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The Use of Acoustic High Resolution Sub-Bottom Profilers for Geo-Archaeological Survey

Results from Jungshoved, Kerteminde Firth and Haithabu/Hedeby

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Introduction

Recently increased economic and environmental interest in the oceans has caused a rapid development of marine technologies. Combined with the navigational facilities of modern warfare that are now available on a commercial basis, several of these technologies may yield substantial contributions to archaeological methodology.

Since the Research Centre for Maritime Archaeology in Roskilde was formed as a department under the Danish National Museum in 1993, the application of modern technologies to archaeological surveys in wetlands and coastal zones has played an important role in its activities. This work has been carried out in close contact with the Department of Geology, Aarhus University. German interest in further investigation of the harbour area of the Viking Age trading centre Haithabu/Hedeby, and the defensive structures related to it, together with geo-archaeology in general, has led to a broader collaboration between these institutions and the GEOMAR Research Center for Marine Geosciences in Kiel, the Archäologisches Landesmuseum der Christian-Albrechts-Universität in Schleswig, and the Institut für Ur- und Frühgeschichte der Chistian-Albrechts-Universität in Kiel.

The collaboration has until now focused on the use of acoustic systems such as acoustic high resolution sub-bottom profilers and side scanners for survey in water bodies, and in the verification of the observed anomalies by underwater excavations or underwater survey by scuba divers, borings and scientific analysis.

The primary purpose of the use of acoustic bottom profiling in geo-archaeology hitherto has been to distinguish larger geological structures such as coast lines or the beds of water courses, which may have played an important role in man's use of landscapes submerged today (VAN ANDEL/LIANOS 1984), or to distinguish larger archaeological structures such as ship-wrecks. An essential element has been to gain experience by using different sub-bottom profilers on a series of known structures to compare their archaeological potential and to see what types of elements could be distinguished in the profiles.

This paper outlines the research strategy developed for survey in shallow water and discusses some of the first results obtained on three archaeological sites (fig. 1).

The physical principles

Sediment echosounders or sub-bottom profilers are echosounders which are able to penetrate into the bottom sediments and thus can produce profiles showing the geological layers and other features below the seabed level.

Many of the systems use only one frequency. The lower the frequency the better the penetration obtained, but the worse the vertical resolution. This means that low frequencies make it possible to see deeper into the sediment but are not able to distinguish as fine details as higher frequencies can (low resolution). The higher the frequency the worse the penetration but the more detailed the picture obtained (higher resolution). To be able to observe archaeological structures it is necessary to have a relatively high resolution, but also some penetration. A common compromise is a frequency around 30 kHz.

Sometimes it is difficult to get penetration with one frequency whereas others may have a good penetration. Therefore systems using several frequencies are attractive. A new generation of sub-bottom profilers is the Chirp-system which sweeps an interval of frequencies. This makes it possible, to some degree, to combine the advantages of low and high frequencies.

