Reburial as a method of preserving archaeological remains.

A presentation of the Marstrand project.

Thomas Bergstrand, Bohus County Museum, Sweden.
Charlotte Gjelstrup Björdal & Thomas Nilsson, Dept of Wood Science, Swedish University of Agricultural Sciences, Sweden.
Carola Bohm & Eva Christensson, National Heritage Board, Sweden.
David Gregory, National Museum of Denmark, Denmark.
Inger Nyström, Studio Västsvensk Konservering, Sweden.*
Elizabeth Peacock, Vitenskapsmuseum, The Norwegian University of Science and Technology, Trondheim, Norway & Gordon Turner-Walker, National Yunlin University of Science & Technology, Touliu, Taiwan, R.O.C.
Vicki Richards & Ian MacLeod, Western Australian Maritime Museum, Fremantle, Australia.

Abstract
In connection with recent large-scale underwater archaeological excavations along the coast of Western Sweden, the need for alternative preservation strategies and methods to secure their future became critical. Approximately 85 % of the finds, recovered from marine archaeological excavations in Marstrand harbour, were reburied in defined trenches in the harbour sediment. Furthermore Studio Västsvensk Konservering, along with Bohus County Museum, initiated a long-term research project to evaluate reburial as a method for preserving wetand waterlogged archaeological artefacts. The 50-year long research project, "Reburial and Analyses of Archaeological Remains" (RAAR) was launched in 2002 and consists of six sub-projects. These cover the most common types of material found in archaeological contexts such as: metals, wood, leather, textile, bone, ceramic and glass. In addition the suitability of materials used for packing and marking finds in the re-burial were assessed. The final sub-project addresses the monitoring of the environmental parameters that exist in Marstrand harbour. Each sub-project is co-ordinated by Universities or Institutes in Sweden, Norway, Denmark, and Australia with relevant expertise (see www.svk.com/reburial/index.htm).

1. Background

Archaeological investigations underwater and in other waterlogged environments often generate an excess of artefacts of all sizes, which are in great need of conservation. To carry out full conservation of all the findswould in some cases mean an unrealistic economic set back for the investigation as a whole and thereby also for the scientific quality of the work. Also it is questionable whether the benefits of total conservation would be worth the cost. The reasons for reburial as a preservation strategy are often diverse, but almost certainly include financial limitations as well as consideration of the historic value of the artefacts.

To rebury in the marine environment is to create a waterlogged storage and with restricted possibilities to conserve, reburial seems a realistic option for saving the archaeological material instead of discarding it. The method has been tried in Sweden and abroad but there have been few long-term evaluations published. [1, 2]

In 1998 and 1999, extensive marine archaeological excavations were carried out in Marstrand Harbour on the Swedish west coast. The two main archaeological investigations concerned culture layers along the quay and the excavation of a 18th century frigate, *Fredricus*. Due to a

number of constraints preventing the conservation of the entire collection of recovered cultural remains, a large reburial was initiated in the harbour. Reburial trenches were dug in close proximity to the excavation site and after documentation approximately 85% of the artefacts were reburied in the sediments [3].

However, since neither the long-term preservation effects nor the jurisdictional implications of the method were fully understood, two seminars were held in 2001. The first seminar concerned the scientific aspects of the method and the setup of a long-term research project at the reburial site in Marstrand. The second seminar focused on the administrative and jurisdictional status of a reburial site. [4]

2. Objectives

The general purpose of the project "Reburial and Analyses of Archaeological Remains" (RAAR) is to evaluate reburial as an alternative method for storing and preserving wet archaeological remains. The study aims to determine the effects of the burial environment on a wide range of material types and concurrently to monitor the burial environment. Hopefully this wide-ranging study will provide valuable information linking environmental parameters and the materials degradation. Studying the environmental parameters and the degradation of test materials will also provide an idea of the preservation status of the reburied artefacts.

3. Design

The subprojects and co-ordinators
We wanted to study the most commonly encountered archaeological materials and how they behaved in the reburial environment. Since a reburial area is to be considered as a museum storage it also became important to investigate the stability of the materials that give each find its identity and keep it separate from the other finds. The project is divided into six sub-projects, each one with its own co-ordinator (Table 1). For obvious reasons a study like this had to be conducted by people with different specialities within the conservation field. Initially the project had purely a Nordic base, but has since included Australia.

Table 1. The six subprojects and their co-ordinators

Sub-project	Co-ordinator	Institute/University
Silicates	Carola Bohm & Eva Christensson	The National Heritage Board, Sweden.
Metals	Vicki Richards & Ian MacLeod	Western Australian Museum, Fremantle, Australia.
Wood	Charlotte Björdal & Thomas Nilsson	Swedish University of Agricultural Science, Uppsala, Sweden.
Other organic material	Elizabeth Peacock	The Norwegian University of Science and Technology, Trondheim, Norway
Materials to pack & mark finds	Inger Nyström	Studio Västsvensk Konservering, Göteborg, Sweden.
Environmental monitoring	David Gregory	The National Museum of Denmark, Brede, Denmark.

Timetable

In order to determine the long-term effects of reburial, sufficient samples have been buried to allow sampling to continue for up to 48 years. The sample units will be retrieved and analysed in a predetermined order of 1, 2, 3, 6, 12, 24 and 48 years (Table 2). The first phase covers a three year time interval.

Table 2. Pre-determined retrieval of sample units.

