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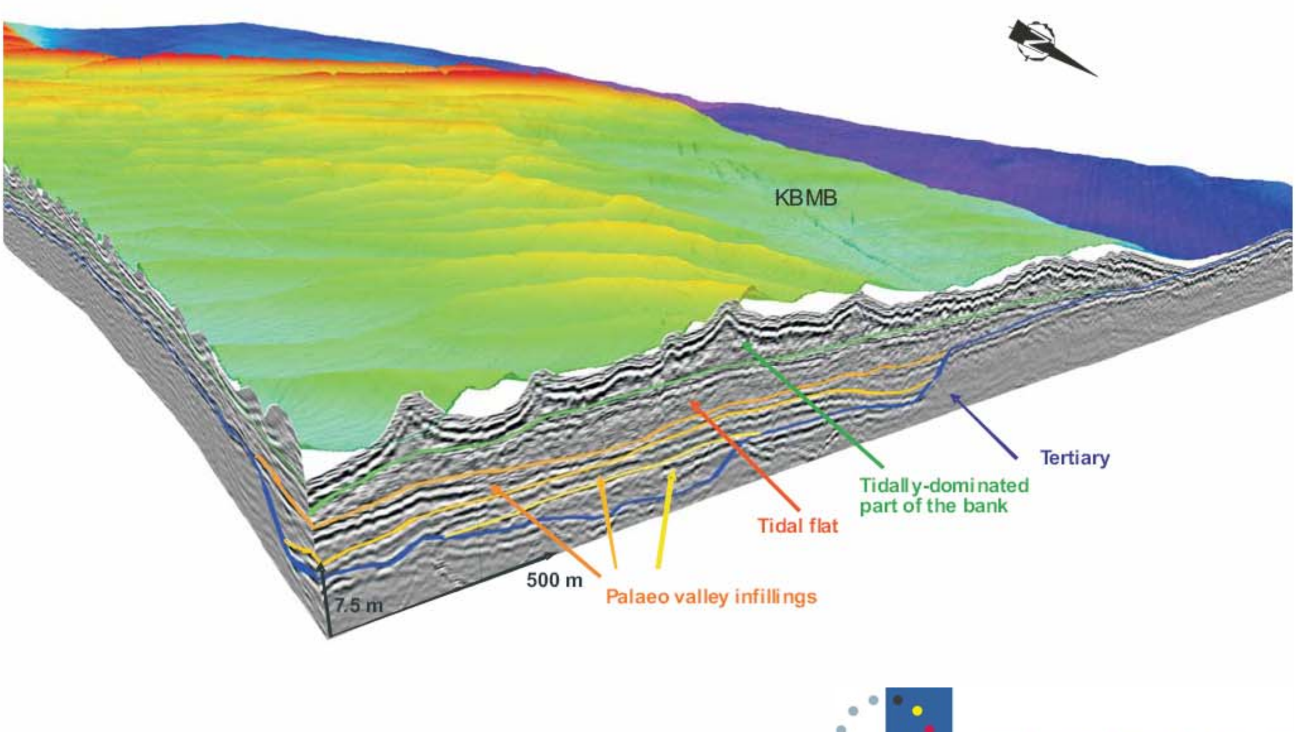
Towards a high-resolution 3D-analysis of sandbank architecture on the Belgian Continental Shelf 'RESOURCE-3D'

FINAL REPORT



BELGIAN SCIENCE POLICY

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Abstract

Revealing the internal structure of sand banks by means of high-resolution seismic (acoustic) methods remains one of the classic methodological challenges in shallow marine geophysical prospection. This is mostly due to the strong heterogeneity of the sand-bank body in combination with complex sea-floor morphology.

This study has focussed on the optimisation of a methodological-technological approach through a comparison of various state-of-the-art high-resolution seismic source/receiver configurations for the investigation of the internal architecture of sand banks. On the basis of a dense network of seismic profiles, the 3D architecture of a test site on the Belgian Continental Shelf was studied in detail. Digital acquisition of the data enabled post-acquisition processing and data enhancement. Specialised software was used to identify, trace and map the structuring sediment bodies. To translate the "acoustic information" in a most unbiased way, in terms of its lithological and sedimentological nature, UGent-RCMG's knowledge database and available background information on the Quaternary geology of the Belgian part of the North Sea has been used intensively. Finally, the interpreted seismic data were integrated with other datasets, such as multibeam bathymetry. This enabled a high-resolution 3D quantitative analysis and representation of the sand-bank architecture and its economical potential.

After comparison of the acquired test data sets, a set of recommendations is formulated regarding the most optimal strategy for future 4D prospecting of marine aggregates on the Belgian Continental Shelf.

Keywords: sand bank; very-high resolution seismics; 4D monitoring

Introduction

Revealing the internal structure of sand banks by means of high-resolution seismic (acoustic) methods remains **one of the classic methodological challenges in shallow marine geophysical prospection**. The short-wavelength sound waves that are needed to obtain the required resolution are quickly absorbed in the heterogeneous coarse-sandy sediments that typically make up the sand banks and they usually do not penetrate until the base of the sand banks (which are typically 20-30 m thick). Moreover, various bedforms at various scales at the surface of the sand banks generally cause a strong additional scattering of the acoustic signal.

In spite of these inherent methodological difficulties, sand banks have been the subject of detailed seismic investigations, worldwide, and since several decades. Many of these studies took place in the English Channel and in the southern North Sea: e.g. in Great Britain, the Netherlands, France, but also along the Belgian part of the North Sea (BPNS).

Already since the beginning of the 80’s seismic studies on sand banks have been carried out on the BPNS, and this primarily by UGent-RCMG, or by international research partners in cooperation with UGent-RCMG. In these studies different types of seismic sources were used (e.g. waterguns, sparkers, boomers, pingers). As an outcome of these studies numerous published and non-published seismic data sets currently exist –albeit of variable quality– that hold important information about the internal structure of nearly all the sand banks on the BPNS. The majority of these data –i.e. a total of more than 16,000 km of profiles crossing the entire BPNS– is stored in the analog or digital archives of UGent-RCMG.

By combining this extensive seismic data base with available information from cores, Mathys (2009) recently could achieve a much better understanding of 1) the regional stratigraphy of the sand banks; 2) the reasons for the strong variability in internal structure; and 3) the actual lithological and sedimentological composition.

During previous seismic studies of the sand banks on the BPNS, **sparkers**, **boomers** or **subbottom profilers** were the main seismic sources used:
(1) SIG and Centipede sparker, in combination with a single-channel streamer: successful and good penetration on all sand banks, but with a rather limited resolution (e.g. De Batist & Henriet, 1995);
(2) boomer, in combination with a single-channel streamer: outer harbour of Zeebrugge and Paardenmarkt, very good resolution, but highly weather-dependent (e.g. Missiaen et al., 2002);
(3) IKB Seistec boomer/receiver system: Kwinte Bank, very good resolution, but limited penetration and highly weather-dependent (Bellec et al., in press);
(4) 2.5 kHz subbottom profiler: Middelkerke Bank, good resolution, but limited penetration (e.g. Trentesaux et al., 1993);
(5) 3.5 kHz subbottom profiler: near coastal zone and Goote Bank, good resolution, but limited penetration (e.g. De Maeyer et al., 1985).

In the international literature (Europe, USA, Canada, Australia, China, Korea), the same range of seismic sources can be found for sand-bank research.

The aims of this project were i) to propose the most suitable seismic system for sand-bank research on the BPNS, and ii) to determine the internal structure of sand banks on the BPNS and the thickness of gravel fields with a sediment profiler. Additional conditions were: i) joint deployment of the profiler with the multibeam system on the R/V Belgica, and ii) to evaluate the Quaternary deposits up to the Tertiary surface with a maximum resolution (thickness: up to 20 m). These criteria *a priori* exclude the use of high-frequency subbottom profilers and parametric sources, because of their limited penetration capability (only the first 2-5 m –

dependent on the sediment type), and because they can potentially interfere with the multibeam system of R/V Belgica. High-frequency chirp-type subbottom profilers might, on the other hand, due to their characteristic frequency-modulation, provide sufficient penetration (e.g. Goff et al., 2005).

Building on this historical perspective and on UGent-RCMG's experience, this investigation has addressed:

(1) methodological-technological issues: i.e. determining the best seismic methodology/strategy to uncover the internal structure of the sand banks on the BPNS with the highest resolution, which is also most suitable for the Commissioner; and

(2) interpretation issues: i.e. interpreting in a reliable way the seismically revealed internal structure, in terms of 3D architecture and sedimentological and lithological composition and based on the knowledge and available background information on the Quaternary geology of the BPNS, available at UGent-RCMG.

In consent with the Commissioner, the issue of determining the thickness of gravel fields in between and below the sand banks was not addressed. It was also mutually decided to focus on the Kwinte Bank, as a test site, as this is the sand bank most heavily exploited on the BPNS.

Seismic sources[1]

Very-high-resolution (VHR) seismic technology offers a wide range of high-frequency acoustic sources, including piezo-electric transducers, sparker, watergun, and boomer sources. Watergun sources mostly lack high frequencies ($f_m \approx 350$ Hz), but are marked by a good repeatability. Sparker sources have a fairly broad bandwidth, but their dominant frequency is rather limited ($f_m = 0.6\text{-}1$ kHz) and they often show low repeatability (Verbeek, 1995). UGent-RCMG's in-house developed Centipede sparker produces a seismic signal with a peak frequency of 1100-1200 Hz, corresponding to a vertical resolution of ~ 35 cm. A SIG sparker (see below) is characterised by a lower peak frequency of 800-900 Hz, corresponding to a resolution of ~ 50 cm. Transducer sources are generally marked by a high dominant frequency ($f_m = 4\text{-}10$ kHz) and good repeatability, but have a limited penetration depth. Their built-in receiver system often has the disadvantage that it records the envelope of the data, which contains amplitude information only and no phase information.

Boomer sources combine high frequencies ($f_m \approx 2$ kHz) with a broad power spectrum, and seem to offer a good compromise between resolution (order of 20-25 cm) and penetration (tens of meters at least) for shallow water site surveys. They generally have a good repeatability although this will depend on the sea state (a rough sea will constantly change the source direction, thus reducing the repeatability). The IKB Seistec boomer also supports a line-in-cone receiver, and is marked by a large operational bandwidth, ranging from roughly 1 kHz to well over 8 kHz (dominant frequency 3-4 kHz). The suitability of boomer sources in very-high-resolution (VHR) 2D and 3D seismic work has been demonstrated on various occasions (e.g. Henriet et al., 1992; Missiaen et al., 1996; Davies & Austin, 1997; Mosher & Simpkin, 1999; Missiaen et al., 2002; Müller et al., 2002).

Chirp profilers are digital, frequency-modulated (FM) sources with a predetermined and repeatable source signature for high-resolution, normal incidence seismic reflection data acquisition. The Chirp systems comprise calibrated, linear electronic components and transmit signals containing pre-determined phase and amplitude corrections (Quinn, 1997). This ensures that no anomalies occur in the transducers or the transmitting and receiving electronics. The signal-to-noise (S/N) ratio of Chirp data is improved through matched filter processing by correlating the reflection data with the pre-determined transmitted pulse. If

[1] Based on Missiaen (2008)

reflections or noise do not match the outgoing Chirp waveform, the filter attenuates the unwanted signal. See Quinn (1997) and Quinn et al. (2000) for a description on (frequency-wave number) migration, filtering and the application of a dynamic signal/noise filter. For additional information, see also Yilmaz (1987).

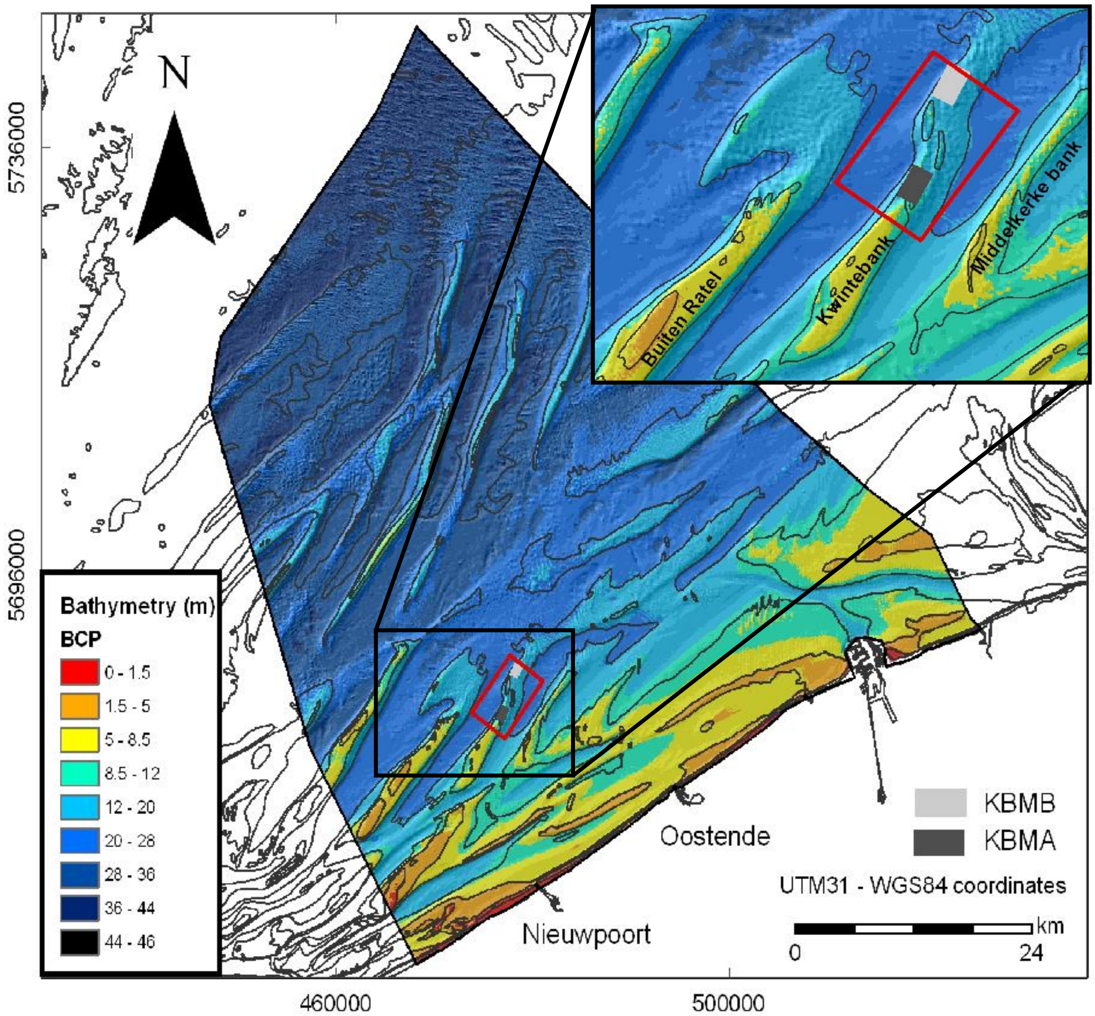


Figure 1: The Belgian part of the North Sea with indication of the Kwinte Bank.

Study area: the Kwinte Bank

The Kwinte Bank is a SW-NE oriented sand bank with water depths of around 5 to 22 m in the swales (Figure 1). It is ~ 15 km long, and its width varies from ~ 2 km in the southern part to ~ 1 km in the northern part. The southern part is the shallowest (~ 5 m depth). The Kwinte Bank shows a NW-oriented steep side, subdued to the flood, and a SE-oriented gently-sloping side, subdued to the ebb. Large to very-large dunes (*sensu* Ashley, 1990; with heights of respectively > 0.75 m and > 3 m) cover the sand bank extensively.

Fine to medium-sized sands characterise the surface sediments of the Kwinte Bank. The grain-size coarsens from south to north; 180 to 240 µm is found over the southern part, while coarser sediment (of up to ~ 400 µm) characterises the middle and northern part.

The specific morphological and sedimentological characteristics of the Kwinte Bank are discussed in more detail in Bellec et al. (in press) and Degrendele et al. (in press).

Marine aggregate extraction is very intense on this sand bank and time series indicate erosion on the longer term (for an overview, Van Lancker et al., in press). Two zones have been defined where extraction is most severe (KBMA and KBMB) (Degrendele et al., in press). Since the commencement of multibeam monitoring in 1999, an overall deepening (by 0.5 m) of the entire KBMA monitoring zone is observed, until the cessation of dredging, in February 2003 (Degrendele et al., in press). Subsequently, the deepening slowed down and the variation in sediment volumes became similar to that of an adjacent non-exploited sand bank. KBMB was closed only recently.

Material and methods

For this comparative analysis of high-resolution seismic systems, UGent-RCMG’s sources SIG sparker, Centipede sparker and the IKB Seistec boomer/receiver system were used, and through subcontracting a C-Boom boomer (Magelas) and an Edgetech X-STAR chirp subbottom profiler (TNO, Built Environment and Geosciences) were made available as well. The ‘sediment profiler’ of IFREMER was not operational during the period of the field tests. A single-channel streamer, composed of 10 hydrophones and with a length of 4.5 m was used as a receiver in combination with the SIG sparker, Centipede sparker and C-Boom boomer. The survey speed with all sources and systems was optimally kept at 3-4 kts.

Data acquisition

Survey design

In order to achieve the goals of the project, we adopted a 3-phase approach, comprising the following steps:

(1) Comparative study of different seismic systems along a reference track line. The following key criteria for selection were taken into account: (i) possibility to use the system from R/V Belgica, in combination with multibeam echosounding (and without causing interference); (ii) user-friendliness of the system for the Commissioner; and (iii) performance of the system (i.e. producing high-quality seismic information on the structure of the subsurface over the whole thickness of the sand bank and this with the best possible resolution), the latter being also dependent on the nature of the subsurface in the proposed test site(s). The sources used are listed in the following paragraph.

(2) Selection of the most suitable system, based on the results of the comparative test recordings along the reference track, and taking into account all other selection criteria.

(3) With the selected seismic system, collection of a dense grid (250 m interval) of perpendicular cross-profiles (pseudo-3D approach) in order to image the complete 3-dimensional complexity of the sand bank. The position of the lines was chosen in correspondence with the seismic grid on the adjacent Middelkerke Bank.

All data acquisition (steps 1 and 3) has taken place during ship-time slots on-board of R/V Belgica. Initially, it was planned that ship time of the Commissioner would be used for the project data acquisition. However, successive technical problems with R/V Belgica caused a significant delay, so that eventually also ship time of UGent-RCMG had to be used. In total, 4 campaigns were cancelled due to the technical problems of R/V Belgica: (1) ST0614: 03-06/07/2006 (Campaign PD-ECON); (2) ST0615: 10-14/07/2006 (Campaign UGent-RCMG); (3) ST0620: 02-06/10/2006 (Campaign PD-ECON); and (4) ST0621: 16-20/10/2006 (Campaign UGent-RCMG). This also had an impact on the availability of UGent-RCMG’s seismic sources and receivers, and also on the availability of seismic systems of the subcontractors. The cumulative delay was of such extent that the project duration had to be extended up to 28/02/2008.

Despite these logistic difficulties in organising and planning the data acquisition campaigns, most of the equipment has eventually been tested on the test area of the Kwinte Bank and sufficient data could be collected with the best-suited seismic system in order to image the internal sand-bank structure. This took place during two campaigns: i.e. ST0709 and ST0717.

Information on the final data acquisition period is listed in Table 1.

Table 1: Resource-3D campaigns, R/V Belgica, test area Kwinte Bank.

Campaign id	**ST0709**	**ST0717**
Period	16–20/05/2007	16-19/07/2007
Ship	R/V Belgica	R/V Belgica
Equipment	IKB Seistec, SIG, Centipede, C-Boom	X-STAR
Track lines sailed (x)	Line 1-26 and some N-S lines	Line 3-5, 14-20
Weather conditions		
Mean wind velocity	Figure 4	Annex 4
Mean wave height	Figure 4	Annex 4

All of the data were acquired with the R/V Belgica sailing on electrical propulsion. The lines cover the monitoring zones KBMA and KBMB of the Fund for Sand Extraction (Figure 2). The test lines were sailed in the northern, central and southern part of the study area with 2 test lines per source in each part (Figure 3). Those parts were chosen because of the difference in their sediment distribution. The surface sediments in the northern part are coarser-grained; those in the middle part are known to be very rich in shells and those in the southern part are characterised by medium-grained sand.

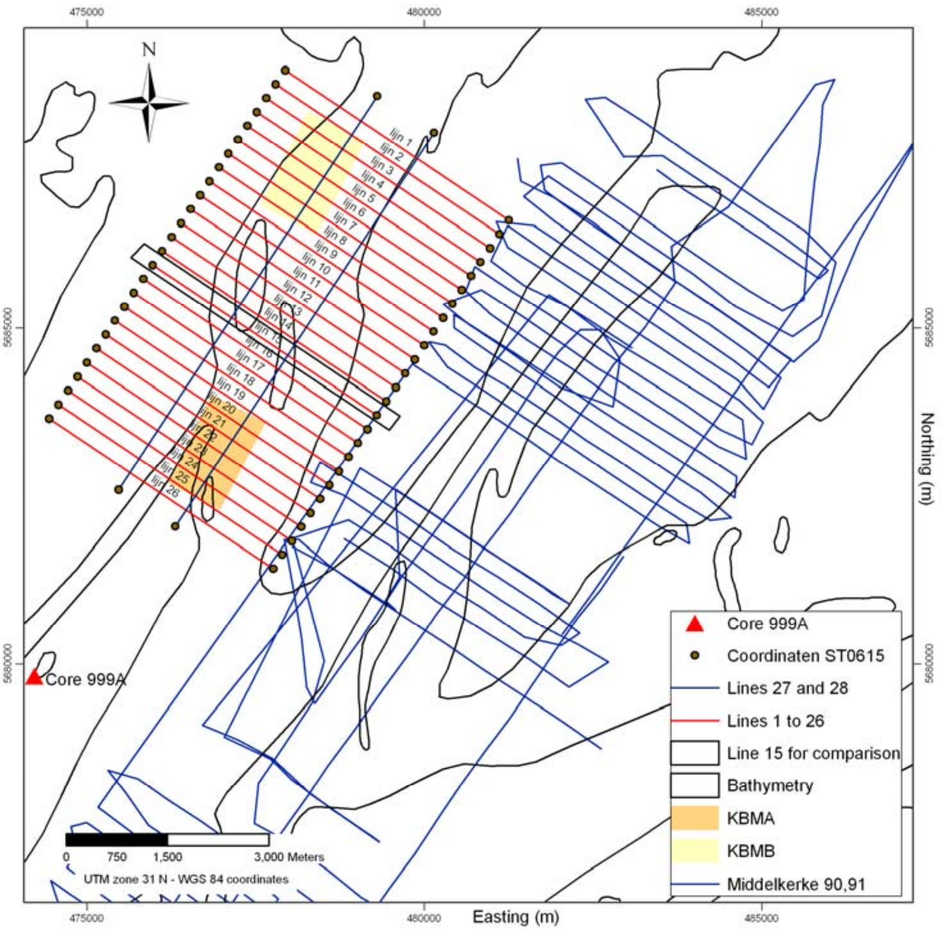
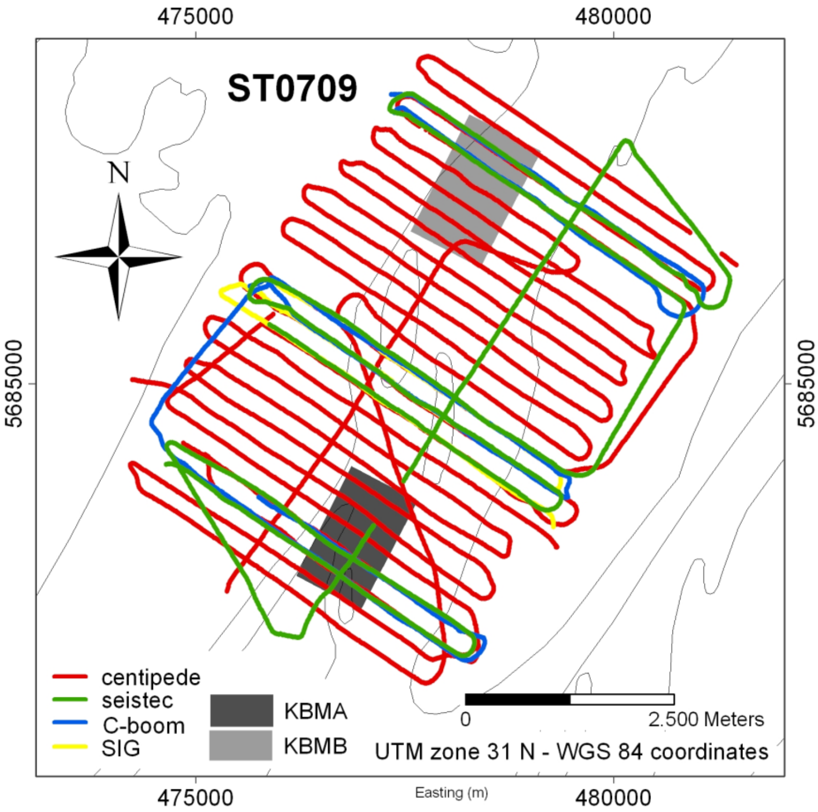


Figure 2: Survey grid over the Kwinte Bank. Red: track lines perpendicular to the bank axis; spacing = 250 m; length = 4 km. Blue: track lines parallel with the bank axis; spacing = 1 km. Coordinates of the track lines: Annex 1. The grid spacing was chosen in agreement with the seismic grid previously acquired on the Middelkerke Bank. Track line 15 has been used in this report as reference profile to compare the different seismic sources.