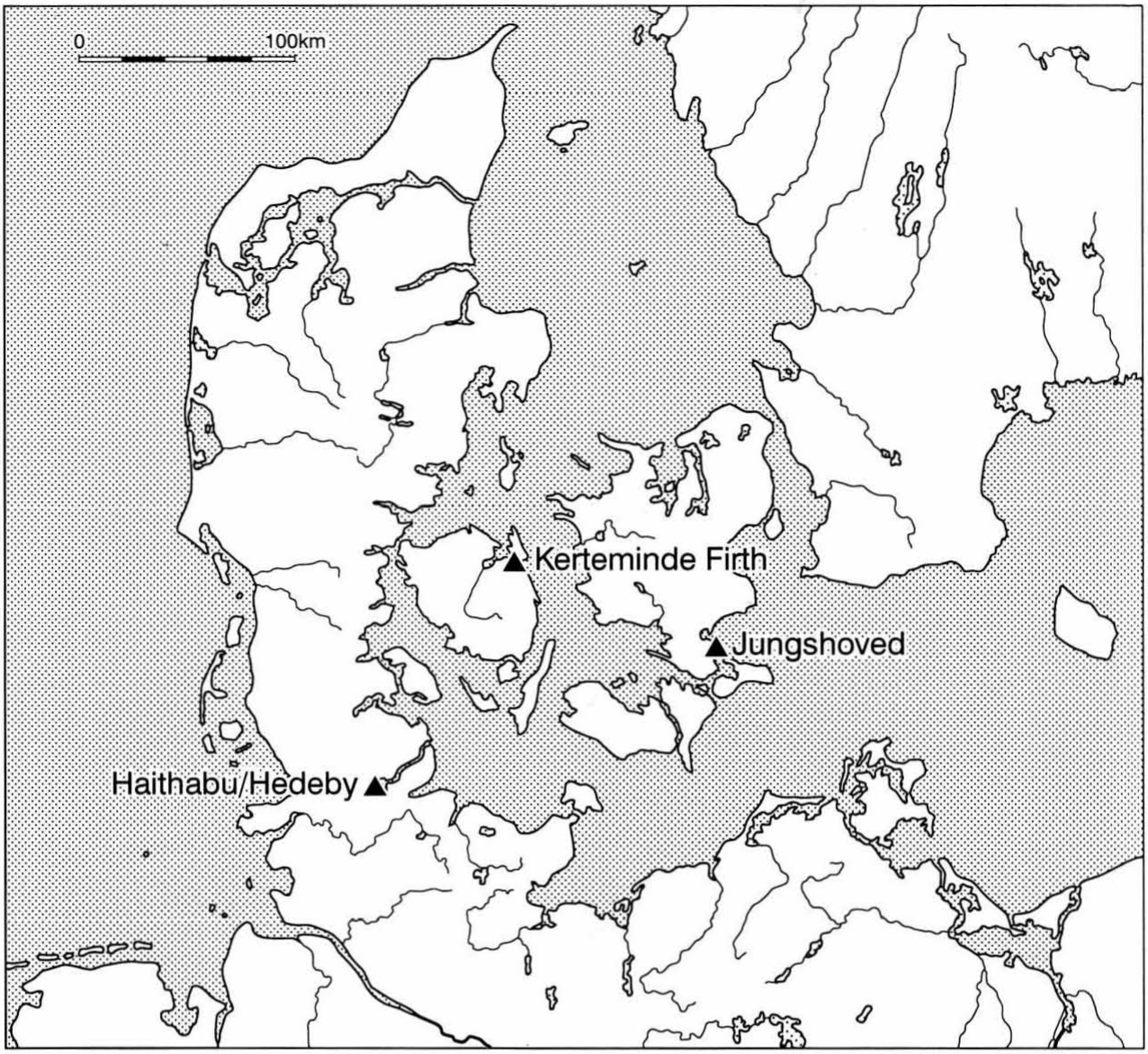


Fig. 1. Location of the research areas in Denmark and Germany.

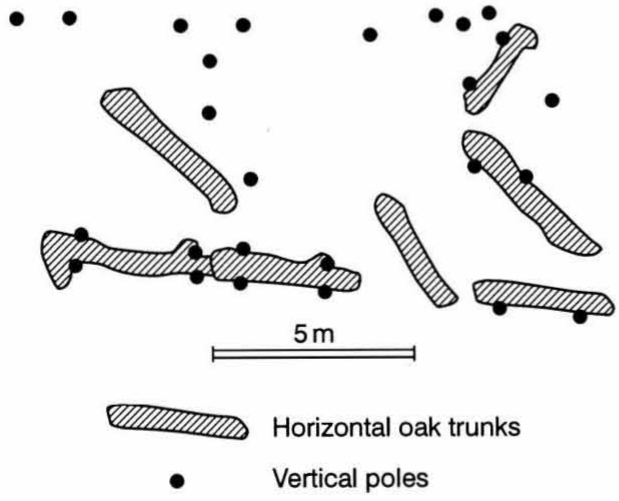


Fig. 2. Jungshoved. Sketch of structure "A".

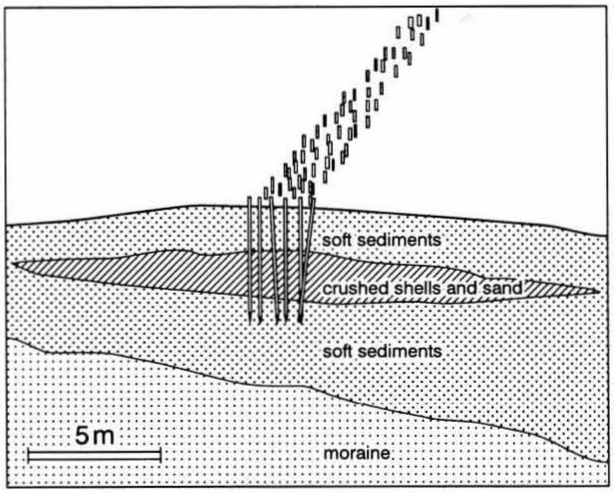


Fig. 3. Kerteminde Firth. Sketch of the situation.

Traditionally the same hydrophone-element was used as sender and receiver of the sound signals: When the transducer had sent a signal it needed some time to stop its own vibration before it could listen for the reflection. As a consequence reflections from a bottom only one or two metres below the transducer arrived too early to be registered properly. The separation of senders and receivers in the more advanced modern systems means that it is possible to operate in less than 0.5 m of water with good penetration. This is a very important development for investigations in shallow water areas.

The fact that archaeological as well as geological features are revealed in the profiles makes work with sub-bottom profilers an obvious field for interdisciplinary geo-archaeological collaboration.

Research strategy

It has been regarded as important to develop a research strategy that could be applied to the shallow water areas, typical for the coastal areas in the western Baltic, as well as to rivers and lakes. As mobility has also been given a high priority, a basis for the strategy developed was that it should be possible to operate all the survey equipment from a small boat which could be transported on a trailer.

Experience showed that a 15 ft glassfibre boat was sufficient and that a closed cabin was absolutely necessary to protect electronic equipment. The boat chosen can operate in 0.3 m of water.

