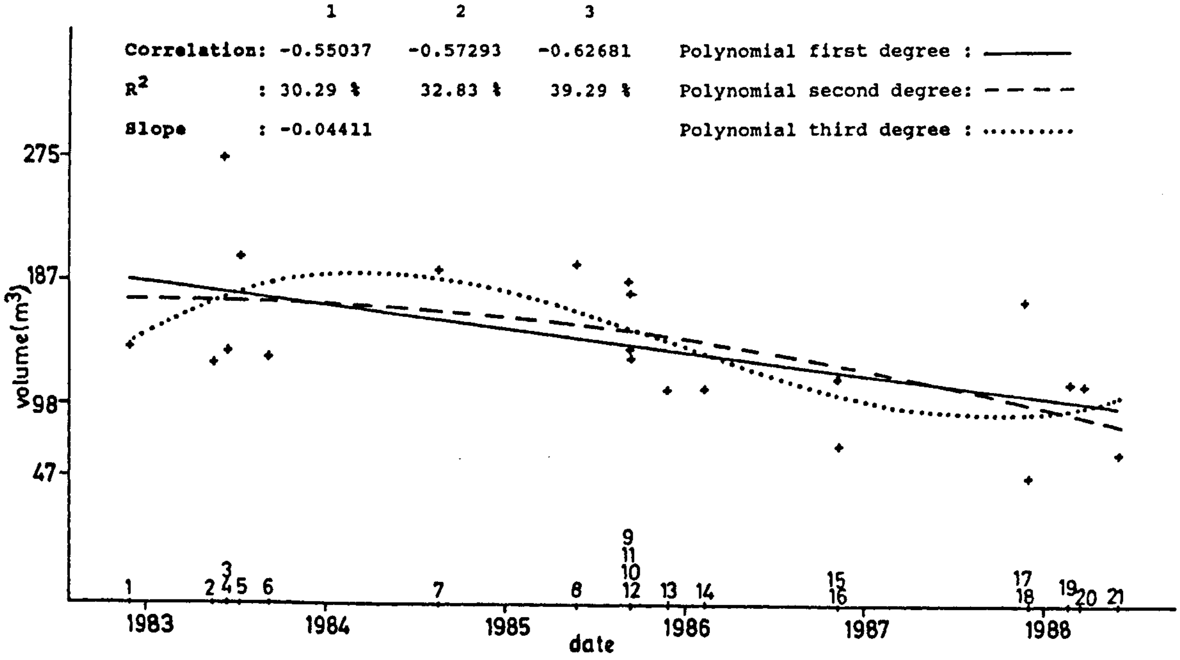


Kwinte Bank **Reference line: rH01.00**

Bank volume above: -12.5 m

1. 30/11/82
2. 07/05/83
3. 16/05/83
4. 10/06/83
5. 11/07/83
6. 07/09/83
7. 21/08/84
8. 28/05/85
9. 11/09/85
10. 11/09/85
11. 11/09/85
12. 13/09/85
13. 28/11/85
14. 11/02/86
15. 11/11/86
16. 12/11/86
17. 24/02/87
18. 23/11/87
19. 30/11/87
20. 22/02/88
21. 21/03/88
22. 01/06/88
23. 08/11/88

Fig[illegible]. Unit-volumetric time series with regression [illegible]nes.
Kwintebank total unit-volume along reference line rH00.