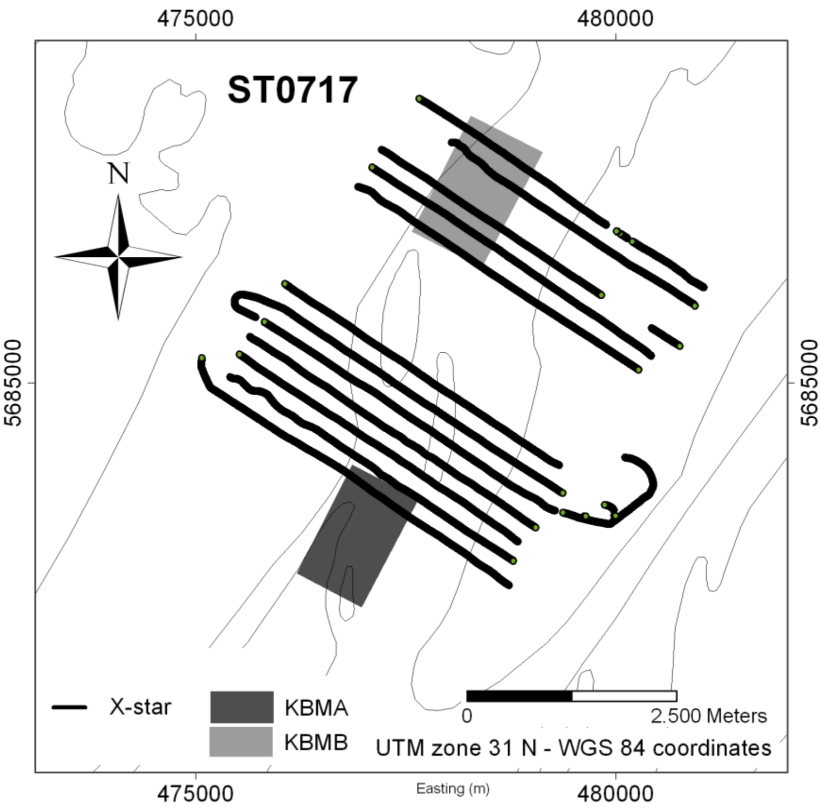


Figure 3: Track lines sailed during campaign ST0709 and ST0717 (R/V Belgica).

The ship's speed during acquisition was set preferably at 3 kts. Weather conditions were ideally less than 3 Bft (Figure 4, Table 1, Annex 4). Increasing sea states largely deteriorate the quality of the data.

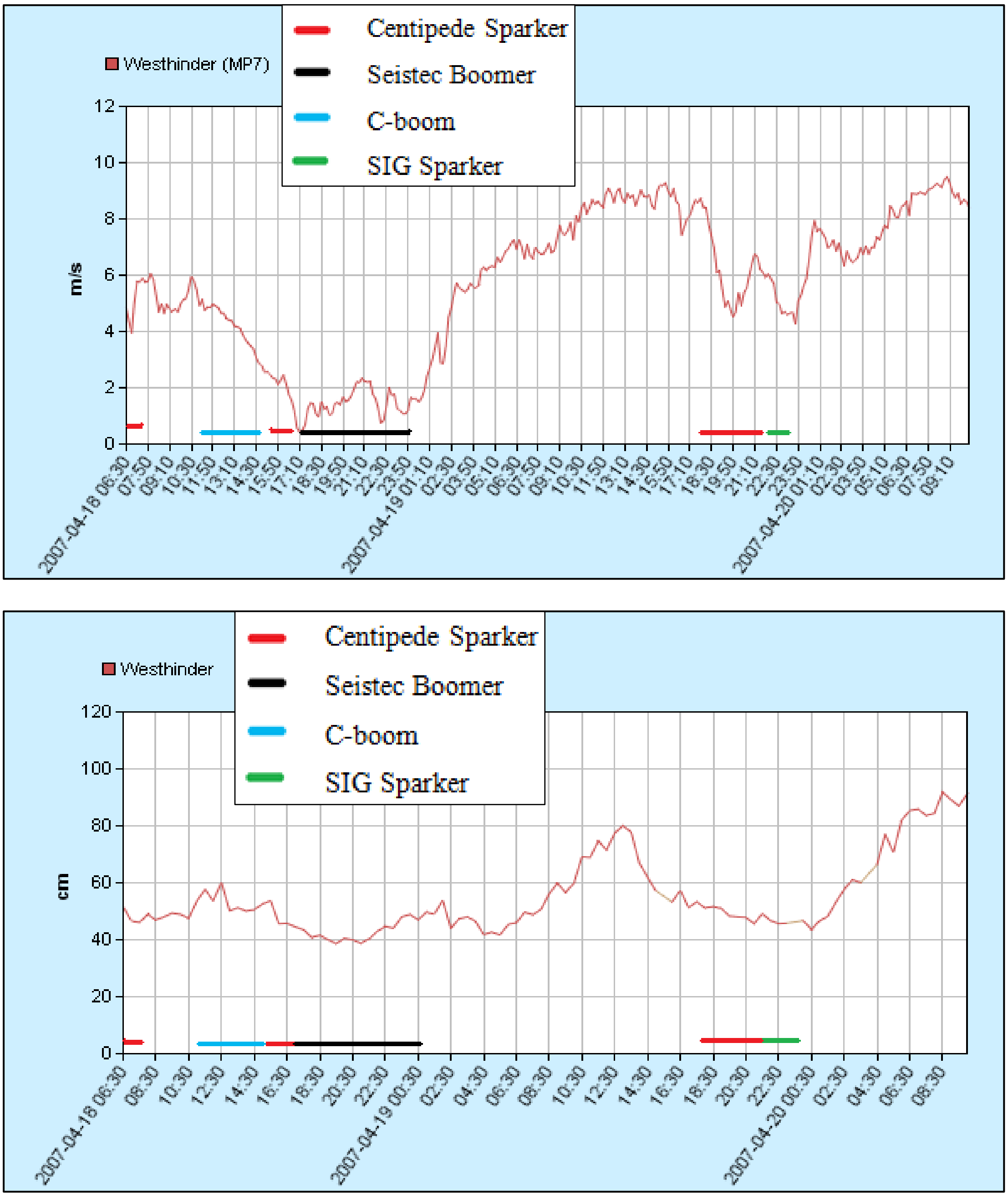
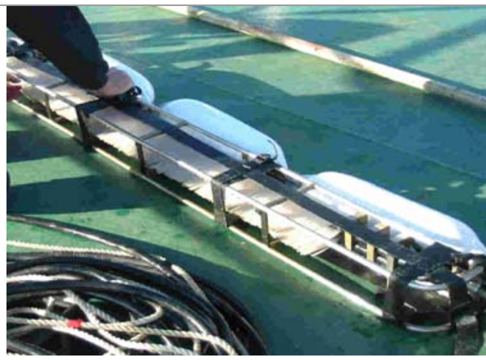
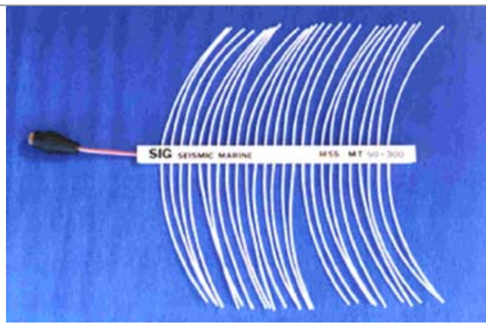


Figure 4: (upper panel) Mean wind velocity; (lower panel) significant wave height, measuring pile Westhinder during campaign ST0709. Source: © AWZ | VLIZ http://www.vliz.be/.

All data were recorded digitally, using UGent-RCMG's Triton-ELICS Delph2 system (for the SIG and Centipede sparker, and for the IKB Seistec and C-Boom boomer data); the X-STAR chirp subbottom profiler has its own recording system. The data were recorded in standard SEG-Y format. The SEG-Y file format is one of several standards developed by the Society of Exploration Geophysicists for storing geophysical data. It is an open standard, and is controlled by the SEG Technical Standards Committee. The SEG-Y format allows for recording of technical-parameter and position data together with the actual seismic trace data. Each shotpoint in the navigation file has a position and time stamp. Time is recorded in UTC; the position in UTM31-WGS84 coordinates. An offset of 40 m has been applied to correct for the distance between the GPS antenna and the actual source-receiver location behind the vessel.

Details on the seismic sources used

Boomer (IKB Seistec) (UGent-RCMG): - 1000-5000 Hz (main frequency: 2500 Hz) - frame: 257*73*65 cm; 100 kg - line-in-cone hydrophone receiver-array	
Sparker (Centipede) (UGent-RCMG): - 800-2000 Hz (main frequency: 1100 Hz) - frame: 195*20*20 cm; 25 kg - receiver: SIG-streamer (10 hydrophones; spaced 30 cm)	
Sparker (SIG) (UGent-RCMG): - 300-1800 Hz (main frequency: 800 Hz) - frame: 40*100 cm; 1.25 kg - receiver: SIG-streamer (10 hydrophones; spaced 30 cm)	
C-Boom boomer (Magelas): - 1000-4000 Hz (main frequency: 1700 Hz) - Catamaran: stainless steel tubular frame assembled with floats 0.9*1 m, 15 kg - receiver: SIG-streamer (10 hydrophones; spaced 30 cm)	

Full Spectrum digital X-STAR 3200 xs (SB-512i) Sub-bottom Profiler (TNO) - selectable frequency ranges and sweep lengths - during survey (low frequency range): 0.5-8.0 kHz, 5 ms sweep length (“bad”) 0.5-4.5 kHz , 50 ms sweep length - tow-fish: 160 * 124 * 47 cm; 190 kg	

Table 2: Comparative table of the main differences in performance of the seismic sources used.

Equipment	Main frequency	Resolution	Penetration
SIG sparker and streamer (UGent-RCMG)	800 Hz	75 cm	in a sandy sea bottom, up to 100 m
Centipede sparker and streamer (UGent-RCMG)	1100 Hz	40 cm	in a sandy sea bottom, up to 50 m
IKB Seistec source-receiver system (UGent-RCMG)	2500 Hz	20 cm	in a sandy sea bottom, up to 10-20 m
C-Boom (Magelas)	1700 Hz	min. 30 cm	not known
EdgeTech X-STAR 3200 xs (TNO)	Frequency sweep: 500 Hz – 12 kHz	8-20 cm *depending on frequency*	in a sandy sea bottom, up to 10-20 m *depending on frequency and sweep length*

Acquisition parameters

The settings of the acquisition parameters for each of the seismic sources are listed in the cruise reports (Annexes 2 and 3).

Multibeam surveying

Simultaneously with the recordings of the selected seismic source, multibeam measurements were performed with R/V Belgica’s Kongsberg Simrad EM1002 (95/98 kHz) (Kongsberg Simrad, 1999-2001a). The system has 111 beams of 2° (athwart) x 3.3° (fore-aft) width, working at a nominal frequency of 95 kHz, with a ping-rate of around 4 to 6 Hz. The data are corrected in real-time for roll and heave, using a Seatex MRU5 motion sensor and, for heading, using an Anschütz Standard 20 gyrocompas. A Thales Aquarius 02 GPS is used as positioning system with a theoretical precision of 10 mm. The datum used is WGS84. Data were acquired at the speed of the seismic recordings (3-4 kts).

No interference problems were encountered between the multibeam and seismic acquisition. Due to time constraints no full coverage imagery was obtained (Figure 5).

Data processing

The digital recording allows **post-acquisition treatment and processing** of the data. The raw data was processed with industry-standard software for seismic processing **ProMax**, in combination with some in-house developed **Matlab** routines. Matlab routines were used to correct for the tide, as well as for swell filtering.

Bandpass filters (i.e. range of frequencies allowed to pass) were used to attenuate or remove unwanted acoustic noise. Normally, the frequency band is selected by two independent controls, one for the low cut-off frequency and one for the high cut-off frequency. This allows for great flexibility in selecting both the bandpass frequency range and the location of the centre frequency within the acoustic spectrum of the source.

Swell filtering in high-resolution seismics or subbottom profiling refers to the static correction that restores the coherence of a high-resolution seismic profile. The coherence of the image gets lost because of the relative movement (a function of the wavelength of the signal and the swell) of the source and receiver during the recordings, and by slight errors in the absolute positions (due to movement of the positioning antenna). A swell filter minimises these positioning errors, though for this study it did not allow to line-up the arrival times correctly; this was due to the presence of small-scale bedforms, which are not handled properly by the swell-filter routine.

Before loading the data into the interpretation workstation, the seismic profiles had to be corrected for the **tide**, i.e. converted to a common datum. This involved the application of a static correction for differences in tidal amplitude during acquisition, which can generate discrepancies in water depth of more than 4 m for the same location. A mathematical tidal model delivered the theoretical water depth for every position along the sailed tracks, at the given time, using the actual water depths of Nieuwpoort, Oostende and Zeebrugge (Vlaamse Hydrografie - Afdeling Kust, former ‘Administratie Waterwegen en Zeewezen (AWZ)). FPS Economy, SME’s, Self-Employed and Energy (Fund for Sand Extraction) provided the tidal correction factors.

Remaining discrepancies in water depth at the tie-points of two intersecting seismic lines can be due to differences in towing depth of the seismic source or receiver, or caused by waves or swell.

Additional processing included deconvolution, autocorrelation, power-spectrum analysis (frequency content), though these processing steps did not significantly improve the quality of the data. This was mainly due to the relatively high noise content in the recordings, caused by weather and sea-state conditions.

Depth conversion is an important step of the seismic reflection method, which converts the acoustic wave travel time to actual depth, based on the acoustic velocity of the subsurface medium. The time-to-depth conversion was done using an average sound velocity of 1500 m/s in the water column and 1650 m/s in the mainly sandy Quaternary deposits (Maréchal and Henriet, 1983). This sound velocity gave excellent results for the correlation of core data with seismic profiles (De Batist, 1989). Due to the time-to-depth conversion, any occurrence of ‘velocity-effects (i.e. pull-ups or pull-downs)’ was avoided. All depths are referred to MLLWS (mean lowest low water at spring time), which is about 2.5 m below MSL (mean sea level) at Zeebrugge.

Data processing of the multibeam data involved data correction (including tides) and cleaning in the software package **Neptune** (Kongsberg Simrad, 1999-2001b) (Figure 5).

Data interpretation

All data has been integrated in **The Kingdom Suite (SSL)**, an industry-standard seismic interpretation system, for the analysis of the acoustic facies, reflection configurations and terminations, and seismic attributes, as well as for the visualisation of the interpretations. Seismic-stratigraphically significant boundaries between sediment bodies were identified, picked and mapped. The Kingdom Suite package allows integrating and comparing the project data with UGent-RCMG’s entire digital seismic archive (PhD Mathys). This database was recently integrated with the coring results of RBINS-GSB that relate to the Quaternary geology. As such, this valuable data and knowledge base was also used during the interpretation of the newly acquired project data. The powerful visualisation software package **Fledermaus (IVS 3D)** allowed integrating the seismic data to external datasets, such as the simultaneously acquired multibeam bathymetry data, to obtain a very-high resolution integrated representation of the sea-floor morphology and the subsurface in full 3D. **Surfer (Golden Software)** and **CorelDRAW (Corel)** were used for the production of figures.

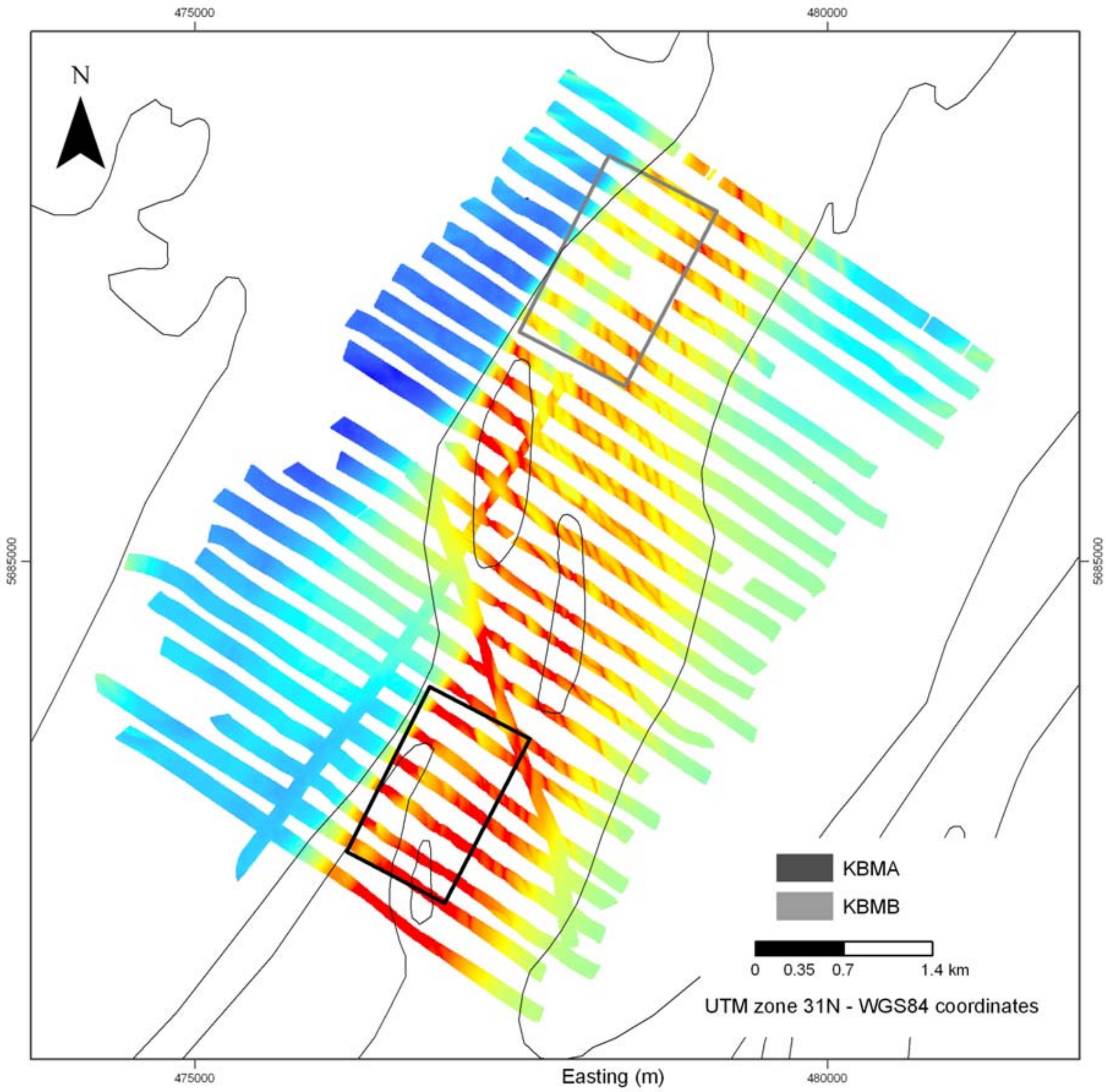


Figure 5: Processed multibeam lines, simultaneously acquired with the seismic data recordings. Track spacing of 250 m.

Interpretation constraints and uncertainties mainly relate to the strong reverberation of the acoustic signal. This is due mainly to the shallow water depth in the area, and the hardness of the sediments, causing a highly reflective seabed. Under such conditions, a train of closely spaced multiples can be generated that severly obscure the primary reflections; as such it sometimes becomes impossible to interpret reflections beneath the arrival of the first seabed multiple.

Data analysis

On all collected profiles, the seabed, the base of the tidally-dominated part of the sand bank and the base of the Quaternary were picked. These picked horizons were exported from the **Kingdom Suite** software and imported into **Surfer**, where each of the surfaces was interpolated (inverse distance to a power) to a grid with a resolution of 50 x 50 m. In Surfer, the volume between 2 horizons was also calculated according to 3 methods: i.e. ‘Extended Trapezoidal Rule’, ‘Extended Simpson’s Rule’ and the ‘Extended Simpson’s 3/8 Rule’. The difference in results is a measure of the accuracy of the volume calculations. The average of the three can be retained as a final result.

To estimate the **error** on the calculated volumes, emphasis was put on the error introduced by miss-picking a horizon: i.e. due to the noise and reverberations affecting the signature of the acoustic pulse, it is not always clear which phase to pick as the onset of a reflection. Assuming a potential miss-pick of ~ 0.1 ms, each of the identified horizons was shifted with this value and new volume calculations were performed. The difference in volume can be regarded as the absolute error on the volume calculation. The relative error takes into account the surface area of the profile. This analysis has been performed on 4 lines.

Data integration

The interpreted seismic data has been integrated with other available information of the test site, such as **multibeam bathymetry and coring data** (where available). As no full-coverage multibeam bathymetry was sailed simultaneously with the seismic recordings, the digital terrain model of the FPS Economy, SME’s, Self-Employed and Energy of 2001 was used for the coupling with the seismic grid. This integration was done using **Fledermaus**.

Results

Comparative results of different seismic sources – campaign ST0709

During campaign ST0709, 4 seismic systems were available for evaluation: (1) Centipede sparker; (2) C-Boom boomer; (3) SIG sparker; and (4) IKB Seistec boomer. Profiles around line 15 were used for the comparison of the different seismic sources, available for this study (Figures 6-9). Table 3 provides details on the settings that were used for bandpass filtering. It needs emphasis that the lines were shot under differing conditions of sea state (3-5 Bf), even if they were acquired during the same campaign.

Table 3: Bandpass filter used for the different seismic sources.