Phase	Year of retrieval	Comments
1	2003, 2004 & 2005	Ongoing project
2	2008 & 2014	
3	2026 & 2050	

All samples have been buried in unused sections of the two trenches previously dug for the archaeological finds. All the sample units, except for the metals, were buried in September 2002, whereas the metals samples were reburied in September 2003. The test units with silicates and organic material other than wood, as well as the packing and labelling material are all mounted in perforated crates, whereas the wood and metal samples are mounted vertically on poles. The crates are all covered with approximately 50 cm of clay from the surrounding area, while the wood and metal are exposed in and above the sediments on several levels. Reference units of all the sample materials are kept by each co-ordinating institution.

The reburial site

The metal samples are positioned in the metal trench in two parallel lines and the other units are placed in defined areas based on the year of their retrieval. These areas are approximately 1x1.5m^2 (Figure 1).
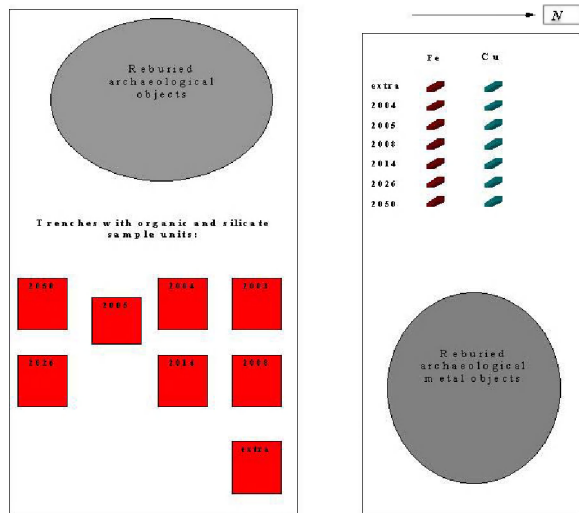
Figure 1. Schematic plan of the reburial trenches

4. The sub-projects
Degradation of Ceramics and Glass

Experience from examining and treating ceramic and glass wares recovered from marine archaeological excavations indicates that this category of materials often survives underwater conditions relatively well. Common to all ceramic and glass objects is their brittleness and they are seldom found intact, but if we just look to the material, a majority of ceramic objects, with majolica ware as a notable exception, are often well preserved after many centuries, even millennia, in a marine environment. They might therefore be suitable candidates for successful reburial. Glass, however, is much less resistant to water and its deterioration is much more unpredictable. This project provides the opportunuity to obtain measurable data to confirm such empirical observations

Materials
The test material for the project was selected, from authentic archaeological finds from the excavations in Marstrand harbour and from a parallel set of samples of non-archaeological origin. Since the primary purpose of this investigation is to study reburial, it was considered important to use authentic samples with different extents of degradation. It also seemed necessary to have a set of samples which, at the outset, were more homogeneous and which would allow for a more reliable interpretation of any alterations. The archaeological material was insufficient with regard to porcelain and majolica ware. Modern majolica ware is not comparable to that which was produced in earlier centuries and this category was omitted altogether, whereas a modern porcelain sample was included even though an archaeological equivalent was not available. Twelve sample materials were selected.

The archaeological samples, from the Marstrand excavations, quay site and frigate *Fredricus,* are:
- Earthenware, lead glaze
- Stoneware, salt glazed
- Flintware, lead glaze
- Clay pipes, ball clay
- Bottle glass, dark green potash glass
- Clear table glass, 1) mixed alkali 2) potash glass

The "modern" samples of 20th century production, ca. 1930's, 40's, 50's are:
- Earthenware
- Stoneware, feldspatic glaze
- Flintware, lead glaze
- True porcelain, feldspatic glaze

All modern samples are cut from the same object, whereas several of the archaeological samples have two "mother" sherds since no one sherd was sufficiently large enough.

Model glass was made to order:
- Soda glass, balanced composition
- Potash glass, unbalanced composition (high potassium, high calcium)

The potash glass was included for its rapid degradation qualities so as to provide a sample with visible results within a relatively short period of time. The formulation has been developed at the Fraunhofer Institut für Silikatforschung specifically for purposes of artificial ageing and the samples were prepared at the Glass Research Institute in Växjö.

To monitor the influence that packaging might have, we included three different packing regimes for each sample material: sealed PE Zip-lock bags ®, permeable PE netting and semi-permeable Geotextile PP/PE 70/30. To ensure that identification of the samples would be possible in the distant future, we used four different labelling techniques in each sample package: embossed plastic (PVC) and aluminium Dymo ® strips and Tyvek ® marked with both ballpoint and permanent marking pens. All samples were weighed and photographed prior to packing.

Each full set of 36 samples was finally tied down into perforated HDPE crates (Figure 2), seven for planting at the underwater site and one that is stored in ambient conditions for reference.

Figure 2. One of the 7 batches prepared for reburial. Each batch includes 36 samples.

Analytical methods
Primarily, the analytical work focuses on alterations in the surface composition of the sample material – identification of depleted layers or of ion exchange. Secondly, we are also interested in extraneous elements and particles that may have penetrated or deposited on the sample material, particularly if they can be shown to contribute to the degradation. The results reported in the following are based mainly on analyses carried out with a scanning electron microscope LEO1455VP with an EDS unit for microanalysis LINK/Inca-400. Analytical experts have prepared a detailed manual with recommendations for the analytical work, in order that, as far as possible, the analyses will be comparable throughout the project. [5] This includes specifics about sample preparation, the equipment, recommended pressure, voltage, magnification, standards, etc. Clearly, no one person involved in this project today is likely to be in a position to follow it through to the end. Nor are the analytical instruments likely to remain the same. In the event that further analytical techniques should be found appropriate to use in the future, all sample material is saved.

