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Processing and mosaicking digital side scan sonar images: two examples from the western Baltic Sea

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Side scan sonar as a method of acoustic remote sensing is used for mapping sediments and seafloor structures. Recent technological advances have brought the objective of complete area mapping into the mind of researchers. A typical survey includes several profiles, run on parallel tracks with a certain amount of overlap. The main purpose of digital image processing was to focus on the specific characteristics in the sonar imagery and to correct them geometrically. In a second step the profiles were transferred into a geographical information system (GIS) and combined to mosaics. Two image examples from different sedimentary environments of the western Baltic Sea, a sand wave field in Fehmarn Belt and the glacial channel structure Wattenberg Channel, are presented.

▱ Western Baltic, side scan sonar, image processing, sediments, glacial channel, sand waves.

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INTRODUCTION

Side scan sonar images have been used to get detailed information about the seafloor for more than 30 years (Newton *et al.* 1973, Flemming 1976, Stefanon 1985, Fish & Carr 1990). During the last two decades, advanced technologies lead to the increased use of digital data collection with side scan instruments.

In fact a side scan sonar image is not an imagery of how the seafloor would look like, if the water were somehow removed from the ocean. Instead, it is rather a graphical presentation of how the seafloor interacts with acoustic energy. Two of the main parameters affecting the backscattered energy (Sutton 1979) are the roughness or texture and density of the surface cover (e.g. rock, sand, biologic type of the seafloor). Bright tones in our images represent areas with low backscatter and vice versa.

Years ago, the first analogue side scan sonar data could only be displayed on wet-paper recorder. Single profiles had to be photographed and stacked together by hand onto a map to originate an image of a complete area (Belderson *et al*. 1972, Werner *et al*. 1976).

Development of digital side scan processing was started by the United States Geological Survey (USGS) in 1979 (Teleki *et al*. 1981, Chavez *et al*. 2002) using expertise developed to process and analyse side looking airborne radar. Technical advantages within the digital domain provide now the possibility to store, enhance and display the data. The main purpose of these procedures is to geometrically correct the image and to emphasize special characteristics in the profiles.

Geographical corrected side scan sonar profiles are implemented into a Geo Information System (GIS). For the interpretation of seafloor characteristics and structures, several parallel lines of profiles are combined to a mosaic. Depending on backscatter characteristics, several types of sediments can be distinguished after ground truthing. Using additional information, such as water depth and thickness of different sediment layers, the bottom character can be specified (Johnson & Helferty 1990).

The objective of this paper is to describe the processing and manipulating capacities used to generate digital mosaics and to apply these techniques to two case studies from the western Baltic Sea: (1) a formerly surveyed sand wave field in Fehmarn Belt and (2) a glacial channel structure (Wattenberg Channel) with highly diverse seafloor characterisation are presented (Fig. 1).

SYSTEM CONFIGURATION AND DATA PROCESSING

A commercial digital side scan sonar (Klein System 2000) was used for the surveys. It consists of a dual frequency (100 kHz and 500 kHz) sonar fish, cable, and digital recorder and is combined with a 3.5 kHz sub-bottom profiler (SBP). Side scan sonar and SBP data are recorded digitally in the sonar fish. The data are transferred via the cable to the recorder for further processing on board the ship. The raw data are compressed and stored on cartridge tapes. Navigation data are read from serial link and stored together with the raw data. The data are displayed on a video display and on a grey scale recorder. Water depth is measured through a hydrographic echo sounder (single beam, 30 kHz or 200 kHz), installed on board the research vessel. Preprocessing and processing is done using the Triton Elics ISIS Seafloor Imaging software package (Charlot *et al*. 1994).

Special computer techniques are used to correct and manipulate the data to focus on the specific characteristics in the sonar images. Fig. 2 shows a flow chart of the different preprocessing and processing steps performed by the Triton Elics software.

Processing is separated into two different stages: preprocessing and post-processing or information extraction. Preprocessing of the side scan sonar data includes two different steps: (1) geometric corrections and (2) radiometric corrections (Blondel & Murton 1997). Navigation data are merged during the survey in the recording system. The raw data file for each record include subbottom profile, 100 kHz and 500 kHz side scan data and the navigation data.

(1) Geometric corrections include the water column offset, slant-range correction or slant-range to ground projection, the aspect ratio and changes in ships velocity. The aspect ratio determines the spatial position of a pixel.

Side scan sonar systems start recording data as soon as they transmit an acoustical wave. Therefore a certain number of pixels to both sides of the nadir (centre of swath) contain information about the water column. The nadir pixels are offset on both sides as a function of water depth or fish altitude. The altitude is given by the first significant echo received on each scan line. Due to the geometry of the side scan sonar the image obtained is distorted in the across-track direction and must be corrected for obliqueness, the so-called slant range correction.

