Distribution, geometry and orientation of megascale bedforms on the inner shelf, coast of Holland, 52-53º N, based on echosounder data and side-scan sonar

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Abstract

The distribution, geometry, and orientation of megascale bedforms was recorded using side-scan sonar images and echosounder data. Megaripples (spacing 3-18 m) were observed in the entire research area, in the south superimposed on sand waves (spacing <100-859 m) and in the north of the study area on tidal ridges (spacing 10 km). The average orientation of megaripple crests is SW-NE in the sand wave area to W-E in the north, which is perpendicular to orientation of the tidal ridges. The tidal ridges change shoreward from linear to s-shaped with a decreasing amplitude (max. 20 m). Enigmatic large symmetric sand waves are present on the steep sides of a ridge and probably indicate convergent residual sand transport directions. Sandwaves are rotated clockwise at the ridge crests.

Side-scan sonar en echosounder data prove to be valuable in monitoring and mapping bedform geometry, distribution, and orientation. The advantage of single beam echosounder data is that processing is relatively easy for large areas and it provides important information on the characteristics of large-scale bedforms, such as tidal ridges. Side-scan sonar data is especially suitable for defining the characteristics of subaquatic dunes, such as megaripples and sand waves.

1. Introduction

Coastal engineering projects require an understanding of the distribution and mobility of megascale bedforms. Previous studies have demonstrated that tidal ridges, sand waves, and megaripples cover the shelf in the Southern Bight of the North Sea (Terwindt, 1971; McCave, 1971; Van Alphen and Damoiseaux, 1986). One of the major challenges, since then, has been to understand the interaction between these bedforms, and their relation to the hydrodynamic regime (e.g., Hennings et al., 2000). A major question is whether sand waves and sand banks are relic features of a lower sea level position or that they are equilibrium bedforms with respect to the present conditions. Morphodynamic models have been used successfully to predict the distribution of bedforms in the Southern Bight of the North Sea (Hulscher and Van den Brink, 2001). However, new data can contribute to improve the models by providing realistic estimates of boundary conditions, such as e.g. bed roughness caused by megaripples.

The geometry and orientation of bedforms provide an indication of residual bedload transport directions. Small bedforms have small storage capacity and are changing position rapidly in response to changing flow conditions, but e.g., short tidal cycles do not allow sufficient time for larger bedforms to be significantly reworked (Ashley, 1990). Large composite bedforms are in equilibrium with the relative strenghts of all operating flow regimes. Each flow regime causes migration of a particular set of superimposed bedforms, which affects the geometry of the large bedform. Therefore, the distribution of megaripples and sand waves on tidal sand ridges should reflect the mechanisms forming and/or maintaining these ridges. In addition, the geometry and bedform configurations of the present inner shelf are helpful when interpreting the architecture of ancient shelf ridges. Here the distribution, geometry, and orientation of bedforms in an area offshore the Dutch coast are characterized using data collected from side-scan sonar and echosounder.

2. Study area

The study area is situated between 52 and 53º N in the Southern Bight of the North Sea. The bathymetry of the area is < 45 m, with the greatest depths in the southwest. North-south oriented tidal sand ridges are present in the Northern part of the area (Fig.1), whereas sand waves > 6 m high dominate in the southern part (Van Alphen and Damoiseaux, 1989). Median grain-sizes of seabed sediments (0-20 cm) measured by Malvern laser particle sizer (1989-2001) diminish from the southwest to the northeast. The sediments are well-sorted (D60/D10<1.8) in the entire area, except for some locations on the shoreface.

