Chapter 6

Identification of submarine hard-bottom substrates in the German North Sea and Baltic Sea EEZ with high-resolution acoustic seafloor imaging

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Abstract

Submarine hard bottoms (e.g., boulders, outcropping strata) are of particular ecological importance. They were investigated in the Exclusive Economic Zones (EEZ) of the German North Sea and the Baltic Sea, using high-resolution seafloor imaging techniques (i.e., sidescan sonar and multibeam echosounder). Examples are shown from the research areas *Sylt Outer Reef* (*Sylter Außenriff*; North Sea), *Kadet Trench* (*Kadetrinne*), and *Adler Ground* (*Adlergrund*) (both in the Baltic Sea). There exist distinct differences between the two continental shelf seas regarding the distribution of boulders and the density (percent coverage) of boulders per unit seafloor. The observed differences are attributed to (a) different geological evolution of the seafloor, and (b) different forcing by waves, tides and currents, which are responsible for the redistribution of sediments.

1 Introduction

Submarine hard bottoms such as boulders or outcropping strata generally support a diversity of marine plant and animal species and are therefore of great ecological importance. Detailed knowledge of the locations of submarine hard bottoms is a prerequisite for their further investigation, protection, and management. Unfortunately, published maps of the seabed geology of the German North Sea and Baltic Sea shelf areas lack the resolution necessary for detailed habitat analysis. The reason for this is that such maps were mainly produced based on surface samples (e.g., Figge 1981, Tauber and Lemke 1995, Tauber et al. 1999), which then introduced errors, whether numerical or manual, during the process of interpolation. Furthermore, boulders are probably underrepresented owing to the fact that the sampling instruments used are mainly constructed to sample mud, sand, and gravel.

These problems can be addressed by the application of acoustic seafloor imaging techniques such as high-resolution sidescan sonar or multibeam bathymetric technology (e.g., Cochrane and Lafferty 2002, Kostylev et al. 2001, Ojeda et al. 2004). A large body of sidescan sonar data from the German North Sea and Baltic Sea already exists (e.g., Niedermeier-Lange and Werner 1988, Schulz and Tauchgruppe Kiel 1983, Tahrir 1984, Werner et al. 1974, 1976, Werner 2004, Winn and Werner 1984, Winn et al. 1982), but results are spatially restricted. Moreover, data were gathered as analogue paper records and with limited positioning accuracy. Thus, we collected new data on sediment distribution patterns and seafloor topography in pre-defined research areas in the German North Sea and Baltic Sea EEZ (between 12 and 200 nautical miles from the coast) in order to provide a basis to outline the occurrence of submarine boulders.

2 Regional setting

During the last glacial maximum (ca. 21,000 years ago), the global sea level was ca. 125 metres lower than present levels (e.g., Fleming et al. 1998), exposing the world's continental shelves to subaerial processes. The subsequent flooding ("marine transgression") of the continental shelves during deglaciation took place with high rates until ca. 7,000 years ago, followed by a slower rate. Due to this relatively short time span, the continental shelves of the world's oceans presently exhibit relict features (Emery 1968) which are inherited from this subaerial exposure and modified by marine transgression. Typical examples in formerly glaciated regions are moraines deposited by glaciers and river valleys, which are sometimes deeply incised due to the formerly low-lying sea level. The veneer of marine sediments, which have been deposited since the flooding of the shelves, is still relatively thin (in metre-scale) or even absent, except in areas of high sediment input (e.g., river deltas and former river valleys).

According to the map of Figge (1981), large areas of the seafloor of the German North Sea are covered with sand of varying grain-size composition. The thickness of the marine sand veneer generally amounts to less than 2 metres (Figge 1981). Thicker marine deposits are restricted to the NW–SE-trending Pleistocene Elbe valley, where silty fine sands accumulate (Figge 1980), and to the shoreface of the *German Bight* (*Deutsche Bucht*) in water depths down to ca. 10 metres below mean sea level (Zeiler et al. 2000).