Procedures and problems
We received the retrieved material, including its surrounding sediment, re-packed in two sealed PE boxes. As it was not in our interest that the samples should be over-clean when examined, the retrieved packages were just quickly flushed with tap water to remove most of the attached sediment. The samples were then removed from their packing, weighed, allowed to dry slowly under cover and weighed again. They have been examined under optical microscope for visible alterations, then run in the SEM and the element composition determined.
Retrieved samples have been run parallel to the reference samples and directly compared with these. Where necessary, archaeological reference samples have been broken to allow for analysis of an " unaltered core" with an elemental composition close to the original. Detected elements are calculated as oxides and all data has been registered in an Excel file. Relevant weights before and after reburial are also included in the file along with any other diagnostic observations.
A serious problem, that was not acknowledged initially, concerns the weights registered for the archaeological samples. This material had been stored in tapwater since the excavation and they

could not be weighed in a dry state prior to reburial. We had unfortunately not made arrangement for weighing in water and the amount of water included in the registered weights is impossible to calculate. As information for any alterations that may have occurred during the reburial stage, this data has therefore proved useless. The weights of the modern samples will, however, be monitored.

Results
As anticipated, the archaeological samples are difficult to interpret although it is within this group that the most obvious differences between the retrieved material and the reference material can be observed. The modern samples have, as yet, undergone little or no change.
The non-porous wares, stoneware and porcelain, show no detectable alterations whatever, neither chemical nor visibly apparent. The porous wares, earthenware and flintware, have not visibly altered either, but have predictably absorbed sodium chloride, sulphur and iron from the environment. This is observed particularly on the archaeological samples in the breaks and in fine cracks in the glaze. The clay pipes are also highly absorbent samples and here a clear difference can be seen between samples deposited in sealed Zip-lock bags ® and those in the netting – the latter also having salt deposits on the surface.

The glass samples are, on the whole, those that show the most clear alterations. The model potash glass has degraded heavily and a substantial proportion of the surface area has flaked off. On these we can also register weight loss. As was observed with the clay pipe samples, the Zip-lock bags ® appear to have offered a certain amount of protection to these glass samples (Figure 3 a, b).
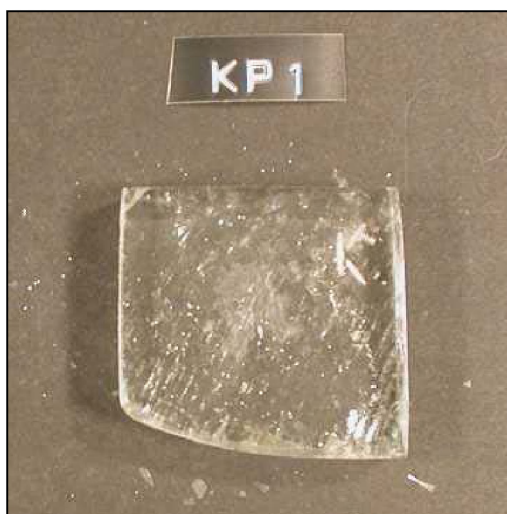

Figures 3 a and b. Retrieved potash model glass sample deposited in Zip-lock bag ® (left) and deposited in netting (right).

The soda model glass has no visible degradation, but diminished sodium content was registered.

The archaeological clear glass samples display a thin iridescent surface, barely visible to the naked eye, but clearly detectable as a substantial reduction of the alkali component (potassium, sodium, calcium) in the surface layers (Figure 4 a, b). A similar depletion is also found on the reference sample, the main difference being that this silica-rich layer still adheres to the glass substrate. This glass has clearly been stressed by reburial. The sample deposited in Zip-lock bag ® had also been physically damaged and broken into three fragments.
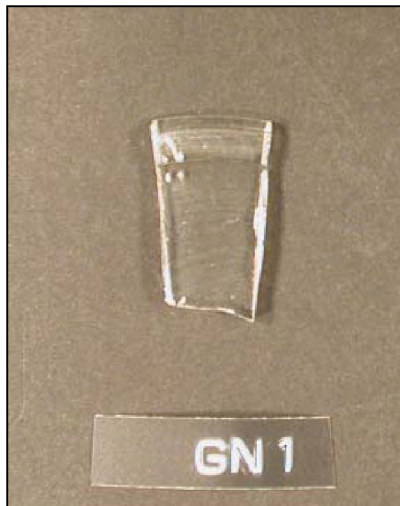
Figures 4 a and b. Retrieved archaeological clear glass sample (left) and SEM image of the clear glass sample (right). The marked area is the weathered layer, the light spiral design is where it has flaked off.

The results on the archaeological bottle glass is the most difficult to interpret. Both the references and the retrieved samples display a very variegated breakdown of the surface with thick silica-rich layers that also have patches of elevated iron content. Are these absorbed or enriched or both? Upon drying, these layers readily flake off on all samples and there is little difference that, as yet, can be ascertained. Also manganese-rich areas were registered (an element which tends to migrate in waterlogged glass) and, again, deposits of sodium chloride and sulphur.