	Centipede	C-Boom	SIG	IKB Seistec
Low cut frequency (Hz)	250	800	200	800
Low pass frequency (Hz)	700	1000	250	1000
High cut frequency (Hz)	2500	5000	2000	5000
High pass frequency (Hz)	3500	7000	3500	7000

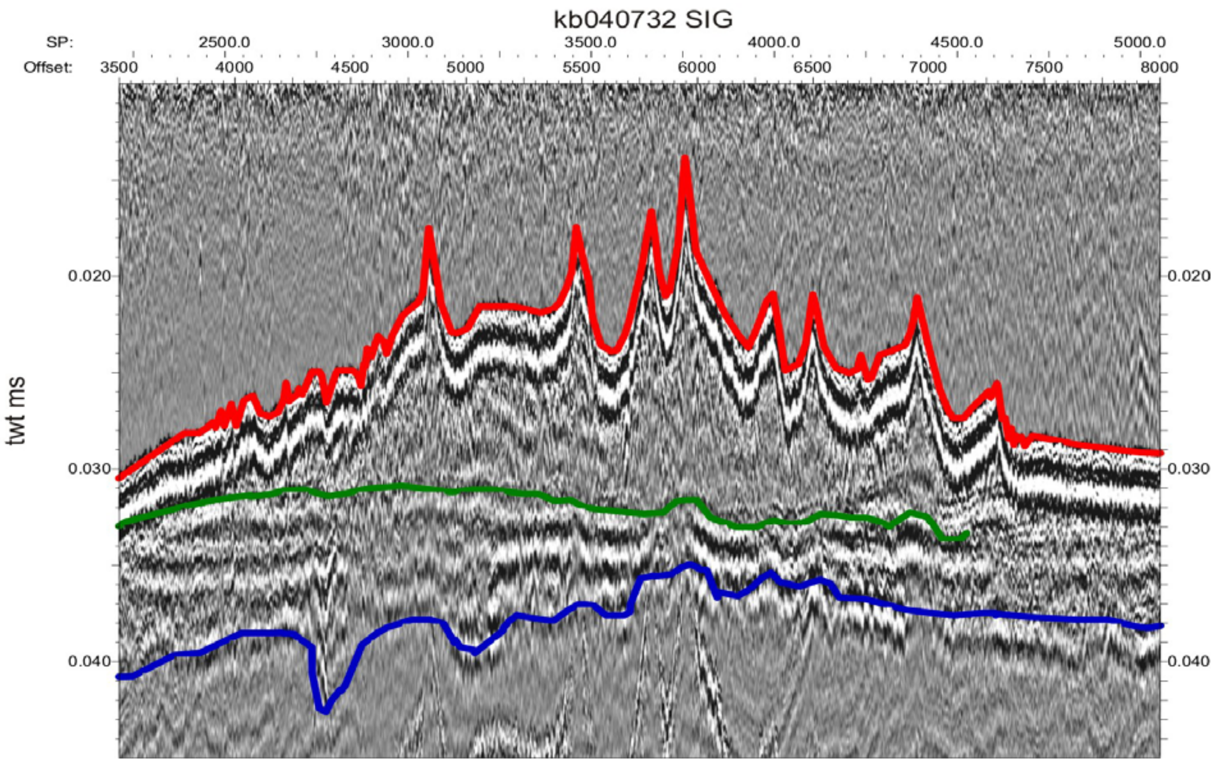


Figure 6: Reference profile, acquired during campaign ST0709, using the SIG sparker.
The following reflectors are indicated: red = sea floor, green = base of the 'tidal' part of the sand bank (seismic unit U7), blue = base of the Quaternary.

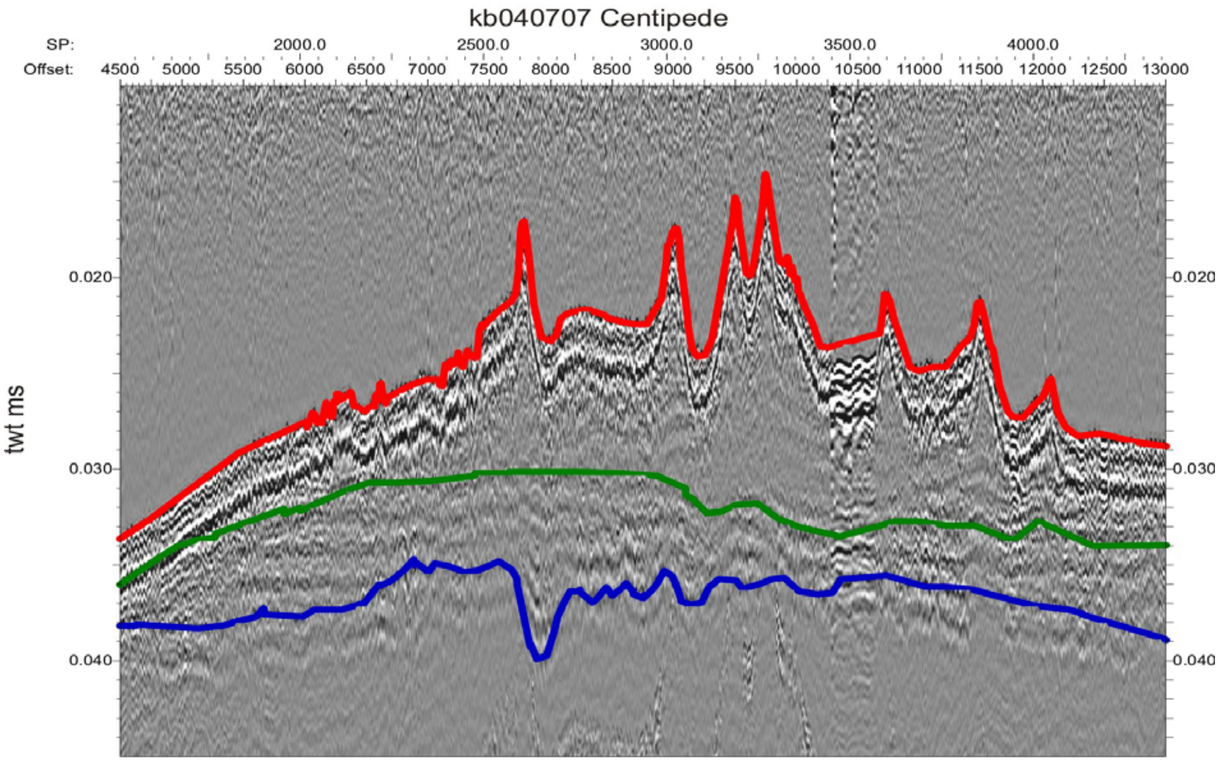


Figure 7: Reference profile, acquired during campaign ST0709, using the Centipede sparker.
The following reflectors are indicated: red = sea floor, green = base of the ‘tidal’ part of the sand bank (seismic unit U7), blue = base of the Quaternary.

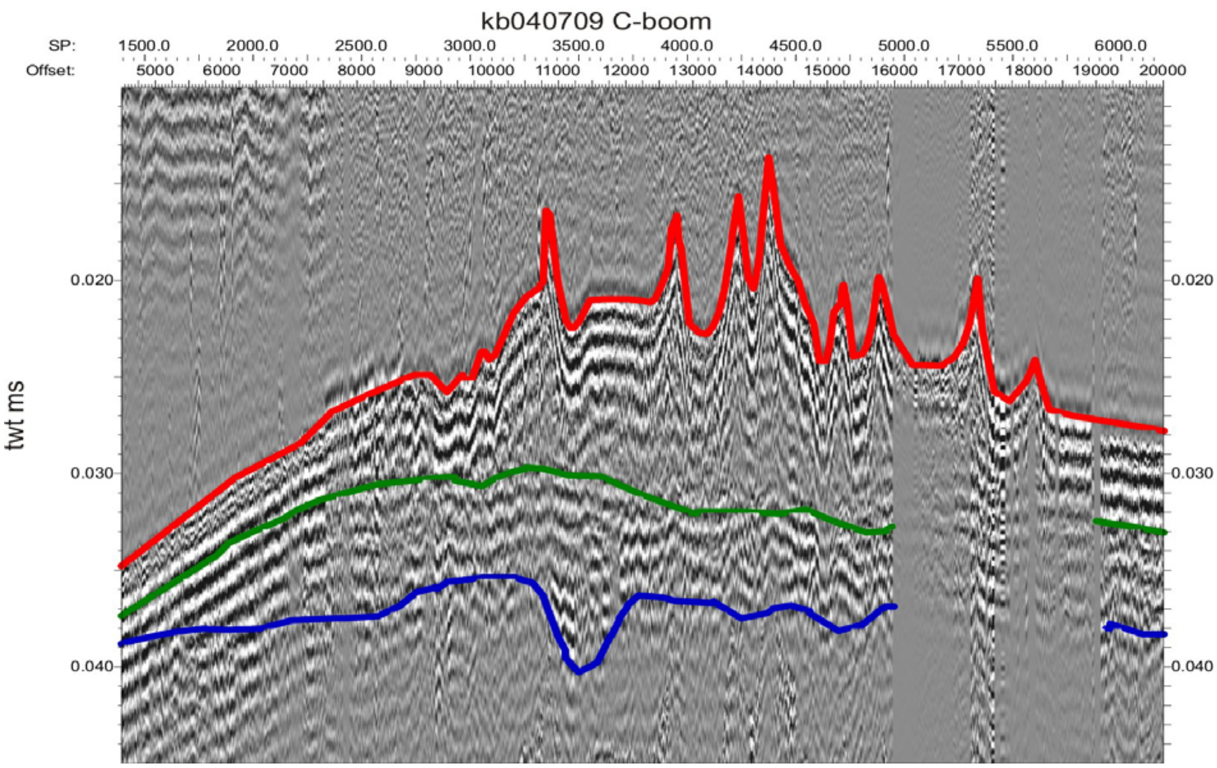


Figure 8: Reference profile, acquired during campaign ST0709, using the C-Boom boomer.
The following reflectors are indicated: red = sea floor, green = base of the ‘tidal’ part of the sand bank (seismic unit U7), blue = base of the Quaternary.

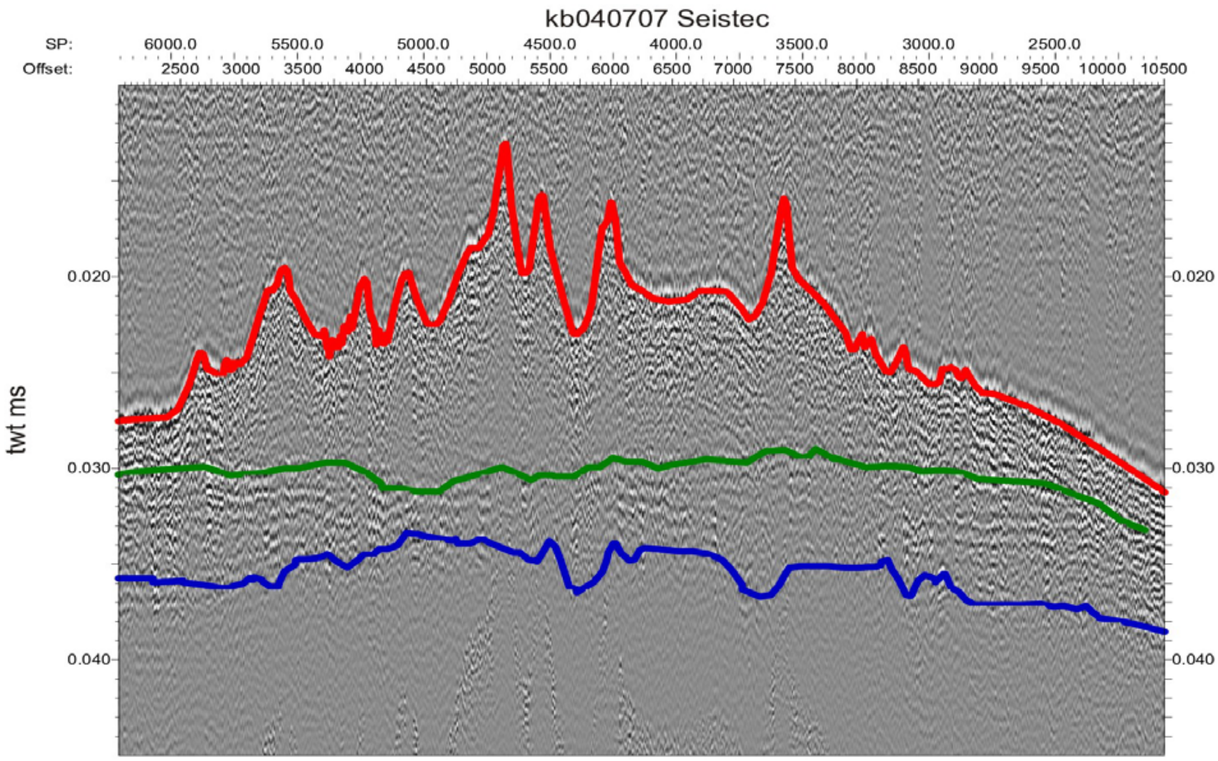


Figure 9: Reference profile, acquired during campaign ST0709, using the IKB Seistec boomer.
The following reflectors are indicated: red = sea floor, green = base of the ‘tidal’ part of the sand bank (seismic unit U7), blue = base of the Quaternary.

From the comparison of the different sources used (Figures 6-9) the following conclusions can be drawn:

(1) The source signal of the SIG sparker (Figure 6) is very strong and relatively long. Due to the length of the signal it is difficult to discern closely spaced reflectors (limited resolution). The SIG signal penetrates the entire bank structure and easily allows imaging the internal structure of the bank and the base of the Quaternary (blue reflector). The record is only marginally affected by ringing.

(2) The source signal of the Centipede sparker (Figure 7) is relatively long, and appears to consist of a “double peak”. The Centipede signal penetrates the entire bank structure and allows imaging the internal structure of the bank and the base of the Quaternary (blue reflector). There is a certain degree of ringing, affecting especially the slopes of the bank structure and the interval between the base of the “tidal” part of the sand bank (green reflector) and the base of the Quaternary (blue reflector).

(3) The source signal of the C-Boom boomer (Figure 8) is very long. The entire record is strongly affected by severe ringing, making it very difficult to image the internal structure of the bank and the base of the Quaternary (blue reflector).

(4) The source signal of the IKB Seistec boomer (Figure 9) is very short and sharp, but weak. The IKB Seistec signal barely penetrates the entire bank structure, making it difficult to image the internal structure of the bank and the base of the Quaternary (blue reflector). There is a certain degree of ringing, affecting especially the slopes of the bank structure and the interval between the base of the “tidal” part of the sand bank (green reflector) and the base of the Quaternary (blue reflector).

From this evaluation –which was confirmed along the other test lines– the two sparker sources (SIG and Centipede) gave the best results. Because of the higher resolution of the Centipede sparker compared to the SIG sparker, preference is given to the former.

Therefore, this source was used to sail the entire network across the Kwinte Bank study area during campaign ST0709.

Comparative results of different seismic sources – campaign ST0717

The X-STAR chirp profiler was only available during campaign ST0717.

Several technical problems (i.e. installation of recording parameters is not straightforward) during start-up prevented acquisition of good data (Figure 10) and only by the end of the available test period, some good-quality data could be acquired (Figures 11-13).

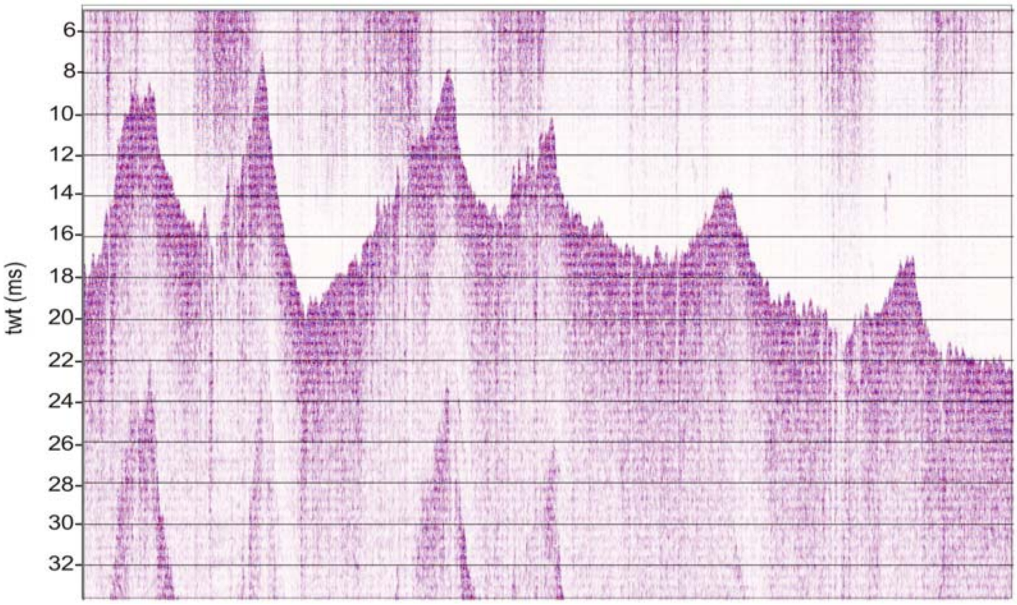


Figure 10: X-STAR data: bad data, due to incorrect settings (pulse length of 5 ms only).
Only the sea-floor reflector is properly imaged.

The following conclusions can be drawn from comparing the X-STAR chirp profiler data with the earlier recorded sparker (SIG and Centipede) and boomer (C-Boom and IKB Seistec) data (Figures 11-13 and 6-10):

(1) The signal of the X-STAR chirp profiler is relatively short and sharp, but still longer than that of IKB Seistec boomer source (vertical scales in Figures 6-9 and 10-13 are comparable). The X-STAR signal, however, penetrates the entire bank structure and easily and clearly allows imaging the internal structure of the bank and the base of the Quaternary. The record is not affected by ringing.

Due to time constraints during ST0717, it was not possible to collect more data with the X-STAR chirp profiler.

The above evaluation comments only apply to the records collected during this specific comparative study, i.e. on these specific locations (Kwinte Bank) and under the specific weather and sea-state conditions that prevailed during acquisition. In other environments, or under different acquisition conditions, the results can differ.

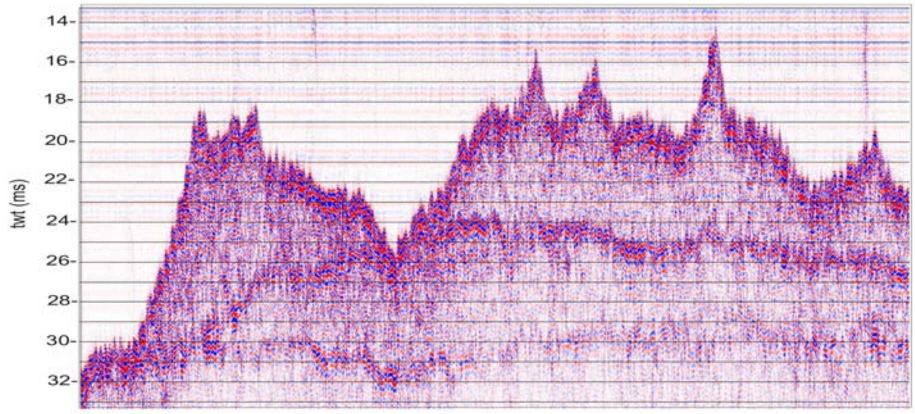


Figure 11: X-STAR data: good-quality data, shot with correct settings (50 ms pulse length). The base of the "tidal" part of the bank and the base of the Quaternary are clearly imaged. This profile is recorded along the northern part of the sand bank, over the monitoring zone KBMB. Exploitation has clearly reached the base of the "tidal" part of the sand bank.

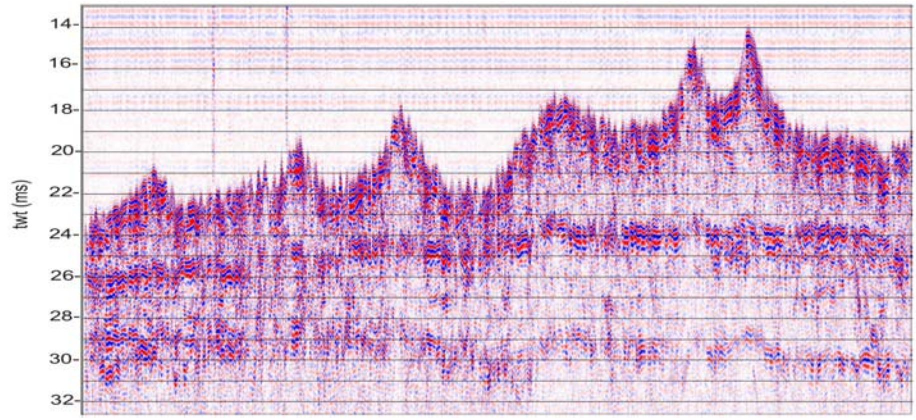


Figure 12: X-STAR data: good-quality data, shot with correct settings (50 ms pulse length). The base of the "tidal" part of the bank and the base of the Quaternary are clearly imaged.

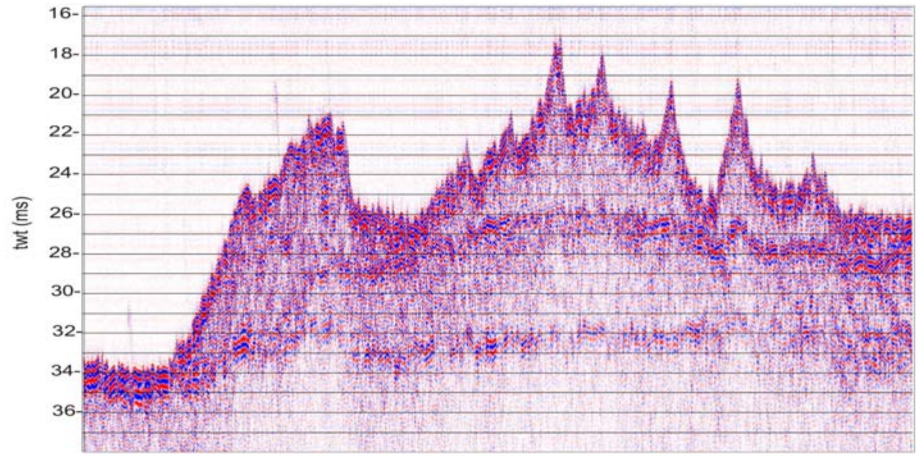


Figure 13: X-STAR data: good-quality data, shot with correct settings (50 ms pulse length). The base of the "tidal" part of the bank and the base of the Quaternary are clearly imaged. This profile is recorded along the northern part of the sand bank, over the monitoring zone KBMB. Exploitation has clearly reached the base of the "tidal" part of the sand bank.

Geological interpretation of the area under investigation

Seismic-stratigraphic interpretation of the data

Figure 14 illustrates the complexity and lateral variability of the internal build-up of the sand bank along profiles in the southern, central and northern part of the study area. Apart from the sea floor, the most prominent reflector below the Kwinte Bank is the unconformity at the top of the Paleogene substratum. The Top-Paleogene unconformity, formerly referred to as the Top-Tertiary surface, also represents the base of the Quaternary deposits in this area. This unconformity represents the erosional boundary and significant stratigraphic hiatus between the NE-dipping Lower and Middle Eocene formations (Thanetian to Rupelian in age, De Batist, 1989) below, and the Quaternary deposits (Jacobs and De Batist, 1996) above.

In the northern part of the study area, the Top-Paleogene surface is clearly incised by paleo-channels (Figure 14).

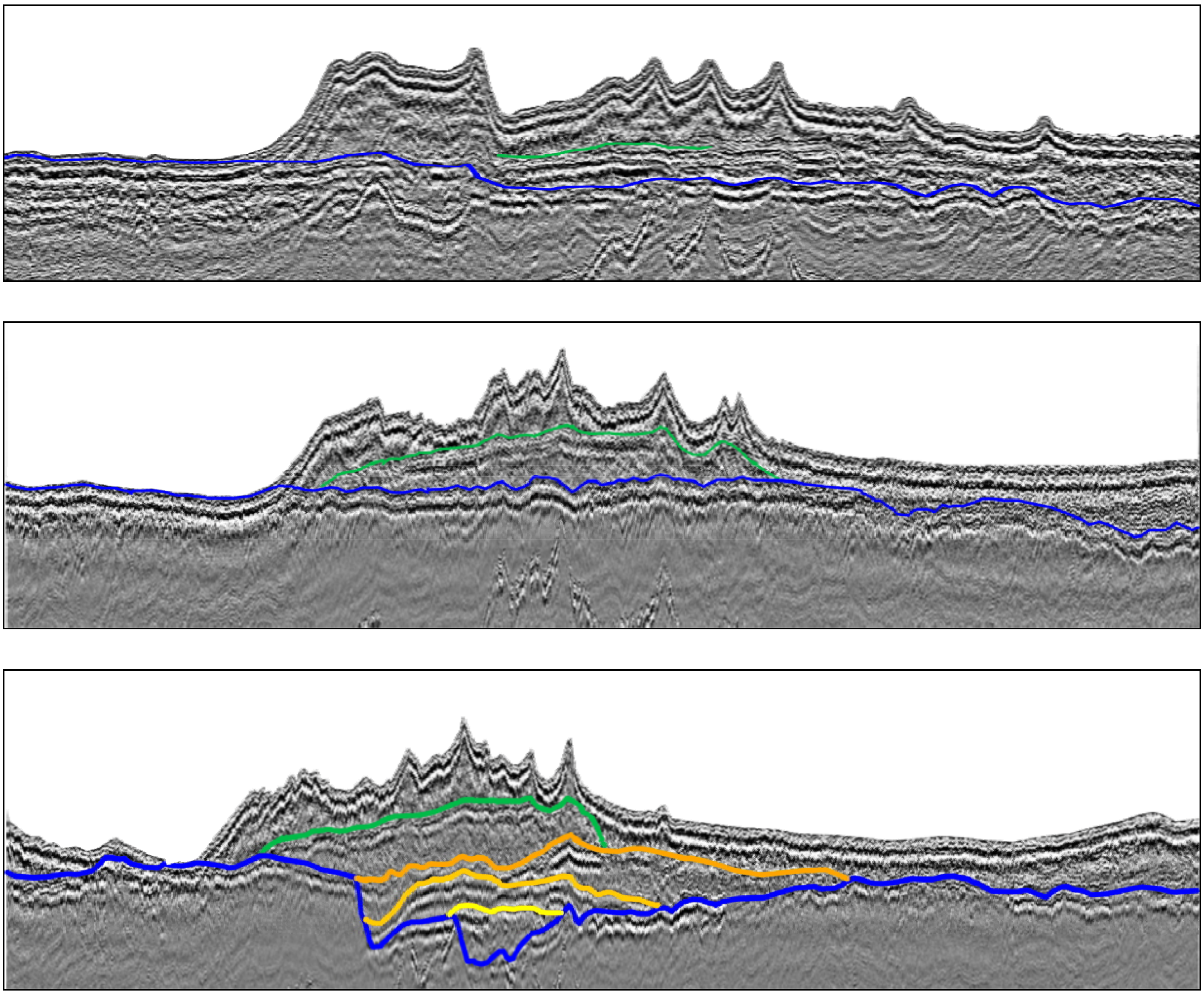


Figure 14: A series of parallel W-E-oriented seismic profiles (acquired with the Centipede sparker source), illustrating the structural complexity and strong lateral variability in the build-up of the sand bank. The upper panel is representative for the southern part of the Kwinte Bank. The central and lower panels are typical for the architecture of the central and northern part of the sand bank. The following reflectors are indicated: green = base of the 'tidal' part of the sand bank (seismic unit U7), blue = base of the Quaternary, yellow and orange: paleo-channels.