The Baltic Sea can be regarded as an epicontinental shelf sea. The sediment distribution in the southwestern Baltic Sea is much more heterogeneous compared to the North Sea. Although the sediment distribution is strongly affected by underlying geologic framework, a depth-dependent overall zonation of seabed sediments can be found (Seibold et al. 1971). Coarse-grained lag deposits (coarse sand, gravel and boulders) form a thin veneer (of a few decimetres) covering morainal deposits, mainly in water depths of 5 to 15 metres along the coasts and on submarine sills. Those sediments are the result of abrasion of morainal material. Fine material up to sand size is removed by waves and currents, leaving the coarser constituents behind. Such lag deposit areas are surrounded by well-sorted fine-to-medium sands. Apart from the immediate proximity of the coast, this sand veneer is relatively thin, for example, 0.5 to 2 metres in the *Kiel Bight* (*Kieler Bucht*) (Seibold et al. 1971). Significant amounts of marine sediments are found in deeper basins and channels of the Baltic Sea, where fine-grained, organic-rich mud accumulates.

In the following, data from three sites are presented. From the North Sea, we show results of an area 70 to 100 km west of Sylt Island in water depths of 25 to 40 metres (*Sylt Outer Reef*, figure 1). From the Baltic Sea, results are presented from *Adler Ground*, located between Rügen and Bornholm Island in water depths of 5 to 25 metres, and *Kadet Trench*, where the research area is located between Fischland-Darss-Peninsula and Falster Island in waters of 10 to 30 metres deep (figure 2).

3 Methods

We employed a towed Klein 595 (Klein Associates Inc.) dual-frequency (100 and 384 kHz) sidescan sonar system (see figure 3) and a hull-mounted Seabeam 1185 (Elac Nautik) 180 kHz multibeam swath-bathymetry system, which also collects co-registered acoustic backscatter. The recorded spatial patterns of backscatter intensity were interpreted in terms of seafloor relief and sediment type. Validation of the data was achieved by grain-size analysis of seafloor sediments and by underwater video surveying. Additionally, single-beam echosounder data were

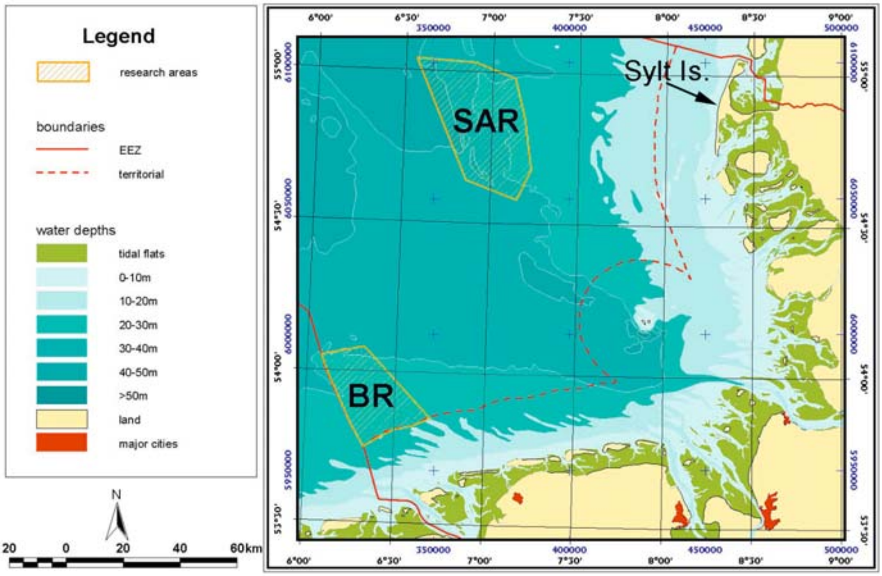

Figure 1. Location of the research area *Sylt Outer Reef* (SAR) in the German North Sea EEZ. BR denotes a further research area (*Borkum Reef Ground – Borkum-Riffgrund*) not discussed in this text