Kwinte Bank **Reference line: rH00.00**

Bank volume above: -12.5 m

1. 30/11/82
2. 16/05/83
3. 10/06/83
4. 13/06/83
5. 11/07/83
6. 07/09/83
7. 21/08/84
8. 28/05/85
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12. 13/09/85
13. 28/11/85
14. 11/02/86
15. 11/11/86
16. 12/11/86
17. 23/11/87
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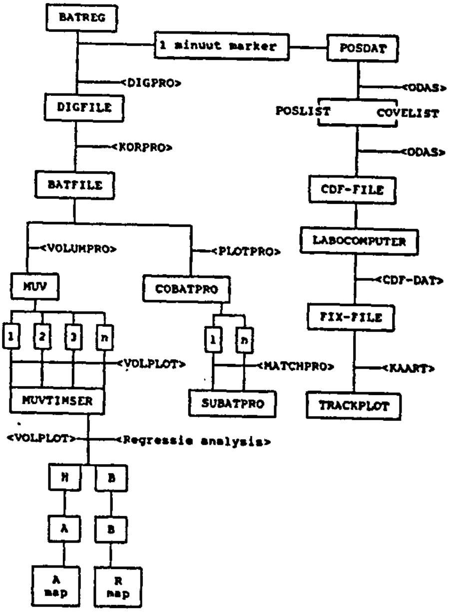
20. 21/03/88
21. 01/06/88



BATREG = Raw bathymetric registration
DIGPRO = Digitalisation programme for BATREG
DIGFILE = Datafile of digitized BATREG
KORPRO = Complex correction programme for BATREG
BATFILE = datafile for corredted digfile
VOLUMPRO = programme for calculation of unit-volumes
MUV = measured unit volumes
VOLPLOT = programme for regression analysis
MUVTIMSER = time series for measured unit-volumes
H = mean daily change of absolute trend unit volume
B = initial trend-unit-volume
A = mean annual change of absolute trend-unit-volume
R = mean annual change relative trend-unit-volume
POSDAT = positioning at 0,01" every 30 sec.
ODAS = MUMM programme for data-acquisition and storage
POSLIST = listing of position-fixes
COVELIST = listing of ground course and ground velocity components
CDF-FILE = HP 1000 Datafile of position-, course,-velocity- and meteorological data
CDFDAT = ODAS to HP600 transformation programme
FIXFILE = HP600 datafile of CDFFILE
KAART = Track plotting programme
TRACKPLOT = map with reference lines and sailed tracks.

Fig. 8. Generalised flow chart.