A survey of the acoustic profilers available on the market resulted in the purchase of a Chirp-II-system from Datasonics (CAP 6000). This system sweeps the interval from 2–23 kHz on two channels and shows a good penetration even in quite sandy sediments and in extremely shallow water. Important for the choice was also that the transducer unit (the "fish") is of such a restricted size and weight that it can be carried by a single person and also can be operated on depths as shallow as 0.3 m.

For efficient survey precise navigation is crucial. The observation of an interesting structure in the profiles is less useful if it takes a diver several days to relocate it. From the beginning it was dedicted that the minimum error acceptable was ± 1 m and that at least one position should be obtained per second. Two Ashtech DGPS-stations are used for satellite navigation, one base station to place in a known coordinate on land and one dynamic station for the boat. The positions are stored on Exabyte tapes together with the seismic data in seg-y format. Experience shows that the navigation error when sailing straight lines is generally smaller than 1 m. The satellite antenna is placed exactly above the fish to minimize this offset. The system with online navigation makes it possible to check the nature of anomalies observed immediately and to register their extension with profiles in different directions. This allows a much more flexible approach than the strategies available earlier (Stümpel/Borth-Hoffmann 1983).

In an early phase of the project it became clear that interpretation of archaeological structures was a far more detailed undertaking than ordinary interpretation of geological layers. Where we had expected to rely on geophysical expertise to distinguish single poles and culture layers, it turned out that we had to find out ourselves what they looked like.

Therefore the first features studied were blockages which have already been documented carefully by divers. To obtain a maximum of information, blockages constructed in different ways and embedded in different types of sediments were recorded. It was dedicted first to focus on blockages because they often are quite massive structures and relatively easy to locate as their function was to block narrow waterways. We plan to widen the field of study to wrecks and culture layers later.

First we thought that a strategy combining seismic survey with verification by diving on the anomalies observed would be optimal. Experience meanwhile showed that it is an advantage to separate the operations so we first attempt to interprete the structures observed during recording. This includes running profiles that can elucidate the character of problematic structures during the recording phase but involves no diving. Second phase is a detailed interpretation and mapping of the features observed in scale 1:1,000. Third phase is verification by divers and collection of samples for dating.

It became obvious that the second phase, if the seismic data had been collected properly, could dramatically reduce the number of questions that had to be solved by expensive and time consuming diving. Detailed interpretation often made it possible to pinpoint a few spots where observations and datings could solve the basic chronological and structural problems related to the features studied, and thus to reduce the total costs of survey.

General observations

Single poles

Though blockages and wrecks may cause a local deposition of sandy sediments or the formation of banks around them of shell fragments, gravel and sand, we cannot conclude, that the presence of such secondary deposits always represent blockages or wrecks. To improve the quality of the acoustic survey it is necessary to be able to distinguish features typical for the construction elements in the structures surveyed. Therefore it has become an essential question whether larger wooden pieces and poles can be recognized as single bodies.

The recordings from a series of blockages and "palisades-structures" in Vordingborg, Jungshoved, Haderslev Firth, Kerteminde Firth and Haithabu/Hedeby show that single horizontal and vertical poles embedded in softer sediments can be distinguished when a trig rate of 0.125 (= 8 shots per second) and a vertical resolution of 2,048 samples is used. It seems possible furthermore, to distinguish between single vertical and horizontal timbers, but this aspect will be elucidated further in future.

Some vertical poles appear as "empty" channels surrounded by a thin tube-like "shell" in the sediments. This may be due to the fact that they consist of water-filled cells with rather thin walls and thus may have acoustic characteristics close to those of water. We have seen this type of reflection not only from vertical poles but also from items with a quite strong inclination. Their angle in relation to the direction of the signal seems not to be essential. It is possible that the acoustic characteristics of poles may depend on the type of wood they consist of and how soft the sediments are they are embedded in.

The observations mentioned here have been confirmed by recordings of poles from pound nets and other modern pole structures. There seems to be a linear relation between the diametre of poles and their reflections in the profiles. This facilitates an estimation of the pole diametres on the basis of the recordings. Single poles with diametres smaller than 10 cm have not been observed as single bodies. Hopefully, experimental work conducted in collaboration with the Department of Geophysics at Aarhus University can elucidate the general acoustic symmetries of poles embedded in the sediments further.

Due to the angle with which the acoustic signal spreads through the water it seems unlikely that single poles embedded in the sediments can be distinguished at greater depths. This should, meanwhile, also be a case for further study.

"White-out"

Whereas poles standing at some distance from each other seem to be distinguishable as single bodies, another effect appears where large amounts of poles stand close together. They simply seem to absorb the signal. We call it "white-out". In the blockage "Æ Lei" in Haderslev Firth and the newly discovered one from Kerteminde Firth, the more dense parts show this effect. A similar effect has been observed on modern duc d'Alphs with numerous large poles rammed into the bottom.

The Jungshoved blockages

Since no archaeological conclusions can be drawn on the basis of the acoustic results only, verification and dating of the supposed archaeological anomalies is essential. At the moment eight acoustic anomalies have been interpreted as underwater blockages, two as harbour structures and two as either bases for defensive towers close to the coast or old ferry landings. These features are found in six locations in Denmark and Germany. The recordings from some more locations are being interpreted at the moment.