3. Methods

For the Netherlands Continental Shelf, echosounder data and side-scan sonar records collected by the Hydrographic Survey of the Royal Dutch Navy are processed and available in the archives of TNO-NITG Geo-Marine and Coast. For this study, 40 high quality intervals of sonar images collected between 1991 and 2001 were studied. Side-scan sonar records covering a total length of 353 km of seafloor were investigated. The scanned width of sea floor in each image was between 300 and 500 m. Wave lengths, amplitudes, and crestline orientations of 776 individual sand waves were measured on the side-scan sonar images. Geometries of the sand waves were classified as asymmetrical or symmetrical, and crest types were classified as catback (sensu McCave, 1971), multiple crested, sinusoid-crested, and straight-crested. Average wavelenghts of superimposed megaripples were measured by counting the number of megaripple crests along a measured distance. Average crestline orientations of megaripples were also recorded. Gridding of the data occurred in Surfer 7 using the “Natural Neighbours” interpolation method, which is especially useful when gridding geophysical datasets (Sambridge et al., 1995). Contour plots of the grids provide information on the spatial variation of the bedform parameters. The bathymetry of the area was reconstructed from echosounder data and gridded in the computer program ZYCOR with a 200 x 200 m grid cell size. A relief map was created by substracting a trend surface (cf. Davis, 1986) from the bathymetric data to extract the regional data from the local variations in bathymetry. Within the framework of the Delft Cluster project “Ecomorphodynamics of the Sea Floor” a research plot within the present study area was monitored with multibeam sonar and box-core sampling in 2001 and 2002. Some data collected within this project are also discussed.

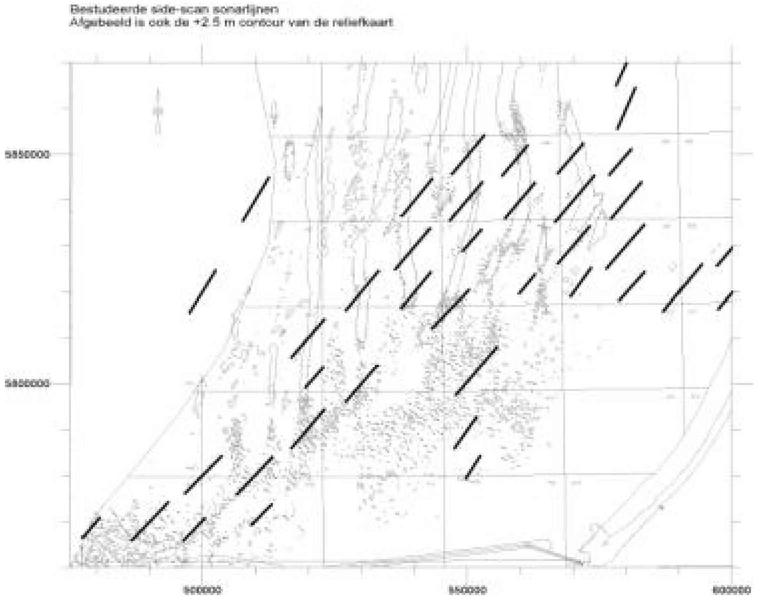

Fig. 1 – Location of studied side-scan sonar lines in study area 52-53º N. Contours indicate +2.5 m relief.

4. Results and discussion

Sandwaves are recorded on 35 out of the 40 sonar records and cover most of the study area. They occur in well-sorted sands with median grain-sizes > 300 µm as determined by laser particle sizer (compares to >250 µm for conventional sieve analysis). Megaripples are observed on 39 out of 40 records, and small-scale ripples only on 1 record out of 40, although this may have been caused by the resolution of the side-scan sonar images. The bedforms occur superimposed on each other and on tidal sand ridges.

4.1 Megaripples

Megaripples are observed on steep and gentle slopes of sand waves, and in areas where sand waves are absent. Average wavelenghts of megaripples are 3-18 m. Crest orientations of megaripples are both rotated clockwise and anti-clockwise with respect to orientations of sand-wave crests. Orientations of megaripple crests suggest that deflections of residual tidal currents are controlled by bathymetry and the presence of the tidal sand banks. Average crestline orientations are 90-110º N, but with a strong spatial effect (Fig. 2). Spatial variations are also apparent in the distribution of maximum wavelenghts of megaripples, which decrease towards the north. Two types of megaripples are observed. Straight 2D ripples are the common types, but wider-spaced 3D megaripples are present at the crests of some sand waves (Fig. 3). Hennings et al. (2000) observed maximum current velocities for sand wave crests and minimum current velocities for sand-wave troughs. In contrast, on the tidal ridges parallel to the mean flow, megaripples have greater average wavelenghts in the troughs than on the bank crests, which would be consistent with stronger currents in the troughs than on the bank crests.