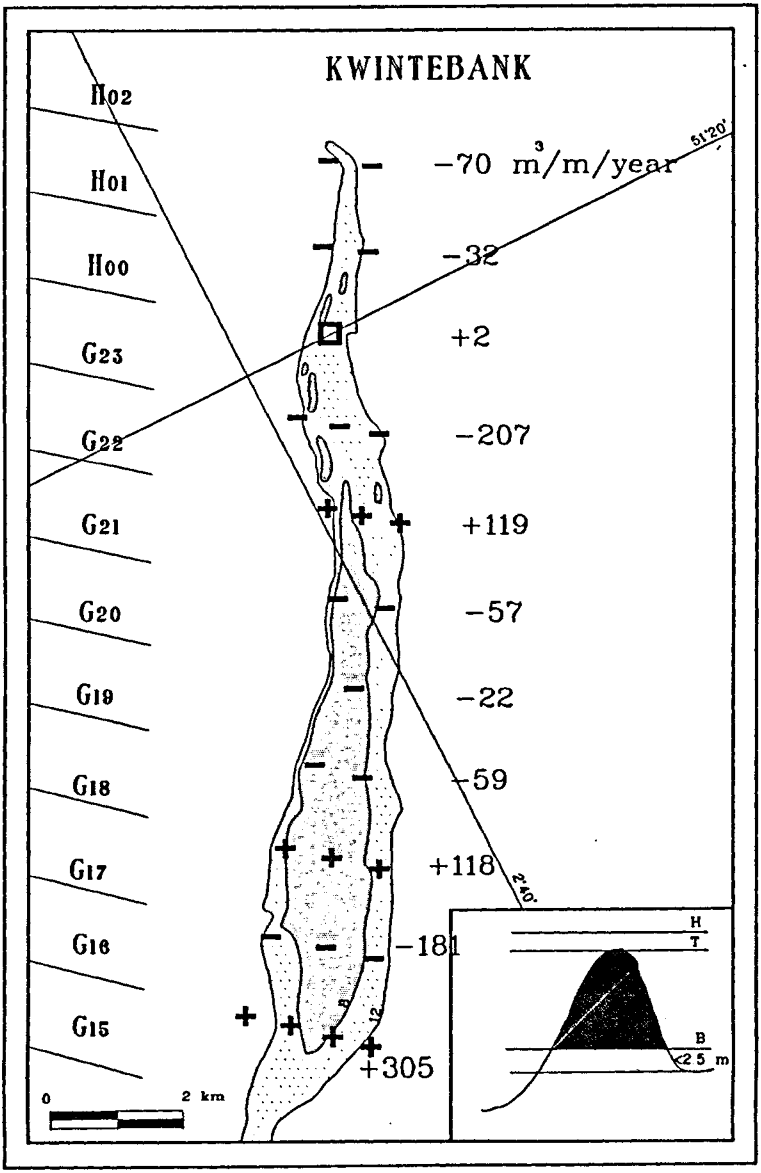


Fig. 9. Kwintebank; period 1983-88; A $(m^3.m^{-1}.y^{-1})$; absolute mean annual change of the total bank unit-volume

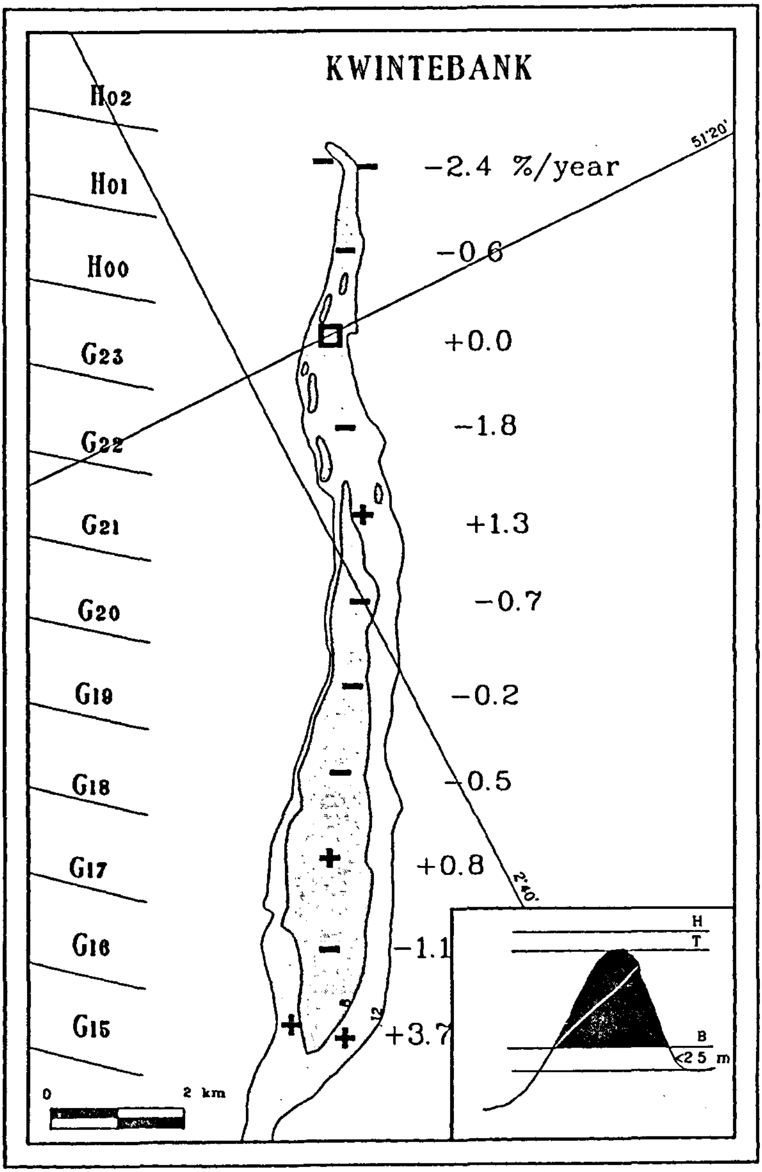


Fig. 10. Kwintebank; period 1983-88R; R (%.y^{-1}); relative mean annual change of the total bank unit-volume