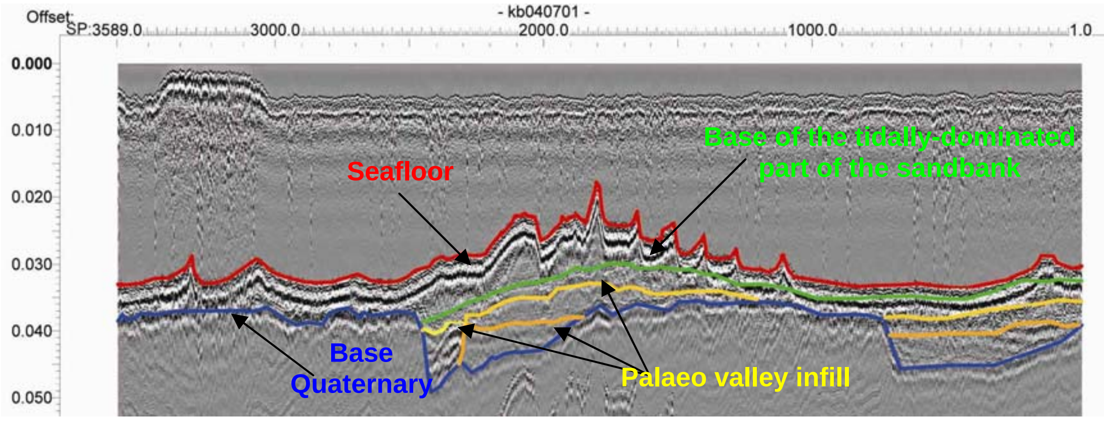


Figure 15: Geological interpretation of line 1.
Vertical axis: 2-way travel time in ms. Horizontal axis: shot points.

In the Kwinte Bank region, five seismic units have been identified between the sea floor and Top-Paleogene reflector (Figure 15). They are bounded by strong reflectors. The lower three units (i.e. seismic units U1, U2 and U3 of Mathys, 2009) represent the infill of the deeply incised channels, and they are only present where these channels exist. The fourth unit (i.e. seismic unit U4 of Mathys, 2009), on the other hand, extends below the entire Kwinte Bank (Bellec et al., in prep.; Mathys, 2009). Its base and top reflectors are continuous and characterised by high reflection amplitudes. Where seismic unit U4 is thick enough, it is characterized by a complex variety of prograding seismic reflector patterns, slightly wavy parallel internal reflectors, and many channel structures. The fifth unit (i.e. seismic unit U7 of Mathys, 2009) is the uppermost unit of the Kwinte Bank, and it is the only unit that is exposed at the sea floor. The presence of (sand) dunes at the top indicates that this unit is in accordance with the present-day hydrodynamic regime. Unit U7 consists mainly of bank-shaped deposits with a prograding (tangential and parallel-oblique) internal seismic reflector pattern. This upper unit is considered most important for this study, as it lies at the sea floor and is thus easiest to exploit. Note that seismic units U5 and U6 of Mathys (2009) are not present in the Kwinte Bank area; they occur mostly closer to the present-day coastline.

Careful picking of the top and base reflectors of each seismic unit on all acquired seismic data across the Kwinte Bank allowed combining the horizon picks in surface grids, which were used to construct structural contour maps (i.e. isobath maps) of each stratigraphic horizon.

Figure 16 represents the morphology of the three most important seismic-stratigraphic boundaries within the Kwinte Bank: i.e. the sea floor, the base of the tidally dominated part of the sand bank (seismic unit U7) and the base of the Quaternary cover. The base of the tidally dominated part of the sand bank is a composite surface, composed of the top surface of units U4 and U3 and of the Top-Paleogene surface where units U4 and U3 are absent.

The surface grids were also used to construct thickness maps (i.e. isopach maps) of the tidally dominated part of the sand bank (seismic unit U7) and of the entire Quaternary cover of the study area (Figure 17).

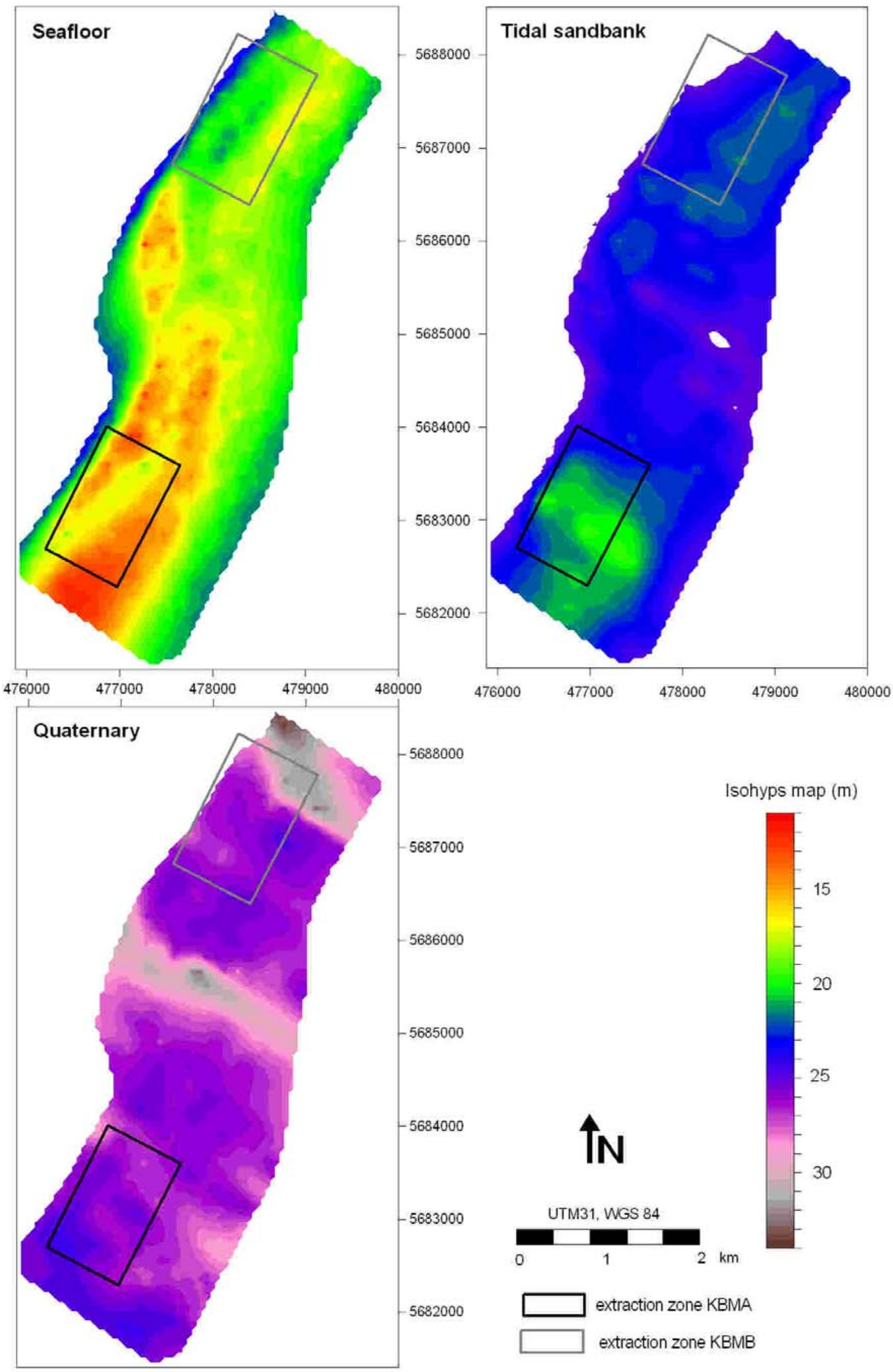


Figure 16: Isobath maps of the sea floor, the base of the 'tidal part' of the sand bank (seismic unit U7) and the base of the Quaternary cover. The monitoring zones KBMA and KBMB are also indicated.
Depth is in m below MLLWS.

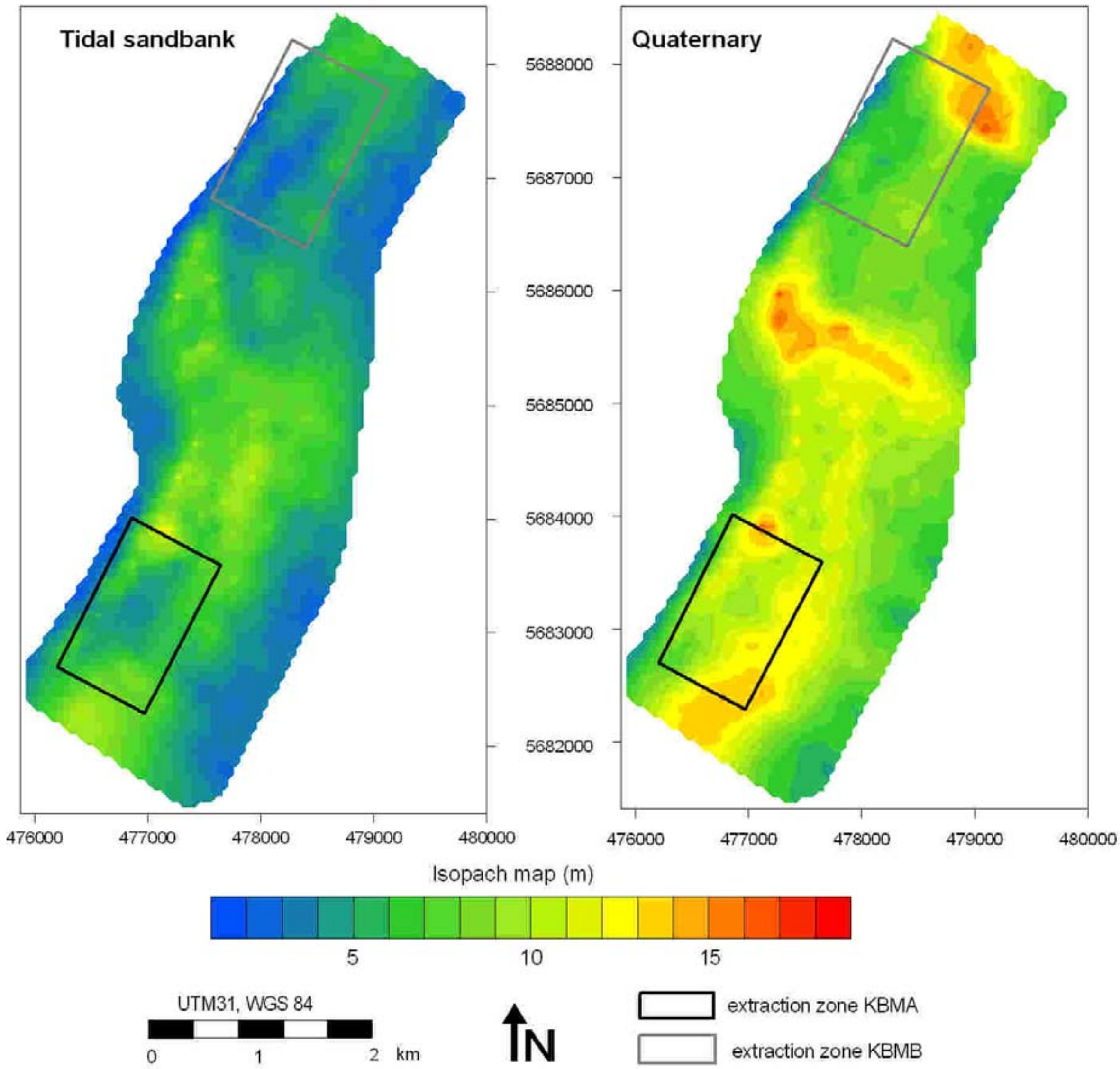


Figure 17: Isopach maps of the tidally-influenced part of the sand bank (seismic unit U7) and the complete Quaternary cover. The monitoring zones KBMA and KBMB are also indicated.
Thickness is in m.

Volume calculations, error analysis

To assess quantitatively the sediment volume of the surveyed area of the Kwinte Bank (Figure 17), volume calculations were performed of the tidally-dominated part of the sand bank (i.e. the sediment package enclosed between the sea floor and the base of unit U7) and of the entire sand bank (i.e. the sediment package enclosed between the sea floor and the base of the Quaternary. The results of the calculations are given in Table 4.

For the surveyed area, the Quaternary deposits amount up to **125 * 10^6 m^3**. Of this total volume, **67 * 10^6 m^3** (or 54 %) is interpreted to be built-up by tidal action mainly.

Table 4: Volume calculations for the area surveyed during campaign ST0709.
SF: sea floor; GB: base of the tidally-dominated part of the bank; QB: base of the Quaternary.

Grid (50x50M)		Volume (m³)				
Grid 1	Grid 2	Trapezoidal Rule	Simpson's Rule	Simpson's 3/8 Rule	Mean (m³)	Area (m²)
St0709_KB_SF	ST0709_KB_GB	67071382	67052645	67053327	67059118	12643599
St0709_KB_SF	ST0709_KB_QB	124632981	124629733	124577322	124613345	12643599

The exact error on these values is difficult to assess, and may be due to various causes, such as positioning errors (x, y), bedform mobility (i.e. for data sets acquired in different periods), and interpretation errors. Here, only the interpretation error will be quantified. Because of acoustic noise and the shape of the seismic signal, a miss-interpretation of ~ 0.1 ms is likely to occur.

Table 5 gives an overview of the calculated volumes if this margin is taken into account. The interpretation error on the calculated volumes is in the order of ~ 2 %.

Table 5: Error analysis along some track lines, surveyed during campaign ST0709. (SF: sea floor; GB: base of tidally-dominated part of the bank). An interpretation error of 0.1 ms has been assumed.

Grid		Volume (m³)				Error		
Grid 1	Grid 2	Trapezoidal Rule	Simpson's Rule	Simpson's 3/8 Rule	Mean	Absolute	Extra (%)	Relative (%)
kb040703_SF	kb040703_GB	618676	595994	608719	607796			
kb040703_SF	kb040703_GB+0.1ms	631124	607886	621057	620022			
						12226	2.0	2.0
kb040704_SF	kb040704_GB	769142	747564	782781	766496			
kb040704_SF	kb040704_GB+0.1ms	790468	768262	804360	787697			
						21201	2.8	2.7
kb040703_04_SF	kb040703_04_GB	1803376	1799550	1801551	1801492			
kb040703_04_SF	kb040703_04_GB+0.1ms	1848180	1844281	1846019	1846160			
						44668	2.5	2.4
kb040730_SF	kb040730_GB	2438247	2502580	2446142	2462323			
kb040730_SF	kb040730_GB+0.1ms	2474854	2539919	2482782	2499185			
						36862	1.5	1.5
						Mean error (%)		2.1

Integration with multibeam data

Seismic data and multibeam data were recorded simultaneously during the data acquisition campaigns. The aim was to combine and integrate both datasets into a 3D model. Although, this process is technically perfectly feasible (i.e. using Fledermaus), a number of practical problems were encountered:

1. Multibeam data was acquired at a 250 m interval, perpendicular to the bank’s axis: interpolation of these data was too raw for a good representation of the sand-bank’s sedimentary features; integration of seismic and multibeam data along individual lines was not satisfactory either;
2. The integration was done with a previously obtained high-resolution digital terrain model (2 * 2 m, Degrendele et al., 2002). Within the large time interval between acquisition of the data for this digital terrain model and the acquisition of the seismic data (2001 *versus*

2007) bedforms had altered and migrated, leading to a significant mismatch in alignment of both datasets (Figure 18).

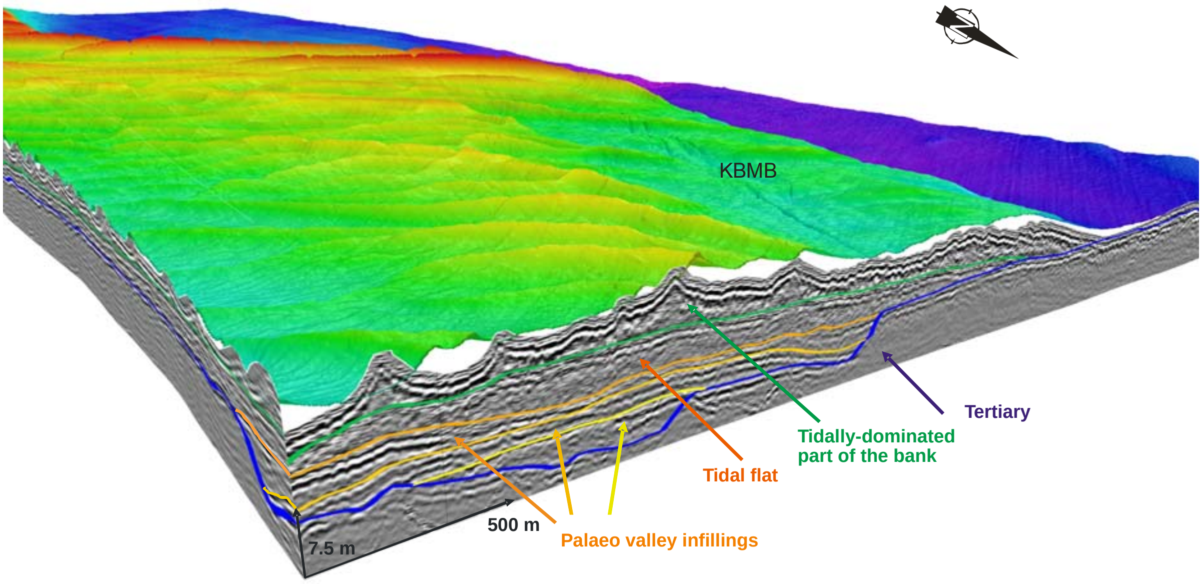


Figure 18: Integration of 2 seismic lines (2007) with full-coverage multibeam imagery from Degrendele et al. (2002). The mismatch in alignment is due to bedform migration in the time period between acquisition of the two data sets.

Illustration of the mismatch between both datasets is given in Figure 19, which shows the depth values extracted from the 2001 DTM along the same location as the profile of April 2007. From this, it is clear that within a time span of 6 years, the position of the bedforms, as well as their shape have changed significantly.

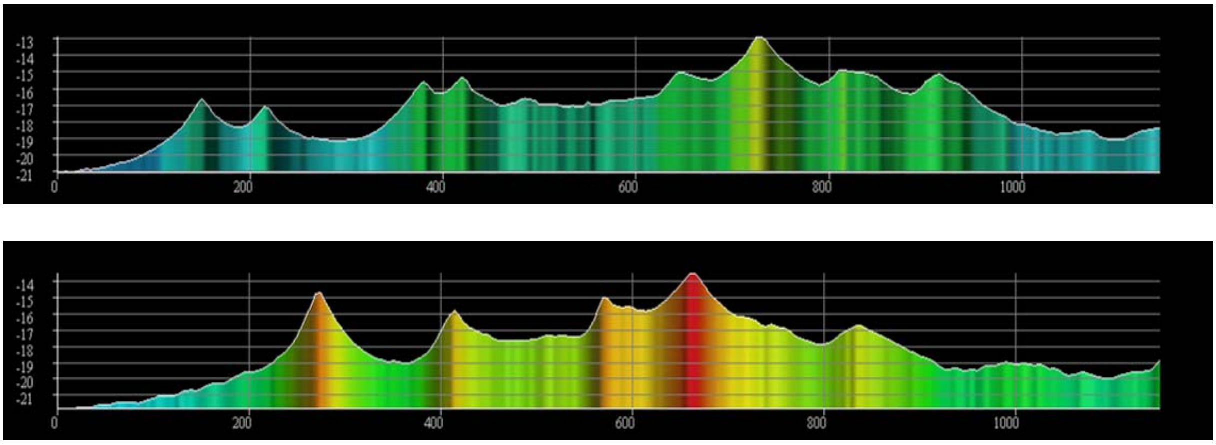


Figure 19: Cross-section along the northern part of the Kwinte Bank.
Upper panel: based on the DTM of Degrendele et al. (2002);
Lower panel: based on the newly acquired data of 2007 (ST0917).

Integration with the Quaternary evolution of the BPNS

To translate the "acoustic information" of the Kwinte Bank in terms of sedimentation environment and geological setting, UGent-RCMG's knowledge database and available background information on the Quaternary geology of the BPNS (Mathys, 2009) was used intensively. For example, the internal structure of the adjacent Middelkerke Bank had already been largely unravelled in previous studies (Lanckneus et al., 1991; De Moor et al., 1993; Stolk and Trentesaux, 1993; Trentesaux, 1993; Berné et al., 1994; Heyse et al., 1995; Stolk, 1996; Trentesaux et al., 1999).

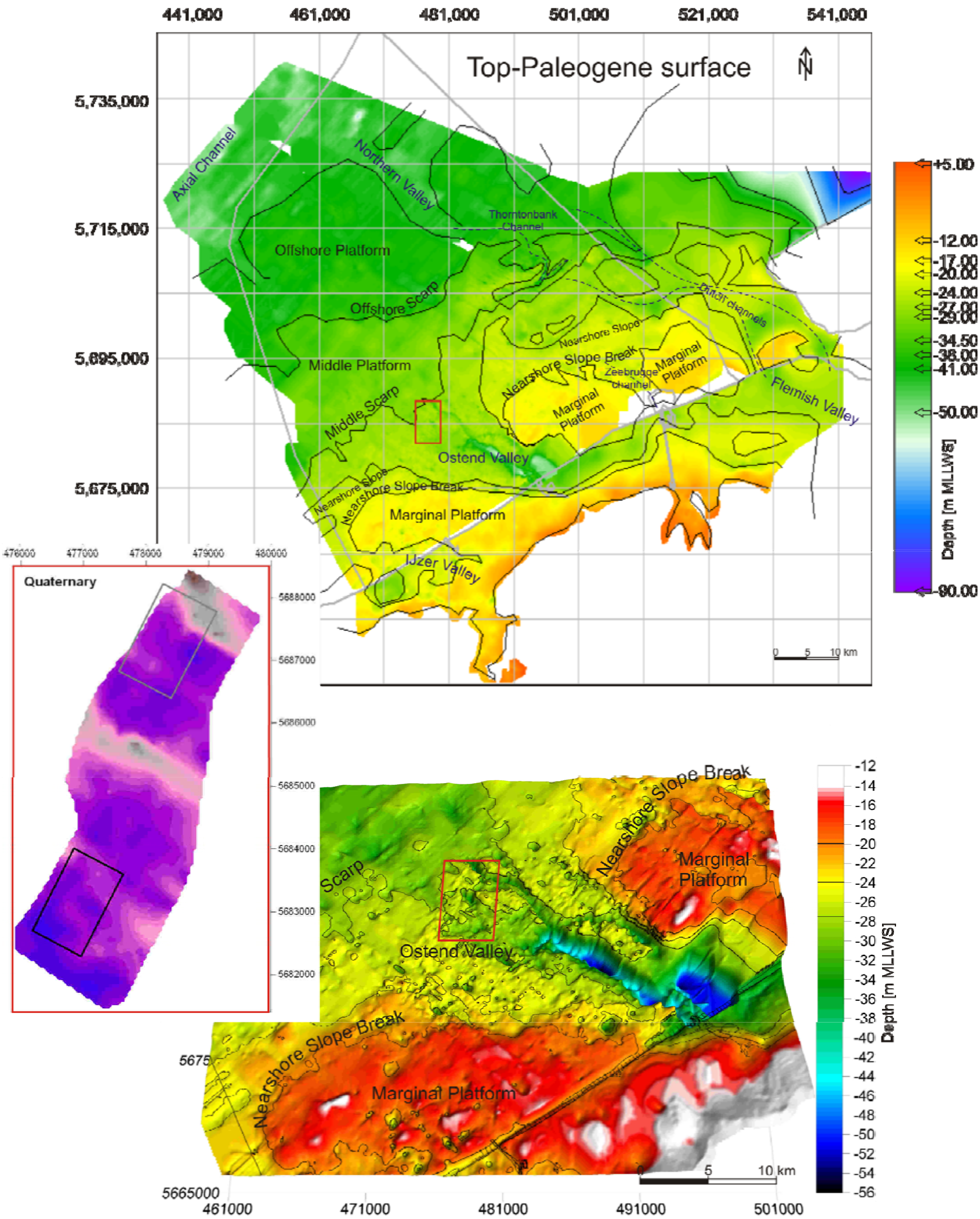


Figure 20: Position of the study area with respect to the variability of the Top-Paleogene surface over the entire Belgian part of the North Sea (Mathys, 2009). It is clear that the Kwinte Bank is largely situated on top of the infillings of the Ostend Valley. This explains the deeply incised channels, in the central and northern part of the Kwinte Bank.