After the sonar image has been corrected for slant range distortion and water column has been removed, prominent across-track variations in signal intensity generally remain in the image. They result in track-parallel stripes of high and low intensity, commonly caused by the beam pattern (having a special

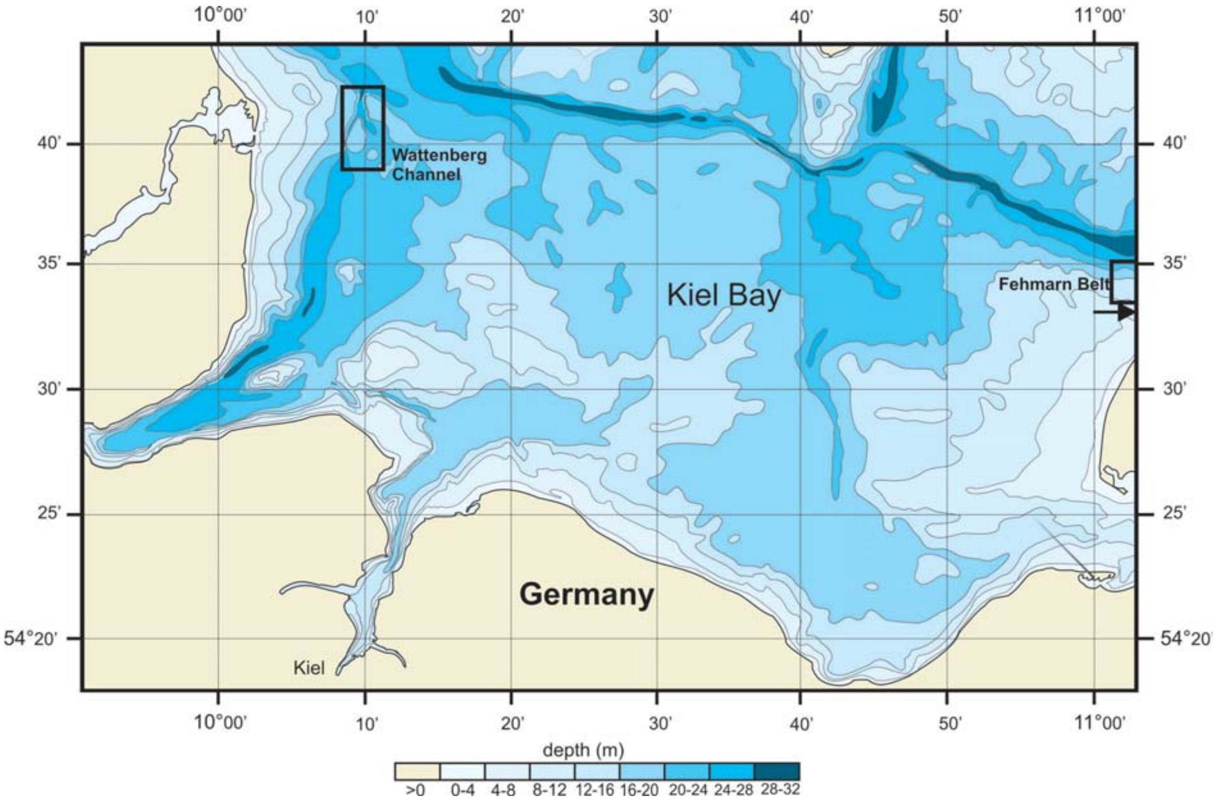

Fig. 1. Location map of Kiel Bay with investigation areas in Wattenberg Channel and Fehmarn Belt. Geographic names are used according to the terminology of Babenerd & Gerlach (1987). The arrow indicates further extension of the Fehmarn Belt sand wave area.

characteristic for each system), which have to be eliminated.

The sampling interval in the along-track direction generates pixels with a spatial resolution different from that in across-track direction, so a correction to give both directions the same spatial resolution is required. Changes in ship's velocity change the spatial resolution of the image in the along-track direction. These distortions are removed by using the positions in latitude and longitude to calculate the distance travelled over a given time frame.

(2) Radiometric corrections change the intensity or the digital value assigned to a pixel (the amplitude of the return signal). They include corrections due to power drop-off from near to far range, corrections of speckle noise and blocky appearance due to extreme aspect ratio differences. A user defined selection of four parameters: gain at the initial sea bed position, gain at the end of the scan line and position and value of the intermediate point can be performed by the software package. Additional filtering for 2D noise and contours can be applied on the image (Charlot *et al.* 1994).

The procedure of digitally mosaicking side scan sonar images is more difficult than those required for other types of remotely sensed data, such as satellite or airplane images, because geometric control is usually available only at nadir and navigation inaccuracies provide both high and low frequency errors (Fiedler & Milkert 2002).

Small jitters in position are filtered out from the navigation data. This is followed by digital processing of the profiles and combining them into a full-scale mosaic. Additional information about the bathymetry from an echo sounder system and the seismic information from a subbottom profiler can be added to the GIS and mosaic.

All mosaics are presented in UTM (Universal Transverse Mercator) Projection at WGS Datum (1984) because this projection provides nearly real metric distances.