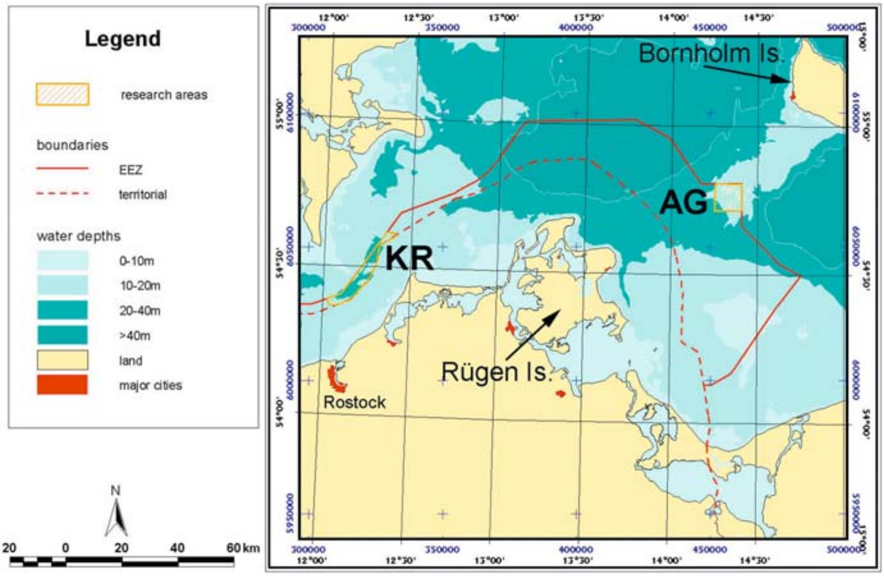

Figure 2. Location of the research areas *Kadet Trench* (KR) and *Adler Ground* (AG) in the German Baltic Sea EEZ

collected routinely. The ship's tracklines were chosen to allow full coverage of the seafloor. Positioning was achieved by differential GPS, which provided an accurate position of the vessel (and therefore also of the multibeam) within a 5-metre margin. The sidescan sonar was towed behind the vessel at a distance of about 20 to 50 metres, depending on the water depth and the range selected. This offset was accounted for by a constant value for each profile when calculating the position of the towfish[1]. The positioning error is thus greater compared to the multibeam, but this is difficult to quantify.

The Klein 595 sidescan sonar system was run in the high frequency mode in order to allow the highest resolution imaging. Due to the limited water depths, the selected ranges were 75 metres (Baltic Sea) and 100 metres (North Sea) on each side of the sidescan sonar. The 126 individual beams of the Seabeam 1185 multibeam system allowed a swath width[2] of about seven times the water depth.

Sidescan sonar data were recorded in digital format employing the Isis software package (Triton Elics International). These data were processed and geo-referenced[3] using the same software in order to create sidescan sonar mosaics of the study areas. Multibeam data were collected digitally with the program HydroStar (Elac Nautik). The post-processing of the raw data was conducted using the software HDPpost (Elac Nautik). The

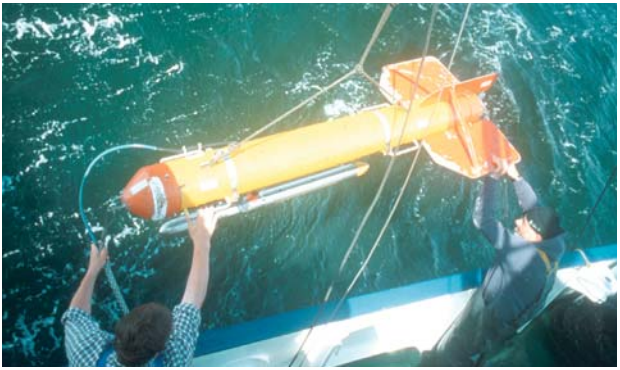

Figure 3. A sidescan sonar system was used (photo © Markus Diesing)

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[1] Towfish: A streamlined body towed behind the vessel upon which sidescan sonar transducers are mounted and in which electronic modules are installed.
Transducer: The electromechanical component of a sonar system that is mounted underwater and converts electrical energy to sound energy and vice versa.

[2] Swath width: The lateral coverage of the sidescan sonar or multibeam echosounder on the seabed.

[3] Geo-referencing: Digitally attaching geographical position data to environmental sensor survey data.

mosaic files were displayed in the geographic information systems Delph Map (Triton Elics International) and Arc View (Esri). Backscatter strength is displayed as grey scale from light (low) to dark (high).

Single-beam bathymetry data were corrected for water-level changes by the Federal Maritime and Hydrographic Agency. In order to achieve a spatial distribution of water depth, the data were gridded including variogram[4] analysis.

Descriptive terms for grain size correspond to DIN 4022: clay: <2 µm; silt: 2–63 µm; fine sand: 63–200 µm; medium sand: 200–630 µm; coarse sand: 630 µm–2 mm; gravel: 2–63 mm; and boulders: >63 mm in diameter.