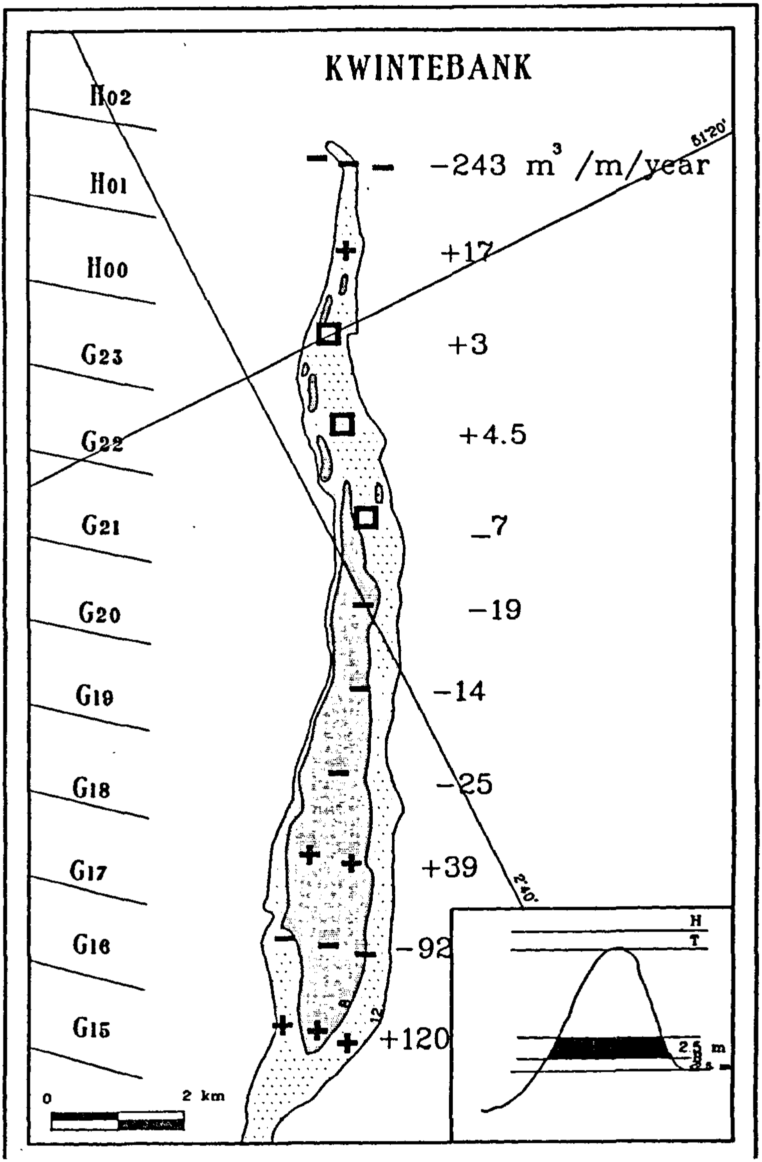


Fig. 11. Kwintebank; period 1983-88; A $(m^3.m^{-1}.y^{-1})$; absolute mean annual change of the unit-volume of the bank base slice