RESULTS

Sand waves in Fehmarn Belt

Fehmarn Belt is one of the main passages for water exchange between the western parts and the central Baltic (Fig. 1). The oscillation in Kiel Bay is stimulated by sea level changes in the Kattegat, generated by atmospheric circulation (Wittstock 1987). Due to the dominating western wind, inflow of water masses (from W to E) must be regarded to have the most important impact on the sea bed in the channel system of Kiel Bay (Werner *et al.* 1987). The distribution of bedforms is generally considered to be a good indicator of current dynamics in shelf seas and it reflects the main current system. In the Fehmarn region sand wave fields occur in restricted areas. These restrictions are not only due to current patterns, but also to other fac-

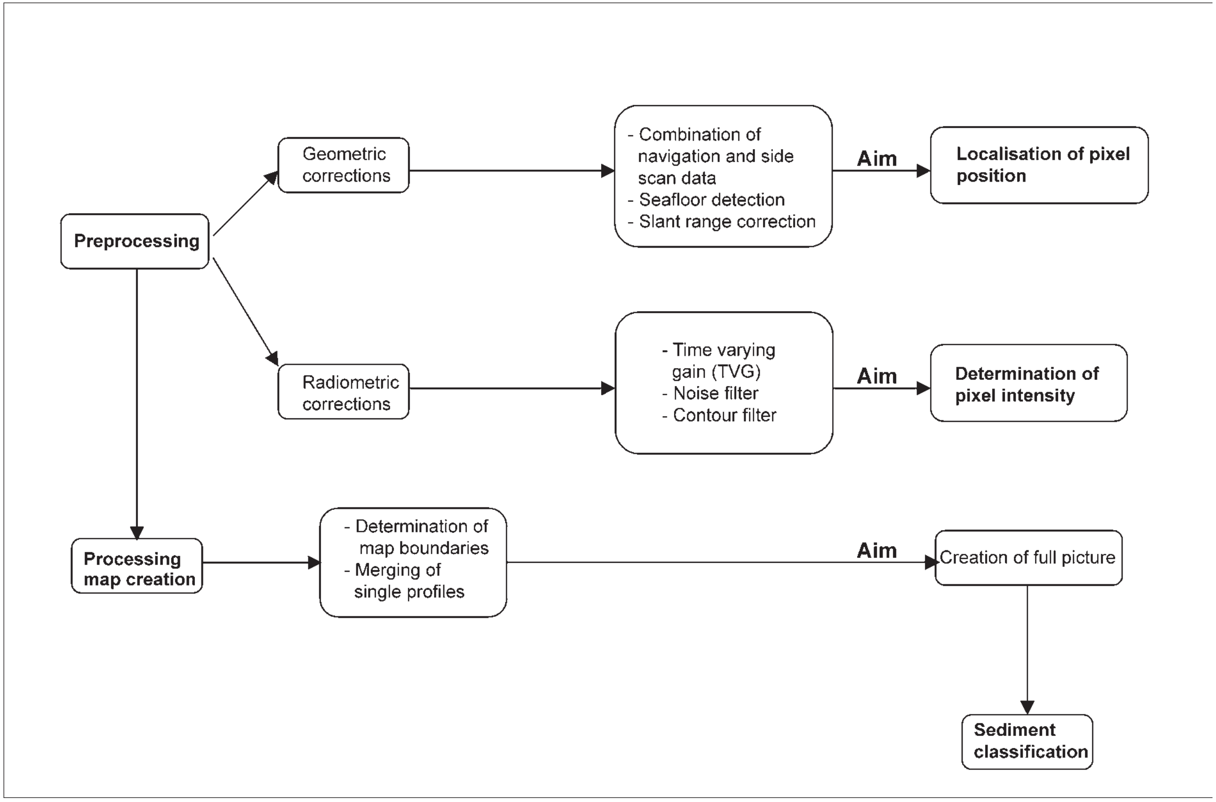

Fig. 2. Flow chart showing the different preprocessing and processing steps performed by the Triton Elics ISIS software.