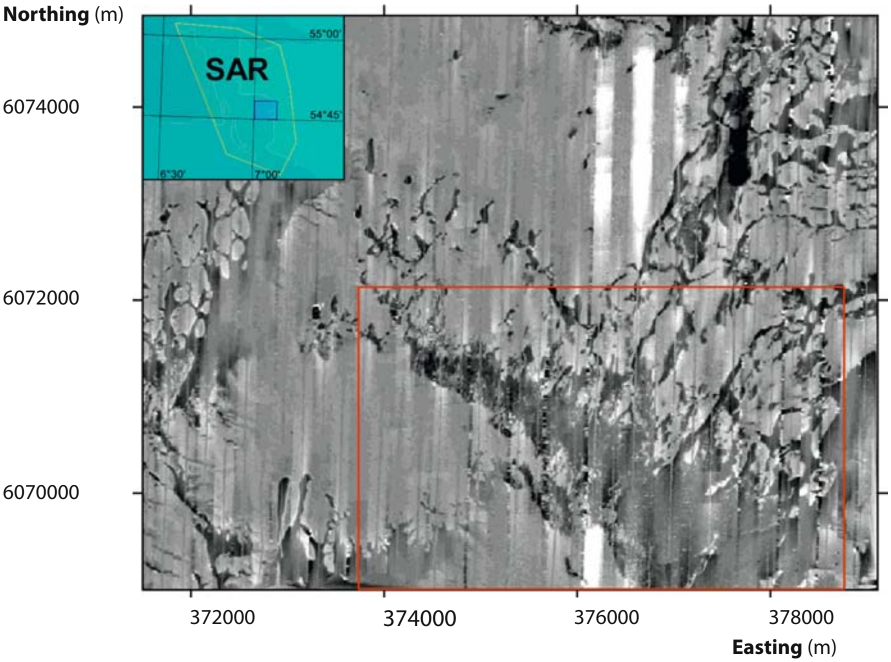

Figure 4. Multibeam backscatter image from the research area *Sylt Outer Reef*. The location of the displayed area is indicated by the blue rectangle in the inset (upper left corner). High backscatter intensity (dark grey) is indicative of coarse sands and gravels, low backscatter intensity (light grey) characterises areas covered with fine-to-medium sand. A strong spatial heterogeneity of seafloor sediments is clearly visible. White vertical stripes are artefacts. The red box indicates the location of figure 6.

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[4] Variogram: A measure of the variance between data as a function of distance.

4 Results and interpretation

4.1 German North Sea EEZ

We mapped a total of 315 km^2 of seafloor with the multibeam system within the research area *Sylt Outer Reef*. Figure 4 shows a typical example of the sediment distribution patterns and a clear image of the spatial heterogeneity of seafloor sediments. Based on different backscatter strength and ground-truthed by surface sediment samples and underwater video observations, three basic categories of seafloor sediments are distinguished: (a) coarse-grained sediment, (b) fine-to-medium sand, and (c) boulders.