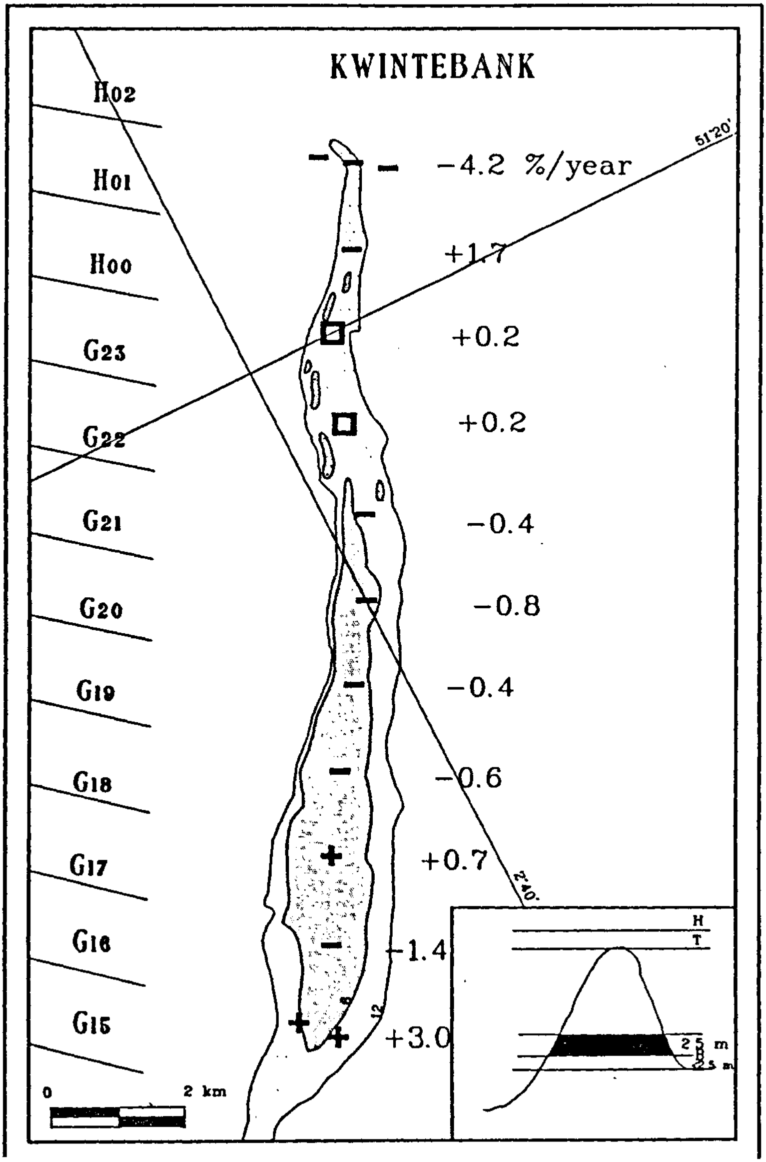


Fig. 12. Kwintebank; period 1983-88; R (%.y^{-1}); relative mean annual change of the unit-volume of the bank base slice