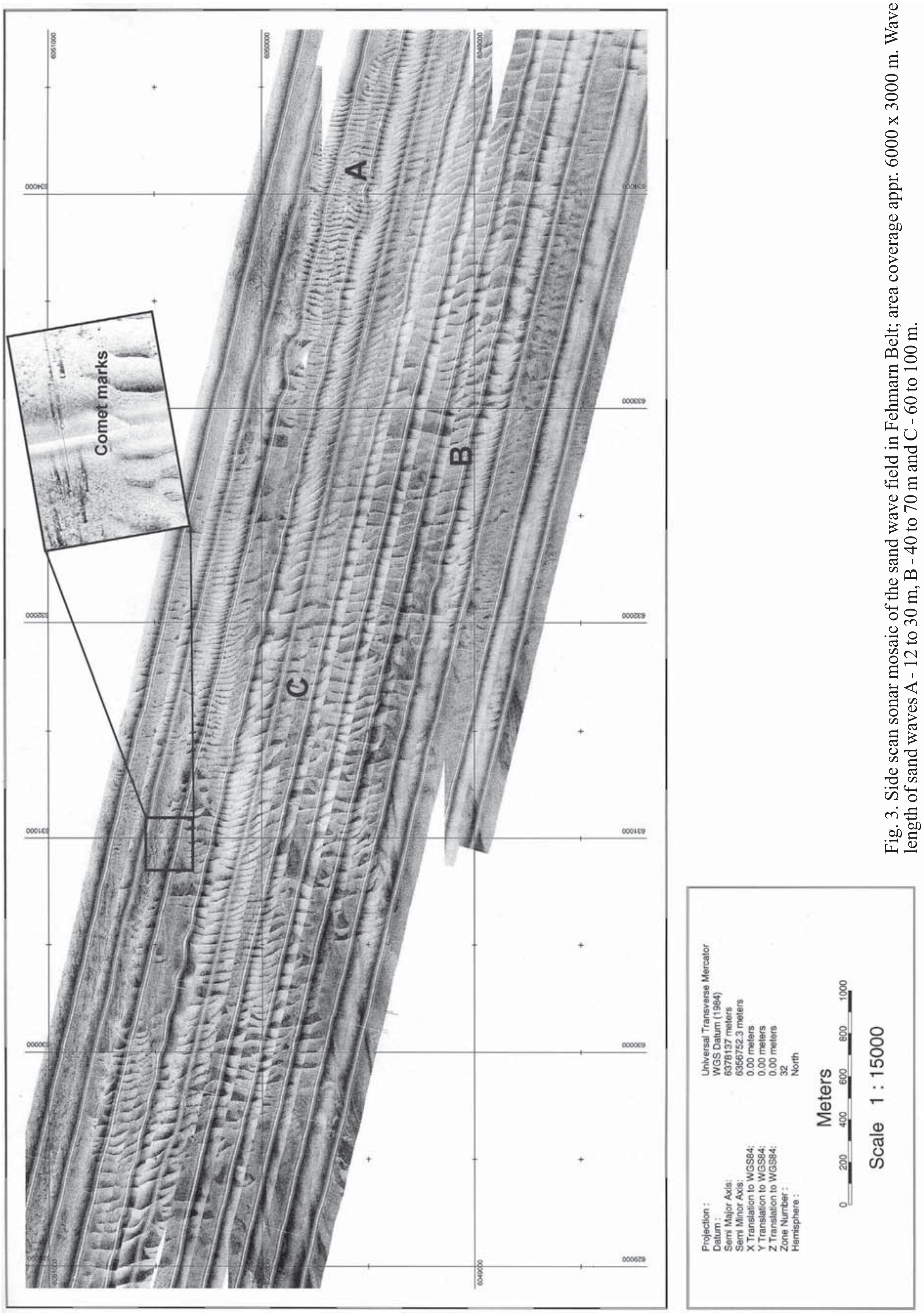

Fig. 3. Side scan sonar mosaic of the sand wave field in Fehmarn Belt; area coverage appr. 6000 x 3000 m. Wave length of sand waves A - 12 to 30 m, B - 40 to 70 m and C - 60 to 100 m.

tors, which have to be seen mainly in connection with the sand transport system, sediment source and local current acceleration due to topographical conditions (Werner *et al.* 1974; Werner & Newton 1975). The sand wave field was completely mapped using conventional analogue side scan techniques by Werner et al. (1974).

The complete coverage of the sand wave field of approximately 6000 x 3000 m in Fehmarn Belt is shown in Fig. 3. It is the first digital mosaic of the Fehmarn Belt area. The data were achieved during a three-day survey (Fiedler 2000). The region proves to be an excellent example for complete mapping of small-scale areas in high resolution. The side scan sonar profiles were run at 100 m range and 150 m distance between each profile in WSW to ENE direction; towing speed was 4 knots. Water depth ranges in the area between 12 and 23 m.

The seafloor at this site contains mainly medium to coarse sand. In the southern part a higher percentage of till material occurs, whereas in the northern part the increase in water depth goes parallel to an increase in mud content. Small-scale ripple structures occur in areas with finer material.

Observations indicate that inflow on the southern side of Fehmarn Belt is steadily superior on outflow probably due to Coriolis force (Fennel 1995), and therefore the sand waves show the fluviatile form type as described by Allen (1982). They exhibit a strongly asymmetric profile with steep leeside angles and rounded crests at their highest elevation (Kaufhold 1988). Observed small-scale ripples on the slopes and sliding structures indicate that sand migrates at least during major events (Kaufhold 1988; Werner 2000). Current crescents and so-called comet marks (Werner & Newton 1975), are formed by a steady flow over an obstacle. They embrace a u-shaped to almost moat-like scour hollow, the arms terminate downstream. In the investigation area comet marks with clear east-west orientation are found just north of the sand wave field (Fig. 3).