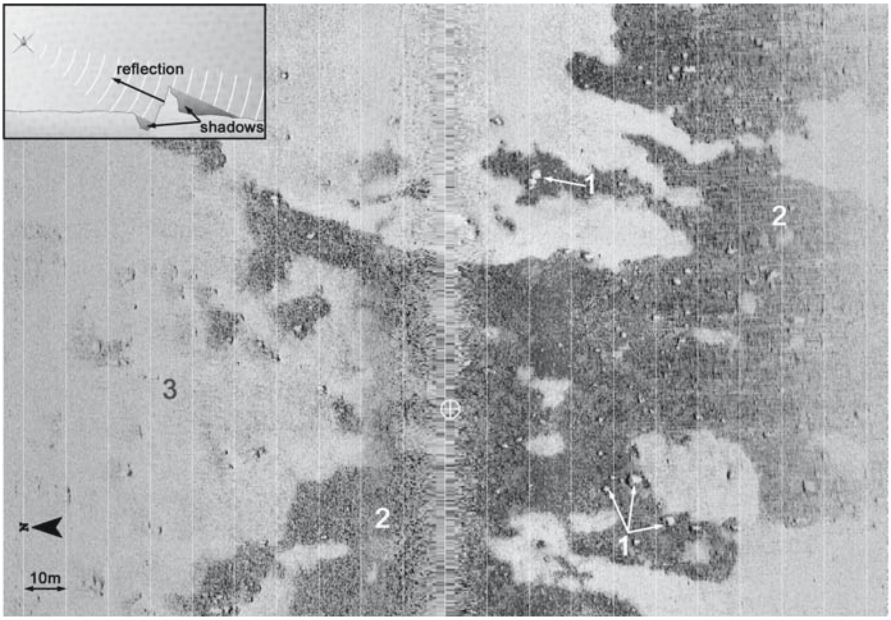

Figure 5. Geometrically corrected sonography of the seafloor from *Sylt Outer Reef*: Single boulders (1) can be identified on a patch of coarse sand (2). Several protruding boulders are visible within an area of fine-to-medium sands (3). The inset in the upper left corner explains how strong reflections and acoustic shadows behind obstacles (e.g., boulders) evolve; after Fish and Carr (1990), modified.

High and homogeneous backscatter (dark grey) is indicative of coarse sands and gravels. These sediments generally show ripple marks with wavelengths of up to ca. 1 metre. Co-registered multibeam bathymetry and backscatter data reveal that the patches composed of coarse material occur in depressions of several decimetres deep. Such sediments resemble "rippled scour depressions" (Cacchione et al. 1984) or "sorted bedforms" (Murray and Thieler 2004), which are widespread on sediment-starved continental shelves.

Low and homogeneous backscatter (light grey) areas are composed of fine-to-medium sands with low contents of mud and gravel (both below 5 weight-percent). Small-scale ripples in the order of a few centimetres wavelength were observed by underwater video. However, they are beyond the resolution of the employed sidescan sonar and multibeam systems.

Detailed investigations with high-resolution sidescan sonar additionally reveal the presence of boulders in some areas (figure 5). They are easily identified in the sonographies by the acoustic shadow they produce and which are interpreted as erosional lag deposits of morainal material. The boulders are found on or near patches of coarse-grained sediment. In the latter case, they protrude through a thin veneer of fine-to-medium sands. The boulders are not equally spaced on the seafloor but are concentrated in distinct areas. The number of individual boulders in such areas is relatively low. Typically, boulders are spaced a few meters (to several decametres) apart.

The relationship between different surface sediments and seafloor topography is visible on the sidescan sonar imagery, especially when merged with bathymetric data. In figure 6, a NW-SE-trending depression is visible. Maximum depth differences between the deepest parts of the depression and the highest parts of the surrounding seafloor are about 10 metres. Coarse-grained sediments are mainly found in the deepest parts and on the northeastern flank of the depression. Fine-to-medium sands dominate the southwestern flank of the depression and the surrounding seafloor. The occurrence of boulders is closely linked to the distribution of rippled coarse sediment.

4.2 German Baltic Sea EEZ

Within the *Kadet Trench* research area, the fieldwork was concentrated on the central part, where the Kadet channel cuts through the NW–SE-striking *Darss Sill* (*Darsser Schwelle*). In this area are found all types of surface sediments described above (see section 2) (figure 7). The largest part of the mapped area is covered by lag deposits, indicated by high and heterogeneous backscatter (dark grey). Their distribution is related to the general topography, that is, lag deposits are often found on the bathymetric highs. Lag deposits are comprised of sediment grain sizes from coarse sand to boulders, which may have diameters of more than 1 metre. Boulders are widely distributed within such lag deposits, but the density of boulders per unit seafloor area varies. Typically, the distance between individual boulders varies between a few decimetres and several meters. The density of boulders per unit seafloor area is therefore higher compared to the results gathered from the North Sea field site.

In the southwest, medium-to-low and homogeneous backscatter (light grey) indicates the presence of fine-to-medium sands. In the transition zones from sand to lag deposit, a strongly heterogeneous and patchy sediment distribution pattern is observed. A field of very large subaqueous dunes (according to the classification of Ashley 1990), with crest spacings in the range of 400 metres and crest heights of up to 5 metres, was detected on a shoal southwest of the investigated area (figure 7).