For the majority of the samples in this category of materials, one year of exposure is a very short time for substantial changes to take place. To present statistically valid data, we must await further retrieval series.

Degradation of Metals

Materials and Methods
This study will ascertain the effect of reburial on the deterioration of archaeological metals commonly found on underwater cultural heritage sites. The corrosion of reburied and exposed modern metal coupons will be examined and compared over time. The corrosion results from the modern metal coupons will then be compared to the archaeological metals recovered from the cultural heritage sites.

The sacrificial metals consists of standard corrosion coupons of known metal composition. The standard corrosion coupons utilised are mild steel, cast iron (grey), brass, copper and bronze. The iron and non-ferrous metals are mounted separately to prohibit galvanic and proximity corrosion. Therefore, seven units for each alloy group have been prepared to allow recovery and analysis after 1, 2, 3, 6, 12, 24 and 48 years. Each unit consists of three sets of metal samples mounted at three different depth intervals (totally exposed, just below the sediment and buried 50cm in the sediment). Each set of metal samples is secured with cable ties to three perforated high density polyethylene plates, attached to a high density polyethylene rod at the specified depth intervals (Figures 5 a and b). The units were placed on-site in September 2003. In addition, three sets of metal samples are appropriately stored in the laboratory to be used as controls. Control samples will be analysed prior to burial, after six years and after 48years.
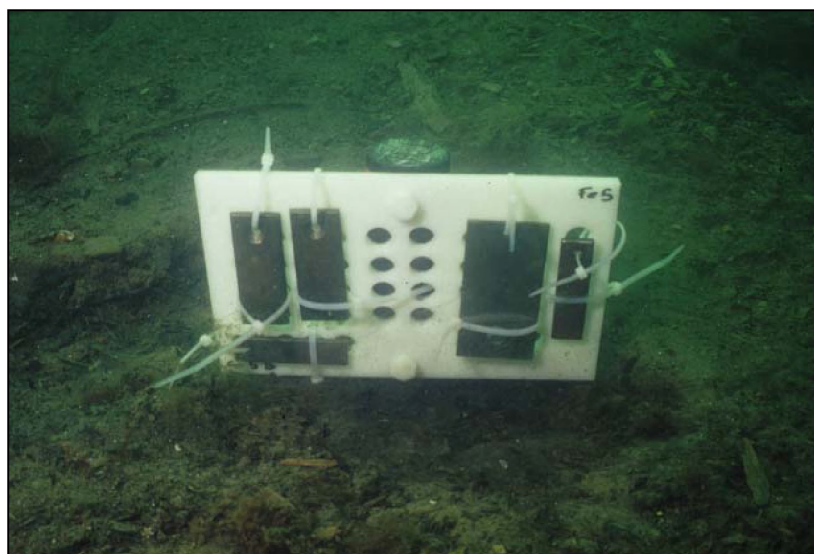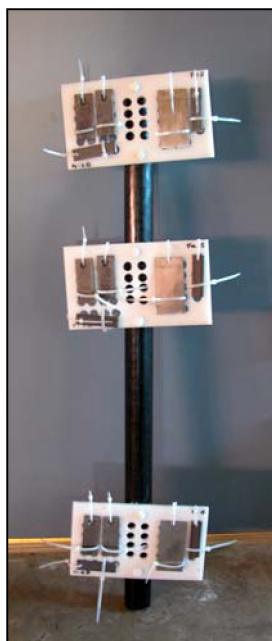
Figures 5a and b. One set of ferrous samples before (left) and after reburial (right)

The corrosion products will be examined by scanning electron microscopy (SEM) and identified with x-ray diffraction (XRD) analysis. The extent of corrosion of the metals will be monitored by weight change and a combination of optical emission spectroscopy and wet chemical analysis utilising inductively coupled atomic emission spectrometry (ICP-AES) and standard Leco techniques.

Core samples of the sediment have been collected in the reburial trench and a control sample adjacent to the trench in an undisturbed area. The sediment samples will be analysed with respect to particle size distribution and weight loss on ignition. These preliminary analyses of the backfilled sediment will provide some indication of if and when and the rate at which the sediment attains baseline conditions again.

Preliminary results
No preliminary results are available since the first retrieval of samples is due in September 2004.

Degradation of Wood
Wood, including historical objects and construction timbers, is degraded in both terrestrial and aquatic environments by fungi and bacteria. In the marine environment wood-borers are an additional group of very harmful degraders. The wide range of degraders has different environmental requirements for their activity. In order to study the biological wood degradation processes at the reburial site close to the wreck *Fredricus*, modern sound wood samples were buried in the reburial trench. Investigations were carried out at different depths in the sediment and applied on different wood species.

The physical frameworks of historical shipwrecks consist mainly of wood. Efforts to understand wood and wood-degrading processes in the natural environment should therefore be bourne in mind, when discussing in situ management, reburial and other preservation strategies for this specific type of cultural heritage.

Materials and Methods
In order to measure the actual wood-degrading processes in the reburial environment sacrificial sound wood blocks were inserted adjacent to the wreck. (This method is very successful in

monitoring the actual wood-degrading processes in the environment, as opposed to examining solely old wood material, where the accumulated decay over time can be studied, but not distinguished from the ongoing decay.)