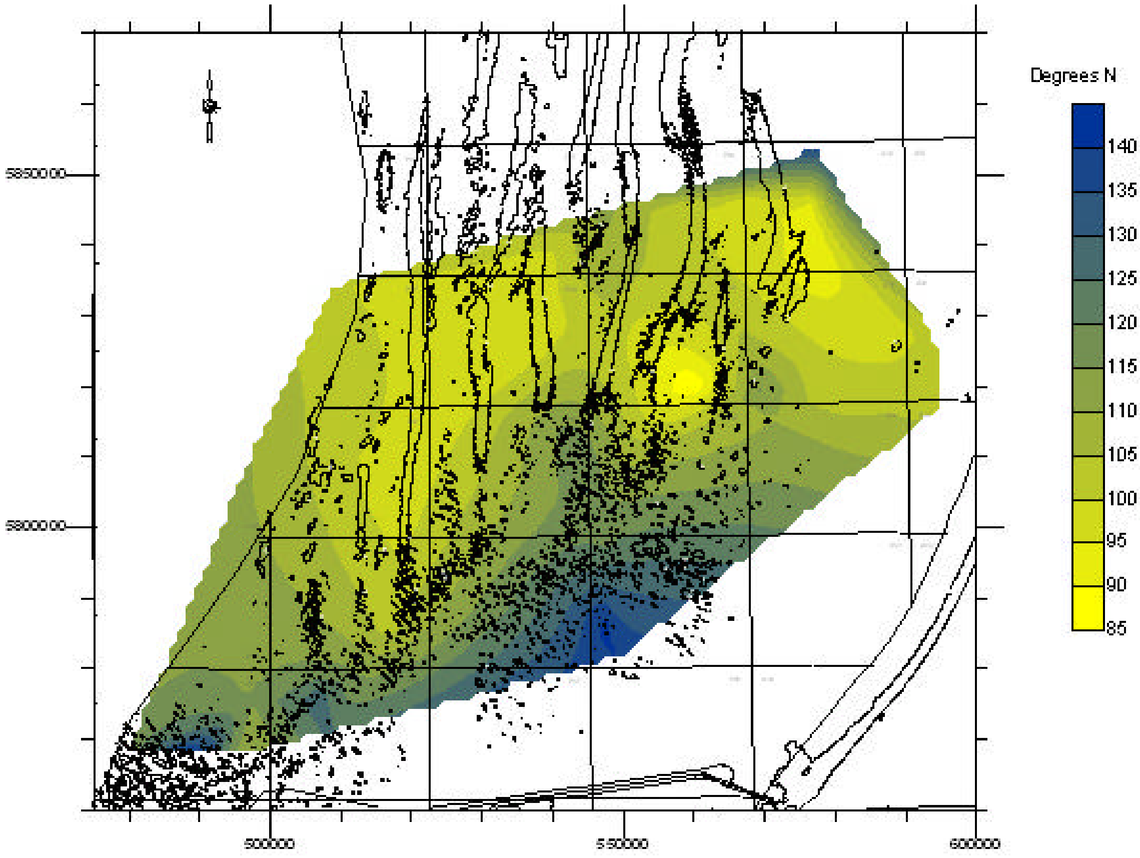

Fig. 2 – Orientation of megaripple crest lines.

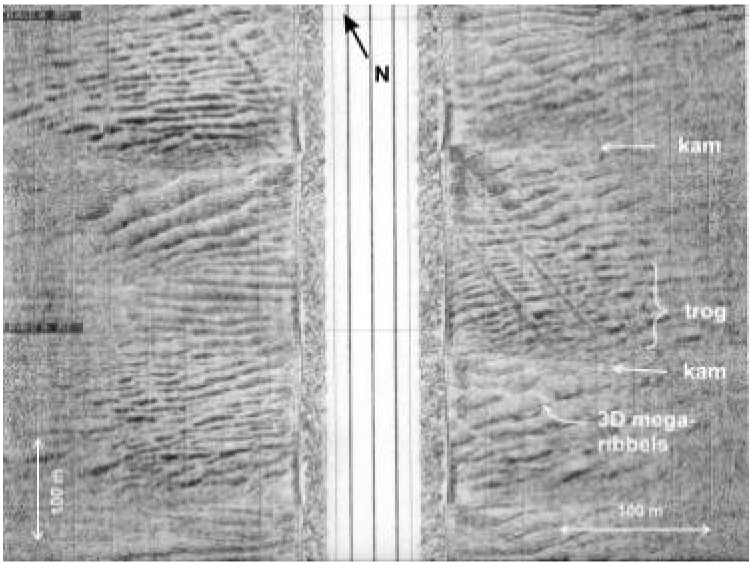

Fig. 3 – 2D and 3D megaripples superimposed on sand waves. Note the change to 3D ripples and the anti-clockwise rotation of the megaripples towards the sand-wave crest (=kam). "Trog" means "trough".