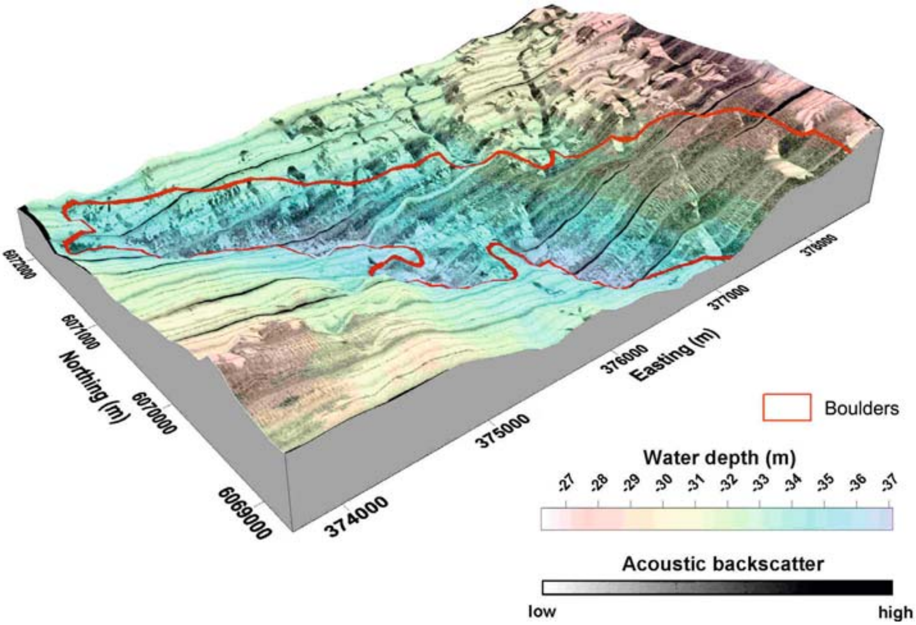

Figure 6. Three-dimensional image of the seafloor within the research area *Sylt Outer Reef*. View is from SW. Bathymetry is shown as 3D-relief and colour-coded water depths. Backscatter intensity is shown in greyscales, draped over the bathymetry. The occurrence of boulders is indicated by the red polygon. Vertical exaggeration: 75-fold.

A patch of low and homogeneous backscatter within the lag sediment area indicates the presence of organic-rich muddy fine sand to sandy mud. These sediments are deposited within a slight depression that favours the sedimentation of fine-grained material.

The research area *Adler Ground* is located at the southwestern tip of a major shoal (*Rønne Bank* (*Rönnebank*)). Here, the seafloor is widely covered by lag deposits, indicated by high and heterogeneous backscatter (figure

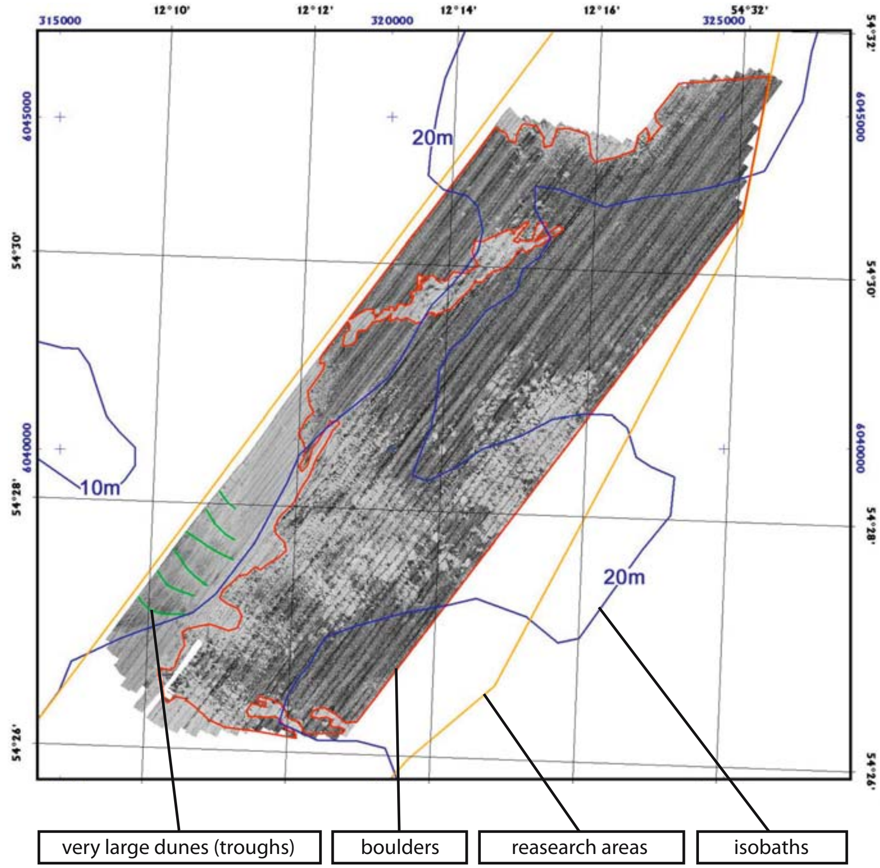

Figure 7. Sidescan sonar mosaic showing the centre part of the research area *Kadet Trench*. Lag deposits (dark grey) are widespread. The occurrence of boulders is closely linked to the distribution of lag deposits. Fine-to-medium sands (light grey) are restricted to the lower half of the image and are especially abundant in the SW, where they built up very large dunes