A shipwreck often contains several different wood species. Due to inherent differences in durability, several wood types must be tested. Therefore, oak heartwood, pine sapwood and birch were chosen as test materials and blocks of 120 x 30 x 8 mm. dimensions were manufactured. Three groups of test samples were mounted on a plastic rack of 70 cm in length (Figure 6). Each group consists of one oak, one pine and one birch stake. The groups are placed 13 respectively 30 cm from each other. Sixteen identical racks were produced and inserted vertically and pair-wise in the reburial trench. On each rack, the upper test group is above the seabed, whereas the other two are embedded at different depths in the sediments (approx. -13 and -50 cm).
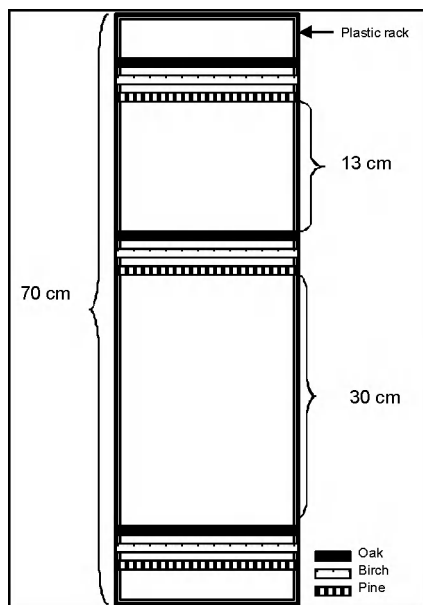
Figure 6. Design of a test rack, where 3 groups of test material, each containing three different wood species, are mounted on an open window-like plastic frame at three different intervals.

According to the project plan, two racks are to be retrieved after six, twelve, twenty-four and thirty-six months of exposure. The remaining eight racks are left buried for long term investigations. After each exposure period, the racks are lifted from the seabed and immediately sent to the laboratory where they are kept in water at 4 °C until the start of examination. Firstly, all samples are dismounted from their racks and rinsed with water to remove dirt and marine related growth. The wood samples are then visually examined in order to localise marine borers on the surface or within the wood. Secondly, thin sections from all wood blocks are cut out by hand with a razorblade, and stained by safranin or aniline-blue before using light microscopy in order to determine the type and degree of microbial decay.

Preliminary results
After 6 months of exposure, microbial decay was observed in all wood samples exposed above seabed. Soft rot fungi and tunnelling bacteria were the main degraders (Figures 7a, b, c). Marine borers were absent. No decay was observed in samples buried in sediment. A different scenario turned up after 12 months of burial. All wood samples exposed above seabed, had (apart from soft rot and tunnelling bacteria decay) been subjected to marine borers (Figures 8a, b, c). Results from microscopic investigations also showed that soft rot fungi, tunnelling bacteria, and erosion bacteria were degrading wood buried at 13 cm of depth. In the sediment, at 43 cm below seabed, erosion bacteria were the only wood degraders present (Figure 9). A summary of the preliminary results of decay type observed after 12 months is listed in Table 3.

The results showed that oak, birch and pine have a different natural durability towards the different forms of decay (Table 4). Pine samples were more subject to marine borers than oak and birch, whereas soft rot decay was most frequent in oak samples. Birch and pine were more subject to tunnelling bacteria than oak, whereas erosion bacteria were present mainly in the hardwoods.

Table 3. Decay types observed in wood samples after 12 months of exposure in varying depth.

Decay type	Above sea bed	13 cm in sediment	43 cm in sediment
Teredo sp.	Yes	No	No
Limnoria sp.	Yes	No	No
Soft rot	Yes	Yes	No
Tunneling bacteria	Yes	Yes	No
Erosion bacteria	No	Yes	Yes

Table 4. Variations in durability against different decay types after 12 months.

	Oak	Birch	Pine
Teredo sp.	x	xx	xxx
Limnoria sp.	x	x	xx
Soft rot	xxx	xx	xx
Tunnelling bacteria	x	xx	xx
Erosion bacteria	xx	xx	x
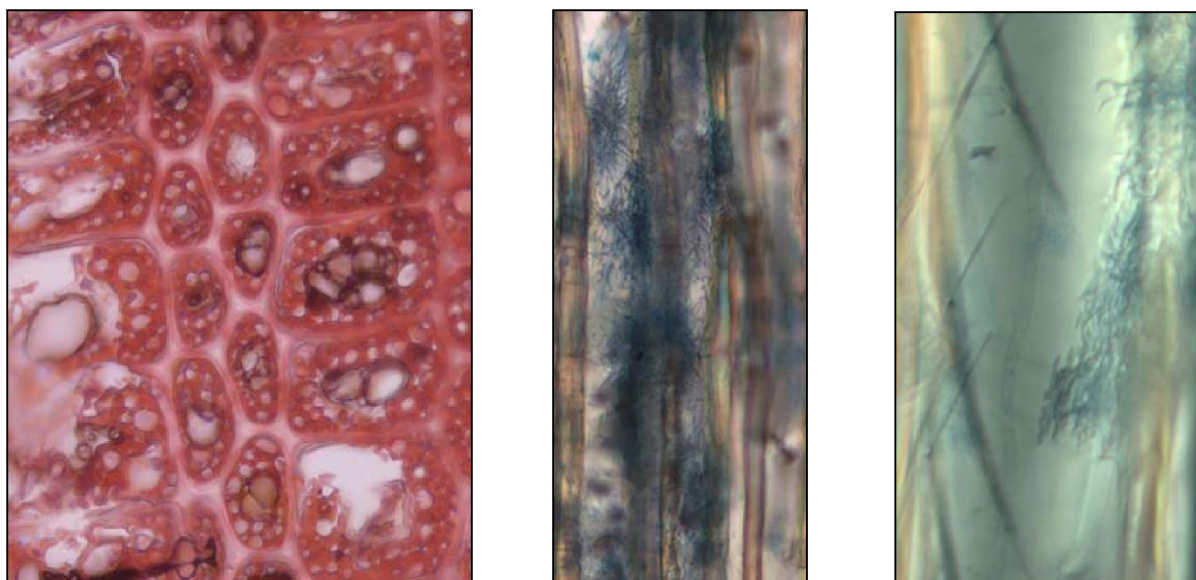
Figures 7 a, b, c. Micrographs showing typical microbial decay pattern observed in pine test samples after 6 and 12 months of reburial above seabed. Cross section showing cavities in cell walls produced by soft rot fungi (a). Fine network of tunnelling bacteria observed in longitudinal section of tracheids (b). In longitudinal section (c), both decay forms are present in one tracheid; soft rot cavities (left) and tunnelling bacteria (right).