4.2 Sand waves

Sand waves are between 1 and 17 m high, but 81% are 1-6 m high. Observed wavelenghts are < 100 to 859 m, with 76% at 100-400 m. Seventy % of crestline orientations are at 100-130º N. Clear spatial distributions are apparent in sand wave height, wavelength, crestline orientation, symmetry, and crestline type (plan view). Most of the sand waves are asymmetrical with steep slopes oriented to the north. Sand-wave height decreases in a northward direction (Fig. 5), accompanied by an increase in linear straight-crested and sinusoid crest types (plan view) and a decrease in median grain-size. McCave (1971) attributed the northward decrease in sand wave height with an increase in suspension transport of sand, and the northward boundary of the sand wave field to a decrease in the tidal asymmetry. Sand-wave wavelength in general increases with decreasing water depth.

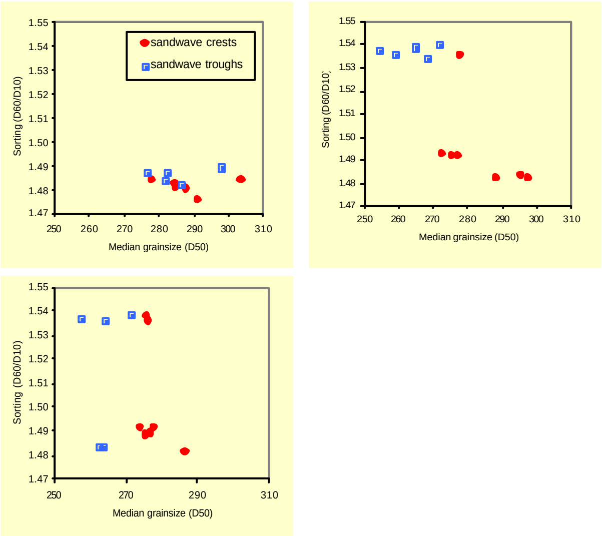

Fig. 4 – Grain-size distributions at several locations on sand wave troughs and crests in March, June, and September 2001, in a 1 x 1 km area.

Grain-sizes of sand-wave troughs and crests were measured in box-core samples during 3 surveys of the Ecomorphodynamics project in 2001 (Fig. 4). In the June and September surveys, clear separation of grain-size parameters between sand-wave troughs and crests was apparent: sand-wave troughs became finer and poorly sorted. Terwindt (1971) also observed grain-sizes that were generally coarser on sand-wave crests than in sand-wave troughs for most of the sand waves he studied, and explained the absence of clear crest-trough variability at some locations to variations in hydrodynamic conditions. The observations of the side-scan sonar images of this study, which show 3D ripples at some sand-wave crests (Fig. 3), but 2D-megaripples on others seem to support variations in hydrodynamics. Differences in grain-size between crests and troughs of the Ecomorphodynamics monitoring area associated with different wind-wave conditions. The March sampling campaign occurred after a three-month period of fair-weather conditions, whereas the June and September campaigns occurred after northwestern seasonal storms with significant wave heights of 3-4 m (Meetpost Noordwijk). Although a relation to hydrodynamics is likely, the effect of macrobenthos distribution cannot be ruled out. In March, no clear distinction existed between benthos in troughs and on crests, whereas in September crests and troughs had different characteristic species compositions (Van Dalfsen et al., 2002).