The first of a series of underwater excavations to verify anomalies was carried out in the little inlet to the west of the medieval castle on Jungshoved, Zealand. In the inlet which is open to the south, four anomalies had been interpreted as blockages and two as towers/ferry landings. The anomalies had been located at depths from 0.3–2.5 m, embedded in the mud. No structures were visible on the surface of the sea bottom.

The DGPS positioning made it possible to mark the anomalies with buoys placed with a precision of ± 1 m. This enabled us to rationalize the use of divers greatly. In three days it was possible to verify five of the six structures and to show that their outline fitted the observed anomalies in detail.

The southernmost structure (A), a 6–8 m broad blockage blocking the mouth of the inlet, consisted of 3–5 m long tree trunks with maximum diametres between 35 cm and 55 cm, each fixed to the bottom with about four smaller poles (fig. 2). The latter were approximately 15 cm in diametre. The southern border consisted of a continuous line of trunks with two lying on top of each other in one case. To the north of this the orientations of the trunks varied. Mostly

they were not parallel with the southern front. Samples for dendrochronology and/or ^{14}C-datings were taken.

The second structure (B) from the south, interpreted as a more narrow blockage, consists of only one line of poles 15–20 cm in diametre and spaced 75–80 cm apart centre to centre. In the eastern side of the inlet it cut the eastern end of the former structure. Samples for ^{14}C-datings were taken.

Of two structures interpreted as blockages surrounding the two defensive towers/ferry landings the southernmost part of the eastern one (C) was verified as a single line of poles 15–20 cm in diametre standing side by side with their tops 50–70 cm below the surface of the mud. According to the acoustic recordings the structure ended where it reached the dredged sailing channel. The penetration in the channel is very bad due to gas from the sediments. The underwater excavation showed that the structure, exactly where it enters the gas area, forms an angle of 90° to the south-southwest and continues at least 5 m in this direction. Samples for ^{14}C-dating have been taken. The western anomaly (D) supposed to represent the pendant to this structure turned out to consist of a line of tree trunks and branches probably deposited in a linear feature in the sediment by accident.

To the north of the zone with the blockages two square structures (E and F) were located, one on each of the shores. Their interpretation as bases of defensive towers was partly influenced by the two anomalies interpreted as half-circular blockages (C and D). Since the western of these two was not an archaeological feature, the most likely interpretation of the two square structures now is that they are the remains of ferry landings. This interpretation is supported by the observation of a ramp on the western side, leading down the slope to the coast, exactly where the square structure was located. Probing showed that the ramp contained numerous stones.

Both square structures consisted of a more or less irregular frame of poles with diametres between 15–20 cm. The western one could furthermore be seen to have more layers of branches and timber lying in different directions as its lowermost layer above the soft sediments. The 30–60 cm thick layers of filling consisted of a mixture of sand, smaller stones and pieces of larger artificially cloven stones. Samples for ^{14}C-dating were taken from both structures.

A "new" blockage in Kerteminde Firth

Acoustic survey in Kerteminde Firth revealed a 20–25 metres broad and 500 metres long structure blocking the relatively shallow threshold at the passage from Kerteminde Firth to Kertinge Nor.

The second underwater excavation was directed at this anomaly, a 3 m broad blockage consisting of a large number of 15 cm thick vertical poles around which a natural 20–25 m broad and up to 30–40 cm thick bank of shells and sand/gravel was deposited (fig. 3). The bank can be seen in the profiles as a broad lenticular structure. Anomalies visible in the central parts of this lens represent the pole structure.

According to information from Hugo Sørensen, Langelands Museum, a blockage excavated in the reclaimed area of Henninge Nor contained a lens of sand deposited on the peaty bottom around the poles. In the profiles from "Æ Lei" in Haderslev Firth is visible a similar lenticular structure. Hopefully it will be possible to make a trench.

The blockage in Kerteminde Firth is important because it has not been damaged by dredging. Access to the firth for larger ships had already been made impossible by the 17th century when a bridge was constructed in Kerteminde. The acoustic profiles indicate that the structure contains a central opening. Connected to this opening are features interpreted as several narrow rows of poles. Since more than 1 m of mud covers the central part of the blockage, it has been impossible to determine the character of this opening during this initial underwater excavation.

Harbour structures in Haithabu/Hedeby

Several archaeological campaigns have contributed to our knowledge about the harbour area of the Viking Age settlement Haithabu/Hedeby, close to the town of Schleswig. In 1953 one of the earliest underwater investigations was carried out in this area, resulting in the finds of several zones with concentrations of poles (Hingst/Kersten 1955). The most impressive pole structure found was the so-called structure I, at least 160 m long and consisting of 7–8 parallel lines of poles 20–30 cm in diametre. A number of smaller areas with concentrations of poles were also located. A burnt Viking ship, structure II, was documented in the harbour area during the 1953-investigation.