Three different areas of sand wave length can be distinguished and are indicated in Fig. 3. In the northern part (area A), wave lengths vary from 12 to 30 m with mean crest heights of 1 m. In area B the sand waves show wave lengths between 40 and 70 m with mean crest heights of 2 m, whereas in area C they display the greatest wave length with 60 to 100 m and a mean crest height of 3 m. Wave lengths increase from north-east with around 20 m to south-west with around 100 m. Crests in western part of the area (Fig. 3) are mainly oriented north-south, in the eastern part 165° is dominating.

The Fehmarn sand wave field was formerly investigated by Werner *et al*. (1974) and Kaufhold (1988) by using analogue side scan sonar records. The field seemed to be stable in extension for decades. This observation was supported by the fact that the crests of the sand waves were densely populated by the long-living bivalves *Mya arenaria* and *Arctica islandica* (Werner *et al*. 1974). According to the observations made by Kaufhold (1988) it was stated that the sand wave field show several inductions for a recent mobility. Sliding structures formerly not observed, but now a widespread phenomenon was described in detail by Werner (2000). Werner (2000) concluded that the field shows a discontinuous mobility and a sensitively reacting morphology, useable as a tool for the development of storm intensity and frequency. According to our investigations the sandwave field shows extension in size to the west.

Future variations of the sand wave field due to extreme weather conditions can be observed by using and comparing the side scan mosaics. It is a further objective of the investigations to present an exact reference map for past and future investigations on bedform migration. This key area of water exchange between the Baltic and the Kattegat might be influenced by the recent bridge constructions in Denmark, Sweden and planned in Germany. The sand wave field proved to be a good marker for changing current intensities.

Wattenberg Channel

Wattenberg Channel (Fig. 1) is one of a series of partly filled glacial channels which dominate the seafloor morphology in the western Baltic. They originated from the glaciers of the last glacial maximum. The channel structures in their present shape and position are a picture of the changing geological influence through time (Gripp 1964). With the beginning marine ingression into Kiel Bay around 8000 years ago, the sea started to shape the channel by erosion and abrasion. Sedimentation predominates the deeper parts. Facies boundaries are generally parallel to the isobaths unless fetch or bottom morphology change suddenly (Seibold *et al*. 1971). Fig. 4 provides the geological map of Wattenberg Channel modified after Lemm (1988). Generally a sediment zonation parallel to water depth contour is obvious. The decrease of wave energy with water depth and the weaker water movements in the deeper parts of the basin are reflected by a general increase in mud content as being the rule in Kiel Bay. In the shallow parts dominate outcropping lag sediments (moraine remains) the seafloor. In the north-western part small patches of different sediments are visible (Fig. 5). Mixed sediments represent a palimpest facies (Werner *et al*. 1987). The thorough mixture of younger fine sediment with coarse relict material is an effect of bioturbation. Mixed sediments occur at places with gentle slopes at the transition zone of sand to mud.

Figure 5 shows a side scan sonar mosaic of around 4000 m x 1000 m in Wattenberg Channel. Included are sample locations and sediment type indications (Fiedler & Milkert 2002). The 3.5 km long channel is between

400 m and 800 m wide. Water depth ranges between 24 and 32 m.

Higher backscatter in parts with outcropping glacial till at the edges of the channel is shown in darker tones (Fig. 5), whereas low backscatter in the muddy sand area are much lighter. The mud filled channel structure can be seen quite clearly, because of the low backscatter. Bottom samples included a variety of different sediment types such as till, sand, mud and mixed sediments.

The integrated 3.5 kHz echo sounder allowed to map the thickness of soft sediments such as mud and small scale transitions from one sediment type to the other (Fig. 6) during the side scan survey. Although the 3.5 kHz sub bottom profiler does not yield optimum records, the essential features are present, and it has the advantage, that only a single is needed and run at the same time. In Figure 6 the glacial moraine, the postglacial sedimentary section and the influence of acoustic turbidity on the sediments are marked separately. A more detailed description of the seismic sections in this part of Kiel Bay was given by Atzler (1995). For our purpose it is important to verify the general differences. The greatest thickness of mud sediments occurs in the south-western corner with more than 8.0 m of Holocene mud. Caused by strong bottom currents only mixed sediments can be observed in some deeper parts of the area. The side scan sonar mosaic compared with bathymetry and thickness of muddy sediments is shown in Figure 7. The interval of depth contour lines is 2 m. In the northwest corner of the area the data density was not sufficient for the depth of mud sediments, therefore depth contour lines are not displayed. According to ground truthing even in the deepest parts of the channel only a thin cover of fine grained sediments is present, and close by a thick trough-filling of Holocene mud occurs.