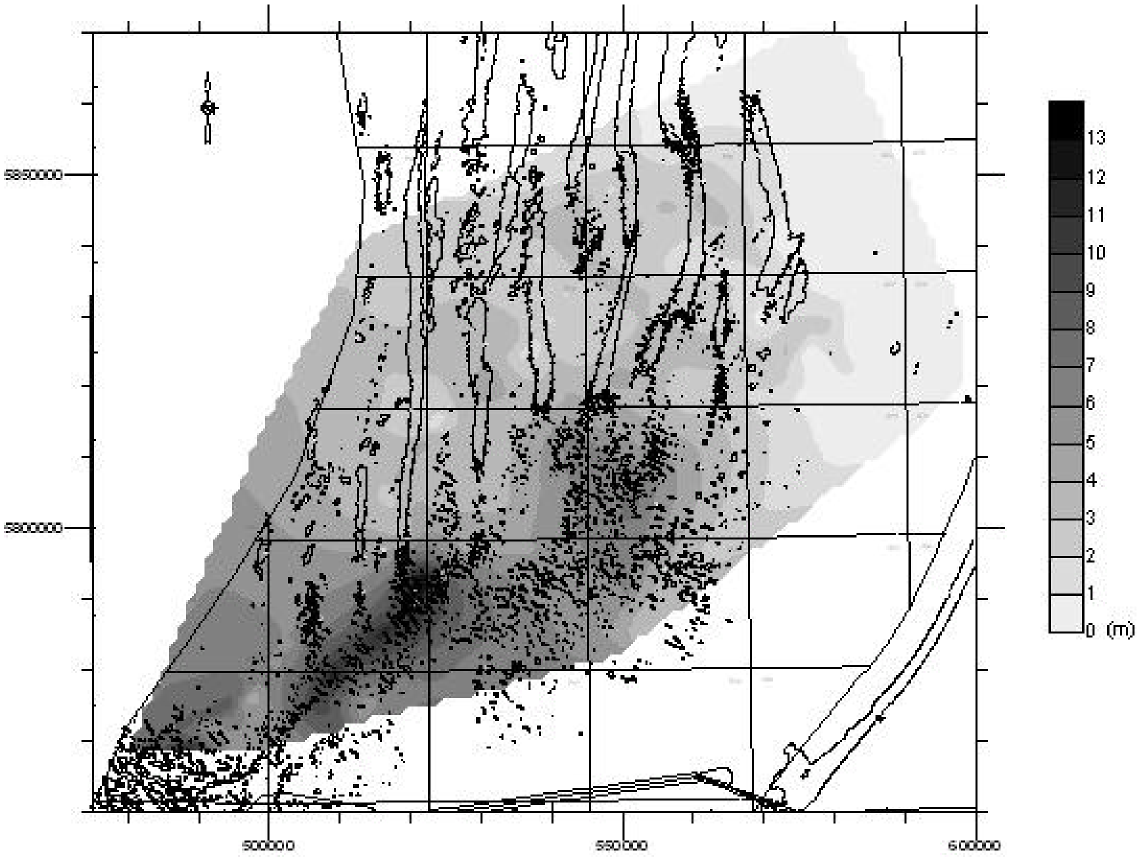

Fig. 5 – Sand-wave amplitude (m).

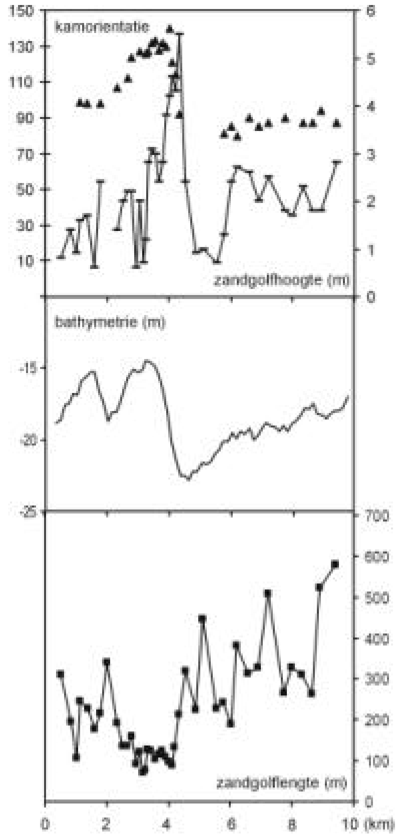

Fig. 6 – Changes in sand wave characteristics across a tidal sand ridge. Upper panel: black triangles= orientation of sand-wave crests (º N), hyphens=sand-wave height (m), kamorientatie= orientation of crests, zandgolfhoogte= sand-wave height. Middle panel: bathymetry (m). Lower panel: wavelength of sand-waves (m).