In connection with the seismic surveys carried out with a 5 kHz "pinger" in the period 1978–1981 further underwater investigations were conducted and a zone with the remains of several more or less overlapping piers was excavated (Crumlin-Pedersen 1997). A pole structure which seems to connect structure I to

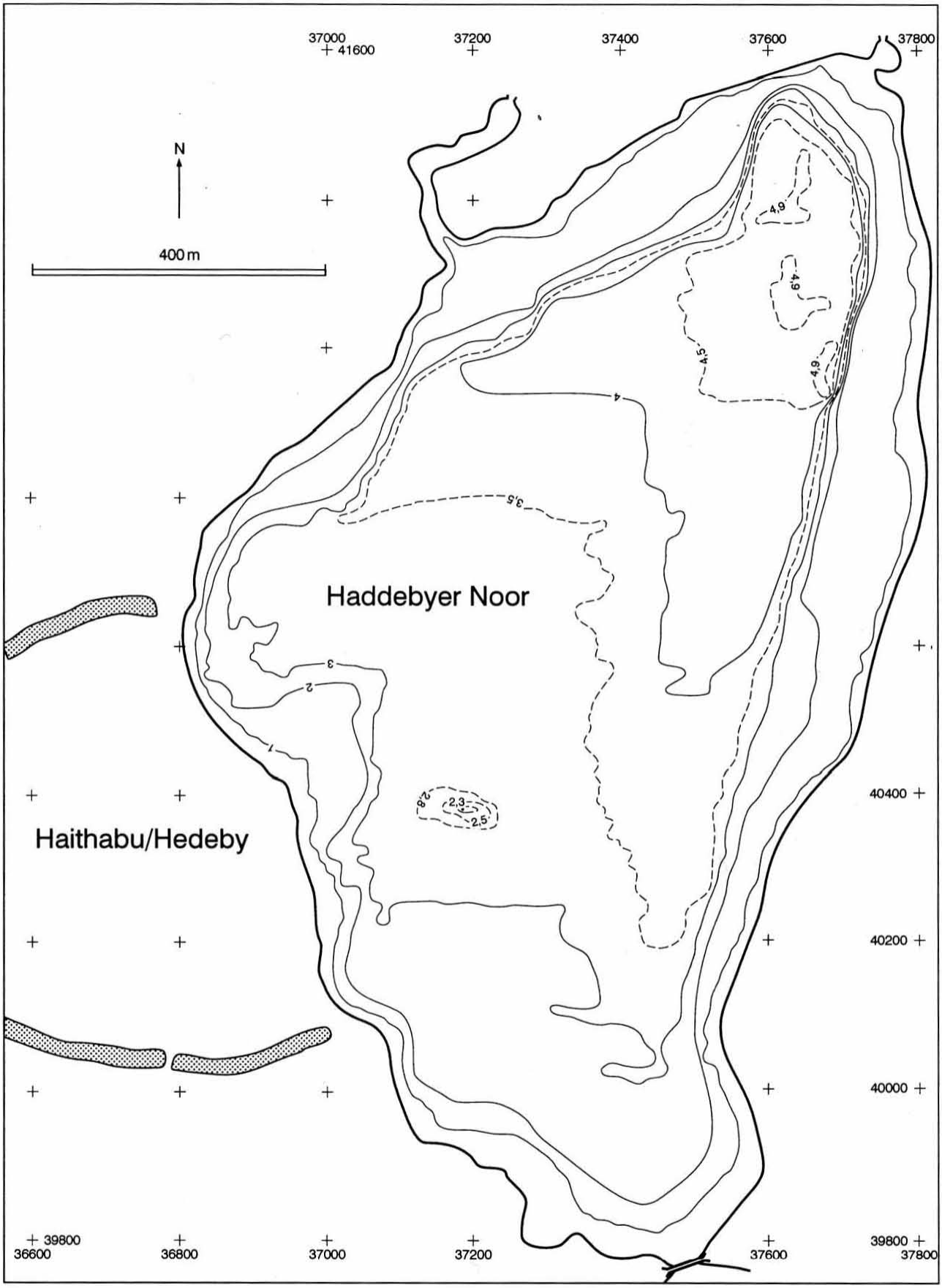


Fig. 4. Haddebyer Noor/Hedeby Noor. Bathymetrical map.