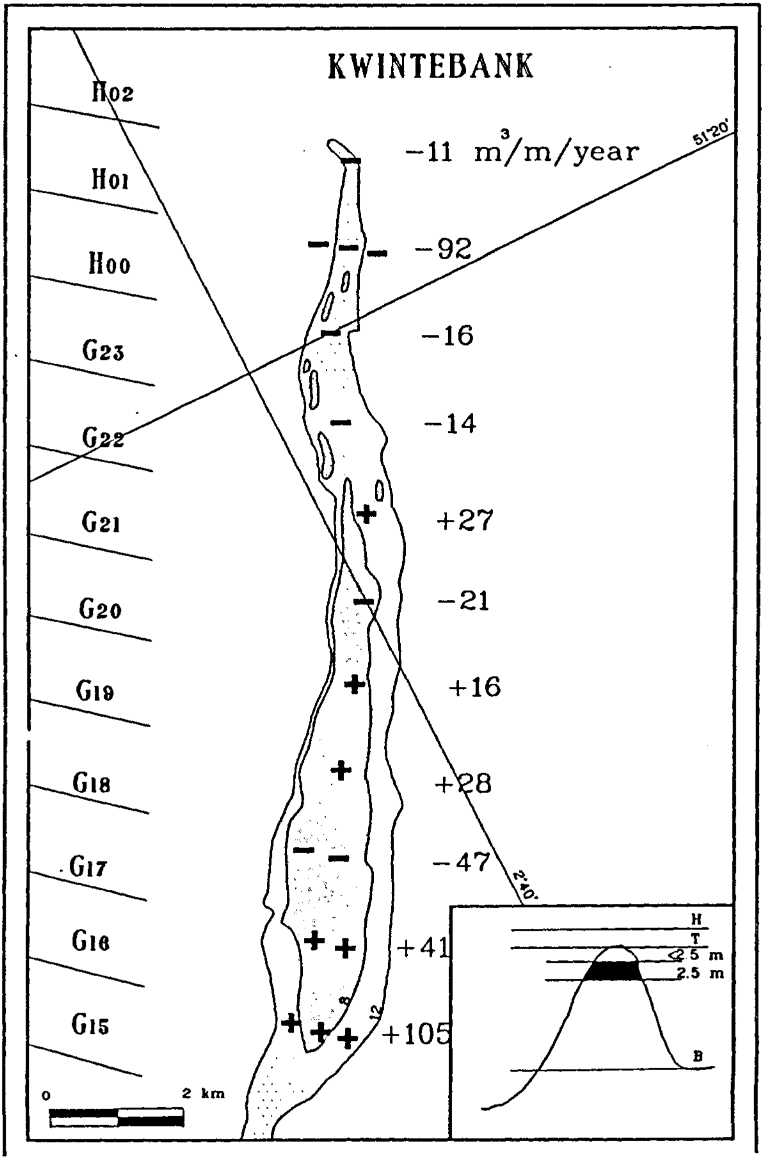


Fig. 13. Kwintebank; period 1983-88; A ($m^3.m^{-1}.y^{-1}$); absolute mean annual change of the unit-volume of the bank top slice