8). Seabed imagery as well as underwater-video data show small-scale changes within the lag deposits, alternating between boulders, gravel, and medium-to-coarse sands. Boulders are often populated by bivalves (*Mytilus sp.*). The density of boulders per unit seafloor is comparable to that in the *Kadet Trench* research area and is much higher than in the North Sea. There is no distinct relationship between the distribution of boulders and that of lag deposits. In some places, lag deposits are covered by a thin veneer of sand. In such situations, boulders may protrude through this cover of sand. Examples are found in the northeast of the investigated area (figure 8).

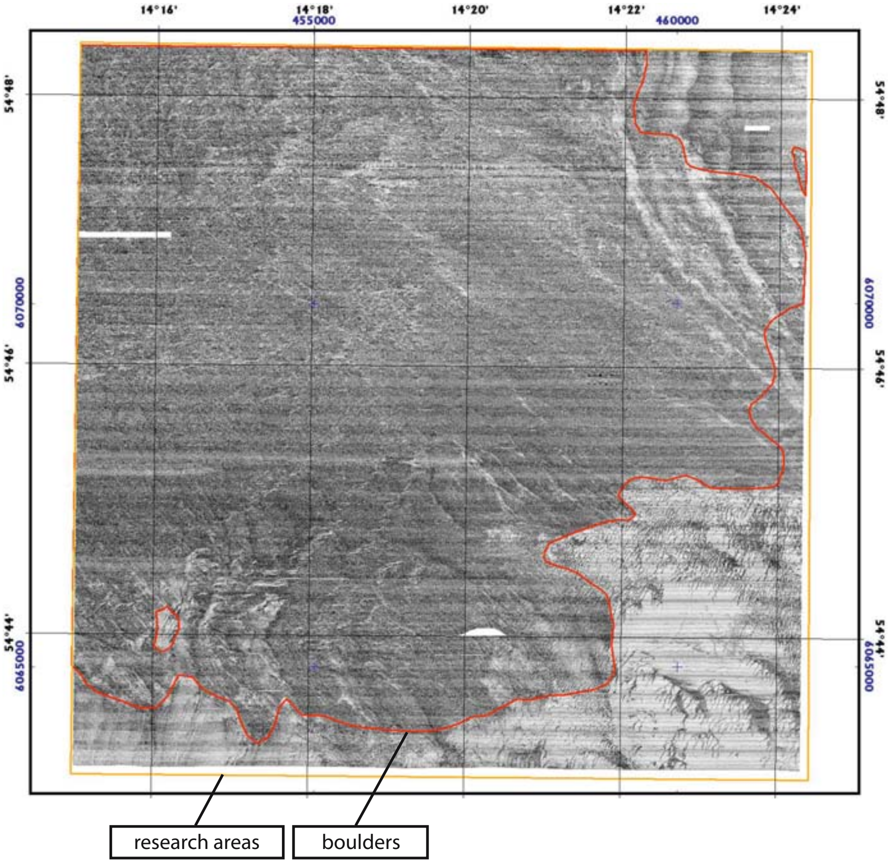

Figure 8. Sidescan sonar mosaic showing the research area *Adler Ground*. Lag deposits (dark grey) are widespread. The distribution of boulders is indicated by the red polygon. Fine-to-medium sands are restricted to the NE, SE, and SW of the image

Within the lag deposits, and in places where they are only covered by a thin veneer of sand, distinct morphological ridges, several metres wide and hundreds of metres long, were found (figure 9). Such ridges are densely covered by boulders, while the surrounding seafloor is often covered by rippled sand and gravel.