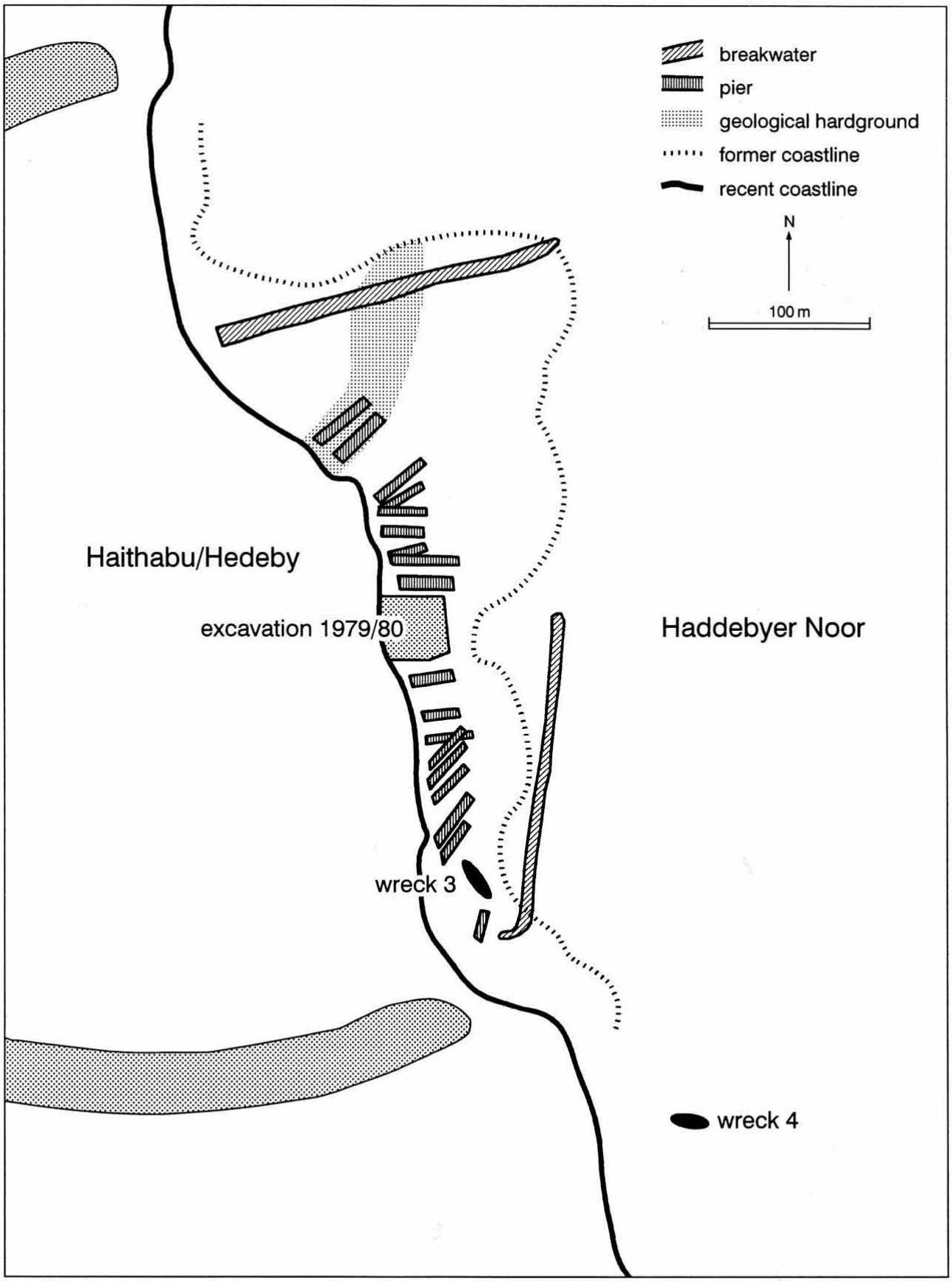


Fig. 5. Haithabu/Hedeby. Map of acoustic anomalies in the harbour area.