Comparing the Top-Paleogene surface below the Kwinte Bank with the one of the entire BPNS (Figure 20), reveals that the deep incisions in the northern and central part of the study area correspond to tidal channels, which are deeply incised in the wide valley offshore Oostende, i.e. the Ostend Valley. The Ostend Valley was most likely incised during the final phase of the Saalian glaciation (MIS6, prior to 127 ka ago). When a proglacial lake, which had formed in front of the Saalian ice sheet, drained, the tributaries of the Flemish Valley sought their way to the receding lake shoreline with dropping base level and the Ostend Valley was created. During the following Eemian sea-level rise, the Ostend Valley developed into a tide-dominated estuary. When the sea invaded the pre-existing river valley, deep incised channels formed due to tidal scouring. The three basal seismic-stratigraphic units (U1, U2, U3) filled the Ostend Valley and represent successive phases of a transgressive estuarine infilling during the Eemian sea-level rise. The three units are bounded by tidal ravinement surfaces.

With continuing sea-level rise after the estuarine infilling, erosion due to marine transgression levelled the infillings with the Top-Paleogene surface, and remnants of Eemian deposits were only preserved in depressions. During the subsequent Weichselian lowstand, a minor sinuous valley was re-incised in the Eemian transgressive surface, where previously the Ostend Valley existed. This surface is not overlain by Weichselian cover sands, but by early Holocene tidal-flat deposits, i.e. seismic unit U4. The base of unit U4 thus corresponds to the Eemian marine transgression surface, which explains why it is expressed as a strong reflector. The tidal-flat environment developed behind a coastal barrier, which migrated landward with the Holocene rising sea level. With time, the barrier migrated over the previous back-barrier deposits, strongly eroding these tidal-flat sediments, which could explain the irregular surface of U4 (i.e. the base of U7, Figure 16). This Holocene marine transgression surface occurs as the continuous high-amplitude reflector at the top of U4.

In the more nearshore part of the BPNS, two extra units (U5 and U6) have been observed (Mathys, 2009). In the sand layer left by the barrier migrating over former tidal flat deposits, coastal storm-dominated banks formed (U5).

These storm-dominated banks have been observed e.g. below the Middelkerke Bank. Offshore Zeebrugge, the upper parts of these banks have been eroded when the barrier stabilised and started prograding seaward again, in reaction to the slowing down in the Holocene relative sea-level rise. Due to this slow-down, the tidal-flat area behind the barrier silted up and an extensive area with surface peat developed. With a renewed expansion of the tidal environment and increasing storm action (so not the result of a sea-level rise), the barrier migrated further landward again, up to the present-day coastline, eroding the underlying clayey tidal-flat deposits and surface peat. The remnants settled in the nearshore area as an alternation of clay and sandy storm layers, i.e. seismic unit U6.

With continuous rising sea-level, tidal sand banks and intervening swales (U7) developed on top of the former deposits, and form now the main features of the present-day bathymetry. This seismic unit is again encountered in the Kwinte Bank. The tidal sand-bank deposit is actually only the top part of what is generally called 'a sand bank' in a broader sense of the word. The lower parts of e.g. the Kwinte Bank consist of remnants of tidal-flat and estuarine deposits.

Lithological and facies interpretation

Unfortunately, only 1 core is available on the Kwinte Bank, in the south of the investigation area (i.e. core 999A; Figure 2). Figure 21 shows the integration of this core with a nearby seismic profile. The Eemian units U1, U2 and U3 correspond in this core to grey-green mud with fine sand; fine sand with mud admixture containing gravel (a.o. flint) and shell fragments; and medium-grey sand containing gravel and shell fragments.

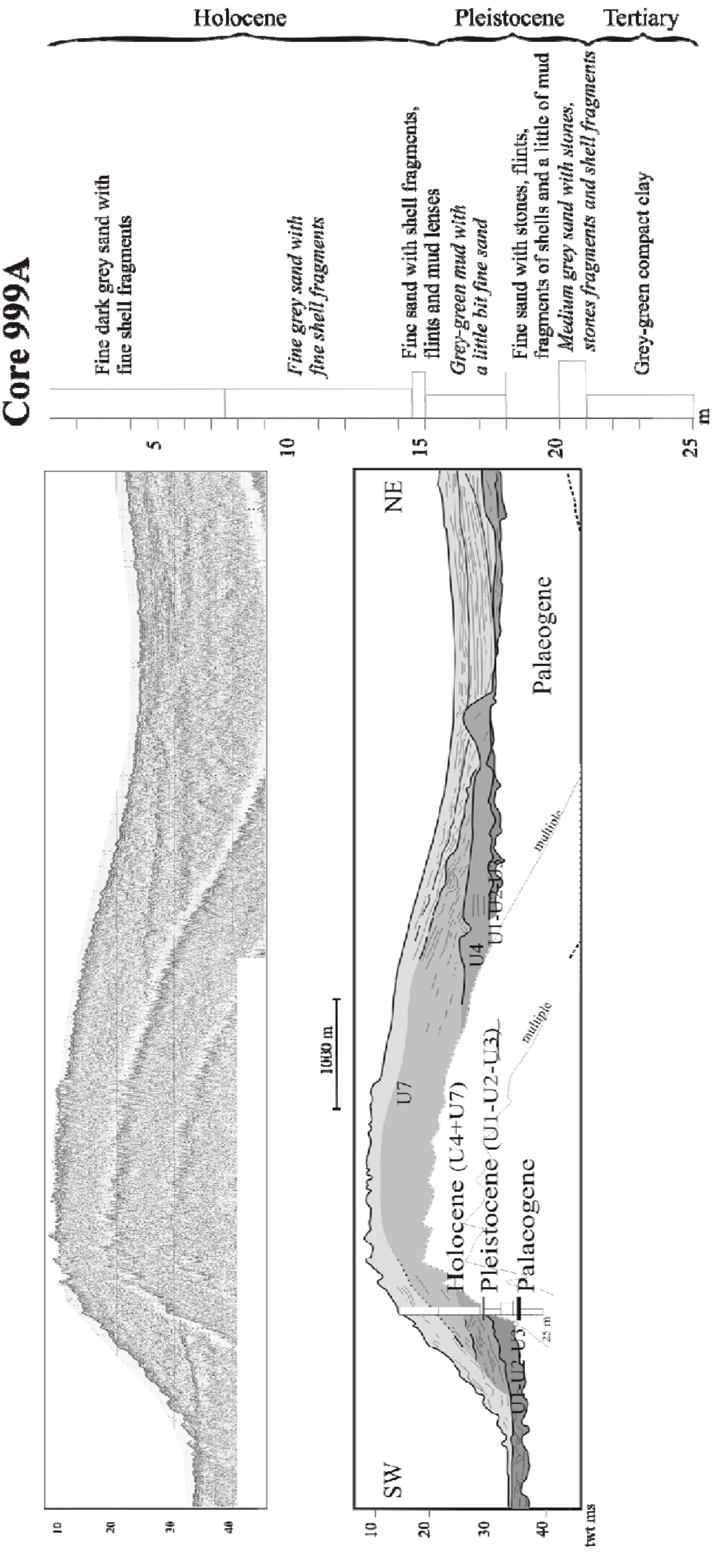


Figure 21: Correlation of core 999A with a Seistec seismic profile acquired prior to this study on the Kwinte Bank (Bellec et al., in prep.).

More information about the lithology of the seismic units can be obtained from cores in the corresponding units elsewhere on the BPNS (i.e. outside the present study area). Seismic unit U1 generally consists of grey well-sorted fine sand with frequent irregularly formed clay laminae and flasers. Occasionally some concentrations of grit and shell fragments occur, as well as bioturbations. The base of the unit is characterised by heterogenic coarse shell sand, containing large amounts of shell grit, fragments (some strongly dissolved), whole shells, gravel and flat rolled clay chunks; also some glauconite is present.

Seismic unit generally U2 consists of a grey-brown to green-brown fine sand with clay-sand laminations, containing humic clay lenses, clay pebbles and peat fragments, some zones with shell fragment concentrations, and zones with high calcium precipitation. At the base a grey heterogenic layer of gravel (a.o. silex) and shells (a.o. *Corbicula*) is present in a clayey and fine sand matrix, which is very calcareous.

Seismic unit U3 generally consists of yellow-green to grey-brown, mostly well-sorted fine to medium sand, with occasional clay laminae (becoming less in seaward direction), zones with few shell fragments alternated with zones containing many shells (a.o. *Hydrobia*), some gravel and clay chunks. The unit becomes coarser grained, and contains more shell fragments in offshore direction, as well as some sea-urchin fragments.

In core 999A, seismic unit U4 consists of fine grey sand with fine shell fragments, overlying a base of fine sand containing shell fragments, silex gravel and mud lenses. Also in other areas of the BPNS, U4 mainly consists of a grey sandy facies. However, an important part of U4 is also characterised by a heterolithic facies, consisting typically of an alternation of clay and sand and/or silt laminae. Occasionally, U4 can also consist, entirely, of silt or shell fragments. Unit U4 often contains peat fragments, fine shell grit and complete shells (a.o. *Hydrobia*), and frequently has a coarse-grained (gravel) lag at the base. The high amplitude at the base of seismic unit U4, which represents the Eemian marine transgressive surface, is likely due to the presence of gravel and shell fragments.

Along the Kwinte Bank, seismic unit U7 is characterised by fine grey sand with fine shell fragments. In general on the BPNS, U7 consists of brown, brown-grey or grey, fine to coarse sands, which frequently contain many shells, shell fragments and sea-urchin needles, although zones with very low shell content occur as well. Some cores contain clay layers and chunks, or a silt admixture, often associated with local shell accumulations. Few cores hold humic particles or plant fragments.

Recommendations

Most suitable source

Performance of the source: resolution, penetration and signal/noise ratio

This study has demonstrated that good-quality, high-resolution seismic imaging of internal structure and build-up of sand banks on the BPNS remains a serious challenge.

The high signal frequencies, the relatively low source energies and the strong susceptibility to sea-state conditions, render boomer sources generally less suitable for this type of seismic investigations. In our test study, the IKB Seistec signal barely penetrated to the base of the bank structure, which made it difficult to image the internal structure of the bank and the base of the Quaternary. The C-Boom boomer signal was affected by severe ringing, and generally did not produce satisfactory results. It should be noted, however, that very good data were acquired with the same IKB Seistec boomer during a prior survey on the Kwinte Bank (Bellec et al., in prep.). This survey was carried out under perfect weather and sea-state conditions. The IKB Seistec system is thus capable of producing satisfactory results, but only during optimal weather conditions.

Sparker sources generally produced good results in our comparative test study. The sparker signals allowed imaging the internal structure and the base of the sand bank in the study area. They were also less susceptible to weather and sea-state conditions and to acoustic noise in general. The SIG sparker produced a stronger and broader signal than the Centipede sparker, and also has a lower main frequency. It consequently results in seismic data of slightly lower resolution.

Also the X-STAR chirp profiler performed very satisfactorily in our study (even if no direct comparison –i.e. during the same acquisition campaign– could be made). The signal is relatively short and sharp, but it penetrates the entire bank structure and easily and clearly allows imaging the internal structure of the bank and the base of the Quaternary. The system appears to be less susceptible to weather and sea-state conditions than the boomer sources.

Important note: the performance of each of the above systems and the quality of the achieved seismic data will be, in any case, strongly dependent on the nature of the sediment and the weather and sea-state conditions during the data acquisition. Even the best source will produce poor results in noisy, bad-weather conditions…

User-friendliness of the source

Another important aspect that needs to be taken into account is the user-friendliness of the system.

Sparker sources require also the deployment of a streamer as receiver and the use of high-voltage power-supplies. This means that during collection of seismic data, two objects are towed behind the vessel, which has implications for navigation, and significant safety precautions must be taken into account. Experienced operators are required to analyse and fine-tune the signal/noise ratio and to calibrate the digital acquisition system. Sparker sources also require a certain degree of basic maintenance (i.e. clipping of the sparker tips).

The X-STAR chirp profiler is much more a "plug-and-play"-type system than a sparker. The entire source/receiver combination is contained in a single tow-fish, making deployment relatively straightforward. Alternatively, the transducers could also be fixed-mounted on the vessel, reducing susceptibility to sea-state conditions. No high-voltage is required. Also the acquisition of the data is relatively straightforward (i.e. the X-STAR acquisition system is often referred to as a “black box”), although selection of the various acquisition parameters requires an experienced and knowledgeable operator.

Interference with the multibeam system onboard R/V Belgica

None of the tested systems interfered with the multibeam system onboard of R/V Belgica, or *vice versa*.

Resource potential of the sand banks

This study has demonstrated that quantitative resource calculations can be made based on digitally acquired and appropriately processed high-resolution reflection seismic data, acquired along sufficiently densely spaced grids, and on the careful 3D mapping of the interpreted seismic-stratigraphic units. To increase resolution and accuracy of the resource calculations, multibeam bathymetry should ideally be used as input parameter for the sea-floor morphology. Unfortunately, 3D integration of multibeam bathymetry and seismic data has not been fully successful in this pilot study, essentially because the available multibeam data had been acquired relatively long before acquisition of the seismic data took place. Any future resource calculations should thus be based on integration of full-coverage multibeam imagery and high-resolution reflection seismic data, with both datasets recorded within the same time span. Although simultaneous acquisition of both datasets is possible (i.e. no interference was observed between any of the seismic systems and the multibeam system), it is recommended to sail them separately, as both techniques require different track spacing and track orientation for optimal recordings. Also the vessel speed during acquisition is significantly different (3-4 kts for seismic data and up to 8 kts for multibeam recording).

Sustainable exploitation ?

From the seismic-stratigraphic interpretation of the data, five seismic units, bounded by strong reflectors, were identified in the Kwinte Bank. From correlations with coring data and more regional information on the Quaternary evolution (Mathys, 2009), it is shown that these units consist of different lithologies with often strong lateral variations and a high degree of heterogeneity. Only, the top unit U7 is representative of the present-day hydrodynamic regime and can be called the ‘tidal’ part of the sand bank. In order for exploitation to be carried out in a more sustainable way, hence maximising chances for regeneration and minimising impacts, extraction should be restricted to this upper sand body, which is also more homogeneous in aggregate quality. For the present study area, this part of the bank comprises 54 % of the total volume of the Quaternary deposits. Its thickness varies from 5 to 11 m. However, in the northern part, the base of U7 often occurs directly underneath the base of the large to very large dunes that cover the surface of the bank. In both monitoring zones (KBMA and KBMB) extraction has reached the base of U7. Changes in aggregate composition are likely.

This study has shown the potential for mapping the base of the tidal part of the sand bank using seismic reflection data. Good data quality is, however, necessary for reliable picking of this reflector. Mathys (2009) mapped the extent of this unit for the entire BPNS, together with extensive interpretations; hence it forms the ideal reference framework for further investigations.

Interpretation constraints

Notwithstanding the strengths of the seismic-stratigraphic interpretation procedures –and more in particular the seismic facies descriptions and interpretations– it remains difficult to translate the “acoustic information” in an unbiased way into a sedimentary environment, and even more so into a sedimentary facies. Especially in a restricted area, it is almost impossible to determine in which environment the respective sediment bodies were deposited based on the seismic facies alone. Integration with a dense enough network of cores is necessary to unravel the sedimentation environment of each seismic unit, and to understand the depositional history of the entire sand bank. This is because a single seismic unit can be characterised by a pronounced lithological heterogeneity, making it impossible to determine its depositional environment from a single core.

Conversely, also core data alone will not be sufficient to reconstruct the depositional history of a sand bank. This is because, due to a constant reworking of in-situ available sediments in an accommodation-deficient environment as the BPNS, lithologically seemingly similar material could in fact belong to completely different depositional environments, and belong to several seismic units. Therefore, a combination of a dense seismic grid and a closely-spaced coring network is necessary in this type of sand-bank studies.

In case of the Kwinte Bank, the lack of core data for interpreting the sediment bodies in terms of depositional environment was solved by integrating the new seismic data with the UGent-RCMG’s knowledge base and background information on the Quaternary geology of the BPNS (Mathys, 2009). One has to be aware, however, that not every phase of the Quaternary history of the BPNS is represented in every sand bank. Some phases have not been preserved, or have never taken place in certain banks. This strongly depends on the position of the bank, both vertically (depth of occurrence) and horizontally (distance from the present-day coastline). To identify a certain depositional phase within a sand bank on the BPNS, the depositional depth of the corresponding seismic unit is an important clue. Because of the strong heterogeneity, caution is always needed when extrapolating the lithology of a seismic unit of a known sand bank to an unknown sand bank.

Conclusions

This study has focussed on the optimisation of a methodological-technological approach through a comparison of various state-of-the-art high-resolution seismic source/receiver configurations for the investigation of the internal architecture of sand banks.

On the basis of a dense grid of high-resolution reflection seismic profiles, the 3D architecture of the Kwinte Bank was studied in detail. The heterogeneity of the acoustic facies could spatially and temporally be correlated with latest insights in the Quaternary evolution of the Belgian part of the North Sea (BPNS).

The following results were obtained:

- Digital reflection seismic profiles were acquired along a series of test lines with different seismic sources;
- In the prevailing conditions of weather, sea-state and ambient noise, and for the typical sedimentary environment under consideration, the Centipede sparker gave the best results. Also the X-STAR chirp subbottom profiler performed very well, and often internal reflectors were more clearly imaged with the X-STAR system than with the sparker;
- Digital reflection seismic profiles were subsequently acquired along a dense network over the entire sand bank, at a track spacing of 250 m;
- Five different seismic-stratigraphic units were identified within the sand-bank body. The three bottom units (U1-U2-U3) occur as the infill of deeply incised channels. A fourth unit (U4) extends below the entire Kwinte Bank, and the fifth seismic unit (U7) is the uppermost unit, and the only unit that is exposed at the sea floor. This unit is called the ‘tidal’ sand bank, since it is shaped and maintained by present-day tidal processes;
- Contour maps of the depth of the basis of the Quaternary and the ‘tidal’ sand bank show incised valleys along the central and northern part of the bank, which run perpendicular to the bank’s axis, and an upwelling of the base of the ‘tidal’ sand bank in the southern part of the study area;
- Corresponding thickness maps show that, locally, in the monitoring zones KBMA and KBMB, where aggregate extraction has been most intense, the thickness of the ‘tidal’ sand bank is at present, respectively, less than 3 and 1 m. Elsewhere, this unit is generally 5-11 m thick. The Quaternary cover is at its maximum at the position of the infilled channels where a total thickness of 15-20 m of deposits can be found. Centrally and in the southern part of the bank, the Quaternary cover is around 11-12 m thick, concentrated at the top zone of the bank. Towards the north, the thickness diminishes to less than 10 m;
- Volume calculations show that –for the surveyed area– the Quaternary deposits amount up to 125 * 10^6 m^3, of which 67 * 10^6 m^3 or 54 % represents the ‘tidal’ sand bank;
- The feasibility of integrating seismic and multibeam data has been demonstrated, though better datasets are needed for high-resolution 3D representations of sedimentary bodies and for more robust volume calculations;
- The seismic results have been integrated with the latest insights in the Quaternary evolution of the BPNS (Mathys, 2009);
- Within this context, the nature of the acoustic facies has been estimated, based on a correlation of the seismic results with existing coring and sedimentological information.

Finally, **recommendations** were formulated with regards to the most suitable seismic sources for the study of shallow sand banks, and for the estimation of their resource potential. It was shown that the strength of the interpretation depends on the extent of the seismic network, the quality of the seismic data, the availability of cores and geological framework to unravel the often very patchy nature of Quaternary deposits.

Results of this study can be **valorised** in different contexts. Obviously, estimation of resources is crucial to develop sustainable exploitation criteria for marine aggregates. In addition, due to their relatively limited water depth, sand banks are preferentially selected for the implantation of large-scale infrastructures, such as windmill farms. Knowledge on the nature and structure of the subsurface is crucial as input to geotechnical studies and stability analyses. This is also of importance for the estimation of the burial depth of pipelines.

Generally, the project results will support and largely stimulate the further extension of the scientific knowledge base on the Quaternary geology of the BPNS. In this framework, additional PhD research will be stimulated.