Figures 8 a and b
Ocular examination of test samples exposed above seabed for 12 months showing a seemingly plain and intact wood surface apart from sporadic growth of marine organisms (a). However, strong decay by shipworms is taking place inside the wood (a, b). Pine and birch were more degraded than oak (middle, b).

Figure 9.
Test samples buried in sediment at 43 cm of depth for 12 months, are solely degraded by erosion bacteria. Micrograph shows the typical decay pattern along one single fibre of birch.

Preliminary conclusions and discussion
Archaeological- and historical wooden-constructions, such as shipwrecks, are subjected to a rapid degradation process when situated above sea bed in marine environments. In less than 12 months marine borers had penetrated the wood interior and caused irreparable damage. Below the sea bed, at 13 cm of depth, wood is protected against marine borers, but not from soft rot fungi, tunnelling bacteria and erosion bacteria. At a depth of approximately 50 cm, only erosion bacteria seem able to degrade the wood.

The reason for the presence or absence of wood degrading organisms is mainly due to their different demands for oxygen. In water, above the sea bed, the concentration of oxygen is much

higher than within the sediment, where oxygen generally decreases dramatically with depth. Marine borers are not active at low oxygen concentrations and therefore wood is protected from these organisms when buried in the sediment. Erosion bacteria are known to be the only active wood degrading organism under near anaerobic conditions. Hence, they are not unexpectedly found in the low-oxygen areas of the sediment. Long-term observations, and the next two years of study, will reveal if these preliminary results indicate a long-term trend.

Degradation of textile, leather, antler, horn and bone

Materials and methods
The aim of this subproject is to evaluate the effect of re-burial in the marine environment on the more sensitive organic materials that make up the marine archaeological record such that recommendations can be made for, or against, the use of similar environments for long-term storage of artefacts made of these materials.

Materials selected for inclusion in this subproject comprise organic materials, other than wood, commonly represented in the marine archaeological record. Samples have been drawn from modern materials of vegetable-tanned leather, dyed and undyed wool fabric, linen fabric, undyed silk fabric, hemp rope, tarred cotton net, antler, horn, and bovine bone (metapodials). Dyestuffs, tanning agents and pre-treatments of the experimental materials were kept as close to those used in antiquity or historical times as practically possible. The leather, wool, linen, antler and bone already form the basis for similar studies of other, different, burial environments on land [6, 7].

Fifteen sets of samples were prepared; fourteen were deposited in the harbour at Marstrand for later retrieval over the 50-year project period. One set of samples is maintained in darkness at constant temperature and relative humidity in the climate-controlled museum stores at Vitenskapsmuseum. The sets of buried samples are housed in perforated trays. There is one tray for each retrieval period, and two sets of samples in each tray (Figure 10). Each set is sewn into an open nylon mesh envelope and one mesh envelope is further enclosed by sewing into a geotextile envelope. Both envelopes are laced into the tray with nylon cording. In this manner, one set of sample materials is exposed to the harbour sediment, while the other is protected in the geotextile envelope. Seven trays were prepared and deposited in Marstrand Harbour in September 2002. One tray was retrieved in September 2003. Upon recovery, it was double bagged in thick polyethylene sheeting and bubblepack and placed in a cool store for several weeks.