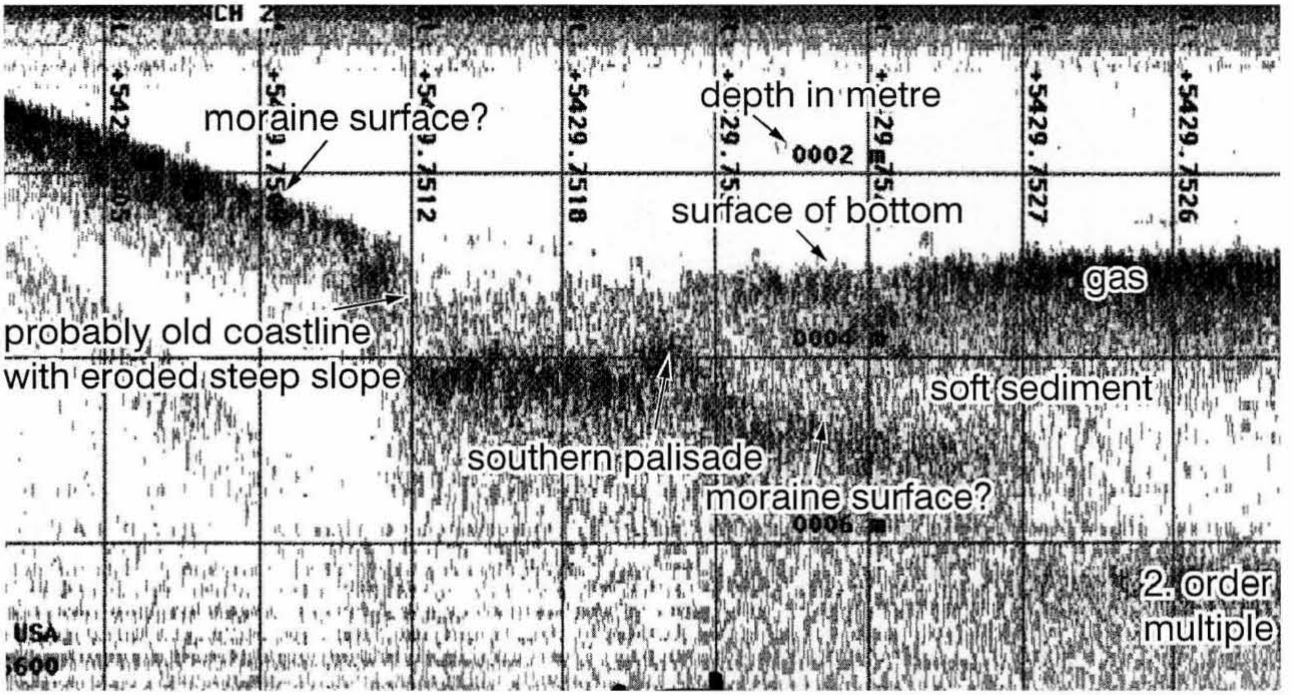


Fig. 6. Haithabu/Hedeby. Record of Chirp-II-profile, showing a cross-section of the southern structure, beginning at the end of the southern rampart of the settlement.

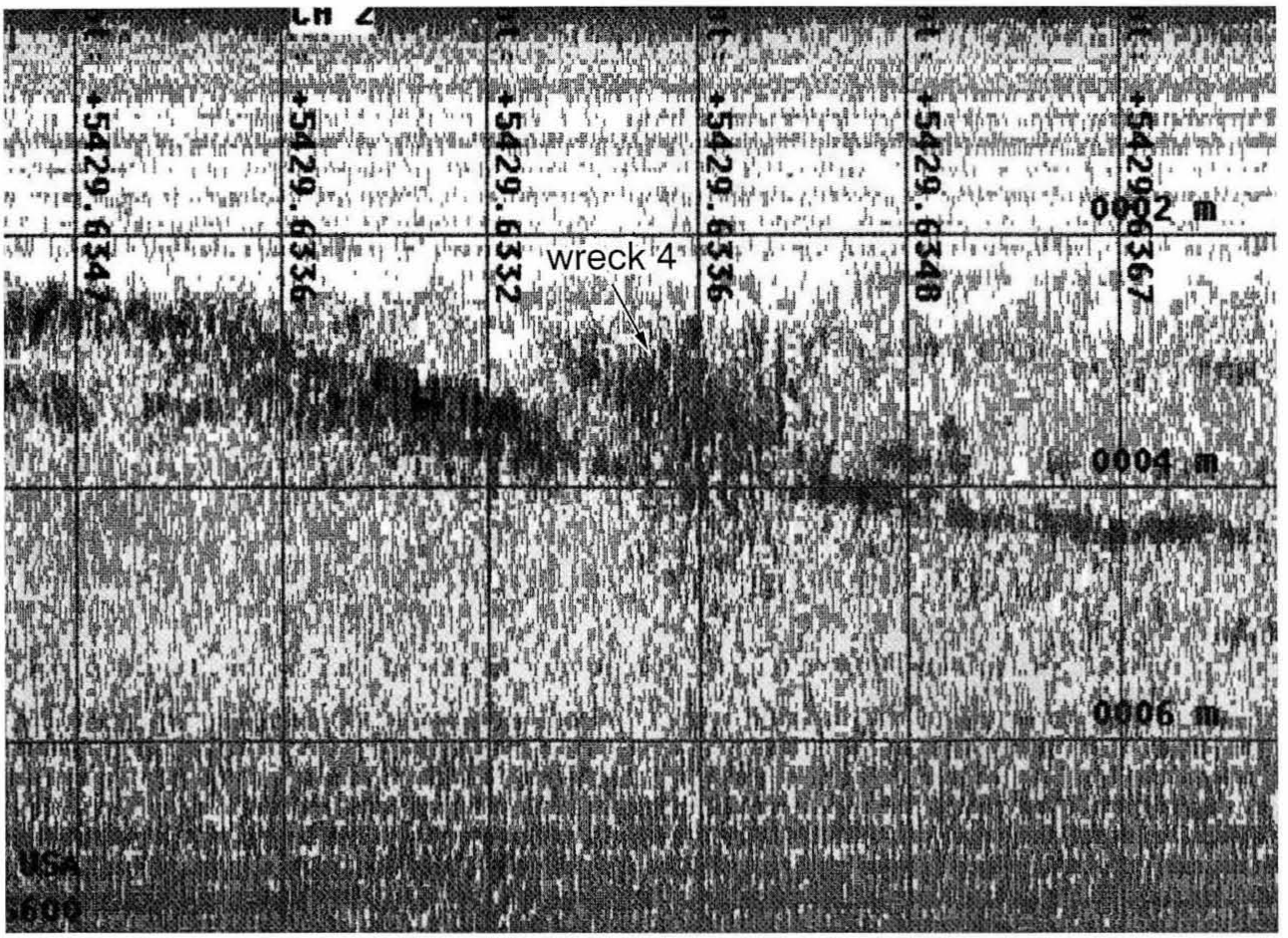


Fig. 7. Haithabu/Hedeby. Record of Chirp-II-profile, showing a cross-section of the newly discovered wreck.

the northern rampart was found. Apart from those two dugout boats a second Viking ship appeared (STÜMPEL/BORTH-HOFFMANN 1983).