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Annex 1: Coordinates of the start and end points of the seismic lines

FID	pl_code	UTM31-WGS84_E	UTM31-WGS84_N	lat WGS84			long WGS84		
0	line 1A	477936	5688839	51	21.024	N	2	40.990	E
1	line 1B	481253	5686604	51	19.825	N	2	43.855	E
2	line 2 A	477796	5688632	51	20.912	N	2	40.870	E
3	line 2 B	481113	5686396	51	19.713	N	2	43.735	E
4	line 3 A	477657	5688425	51	20.800	N	2	40.751	E
5	line 3 B	480974	5686189	51	19.601	N	2	43.616	E
6	line 4 A	477517	5688217	51	20.687	N	2	40.632	E
7	line 4 B	480834	5685982	51	19.489	N	2	43.496	E
8	line 5 A	477377	5688010	51	20.575	N	2	40.512	E
9	line 5 B	480694	5685774	51	19.376	N	2	43.376	E
10	line 6 A	477238	5687803	51	20.463	N	2	40.393	E
11	line 6 B	480554	5685567	51	19.264	N	2	43.256	E
12	line 7A	477098	5687596	51	20.351	N	2	40.273	E
13	line 7 B	480415	5685360	51	19.152	N	2	43.137	E
14	line 8 A	476958	5687388	51	20.239	N	2	40.153	E
15	line 8 B	480275	5685153	51	19.040	N	2	43.018	E
16	line 9 A	476818	5687181	51	20.127	N	2	40.033	E
17	line 9 B	480135	5684945	51	18.928	N	2	42.898	E
18	line 10 A	476679	5686974	51	20.015	N	2	39.915	E
19	line 10 B	479995	5684738	51	18.816	N	2	42.778	E
20	line 11 A	476539	5686766	51	19.902	N	2	39.795	E
21	line 11 B	479856	5684531	51	18.704	N	2	42.659	E
22	line 12 A	476399	5686559	51	19.790	N	2	39.675	E
23	line 12 B	479716	5684323	51	18.591	N	2	42.539	E
24	line 13 A	476259	5686352	51	19.678	N	2	39.555	E
25	line 13 B	479576	5684116	51	18.479	N	2	42.419	E
26	line 14 A	476120	5686144	51	19.565	N	2	39.436	E
27	line 14 B	479437	5683909	51	18.367	N	2	42.300	E
28	line 15 A	475980	5685937	51	19.453	N	2	39.317	E
29	line 15 B	479297	5683701	51	18.255	N	2	42.181	E
30	line 16 A	475840	5685730	51	19.341	N	2	39.197	E
31	line 16 B	479157	5683494	51	18.143	N	2	42.061	E
32	line 17 A	475700	5685523	51	19.229	N	2	39.077	E
33	line 17 B	479017	5683287	51	18.031	N	2	41.941	E
34	line 18 A	475561	5685315	51	19.117	N	2	38.958	E
35	line 18 B	478878	5683080	51	17.919	N	2	41.822	E
36	line 19 A	475421	5685108	51	19.005	N	2	38.839	E
37	line 19 B	478738	5682872	51	17.806	N	2	41.702	E
38	line 20 A	475281	5684901	51	18.893	N	2	38.719	E
39	line 20 B	478598	5682665	51	17.694	N	2	41.583	E
40	line 21 A	475142	5684693	51	18.780	N	2	38.600	E
41	line 21 B	478458	5682458	51	17.582	N	2	41.463	E
42	line 22 A	475002	5684486	51	18.668	N	2	38.481	E
43	line 22 B	478319	5682250	51	17.470	N	2	41.344	E
44	line 23 A	474862	5684279	51	18.556	N	2	38.361	E
45	line 23 B	478179	5682043	51	17.358	N	2	41.224	E
46	line 24 A	474722	5684071	51	18.443	N	2	38.241	E
47	line 24 B	478039	5681836	51	17.246	N	2	41.105	E
48	line 25 A	474583	5683864	51	18.331	N	2	38.123	E

49	line 25 B	477899	5681628	51	17.133	N	2	40.985	E
50	line 26 A	474443	5683657	51	18.219	N	2	38.003	E
51	line 26 B	477760	5681421	51	17.021	N	2	40.866	E
52	line 27 A	480142	5687906	51	20.525	N	2	42.894	E
53	line 27 B	476311	5682047	51	17.355	N	2	39.617	E
54	line 28 A	479305	5688453	51	20.819	N	2	42.171	E
55	line 28 B	475475	5682594	51	17.648	N	2	38.896	E

Annex 2: Cruise report ST0709

BELGICA CRUISE REPORT ST0709

Subscribers

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GEOLOGY - Cruise 07/09 **Period: 16-20/04/2007**

1. Belgica cruise details
2. List of Participants
3. Objectives of the campaign
4. Localisation and measurements; trackplot
5. Operational course
6. Instruments used
7. Remarks on measurement instruments and campaign

1. BELGICA CRUISE ST2007-09

1.	Cruise number	2007-09
2.	Date / hour	Zeebrugge ETD: 16/10, 19h35 Zeebrugge T&G: 17/10, 19h00 Zeebrugge ETA: 20/10, 13h30
3.	Responsible scientist Participating institutions	Dr. Vera VAN LANCKER with Isabelle DU FOUR as assistant chief scientist UG-RCMG
4.	Area of interest	Flemish Banks, Sierra Ventana region
5.	Number of scientists	9 (16/04); 8 (17-20/04)

2. PARTICIPANTS

		April 16	**April 17-20**
UG-RCMG	Vera VAN LANCKER[1]	X	X
	Mieke MATHYS	X	X
	Isabelle DU FOUR	X	X
	Wim VERSTEEG	X	X
	Koen DE RYCKER	X	X
	Katrien Heirman	X	X
	Dries BOONE	X	X
	Els VERFAILLIE	X	X
MUMM	Daniel Saudemont	X	
TOTAL		**9**	**8**

[1] chief scientist

3. PROGRAM OBJECTIVES

RESOURCE-3D (UG-RCMG)
A Belspo funded 'Action in support of the Federal Authority's strategic priorities' and relates to the studies of the Fund for Sand Extraction (FPS Economy, SMEs, Self-employed and Energy).
A methodological and strategic approach will be developed to image/quantify the internal structure of sandbanks in very-high resolution. Several source/receiver configurations will be tested and the optimal approach used to interpret the sandbank architecture in terms of its sedimentological and lithological composition. The results will be integrated with former knowledge databases related to the Quaternary evolution of the Belgian shelf.
For this project, additional seismic source/receiver configurations are being tested. In particular, the C-Boom of Magelas and the X-star chirp profiler of TNO Built Environment and Geosciences (NL).

QUEST4D: QUantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics (UG-RCMG, MUMM, WLH, KUL, UG-MARBIO)
QUEST4D, a Belspo funded project, focuses on the quantification of erosion and sedimentation processes along the Belgian shelf. As such, the sediment state and dynamics will be studied in the space, depth and time domain (4D). The research is timely as indications of a longer-term and broader-scale physical degradation of the seafloor exist and it is unclear whether this is solely due to the increasing anthropogenic influence or to a combination with the natural evolution of the seafloor itself, including the effect of climate change. The latter processes need to be disentangled as their impact needs to be balanced against the industry-related activities.

STUDY OF THE GEOLOGICAL EVOLUTION OF THE BELGIAN CONTINENTAL SHELF (RCMG-MM)
Within the framework of a PhD investigation regarding the development of a genetic model of the geological Quaternary evolution of the Belgium Continental Shelf, additional seismic data are required.

Two areas will be covered during this campaign:
Area A: In the region of the Ostend palaeo-valley itself, some extra seismic lines have to be recorded to obtain a more detailed insight in the palaeo-valley system (Fig.1).
Area B: continuation of cruise B2006-20a, situated near the Oostdyck and Buiten Ratel. This zone is the western equivalent of the Vlakte van de Raan (investigated during cruises B2005-04, B2005-17, B2005-23). Both zones are situated on either side of the Ostend palaeo-valley, which is scoured in the Top-Tertiary surface (Fig.2).

MESH (Development of a framework for Mapping European Seabed Habitats) (RCMG)
MESH is an EU Interreg IIIb-funded international marine habitat mapping programme aiming at the development of international standards and protocols for seabed mapping. Partnership: Joint Nature Conservation Committee (JNCC, coordination) (UK); Ghent University (B); IFREMER (FR); Marine Institute (IRL); Alterra-Texel (NL); TNO Built Environment and Geosciences (NL); Centre for Environment, Fisheries and Aquaculture Science (CEFAS) (UK); Department for Agriculture and Rural Development, Northern Ireland (DARD) (UK); English Nature (UK); Envision Mapping Ltd (UK); National Museums and Galleries of Wales (NMGW) (UK); Natural Environment Research Council (British Geological Survey) (BGS) (UK).

Programme MUMM-Patrick Roose

The project is part of the continuous surveillance and evaluation of the quality of the marine environment in the region of the Belgian continental shelf (BCP) and the Western Scheldt estuary in the framework of international (the Joint Assessment en Monitoring Programme (JAMP) and the Nutrient Monitoring Programme (NMP) of the OSPAR commission) and national programmes (e.g. impact of sand extraction and dredging activities).
MUMM determines nutrients, salinity, suspended matter, dissolved Oxygen, TOC and POC, chlorophyll a, phaeophytine and optical parameters in the water column. Phytoplankton biomass and species composition as well as benthos species composition and biomass are also determined as part of the monitoring programme. The other determinants (e.g. heavy metals and organic contaminants) in sediment and biota are determined in collaboration with the Sea Fisheries department of the Centre for Agricultural Research.
Quality assurance and quality control during sampling and in the laboratory receive a high priority within the project.

4. MEASUREMENTS, LOCALISATION AND RESULTS

Seismic measurements

Areas

I. Kwinte Bank (Resource 3D, UG-RCMG)

Seismic recordings are planned using different sources (Seistec; the sparkers Centipede and SIG and the C-boom of Magelas).

Strategy
Several seismic source/receiver configurations have been tested. Test lines were sailed in the upper, middle and south part of the study area with per source, 2 test lines in each part. Those parts were chosen because of the difference in their sediment distribution. The north part is coarser grained; the middle part is known to be very rich in shells and the south part is characterised with medium grained sand. The best source was used for the mapping of the complete study area.

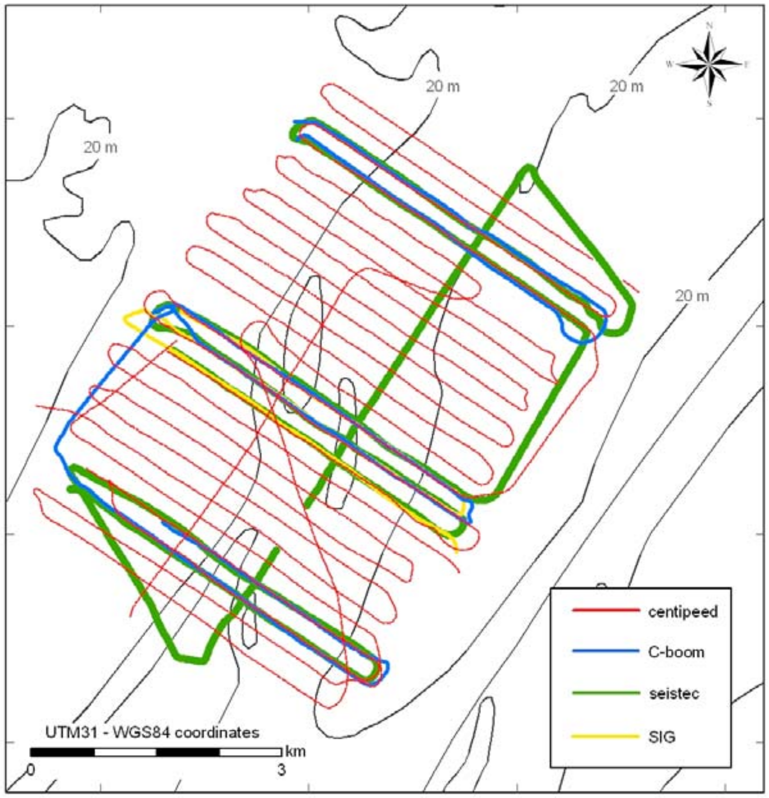


Fig. 1 Location of the seismic lines on the Kwinte Bank.

2. Sierra Ventana region (QUEST4D/MESH, UG-RCMG)

Seismic lines have been sailed in support of vibrocores that have been taken in the framework of the MESH project in November 2006 (Fig. 2).

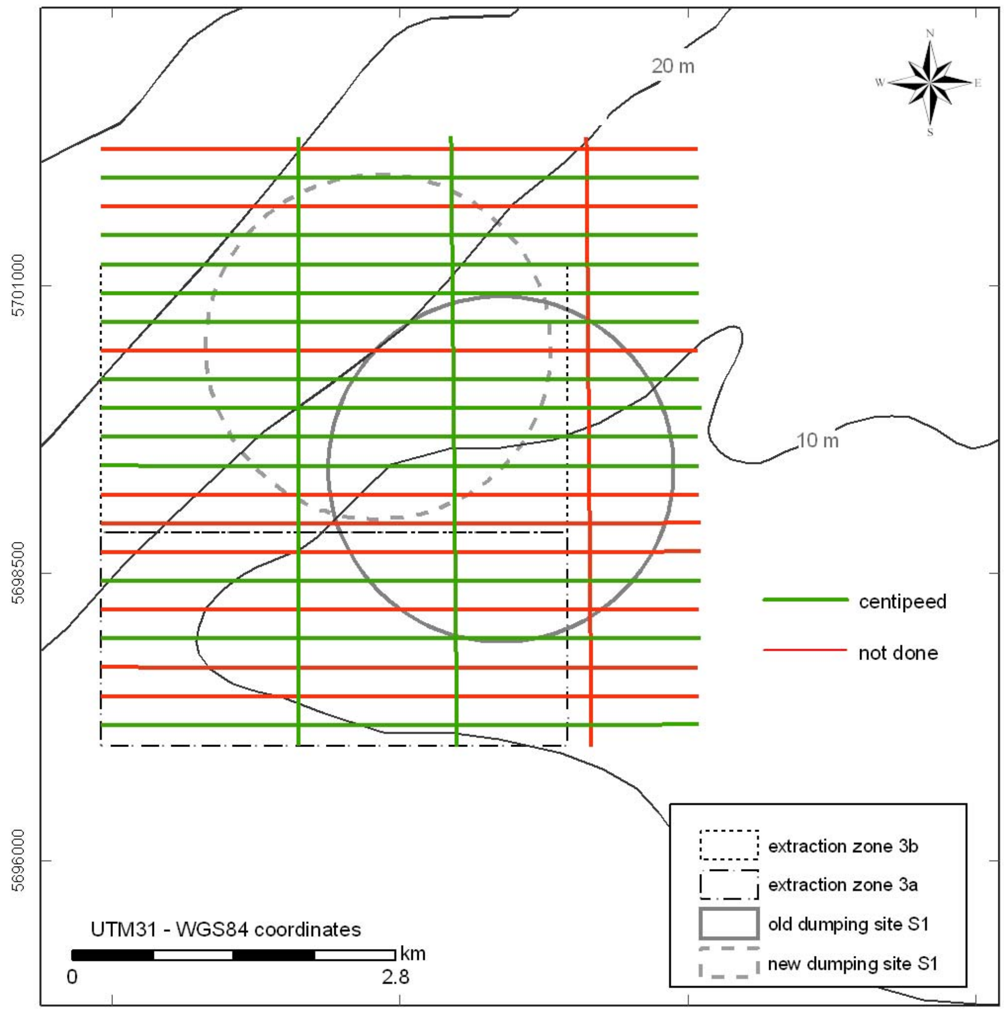
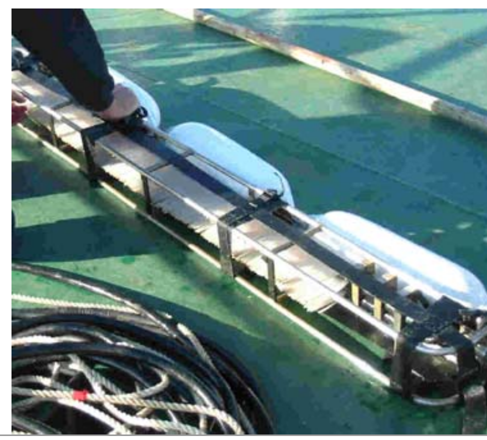
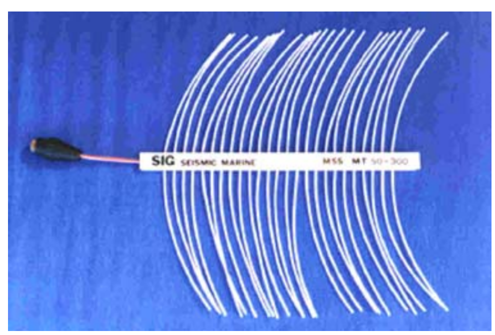


Fig. 2 Location of the seismic lines in the Sierra Ventana region.

Boomer (Seistec) (UG-RCMG): -Until 3 Beaufort -1000-5000Hz (main frequency of 2500Hz) -frame: 257*73*65cm; 100kg -75m cables: 1 signal, 2 high-voltage -30m towrope -SPA-3 receiver unit + lunchbox-pc -HV-power supply: 220V-16A -**winch + A-frame** *foreseen during campaign ST0615*	
Sparker (Centipede) (UG-RCMG: -Until 3-4 Beaufort -1100-1200Hz -frame: 195*20*20cm; 25kg -50m cable -30m towrope -HV-power supply: 220V-16A -streamer (5m + 75m cable); receiver-unit/band-passfilter/lunchbox-PC *foreseen during campaign ST0615*	
Sparker (SIG) (UG-RCMG: -Until 4-5 Beaufort -800-900Hz -frame: 40*100cm; 1,25kg -50m or 75m cable -30m towrope -HV-power supply: 220V-16A -streamer (5m + 75m cable); receiver-unit/band-passfilter/lunchbox-PC *foreseen during campaign ST0615*	

Other seismic source that is used in the framework of the Resource-3D project

C-boom low voltage boomer (Magelas):

Energy Output: 100 joules (Equivalent to 3000v system. Acoustic output comparison)
Firing rate: Up to 6 / sec
Working Voltage: 600v dc
Supply Voltage: Mains 110 / 220 volts ac
Dimensions: Psu – Standard 4u 19" rackmount 0.4 x 0.48 x 0.19
Cable – standard 60m
Transducer – assembled with floats 0.9m x 1m
Weights: PSU – 18 kg, Kevlar Cable – 10 kg, Transducer – 30kg
Connections: 1 EC Euro Main connector
Sound Source Details: In house built transducer. Disc Diameter 360mm
Capacitance Not applicable – see "energy output"
Operational Power
Consumption: 800W ~ 1kW
Power source: 1.5KVA generator
Resolution: 30cm or better.
Environmental: Safe portable equipment
Connections: Input power – mains cord, input trigger - bnc
Dominant Frequency: 1760Hz – measured from pulse signature
Catamaran Details: Lightweight stainless steel tubular frame work.
Hydrophone: TBC

3. Area covering the Oostende Bank and the Oostdyck, Buiten Ratel (UG-MATHYS, RCMG)

Research area: Area covering the Oostende Bank (Fig.1, area A) and the Oostdyck, Buiten Ratel (Fig.2, area B).
Measurements: Seismic recordings were planned using two different sparker sources (Centipede and SIG, see above), depending on the weather circumstances (Table 1). Because of the fair weather the Centipede sparker could be used the entire week.

Results:
About 134km of the planned 137km could be completed, using the Centiped sparker. Due to the perfect weather circumstances the seismic data are of high quality.

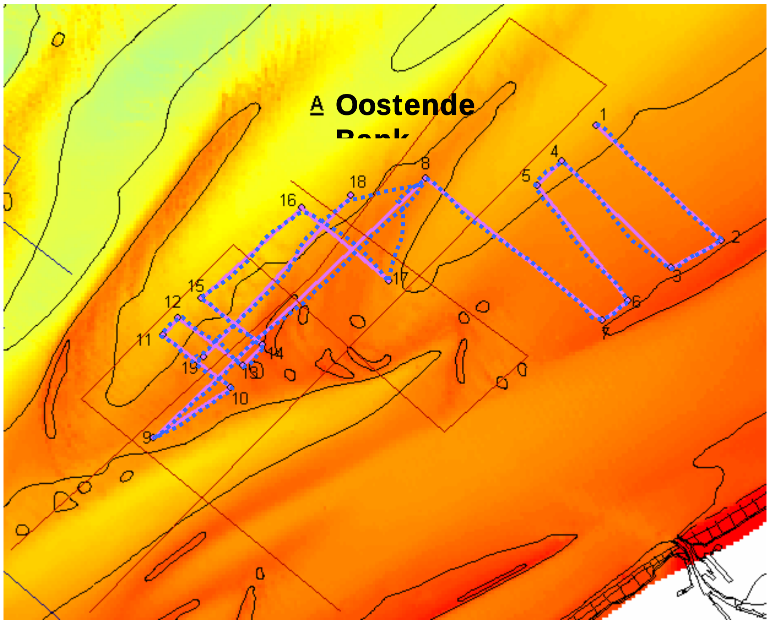


Figure 1: Sailed seismic lines in area A (blue dashed). Order of lines was adjusted onboard depending on the tide.

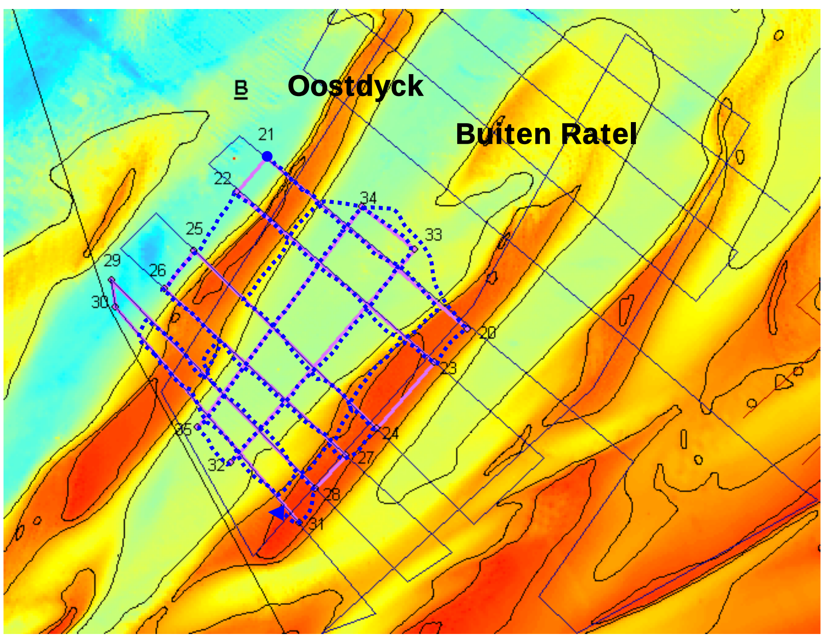


Figure 2: Covered seismic lines in area B (blue dashed). Order and length of lines was adjusted onboard depending on the water depth.

Multibeam measurements (UG-RCMG)

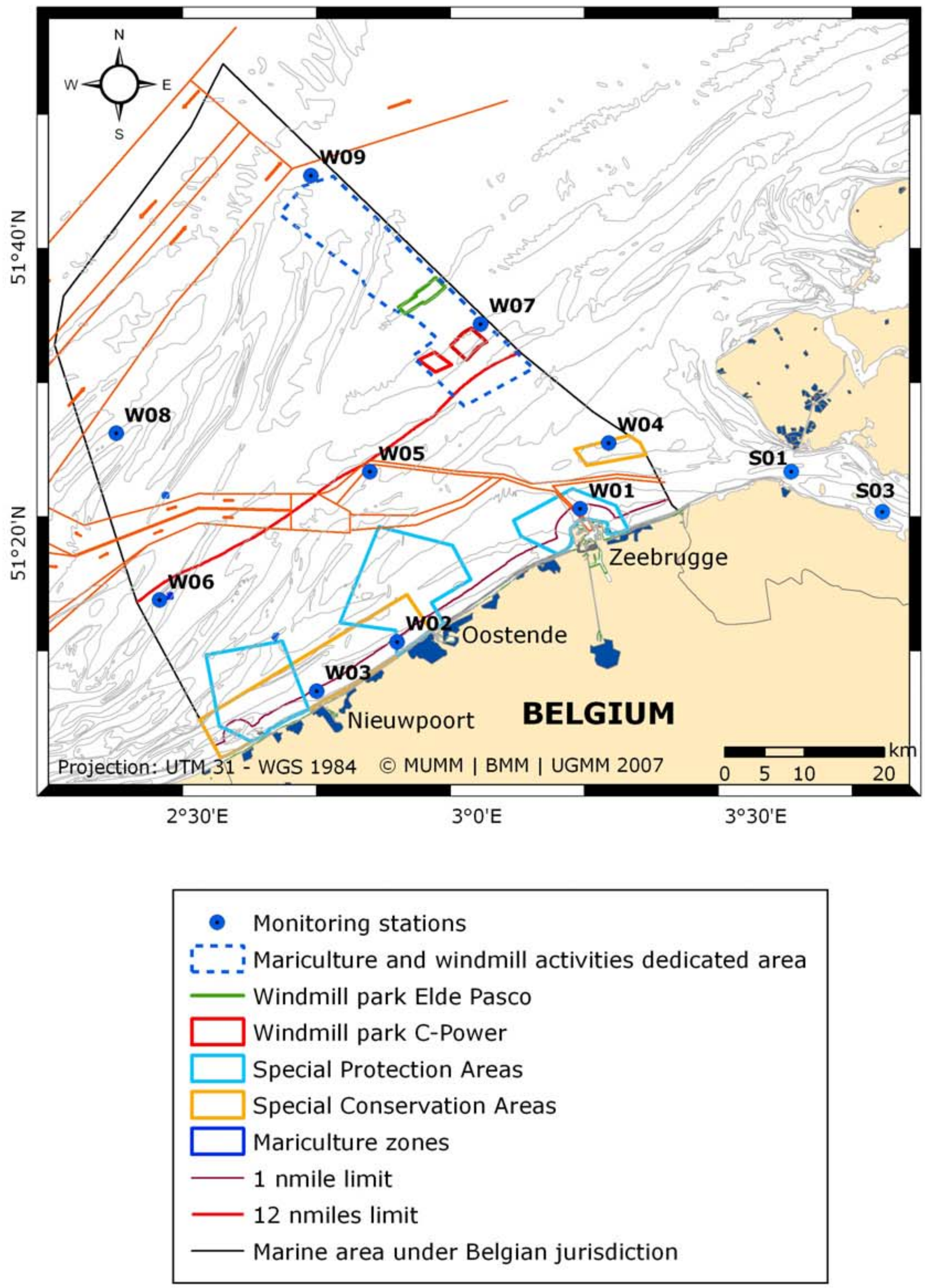
During the seismic recordings on the Kwinte Bank and Sierra Ventana, multibeam recordings have been made.