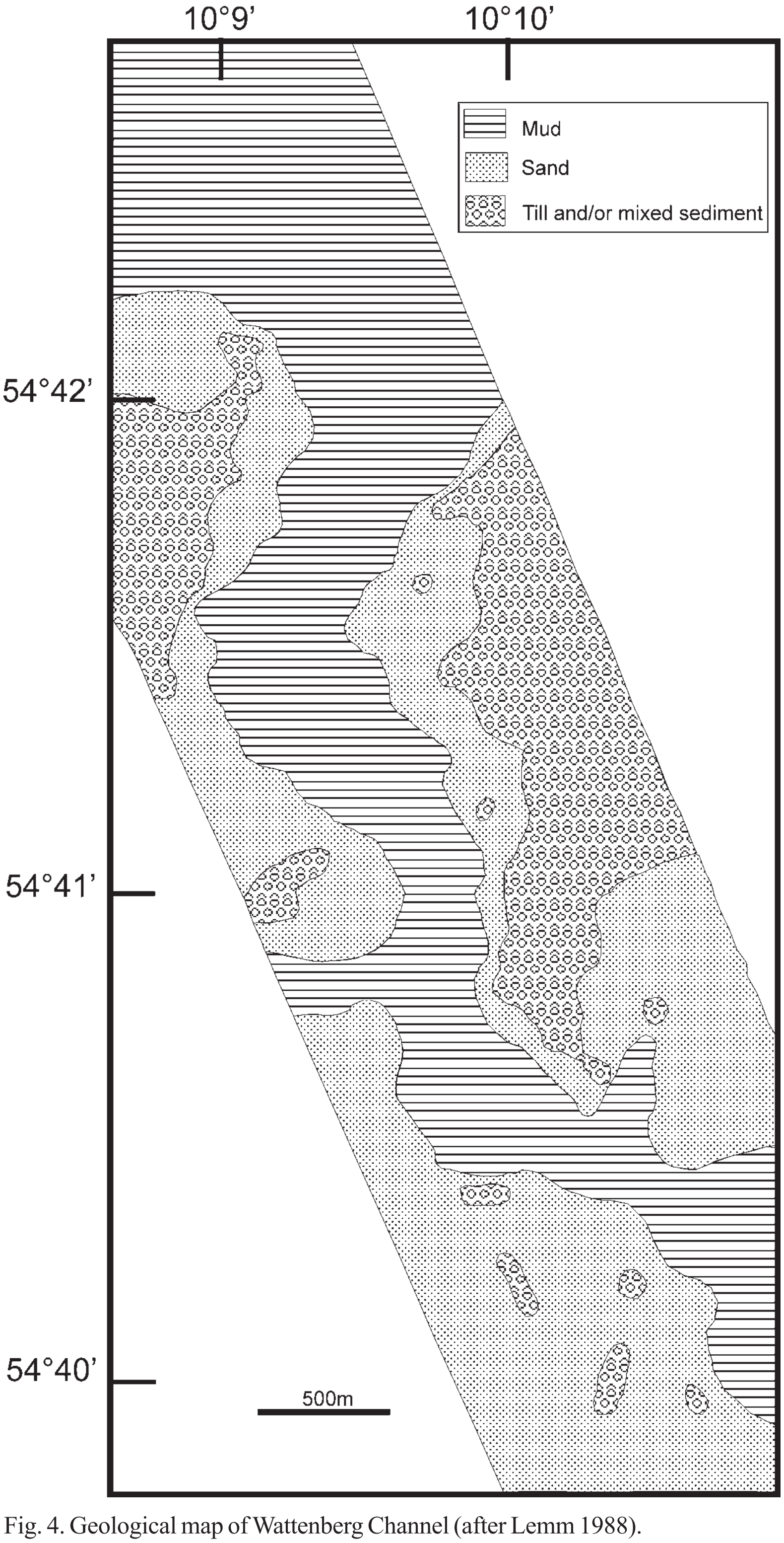

Fig. 4. Geological map of Wattenberg Channel (after Lemm 1988).

CONCLUSIONS

Processing and analysing capacities with the Triton Elics ISIS software package were used to generate digital mosaics from Fehmarn Belt and Wattenberg Channel. The resulting digital mosaics are used to map the seafloor in these areas. The data are based on a conventional Klein Sonar System 2000.

The Fehmarn sand wave field was investigated several times during the last 30 years by side scan sonar (Werner *et al*. 1974, Kaufhold 1988; Werner 2000; Fiedler & Milkert 2000). The first investigations showed that it seemed to be stable in extension for decades due to the fact that the crests of the sand waves were densely populated by the long-living bivalves *Mya arenaria* and *Arctica islandica* (Werner *et al*. 1974). According to the observations made by Kaufhold (1988) it was stated that the sand wave field shows indications for a recent mobility. Werner (2000) concluded that the field provides a discontinuous mobility and a sensitively reacting morphology, usable as a tool for the development of storm intensity and frequency. According to our investigations a further extension of the field to the west could be proved.