In 1995 and 1996 new surveys were carried out by the authors with the Chirp-II-system, to find out whether the new technology could reveal new details of the harbour construction. In November 1995 the first detailed bathymetrical survey was carried out in Haddebyer and Selker Noor by the Bundesamt für Seeschiffahrt und Hydrographie, Hamburg, because the measurements of 1953 were based on a very rough survey (CRUMLIN-PEDERSEN 1997).

The bathymetry has been represented in detailed maps in scale 1:2,000, and shows a very flat area on the western side of the Haddebyer Noor which corresponds more or less exactly with the Viking harbour area (fig. 4).

In the period from April 12th to 19th, 1997, verification of the structures recorded during the seismic survey in 1996 was attempted with research divers from the Institut für Ur- und Frühgeschichte, Christian-Albrechts-Universität, Kiel, and Archäologisches Landesamt Schleswig-Holstein, Schleswig. A very detailed interpretation of the recorded Chirp-II-data was the basis for the investigation. All structures observed were verified and the interpretations demonstrated to be correct (fig. 5).

A very clear, straight and narrow structure consisting of numerous poles was verified from the end of the southern rampart and 200 m to the NNE (fig. 6). It is 4–6 m broad. A similar EW oriented, 220 m long and 10–15 m broad structure was shown to be another pole structure. Together these two "breakwaters" embrace the shallow area well suited for a harbour. Their outer ends are separated by a distance of approximately 200 m.

Between these large breakwaters in the shore zone were seen 21 more or less diffuse oblong acoustic anomalies perpendicular to the coast line. As three of these "features" within a few metres coincide with the piers excavated in 1979–1980 (CRUMLIN-PEDERSEN 1997), it is most likely that these anomalies represent 3–4 already known and 18 hitherto unknown pier-zones (zones were piers have been built and rebuilt through time). Since the piers seem restricted to the area between the two breakwaters all of these structures may well represent a total harbour layout. Its position indicates that it is connected to the half-circular rampart and thus dates to the 10th-century phase of the settlement.

Datings of poles from the different structures will reveal their internal chronology and accordingly the development of the harbour.

Two anomalies observed and verified were wrecks. One is the already known wreck 3, just north of the southern end of the rampart in the southernmost part of the suggested harbour basin (HINGST/KERSTEN 1953). The other is located in a more southern position (wreck 4: figs. 5; 7) outside the harbour basin. The results of the preliminary investigation carried out indicates that it is a flat-bottomed and cravel-built barge, probably of Medieval Times.

Discussion

The results show that high-resolution sub-bottom profilers can successfully be applied to systematic archaeological survey in shallow water bodies with soft sediments. The described locations are typical for the southern Baltic Sea. To minimize the problems with gas, such surveys in extremely shallow waters, according to our experience, should be carried out before June and after August. The present results also indicate that useful results can be obtained in some areas with sandy sediments. However, the interpretation and verification of the recordings from areas with this type of sediments has not been finished yet.

Blockages are ideal structures for survey because they by definition transect the waterbodies they defend. A few profiles in an inlet or a firth should reveal the remains of blockages if the area is not too disturbed by dredging and cable lines. If the formation of hard reflectors, such as sand and shell lenses, around structures with many poles appears to be a general phenomenon, this will make them much easier to distinguish using acoustic equipment.

One aim of the present development of methods will be to learn to use the equipment for locating wrecks and culture layers, i.e. anomalies with a far more restricted extent than the blockages. One should keep in mind the possibilities for locating Stone Age culture layers with sub-bottom profilers. The preliminary results from the Kongemose site Blak in Roskilde Firth give reason to believe that Stone Age culture layers often differ so much from the sediments they are embedded in that they can be observed in the seismic profiles. This may well lead to sites embedded in the sediments and not damaged by erosion (GRØN 1990; 1996). This type of equipment can also be used for reconstruction of earlier landscapes now covered by sediments

Apart from learning how to fine-tune the system and to interprete the profiles, the last year has led to development in research strategy. Where the early surveys focused on quite narrow zones with topographical or historical indications that blockages might be present, the later surveys have attempted to locate

all structures in well defined water bodies such as inlets and firths. It would be waste of resources – and unnecessary – to cover large areas with profiles spaced with only 2–3 m between. The basic approach that has been developed is to make strategic profiles which should reveal the anomalies present. After this, the observed anomalies are studied in detail.

The survey method described here has quite a potential because it speeds up survey and makes it possible to observe features embedded in the sediments which would not be found by divers. As the outlines of the structures according to our experience can be registered directly with ± 0.3 m from the combined seismic and positioning data, the use of divers can be restricted to strategic points where specific problems concerning for example construction or stratigraphy can be solved. This reduces the total costs for survey considerably.

A series of datings from the verified structures is in progress at the moment. With a reasonable number of structures one can hope it will be possible to distinguish a "typological" development of the blockages' constructions.

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