Sampling operations (MUMM-PR)

MUMM sampling stations are indicated on the map below. For this campaign, the sites S01, S03 and W04 have been sampled. At each station 2 10l Niskin bottles were taken as well as a depth profile with the Seacat. Oxygen measurements were also performed.

Station Name	In situ measurements		Water Niskin - GoFlo		
	D.O. YSI-52	CTD Sea-cat	Salinity	pH	Nutrients[1] Chlorophyl
S01	X	X	X	X	X
S03	X	X	X	X	X

[1] NO_x – NO_2 – PO_4 – NH_4 – Si – Total N + P, DON, DOP, PON, POC, SPM


N
W
E
S
W09
W07
W08
W04
W05
S01
W01
S03
51°40'N
51°20'N
W06
Zeebrugge
W02
Oostende
W03
Nieuwpoort
BELGIUM
Projection: UTM 31 - WGS 1984
© MUMM | BMM | UGMM 2007
km
0 5 10 20
2°30'E
3°0'E
3°30'E
Monitoring stations
Mariculture and windmill activities dedicated area
Windmill park Elde Pasco
Windmill park C-Power
Special Protection Areas
Special Conservation Areas
Mariculture zones
1 nmile limit
12 nmiles limit
Marine area under Belgian jurisdiction

5. OPERATIONS

All times are given in local time.

Monday, April 16th

The campaign is postponed because of generator test.

13h30 Embarkment of UG-RCMG personnel

16h Embarkation of instruments and installation of power supply in the work container and recording equipment on the bridge

Testing of generator until 16h30

Installation of seismic equipment

19h35 Sail off from Zeebrugge

Transit to Sierra Ventana region for seismic recordings

21h30 Mulitbeam calibration and sound velocity profile
Seismic source in water

22h35 Start simultaneous recording of multibeam and seismic recordings (source: Centipede sparker). Electrical propulsion.

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**:
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

Tuesday, April 17th

03h Technical problems with thermosalinograph – no sound velocity values are obtained

10h50 Technical problems with A400: programme is halted

Contact with Joan Backers from MUMM to discuss problems.

12h08 End of simultaneous recording of multibeam and seismic recordings

Transit to the sampling points of the MUMM-Roose programme

13h Joan Backers is brought to the RV Belgica with a military Alouette

xh Sampling of W04

15h30 Sampling of S01

16h39 Sampling of S03

Transit to Zeebrugge for the disembarkation of Joan Backers and Daniel Saudemont

19h03 Disembarkment of Joan Backers and Daniel Saudemont with zodiac

19h51 Zodiac back to RV Belgica

Transit to the Oostende Bank for seismic recordings programme UGent-Mathys

21h01 Start seismic recordings (source: Centipede sparker)

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**: 2-3 Bf N
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

Wednesday, April 18th

06h29 End

Transit to Kwinte Bank for seismic recordings programme Resource-3D

06h29 Start simultaneous recording of multibeam and seismic recordings (source: Centipede sparker) (north part of the study area)

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**: 2-3 Bf N
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

7h23 Change of sparker electrode chain (middle to black electrode chain)

10h41 End

11h16 Start simultaneous recording of multibeam and seismic recordings (source: C-Boom) (test lines in the middle and south part of the study area)

Parameter settings	
Source: C-Boom	**Wind/Seastate**: 2-3 Bf
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 700 Hz-7000 Hz 500 Hz-7000 Hz (11h32) 600 Hz-7000 Hz (15h00) Gain : 10 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

shotnr 2000: energy tests from 600 to 500 and 300 J
shotnr 4900: no analogue filter applied
shotnr 5000: tests with the Delph system

15h14 End

15h25 Start simultaneous recording of multibeam and seismic recordings (source: Centipede sparker) (middle part of the study area)

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**: 1-2 Bf Offset source vessel: 20 m
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 (400 ms: 16h) Delay: 0 ms Master: SPA 3

16h47 End

17h12 Start simultaneous recording of multibeam and seismic recordings (source: Seistec boomer) (test lines in the north, middle and south part of the study area)

Source: Seistec boomer (CSP600 power supply)	**Wind/Seastate**: 1-2 Bf Offset source vessel: 20 m
Receiver: Seistec (ch2)/SIG-single	

channel streamer (ch1)	
Acquisition: Rockland 751A Analogue bandpass filter: 800 Hz-1200 Hz Calibratie : 1500 -> 600 nV	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

Thursday, April 19th

00h08 End

Transit to the Buiten Ratel – Oostdijck area for seismic recordings programme UG-Mathys

01h46 Start seismic recordings (source: Centipede sparker)

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**: 4-3 Bf (~7h42)
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

15h58: change of sparker electrode chain

17h04 End

Transit to Kwinte Bank for seismic recordings programme Resource-3D

18h09 Start simultaneous recording of multibeam and seismic recordings (source: Centipede sparker)

Parameter settings	
Source: Centipede 300 J (CSP600 power supply)	**Wind/Seastate**: 2-3 Bf Offset source vessel: 20 m
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

21h27 End

21h33 Start simultaneous recording of multibeam and seismic recordings (source: SIG sparker) (3 test lines in the middle part of the study area)

Parameter settings	
Source: SIG sparker 300 J (CSP600 power supply)	**Wind/Seastate**: 4-5 Bf
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 100 Hz-3000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 400 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

23h15 End

Friday, April 20th

01h04 Start simultaneous recording of multibeam and seismic recordings (source: C-Boom) (2 test lines in the upper part of the study area)

Parameter settings	
Source: C-Boom	**Wind/Seastate**:
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: no analogue filter applied	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 200 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

01h36 End

Transit to south part of the study area

02h10 Start simultaneous recording of multibeam and seismic recordings (source: Centipede sparker)

Parameter settings	
Source: Centipede 200 J (CSP600 power supply)	**Wind/Seastate**: 5 Bf Offset source vessel: 20 m
Receiver: SIG-single channel streamer	
Acquisition: Rockland 751A Analogue bandpass filter: 200 Hz-6000 Hz Gain : 0 dB	**ELICS**: Sampl. freq.: 20 kHz Shooting interval: 500 ms Rec. length: 400 ms Nr. of channels: 1 Delay: 0 ms Master: SPA 3

10h35 End

Transit to Zeebrugge

13h30 Arrival at Zeebrugge
Disembarkment of equipment and personnel

- End of campaign ST0709 -

6. INFRASTRUCTURE AND INSTRUMENTATION USED

Continuous measurements
- Thermosalinograph SCTD-SBE21
- Turner fluorometer
- Sea water pump

Navigation / Meteorology / Bathymetry
- Friedrichs meteo
- DGPS Thales Aquarius
- Atlas Deso 20
- Tss 320B heave compensator
- RoxAnn bottom discriminator
- Kongsberg-Simrad EM1002S multibeam
- Sound velocity probe (side-winch needed)

Seismic recordings (UG-RCMG)
-Boomer (Seistec)
-Sparker (Centipede, SIG)
-Streamer

Seismic recordings (Magelas)
-C-boom

Navigation/Meteorology
- Standard meteorological instruments (wind, atmospheric pressure, PAR)

BMM-Monitoring
Water sampling and in-water instruments (from side gantry and davit)
- Oceanographic cable
- SeaCAT system (SCTD-SBE19, OBS, PAR) with 10 litre and 5 litre Niskin (MUMM)

Storage of samples: deepfreezer and refrigerator in the wet lab, deepfreezer and refrigerator deck
Milli RiOS/ Milli Q system

7. REMARKS ON THE MEASUREMENT INSTRUMENTS AND ON THE OPERATIONAL COURSE OF THE CAMPAIGN

Problems were encountered with A400 workstation.
There were repeated problems with the thermosalinograph.
The problems were solved and were reported.

The officers and crew of the RV Belgica are greatly acknowledged for their cooperation and skilful navigation, notwithstanding the difficulties in this shallow area.

Annex 3: Cruise report ST0717

RV BELGICA ST0717 - CRUISE REPORT

Subscriber: Dr. Vera Van Lancker (UG-RCMG)
Dr. Michael Fettweis (BMM)

Institute: UG - Renard Centre of Marine Geology

Responsibles: Isabelle Du Four (UG-RCMG)

Telephone: +32 9 264 45 73
Fax: +32 9 264 49 67
E-mail: Isabelle.Dufour@UGent.be

GEOLOGY - Cruise 17/07 Period: 16-19/07/2007

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1. Belgica Cruise ST2007/17
2. Participants
3. Program objectives
4. Measurements
5. Operations
6. Laboratory space
7. Infrastructure and instrumentation used
8. Analysis carried out on board
9. Automatic data acquisition
10. Remarks

1. BELGICA CRUISE ST2007-17

1.	Cruise number	2007-17
2.	Date / hour	Zeebrugge TD: 16/07, 10h45 Zeebrugge TA: 17/07, 07h45 Zeebrugge TD, 17/07, 08h15 Zeebrugge TA: 19/07, 08h00 Zeebrugge TD, 19/07, 08h30 Zeebrugge TA: 19/07, 16h15
3.	Responsible scientist Participating institutions	Isabelle DU FOUR (UG-RCMG) UG-RCMG, MUMM, KUL, TNO (NL), WLH, Universität Stuttgart

2. PARTICIPANTS

		16/07-18/07, 20h	**18/07, 20h-19/07, 8h**	**19/07: 8-16h**
UG-RCMG	Isabelle DU FOUR[1]	x	x	x
	Vera VAN LANCKER	x	x	
	Sonia PAPILI	x	x	x
	Jeroen VERCRUYSSE	x	x	
	Peter STAELENS		x	
	Arne BAEYENS	x	x	x
	Mathieu VAN MEERBEECK	x	x	x
KUL	Alessio GIARDINO*		x	x
TNO	Bob PAAP*	x		
WLH	Job JANSSENS			x
Universität Stuttgart	Steffen HAGELE*			x
	Thomas JANCKE*			x
MUMM	Michael FETTWEIS			x
	Jean-Pierre DEBLAUWE			x
TOTAL		**7**	**8**	**10**

[1] chief scientist
* permission to embark is asked for

3. PROGRAM OBJECTIVES

QUEST4D: QUantification of Erosion/Sedimentation patterns to Trace the natural versus anthropogenic sediment dynamics (UG-RCMG, BMM, WLH)

QUEST4D, a Belspo funded project, focuses on the quantification of erosion and sedimentation processes along the Belgian shelf. As such, the sediment state and dynamics will be studied in the space, depth and time domain (4D). The research is timely as indications of a longer-term and broader-scale physical degradation of the seafloor exist and it is unclear whether this is solely due to the increasing anthropogenic influence or to a combination with the natural evolution of the seafloor itself, including the effect of climate change. The latter processes need to be disentangled as their impact needs to be balanced against the industry-related activities.

RESOURCE-3D (UG-RCMG)
A Belspo funded ‘Action in support of the Federal Authority’s strategic priorities’ and relates to the studies of the Fund for Sand Extraction (FPS Economy, SMEs, Self-employed and Energy).
A methodological and strategic approach will be developed to image/quantify the internal structure of sandbanks in very-high resolution. Several source/receiver configurations will be tested and the optimal approach used to interpret the sandbank architecture in terms of its sedimentological and lithological composition. The results will be integrated with former knowledge databases related to the Quaternary evolution of the Belgian shelf.

MOMO project (MUMM):
MOMO stands for the monitoring and modelling of cohesive sediment transport and the evaluation of the effects on the marine ecosystem due to dredging and dumping operations. The primary objective of the project is the study of the cohesive sediments on the Belgian Continental Shelf (BCS) using numerical models and field measurements. The combination of monitoring and modelling will provide information on the transport processes of this fine fraction and is therefore fundamental to answer questions on composition, origin and residence of it on the BCS, the change in characteristics of this sediment due to dredging and dumping operations, the effects of the natural variability, the impact on the marine ecosystem especially due to alterations of habitats, the estimation of the net input of hazardous substances in the marine environment and the possibilities to reduce these last two items.

Modelling of sandwave characteristics on the Belgian Continental Shelf (UG-RCMG)
UG-RCMG has an on-going cooperation with the Università di Genova modelling the wavelength of sandwaves on the basis of hydrodynamic characteristics. First results have been published in the Journal of Geophysical Research (Cherlet et al., 2007). During this campaign, additional multibeam data will be recorded for the validation of the modelling results.

4. MEASUREMENTS

Seismic measurements – Resource3D

I. Kwinte Bank

The efficiency of different seismic sources (Seistec, the sparkers Centipede and SIG and the C-boom of Magelas) for the mapping of the internal structure of the Kwintebank was already tested during campaign ST0709. During the present campaign the tracklines 3-4, 6-8, 14-20, each of 5 km length, were sailed using the EdgeTech 3200-XS Sub-bottom Profiling System (Figure 1). The lines cover the monitoring zones KBMA and KBMB of the Fund for Sand Extraction.

Full Spectrum digital X-STAR 3200 xs (SB-512i) Sub-bottom Profiler (Netherlands Institute of Applied Geoscience TNO)

The EdgeTech 3200-XS Sub-bottom Profiling System is a high-resolution wideband Frequency Modulated (FM) sub-bottom profiler utilizing EdgeTech's proprietary Full Spectrum chirp technology. The system transmits a FM pulse that is linearly swept over a full spectrum frequency. The acoustic return received at the hydrophones is passed through a pulse compression filter, generating high-resolution images of the sub-bottom stratigraphy.

Frequency Range 500 Hz – 12 kHz (Pulse Type FM)
Standard Pulse Bandwidths/Length (other custom pulses available) 2 -12 kHz / 20 ms, 2-10 kHz / 20 ms, 2-8 kHz / 40 ms, 1.5-7.5 kHz / 40 ms, 1-6 kHz / 40 ms, 1-5 kHz / 40 ms, 0.5-5 kHz / 40 ms
Vertical Resolution (depends on pulse selected): 8 – 20 cm
Penetration (typical) in coarse calcareous sand / in clay: 20 / 200 meters
Beam Width (depends on center frequency): 16° – 32°
Transmitters 2; Receive Arrays 4
Size (centimeters) 160 (L) x 124 (W) x 47 (H)
Weight 190 kg
Cable Requirements 3 shielded twisted pairs
Tow Speed 3 – 4 knots optimal, 7 knots maximum safe operation

X-star

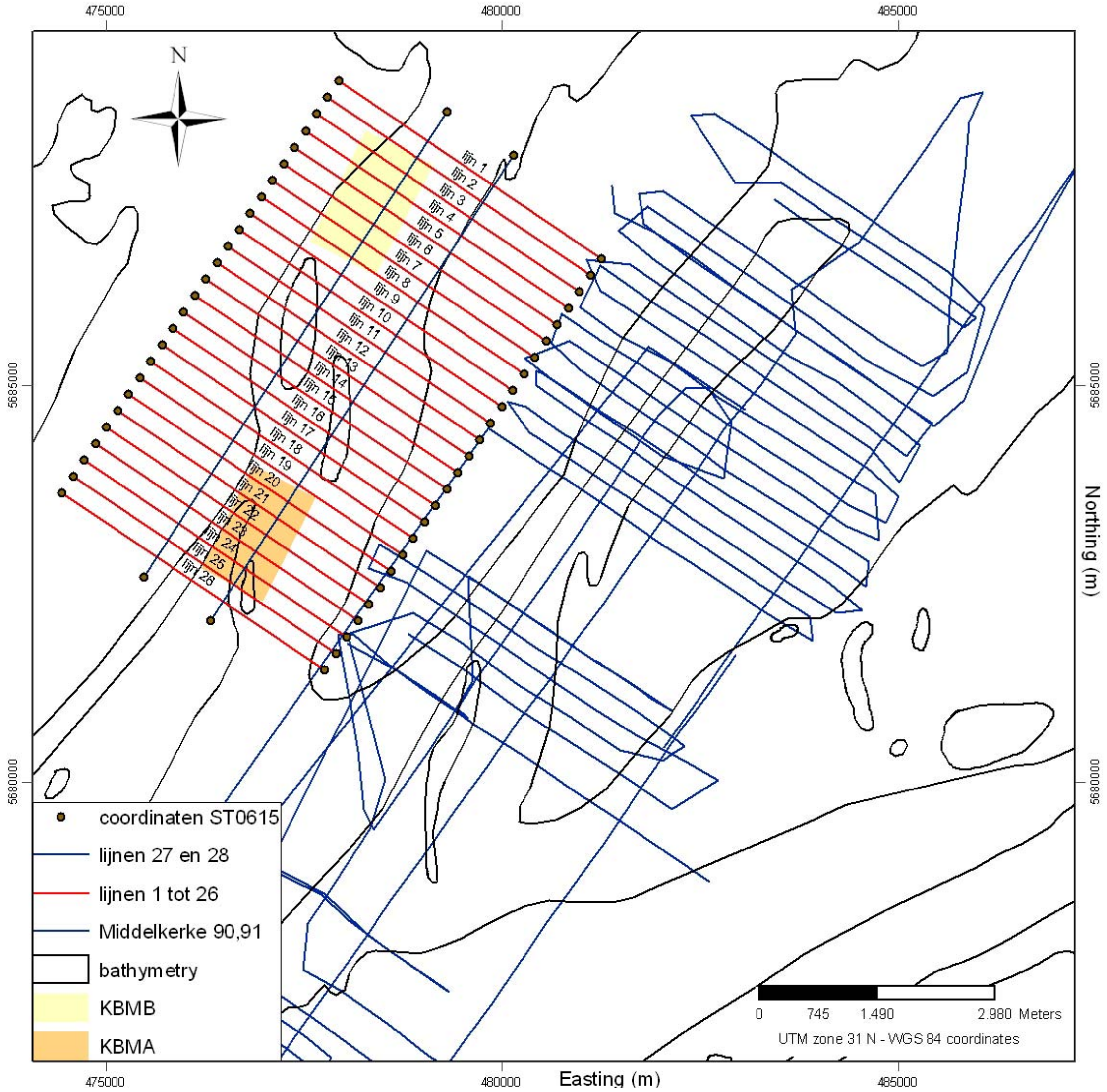


Figure 1 Location of the seismic lines on the Kwinte Bank.

Table 1 Coordinates of the begin- and endpoints seismic lines.

Line	X_wgs84	Y_wgs84	lat_wgs84	long_wgs84	endp_nr
3	499908	5701432	51 27.84	2 59.92	7
3	505094	5701431	51 27.84	3 4.40	8
4	499908	5701182	51 27.71	2 59.92	9
4	505104	5701180	51 27.71	3 4.41	10
6	499908	5700682	51 27.44	2 59.92	13
6	505104	5700677	51 27.43	3 4.41	14
7	499908	5700432	51 27.30	2 59.92	15
7	505094	5700436	51 27.30	3 4.40	16
8	499908	5700182	51 27.17	2 59.92	17
8	505104	5700184	51 27.17	3 4.41	18
14	499908	5698682	51 26.36	2 59.92	29
14	505115	5698685	51 26.36	3 4.42	30
15	499908	5698432	51 26.22	2 59.92	31
15	505115	5698434	51 26.22	3 4.42	32
16	499908	5698182	51 26.09	2 59.92	33
16	505104	5698182	51 26.09	3 4.41	34
17	499908	5697932	51 25.96	2 59.92	35
17	505115	5697931	51 25.95	3 4.41	36
18	499908	5697682	51 25.82	2 59.92	37
18	505094	5697679	51 25.82	3 4.40	38
19	499908	5697432	51 25.69	2 59.92	39
19	505104	5697428	51 25.68	3 4.41	40
20	499908	5697182	51 25.55	2 59.92	41
20	505104	5697187	51 25.55	3 4.40	42

2. Sierra Ventana region

The Sierra Ventana region is, in contrast with the Kwintebank, a sand/mud dominated region. The efficiency of the Centipede, for the mapping the internal structure of the extraction zones 3a/b, was already tested during campaign ST0709. It was planned to sail the same tracklines as during the previous campaign, but due to technical problems only line 9 and 15 of 5 km long were sailed using the EdgeTech 3200-XS Sub-bottom Profiling System (Fig. 2 and Table 2). The testing of different seismic sources at the Sierra Ventana region frames also in the QUEST4D program, which aims at among other tings investigating recent regional sedimentation and erosion patterns.

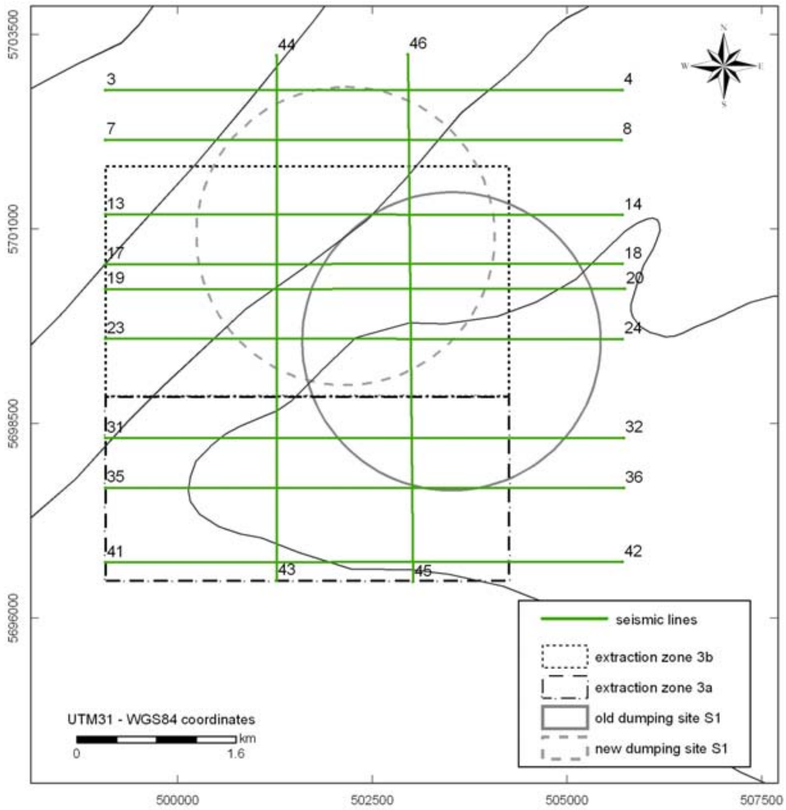


Figure 2 Location of the seismic lines on the Sierra Ventana region.

Table 2 Coordinates of the begin- and endpoints of the seismic lines in the Sierra Ventana region

Line	X_wgs84	Y_wgs84	lat_wgs84	long_wgs84	endp_nr
9	499908	5699932	51 27.03	2 59.92	19
9	505125	5699933	51 27.03	3 4.43	20
15	499908	5698432	51 26.22	2 59.92	31
15	505115	5698434	51 26.22	3 4.42	32

Multibeam measurements – QUEST4D

Multibeam measurements were performed along the ‘De Moor’ tracks covering the Hinderbanken (Fig. 3). The planned tracklines on the Vlaamse banken were not sailed because the Fund for Sand Extraction sailed them during campaign ST0716. For management purposes only the tracks lying in the exploration zone 4 were covered (table 3).