The harbour sediment, which smelt of rotten eggs, had formed a dense layer over the samples. It was excavated under laboratory conditions to removed the sediment and free up the two envelopes. Initial examination of the mesh envelopes showed all the sample materials to be present. Samples were not soaked or rinsed to remove impregnated salts prior to drying. Samples of leather, textile, rope, and net were frozen and dried by vacuum freeze-drying (cooled chamber); samples of horn were controlled air dried at elevated RH. The bone and antler were frozen until required for scientific analysis. Several options were available when considering how to dry these materials, including air drying, vacuum freeze-drying and drying by solvent exchange. Since it was feared that solvent drying may compromise future biochemical analysis of the specimens, and the samples appeared too robust to warrant freeze-drying it was elected to dry the samples slowly in air. After defrosting, these samples were blotted dry and this removed any superficial silt. After drying all samples were equilibrated to 55% RH in the museum store for 72 hours before weighing.
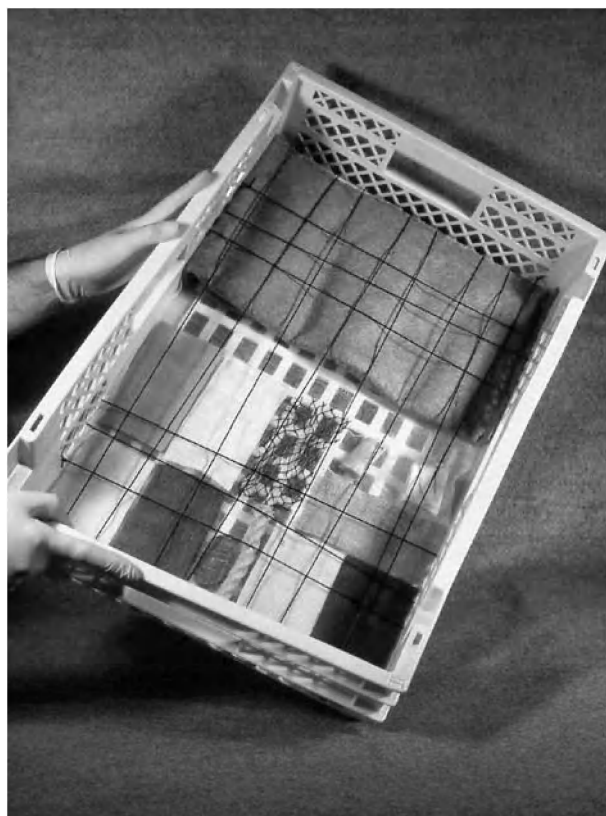
Fig. 10. The sample unit with one protected and one unprotected set of samples before reburial.

Analysis

Typical sample materials were documented prior to burial. This documentation has consisted of macro-photography and scanning electron microscopy (SEM, SEM-BSE, and SEM-EDS) of both surface and interior morphology. Samples selected for burial were also weighed after pre-conditioning to 55% RH. Post-retrieval documentation has been completed for the bone, horn, and antler, and research is ongoing for the other materials.

Preliminary results

Upon initial examination the more delicate organic materials – linen, rope, and wool – fared less well than the more robust materials such as bone, horn, and antler. There was a marked difference in degree of preservation/deterioration between the samples of these materials that were exposed to the harbour sediment and those that were protected in the geotextile envelope.

Table 5. Residual weight of sample materials after 1-year burial

Sample group	Wool undyed	Wool red	Wool blue	Wool yellow	Linen	Silk	Net	Rope
1 yr uncovered	38.5%	106.3%	41.6%	75.7%	16.6%	103.8%	94.1%	48.1%
1 yr covered	101.1%	99.9%	53.9%	77.9%	9.1%	103.8%	97.2%	34.6%

Sample group	Leather	Antler	Bone	Horn
1 yr uncovered	87.3%	104.4%	99.5%	98.3%
1 yr covered	87.8%	100.4%	99.8%	100.8%

The skeletal materials

Bone, antler and horn are much more robust than the leather, textiles and cordage with which they were deposited. Although bone and antler have a high macroporosity, the microporosity of

fresh osseous material is much lower than leather and textiles, which consequently have a much greater capacity to adsorb and retain contaminants from the marine environment. Compared to bone and antler, the porosity (and therefore available surface area) of horn is very low. However, unlike osseous materials, horn is not a mineralised tissue and the proteinaceous matter (keratin) is unprotected by intimate association with a relatively insoluble mineral – hydroxyapatite in the case of bones, antler and teeth. Horn is therefore susceptible to swelling in water, particularly water containing dissolved ionic species. This makes horn much more vulnerable to attack by microorganisms that excrete extracellular proteolytic enzymes and horn is rarely recovered from archaeological contexts.

Very little staining was visible on the skeletal materials, although the bone showed some discolouration in scratches and cuts in the surface made when cutting up the original bone. The most obvious change in the macroscopic appearance was seen in the horn that had shrunk on drying, causing concentric splitting. Otherwise, there appeared to be very little structural change in the hard tissues after one year of sea burial. This observation is consistent with the negligible change in weights in the samples after 12 months of sea burial.

One notable observation on the bone that had been enclosed in the geotextile was traces of a white, waxy deposit lining the marrow cavity. Although this remains to be analysed, it is very possible that this represents adipocere – formed by the hydrolysis of animal fats in waterlogged and anoxic environment [8].

Small samples, approximately 0.5 cm^3 of the bone, antler and horn were removed for electron microscopy (SEM). These were carbon coated and viewed in a Hitachi Low-vacuum SEM in secondary electron mode. At low magnifications (30X to 100X) there was little evidence of surface alteration or contamination apart from occasional grit particles on any of the skeletal materials regardless of whether they had been enclosed in the open mesh envelope and exposed to the harbour environment or protected in the geotextile envelope. At higher magnifications, it was possible to see that the surfaces were littered with fragments of phytoplankton, irrespective of how well the specimens had been enclosed. These fragments have typical sizes in the range 10 to 50 microns and are very easily carried by seawater into small cavities. The other contamination, visible on all the specimens examined was fungal hyphae and fungal spores or *conidia*. These spores were much more numerous on the horn than on the bone and antler specimens, presumably reflecting the easier availability of nutrients on the non-mineralised tissue.