Fine-to-medium sands (light and homogeneous grey in the sonographies) dominate the northeast-, southeast-, and southwest corners of the research area. In the southeast, they alternate with NNE–SSW-directed strips of coarse sand. These features have spacings in the order of 50 metres (figure 8). Such strips of coarse sand resemble those at *Stoller Ground* (*Stoller Grund*), which have been interpreted as being transverse, ripple-like, and current-induced bedforms (Werner et al. 1976).

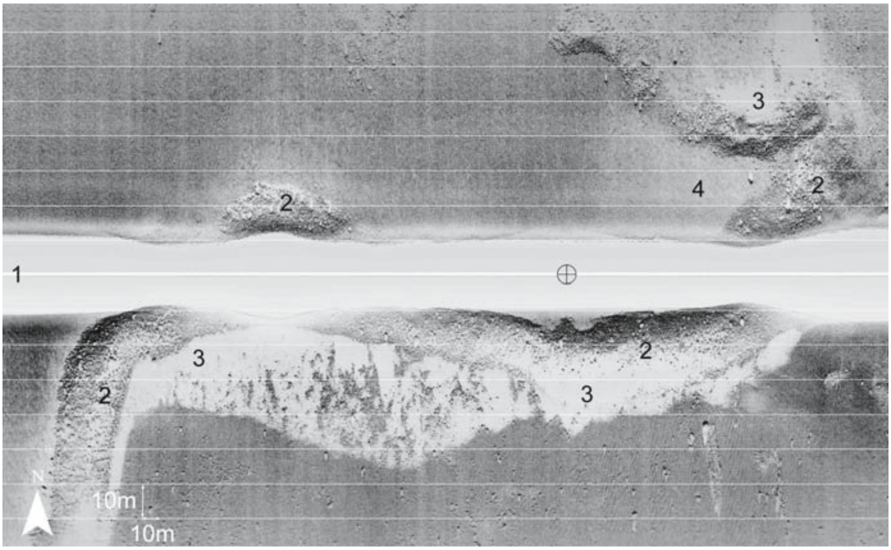

Figure 9. Uncorrected sonography of the seafloor from *Adler Ground*: 1 – water column, 2 – ridges, 3 – acoustic shadow, 4 – sand

5 Discussion

Boulders are present in both the German North Sea and the Baltic Sea as results of the modification of a glaciated terrain by marine transgression. Both areas were affected by glaciations. Consequently, morainal material was deposited. This sediment is comprised of grain sizes from clay to boulders of up to several metres in diameter. It is one of the most important source-sediments for modern redeposition and sedimentation. While the fine components were moved away due to marine reworking, the coarse fractions, especially boulders, remained almost where they were initially deposited. The resulting boulder fields are thus indications of former moraines.

From a practical point of view, this statement can also be read the other way around. If we are looking for submarine boulders, we should investigate continental shelf areas where moraines, especially terminal moraines, are present. For example, the *Darss Sill* is the submarine continuation of a Weichselian marginal (i.e., terminal moraine) line called Velgaster Staffel (Lemke et al. 1994, Lemke 1998). In fact, this area is characterised by the widespread occurrence of boulders (figure 7). In contrast, the situation is much less clear in the North Sea, where the knowledge is still too poor to reconstruct ice-marginal lines (Figge 1983). Here, the continental shelf was not affected by the last (Weichselian) glaciation. Glacial relicts are much older (>130,000 years ago), belonging to the Saalian and earlier glaciations. The time span available to rework, redistribute and level-out these glacial sediments by subaerial and subaqueous processes was thus much longer compared to that in the Baltic Sea, where the deglaciation started only ca. 15,000 years ago (Boulton et al. 2001). Moreover, waves, tides, and currents are much stronger in the North Sea and thus more effective as an erosional agent.

This strong contrast in the geological history of the two different continental shelf areas also explains why the density of boulders per unit seafloor area is much higher in the Baltic Sea, and why boulders in the Baltic are often linked to bathymetric highs while in the North Sea they are not. In the latter, we found boulders at one flank of slight depressions where relict coarse sediments are present (figure 6).

6 Conclusions

High-resolution acoustic seafloor-imaging techniques are suitable tools in order to map and characterise habitats of ecological importance such as boulders. Boulders are present in both formerly glaciated shelf areas, the German North Sea and the Baltic Sea. We observe differences regarding the distribution and density of boulders per unit seafloor between both areas. Such differences are explained by different geological evolution (i.e., timing of glaciation, subaerial exposure and marine transgression) and different intensity of hydrodynamic forcing (i.e., waves, tides, currents).

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