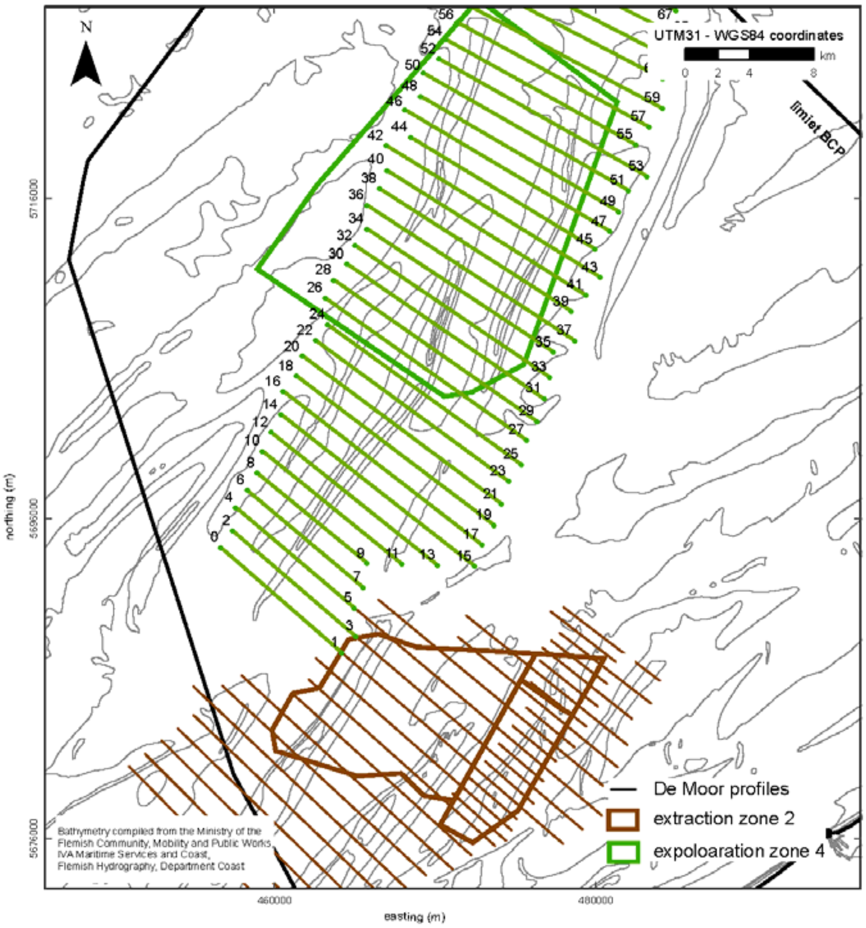


Figure 3 Location of the 'De Moor' tracks on the Hinderbanken

Table 3 Coordinates of the sailed track lines on the Hinderbanken

Line	X_wgs84	Y_wgs84	lat_wgs84	long_wgs84	endp_nr
21BA4	463336	5708111	51 31.375	2 28.291	12
21BA4	475408	5699374	51 26.701	2 38.769	12
21BA5	463182	5709775	51 32.272	2 28.148	13
21BA5	475711	5700886	51 27.518	2 39.024	13
21BA6	463709	5710905	51 32.884	2 28.598	14
21BA6	476369	5702053	51 28.149	2 39.588	14
21BA7	464500	5711911	51 33.430	2 29.276	15
21BA7	476782	5703481	51 28.920	2 39.939	15
21BA8	465011	5713054	51 34.048	2 29.711	16
21BA8	477142	5704858	51 29.664	2 40.244	16
21BAA	465786	5714080	51 34.605	2 30.376	17
21BAA	477376	5706382	51 30.487	2 40.441	17
21BAB	465777	5715563	51 35.405	2 30.360	18
21BAB	478714	5707115	51 30.885	2 41.595	18
21BAC	466534	5716595	51 35.964	2 31.009	19

21BAC	478489	5708934	51 31.866	2 41.394	19
21BAD	467006	5717765	51 36.597	2 31.412	20
21BAD	479382	5709961	51 32.422	2 42.162	20
21BAE	466971	5719302	51 37.426	2 31.373	21
21BAE	480305	5711054	51 33.014	2 42.957	21
21BAF	468479	5719847	51 37.725	2 32.677	22
21BAF	479994	5712834	51 33.973	2 42.682	22
21BB0	468144	5721549	51 38.642	2 32.377	23
21BB0	480901	5713947	51 34.576	2 43.464	23
21BB1	469099	5722401	51 39.105	2 33.201	24
21BB1	481448	5715169	51 35.236	2 43.933	24
21BB2	469288	5723824	51 39.873	2 33.357	25
21BB2	482051	5716497	51 35.954	2 44.451	25
21BB4	470242	5724703	51 40.351	2 34.180	26
21BB4	483206	5717373	51 36.429	2 45.450	26
21BB5	470659	5725928	51 41.013	2 34.536	27
21BB5	482502	5719367	51 37.503	2 44.834	27
21BB6	471340	5726996	51 41.591	2 35.121	28
21BB6	483351	5720479	51 38.104	2 45.566	28

A third area, that was planned to be covered with multibeam, is the area in between the Hinderbanken, Gootebank and Thorntonbank (red triangle in figure 4, coordinates in table 3), all off these banks are already covered with multibeam. However only part of the triangle could be covered (Figure 4).

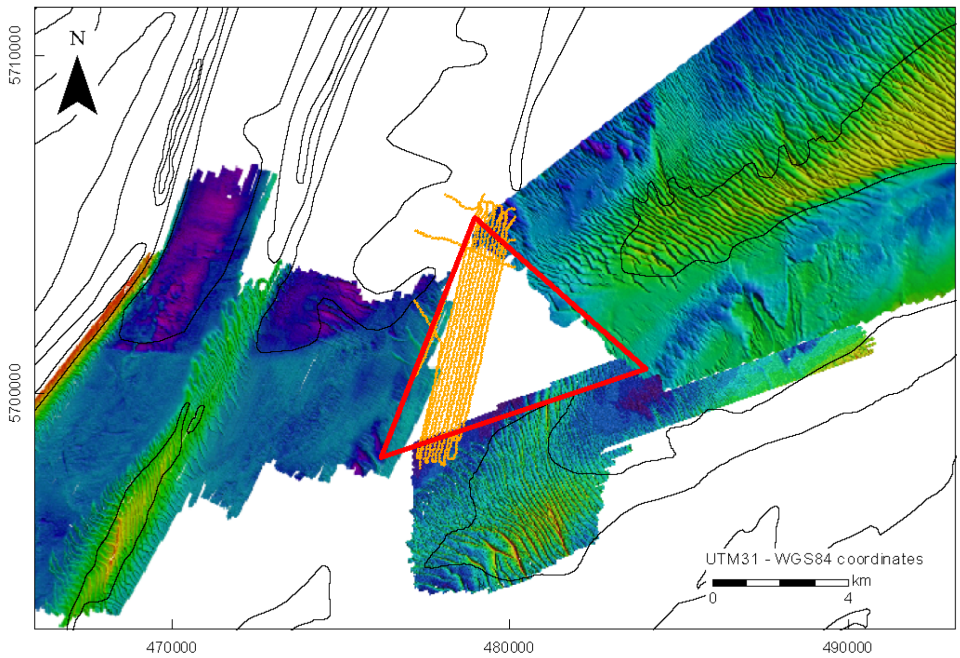


Figure 4 Location of the red triangle, where multibeam data was planned to be gathered and the tracklines that were actually sailed (orange)

Boxcores – QUEST4D

8 of the 12 planned boxcores were only taken due to technical limitations, through which it was not possible to take boxcore behound 15 m of depth. Each time 3 subcores, 2 for the Universität Stuttgart and 1 for WLH, were taken. They will used to calculate the erosion resistance, one of the aims in the QUEST4D project (Fig. 5). The coordinates of the different boxcore locations and the descriptions of their sediments are shown in table 4.

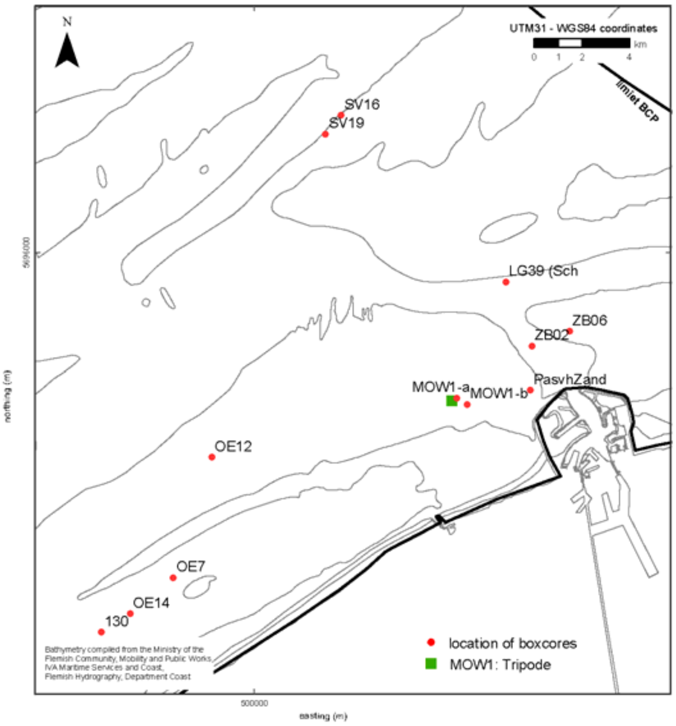


Figure 5 Location of the tripod and boxcores

Table 4 Coordinates of the boxcores with their description

ID	UTC Time	NB (wgs84)	0L (wgs84)	descrip
PvZ	7:28:30	51 22.81	3 10.13	total: 35 cm, 1cm: fine sand with a fluffy layer on top, underneath: very sticky consolidated mud (holocene)
ZB02	7:36:00	51 22.79	3 10.04	grey-green soft mud
ZB06	8:09:40	51 23.04	3 11.26	0,5 cm: very soft sandy mud, very sof sandy mud with in between sandy horizonts of 1 cm thickness, last 5 cm: more consolidated black mud (holocene?) - layered
OE12	9:12:10	51 20.30	3 58.51	total: 45 cm, very soft - allmost liquid - mud with fine sand (sand on mud), underneath: alternation of consolidated mud layers (10cm) and sandy layers with shells (0,5cm)
OE07	10:30:50	51 17.56	3 57.06	extra 10 cm on top, 0,5 cm: very fine sand, underneath: very soft black mud with a slightly H2S smell and more consolidated towards bottom, last 10 cm: sandy mud
OE14	10:53:40	51 16.77	3 55.57	1 cm: fine sand with shells and Lanice conchilega, 3cm: grey-yellow soft mud (liquid), 1 cm: muddy sand with more consolidated soft mud, bottom: 5cm: muddy sand
130	11:17:10	51 16.30	2 53.96	top: fineer layer of grey-green liquid mud, 45 cm: black soft mud which falls down like a pudding
MOW1a	12:54:00	51 21.62	2 7.33	total: 35 cm, 5 cm: very soft grey-green liquid mud, grey fine sand with shells and shellfragments, claylenses, alternating sand and consolidated mud layers

Hydrodynamic measurements – QUEST4D - MOMO

The tripod, which was moored in a previous campaign, was successfully recovered on Thursday at MOW1.

Instrument	Point	Easting (wgs84)	Northing (wgs84)	NB (wgs84)	OL (wgs84)
Tripod	MOW1	508309	5689792	51 21.56	3 7.16

Multibeam measurements – Cooperation UG-RCMG-Università di Genova

Multibeam measurements were performed at 4 locations, of which the coordinates are given in table 5. At each locations two parallel lines were sailed of 1 kilometre length.

Table 5 Coordinates of the locations where two parallel multibeam lines were sailed

line	Location	X_wgs84	Y_wgs84	Lat_wgs84	Long_wgs84
2	Akkaert NE	498507,07	5699746,09	51 26.93	2 58.71
2	Akkaert NE	499324,78	5700409,35	51 27.29	2 59.42
3	Akkaert NE	498563,77	5699676,19	51 26.90	2 58.76
3	Akkaert NE	499381,48	5700339,45	51 27.25	2 59.47
4	Westhinder	471829,19	5692488,22	51 22.98	2 35.71
4	Westhinder	472728,58	5693005,37	51 23.26	2 36.48
5	Westhinder	471874,05	5692410,20	51 22.93	2 35.75
5	Westhinder	472773,44	5692927,35	51 23.22	2 36.52
6	Akkaert Noord	472939,86	5692486,25	51 22.98	2 36.67
6	Akkaert Noord	473915,61	5693005,01	51 23.26	2 37.51
7	Akkaert Noord	472986,80	5692397,96	51 22.93	2 36.71
7	Akkaert Noord	473962,55	5692916,71	51 23.21	2 37.55
8	Kwintebank	477654,74	5688617,17	51 20.90	2 40.75
8	Kwintebank	478436,00	5689403,84	51 21.33	2 41.42
9	Kwintebank	477789,55	5688483,29	51 20.83	2 40.87
9	Kwintebank	478570,81	5689269,96	51 21.26	2 41.54

5. OPERATIONS

All times are given in local time.

Monday, July 16th

09h00 – 10.45 Embarkation of UG-RCMG and Bob Paap of TNO

Transit to the region of the Kwintebank

13h00 - 15h45 Multibeam measurements for the determination of sandwave characteristics – Kwintebank, Westhinder and Akkaert Noord. Delay due to helicopter exercise and passing by of tanker.

16h20 – 18h45 Multibeam measurements along the ‘De Moor’ tracks in the extraction zone 4

Transit to Akkaert NE

20h00 – 20h30 Multibeam measurements for the determination of sandwave characteristics– Akkaert NE

Transit to Zeebrugge due to technical problems with the seismic instruments

22h30 – Solving technical problems

Thuesday, July 17th

– 02h00 Solving technical problems

Transit to Kwintebank

03h30 – 14h45 Seismic recordings, simultaneously multibeam measurements were made

Signaal: 0.5-8.0 KHz, 5 ms pulse length, Sampling frequency = 12.5 KHz, record length = 80 ms, 2 pings per seconde

Line3 SE --> NW
Line4 NW --> SE
!! Line30 NE --> SW (check voor welke lijn het nou werkelijk is!)
Line16 SE --> NW
Line15 NW --> SE
!! Line13 SE --> NW --> Foutieve lijnnaam, dit is Line14
!! Line14 NW --> SE --> Foutieve lijnnaam, dit is Line17
Line18 SE --> NW
Line19 NW --> SE
Line20 SE --> NW

Signaal: 0.5-4.5 KHz, 50 ms pulse length, Sampling frequency = 10.0 KHz, record length = 80 ms, 2 pings per seconde

Line8 NW --> SE
Line7 SE --> NW
Line6 NW --> SE

Transit to Sierra Ventana

16h15 – 18h30 Seismic recordings, simultaneously multibeam measurements were made

Signaal: 0.5-4.5 KHz, 50 ms pulse length, Sampling frequency = 10.0 KHz, record length = 80 ms, 2 pings per seconde

Line18_15 W --> E --> Foutieve lijnnaam, dit is line15. Deze bestaat uit meerdere files omdat er hier getest is met hogere frequentie-banden.
Line9 E --> W

Transit to Zeebrugge

19h30 – 20h15 Disembarkation of B. Paap

Embarkation of P. Staelens and A. Giardino

Transit to Hinderbanken

22h45 – Multibeam measurements along the 'De Moor' tracks in the extraction zone 4

Wednesday, July 18th

– 19h00 Multibeam measurements along the 'De Moor' tracks in the extraction zone 4

19h00 – 22h45 Anchoring due to bad weather conditions

Transit to triangle between Hinderbanken, Gootebank and Buiten Ratel

23h00 – Multibeam measurements

Thursday, July 19th

– 05h30 Multibeam measurements

Transit to Zeebrugge

08h00 – 08h30 Embarkation of MUMM and WLH personnel
Disembarkation of V. Van Lancker, J. Vercruysse and P. Staelens

Transit to near coastal area around Zeebrugge

09h00 – 14h00 Boxcoring at sample locations PvZ, ZB02, ZB06, OE12, OE7, OE14 and 130

Transit to MOW1

14h30 – 15h45 Recovery of the tripod on MOW1

16h15 Arrival at Zeebrugge and disembarkation of scientific staff and material.

- End of campaign ST0717 –

6. LABORATORY SPACE USED

BRIDGE:	Multibeam
WET LAB:	Seismic recordings and Samplings
MICROBIOLOGY LAB:	Storage of instruments (sampling equipment, sound velocity probe)
BIOCHEMISTRY LAB:	Storage of instruments

7. INFRASTRUCTURE USED

Continuous measurements
- Thermosalinograph SCTD-SBE21
- Turner fluorometer
- Sea water pump

Navigation / Meteorology / Bathymetry
- Friedrichs meteo
- DGPS Thales Aquarius
- Atlas Deso 20
- Tss 320B heave compensator
- RoxAnn bottom discriminator
- Kongsberg-Simrad EM1002S multibeam
- Sound velocity probe (side-winch needed)

Sediment sampling
- Boxcorer

8. ANALYSIS CARRIED OUT ON BOARD

9. AUTOMATIC DATA ACQUISITION

Parameters that were acquired:

N°	Parameters	Acquisition rate 0.5 sec	Acquisition rate 10 sec
13	PT/ST SPEED		*
14	DEPTH SPEED		*
15	FO/AF SPEED		*
16	REL. WINDDIR		*
17	REL. WINDSPD		*
19	HUMIDITY_HR		*
20	ATM PRESSURE		*
24	SEATEMP_1		*
30	SOL-RAD		*
34	AIRTEMP.DRY		*
35	AIRTEMP.WET		*
36	SHIP HEADING	*	*
120	IN-WIND DIR		*
121	IN-WINDSPD		*
122	IN-WINDSPD.BF		*
123	CUMUL.DIST	*	*
182	HUMIDITY_DW		*
184	TSS DEPTH-L	*	*
185	TSS DEPTH-H	*	*
186	TSS HEAVE	*	*
191	SBE21 TEMP.	*	*
192	SBE21 SALIN.	*	*
193	SBE21 SIGTH.	*	*
195	TURNER FLUO.	*	*

197	DGPS LAT.N/S	*	*
198	DGPS LONG.E/W	*	*
199	DGPS HG_MSL	*	*
200	DGPS UTCTIME	*	*
201	DGPS SPEED	*	*
202	DGPS COURSE	*	*
203	DGPS QUALITY	*	*
214	MGN DGPS LAT	*	*
215	MGN DGPS LON	*	*
219	ROXANN DEPTH	*	*
220	ROXANN ROUGH	*	*
221	ROXAN HARD	*	*

10. REMARKS ON THE MEASUREMENTS, INSTRUMENTS AND ON THE OPERATIONAL COURSE OF THE CAMPAIGN

Remarks on the measurements

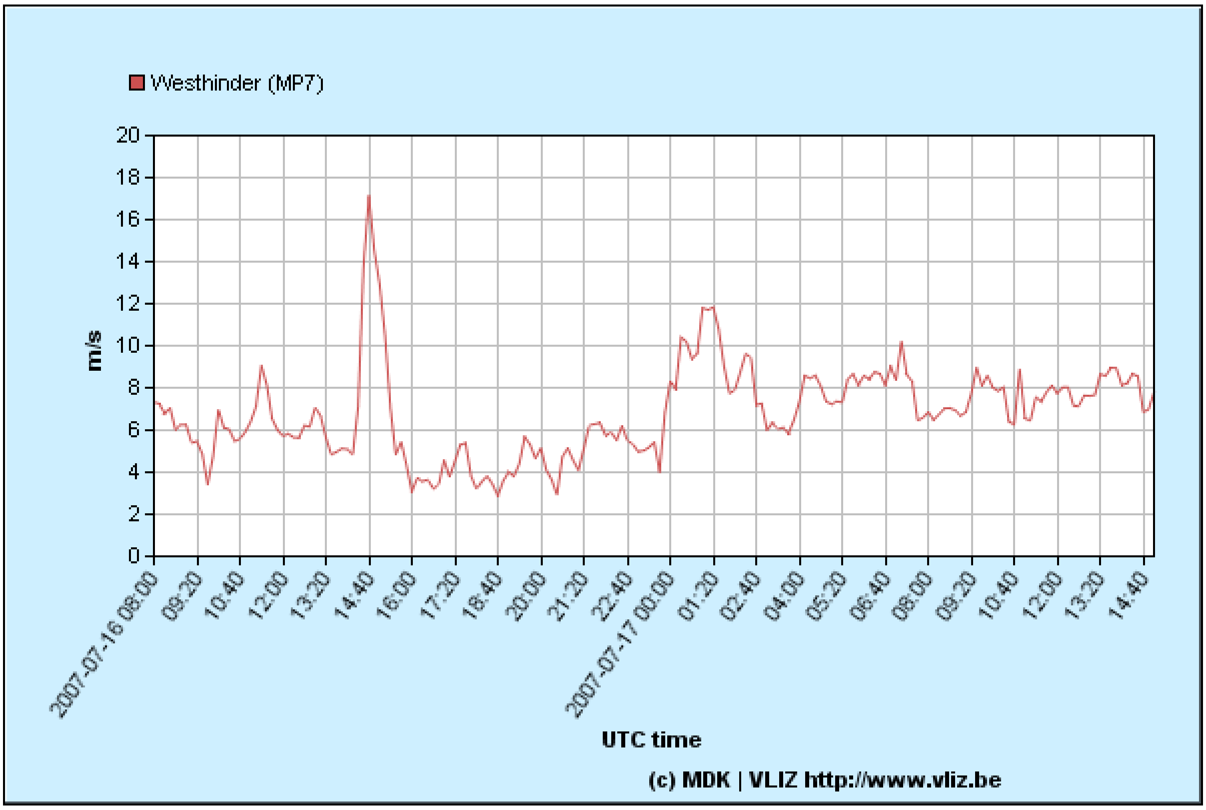
Multibeam system

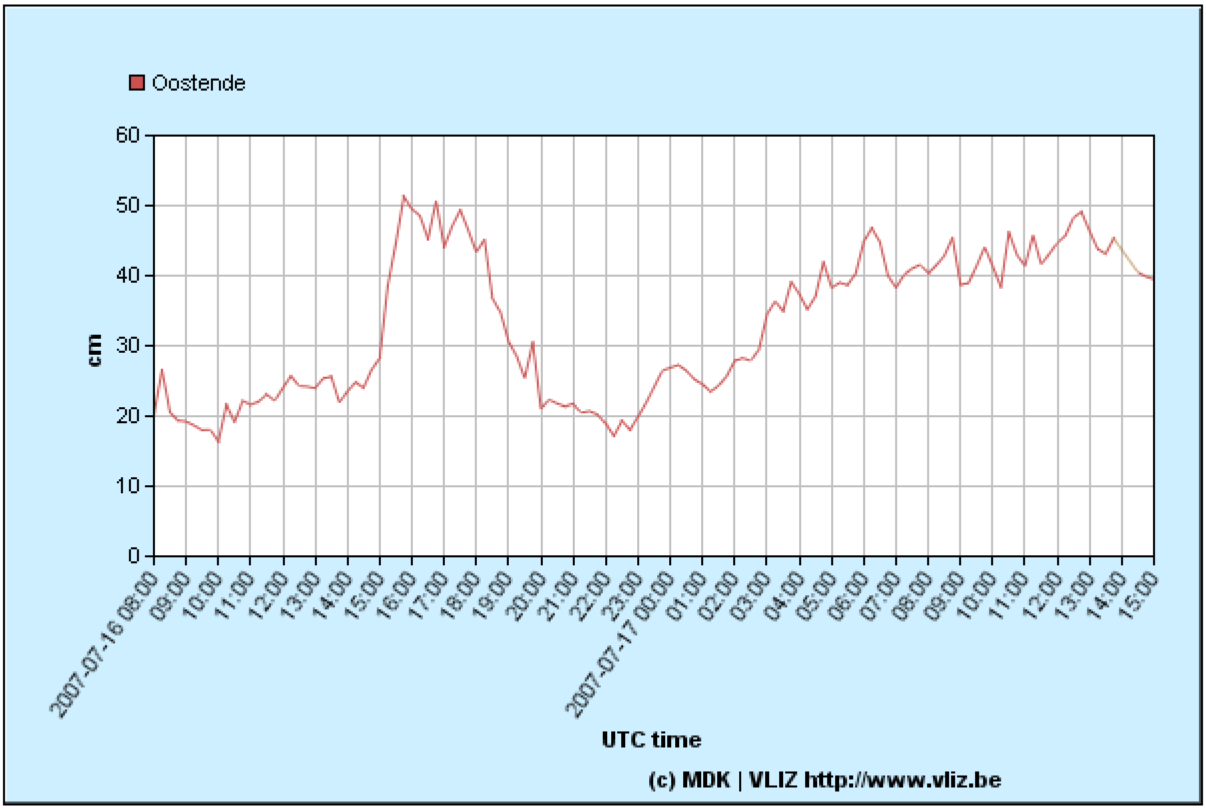
Problems were encountered with the survey display. Data wasn't displayed on the screen, although it was logged. After restarting the system it worked again properly. The cause is unkown.

General remarks

The officers and crew of the Belgica are greatly acknowledged for their cooperation.

Annex 4: Meteorological conditions during ST0717





Upper panel: Mean wind velocity; measuring station Westhinder.
Lower panel: significant wave height; Measuring station Oostende.
Source: © AWZ | VLIZ http://www.vliz.be/.
X-Star data acquisition took place on 2007-07-17 between 03:30 and 14:45