A further objective of the investigations is to present a reference map for past and future investigations on bedform migration. The Fehmarn Belt region as a

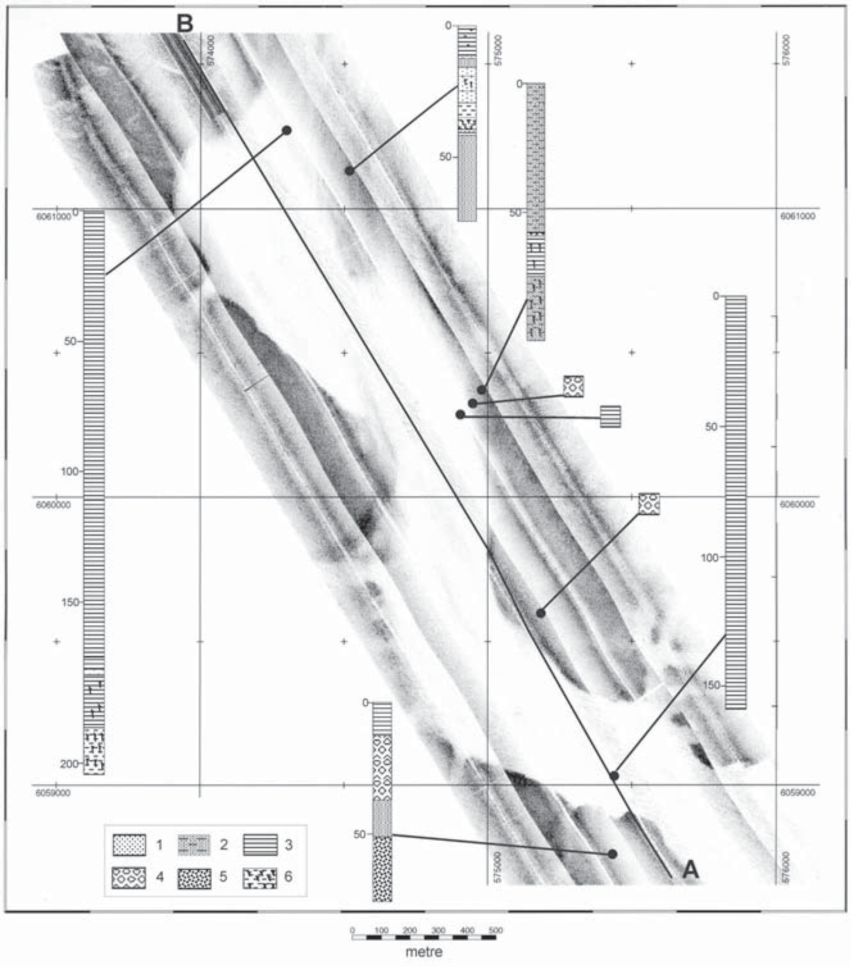

Fig. 5. Side scan sonar mosaic of Wattenberg Channel with coring locations, giving the sediment profile (tick marks: 50 cm). 1- coarse and middle sand, 2- silty fine sand, 3- pelitic mud, 4 - mixed sediment, 5- till, 6- peat. Line A-B shows location of 3.5 kHz echo sounder profile (see Figure 6).

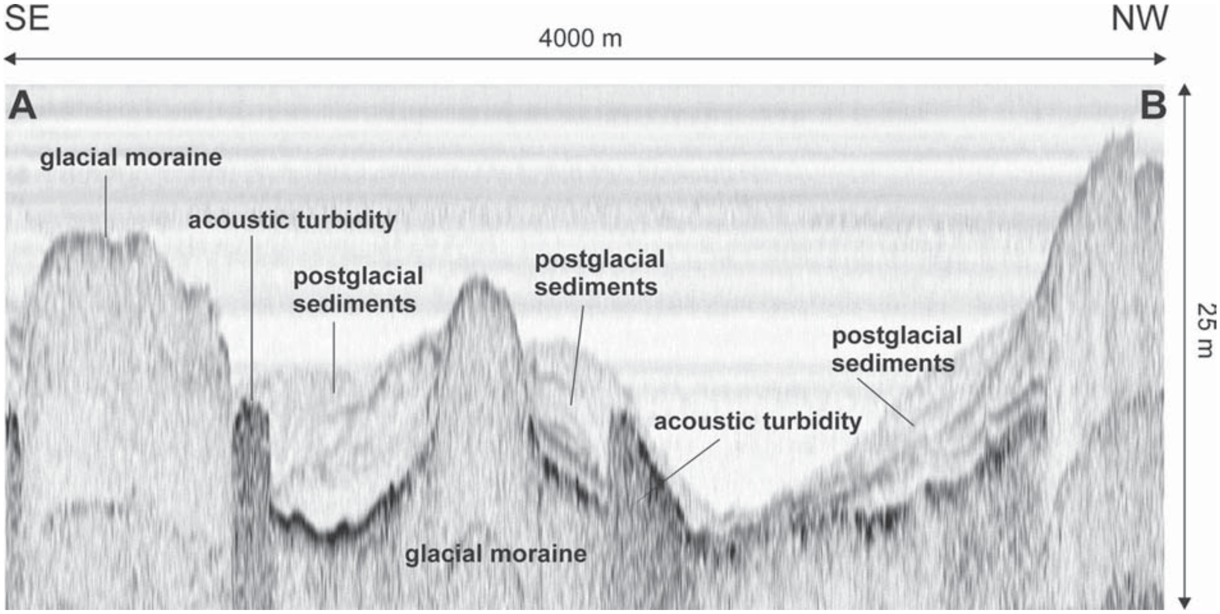

Fig. 6. Echo sounder profile (3.5 kHz), cross section through Wattenberg Channel.

key area of water exchange between the Baltic and the Kattegat might be influenced in the near future by the recent bridge constructions in Denmark, Sweden and in Germany (planned). The sand wave field will therefore to be a good marker for changing environmental conditions.