4.3 Tidal sand ridges

The geometries of the tidal sand ridges are variable but with a clear trend from N-S oriented linear ridges to the west to s-shaped ridges in shallower water depths towards the coast. This spatial distribution is similar to that of the Norfolk Banks near the English coast (Caston, 1972). Deep troughs are present east of the ridges and the amplitude of the ridges is up to 20 m. The ridges are regularly spaced at aprox. 10 km. In this study, observations on interactions between sand waves and tidal sand banks show that sand wave height is at a maximum on the eastern steep side of the ridges. Wavelenghts of sand waves are very small at the ridge crests, and the orientation of the sand-wave crests is rotated in a clockwise direction (Fig. 6). Although sand waves usually occur at an angle to the current direction, the sand-wave crest patterns on the ridge suggest that long-term residual sand transport is across the ridge crest. Large, symmetrical sand waves are found on the steep eastern side of the tidal ridges (Fig. 7). In the south of the study area, symmetrical sand waves can be related to divergent residual sediment transport directions (McCave, 1971). However, the symmetry of sand waves can also be caused by convergent transport or in a shear zone with two regions of sand waves moving in opposite direction (McCave and Langhorne, 1982). In contrast to megaripples in the southern part of the research area, megaripples have a more east-west crestline orientation near the tidal ridges. Megaripples are small-scale bedforms, which are usually good sediment transport indicators, and their orientation suggests transport parallel to the orientation of the ridge crests (Fig. 2). These observations leave room for the formation of large symmetrical sand waves east of the ridges by convergent residual sediment transport in two directions, across the bank and parallel to the ridge crest. These observations are very similar to those of McCave and Langhorne (1982) for the inner ridges of the Norfolk Banks.

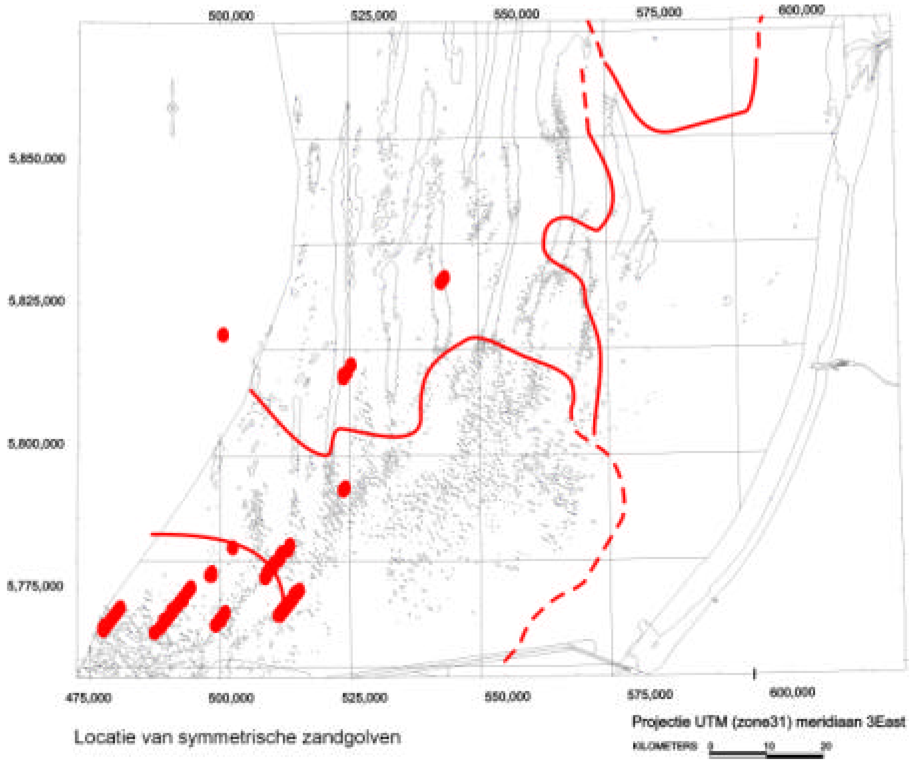

Fig. 7 – Location of symmetrical sand waves (dots).

Acknowledgment

The data discussed here were collected for WL|Delft Hydraulics within the framework of Mare, which is a consortium funded by the Dutch Ministries of Public Works, Spatial Planning, Housing, and Environment, and Economic Affairs, and the aviation sector. The echosounder data and side-scan sonar records were collected by the Hydrographic Survey of the Royal Dutch Navy. Echosounder data were processed by Peter Frantsen (TNO-NITG).

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