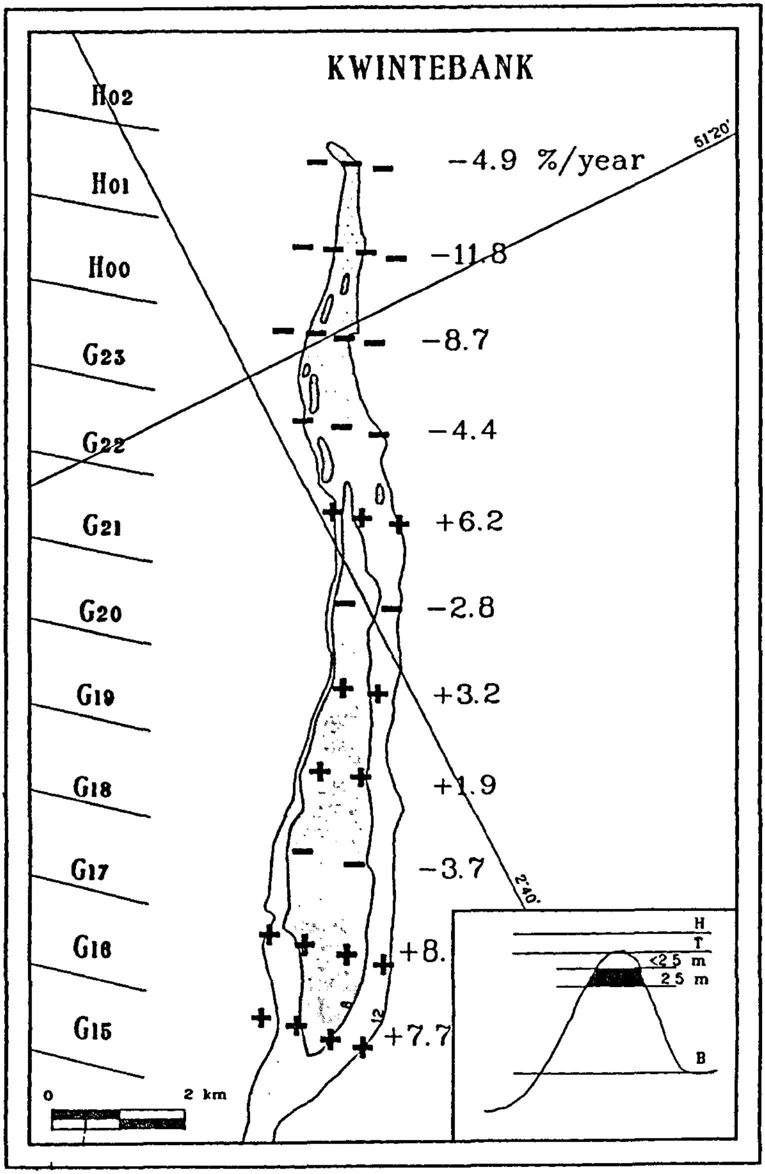
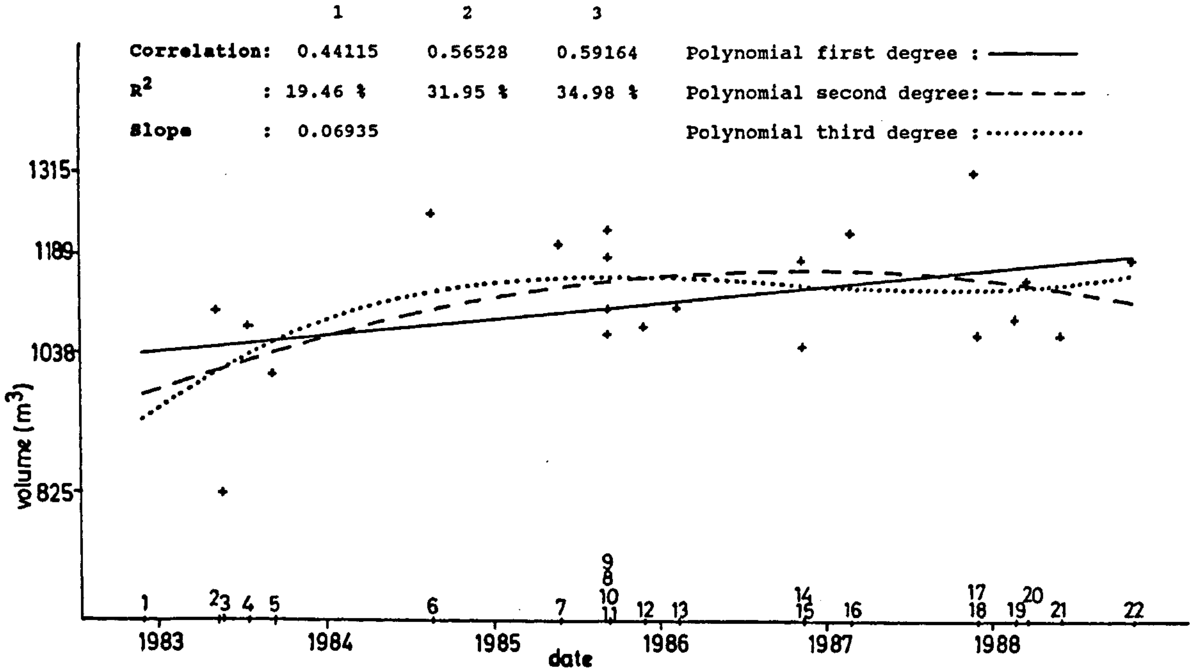


Fig. 14. Kwintebank; period 1983-88; R (%.y^{-1}), relative mean annual change of the unit-volume of the bank top slice

Fig. 15. Unit-volumetric time series with quadratic regression line showing an inversion of the sedimentdynamic evolution. Kwintebank total unit-volume along reference line rH01



Kwinte Bank **Reference line: rH01.00**

Bank volume above: -20.0 m

1. 30/11/82
2. 07/05/83
3. 16/05/83
4. 11/07/83
5. 07/09/83
6. 21/08/84
7. 28/05/85
8. 11/09/85
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22. 08/11/88