Wattenberg Channel represented a typical glacial channel structure of the western Baltic. The mud filled channel structure can be seen quite clearly on the sonar mosaic. The different types of sediment from outcropping till to sand and mud were determined and bottom referenced.

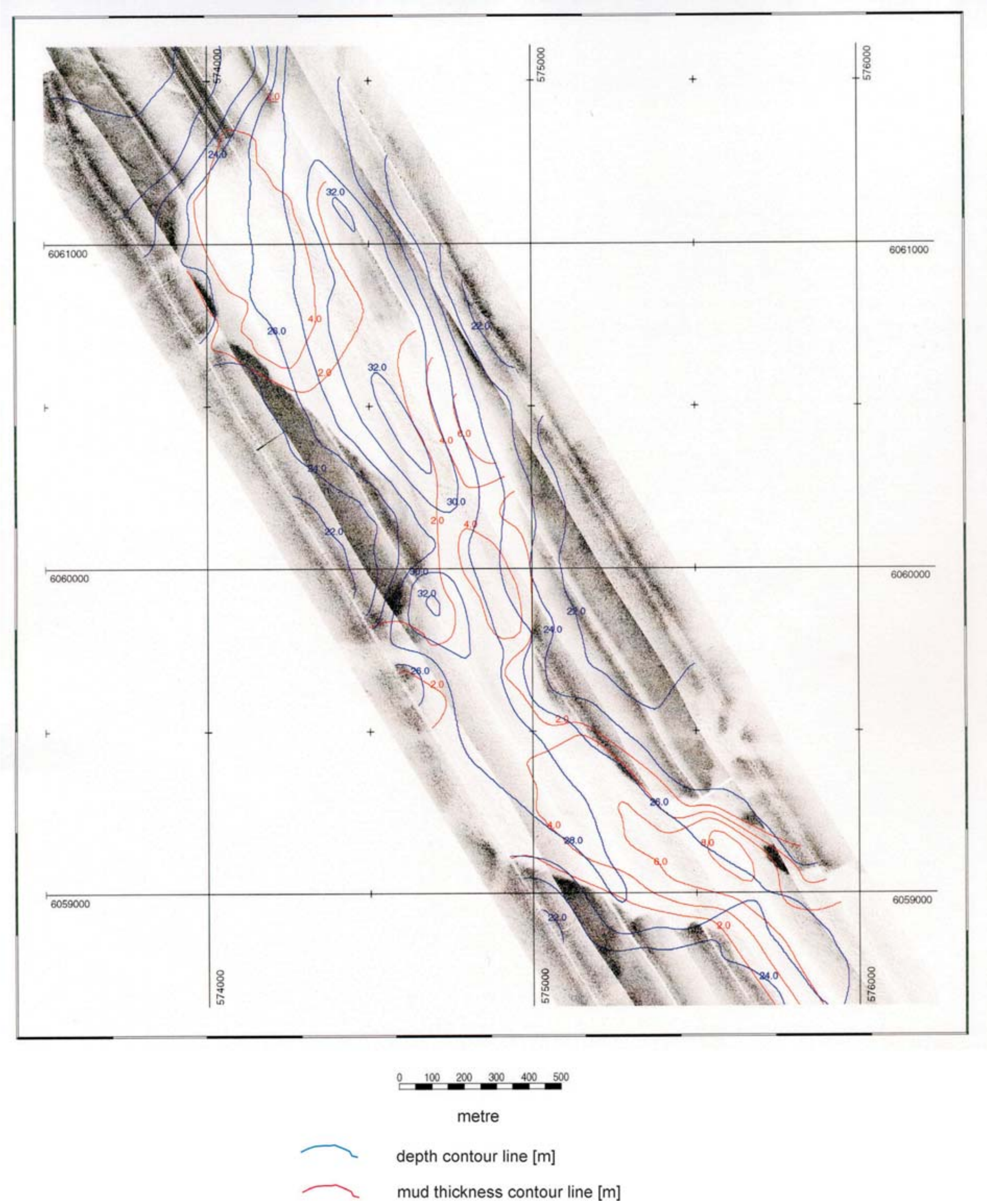

Fig. 7. Side scan sonar mosaic of Wattenberg Channel, western Baltic with overlying depth contour lines (blue lines) and thickness of Holocene mud sediments (red lines); contour interval 2 m, grid 1000 m.

The integrated 3.5 kHz echo sounder allowed to map the thickness of soft sediments such as mud and small scale transitions from one sediment type to the other.

Digital sonar mosaics provide detail information of the seafloor, which can help to gain a better understanding of the geology and near-bottom dynamic processes. The modern processing techniques help to maximize the information, which can be extracted from digital side scan sonar images.

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