The textile materials
In general, the textile materials in the geotextile envelope were less affected by burial than those in the open mesh envelope. Some materials show an increase in weight resulting from residual particulate matter. Both the covered and uncovered samples of the grey linen fabric and hemp rope experienced extensive material breakdown as evidenced by loss of substance, surface fungal mat, and smearing of fibres. The linen was reduced to an open weave veil of collapsed yarns (Fig. 11). The third cellulose-based textile material in the study, cotton fishing net, exhibits no deterioration other than some fungal mat on the uncovered sample and well illustrates the protective nature of the tarring treatment.
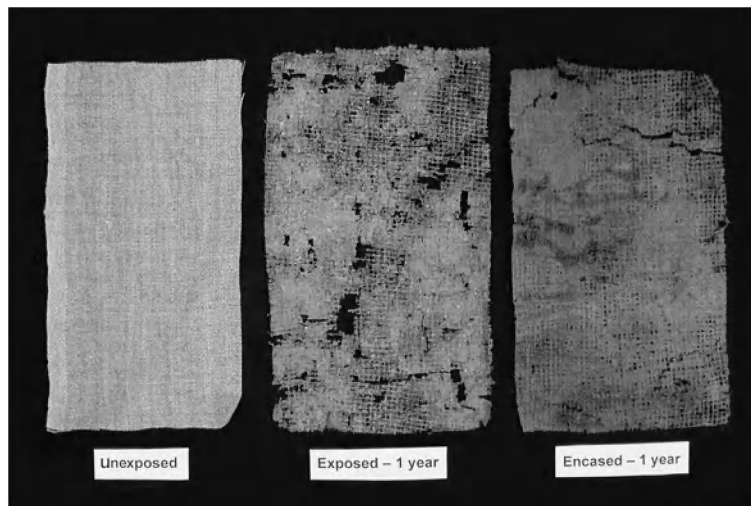
Figure 11. Linen samples with the unexposed reference sample to the left followed by unprotected and protected reburied samples.

There is a marked difference in material breakdown between the two protein-based fabrics. Neither silk sample experienced loss of substance or surface change. However, there is a wide variation in the post-burial condition of the wool samples. The wool fabric is highly fulled twill (vadmel) with a high density of surface fibres. The colours of the dyed fabric are strong. In general, the buried fabric samples faded in colour, and lost surface fibres and substance leading to a thinner fabric and loss of fabric integrity. The uncovered samples fared worse than the covered ones. The indigo-dyed, blue wool fabric samples experienced substantial removal of surface fibres and material substance. The weld-dyed, yellow wool fabric samples were not as extensively broken down as the indigo-dyed samples. The madder-dyed, red wool fabric samples were the least affected of the wool samples. The undyed wool samples experienced the greatest difference in degree of breakdown between the covered and uncovered sample. The uncovered sample was reduced to 38% of its pre-burial weight.

Leather
The leather samples experienced a small and similar weight loss during the first year of burial. Visually their change in colour is also similar for the uncovered and covered samples.

Future work
The SEM examination to date shows only morphological changes to the surfaces of the skeletal samples. More insight into subtle chemical changes will be possible with more detailed study of embedded histological sections. Imaging of cross-sections using backscattered electrons (BSE-SEM) combined with elemental analyses (EDX) will permit profiles to be developed of the penetration of metal and other salts from the seawater and also highlight any destruction of tissues by the action of micro-organisms – either fungi or bacteria [9].

The microscopy work remains for the textile materials and the leather samples. The Marstrand materials (leather, wool, linen, antler, and bone) will be compared with results obtained in similar burial studies carried out in terrestrial environments. In addition, samples of the recovered material are being made available to other researchers investigating different aspects related to the preservation or degradation in burial environments of these organic materials. In this manner, the range of possible information this experimental material can contribute to the research community can be even greater.

Degradation on materials used to separate and mark archaeological objects

In archaeology a range of modern products are used to separate, mark and support archaeological objects during an excavation. These products, often of a polymer origin, are essential for both identifying and supporting the objects. Consequently the durability of these products is of great importance especially when finds are to be reburied after registration and documentation. A reburial environment is likely to be benign for the conservation of polymer material, but present knowledge of their long-term stability is limited. Knowledge of the most suitable products and materials to use not only improves the quality of cultural heritage management but also improves the efficiency of the work that is to be conducted, since the correct material can be used from the start of an excavation.

The aim of this sub-project is to investigate the degradation and durability of relevant products used in archaeology today, to compare and assess their suitability in relation to reburial.

Materials and Methods
The study includes a variety of products and materials mainly of a polymer origin, such as polyethylene (PE), polypropylene (PP), polyester, polyamide or nylon (PA), and polyether/polyurethane (Table 6).

The material samples will are exposed to two different reburial environments:
- *In-situ* in the actual sediments in the harbour under the same conditions as during a normal reburial.
- In the laboratory in the reburial sediment: 1) oxygenated at +23 ± 2°C and 50 ± 5 %RH (chemical degradation) and 2) anoxic at ambient room temperature (bio-degradation).

Nine sample units were prepared, documented and packed during the summer of 2002 and eight of them were reburied in the reburial trench in Marstrand harbour in September the same year. Each unit contains three samples of each material, except for the HDPE crate, which constitutes the container for all the samples (Figure 12). The ninth unit is kept as a reference in cool storage conditions at SVK.

Figure 12. Sample unit with packing and marking material before reburial.

Table 6. The materials and types of analyses chosen in the investigation.

Material	In-Situ Ageing	Accelerated ageing, Chemical degradation	Bio-degradation
Crate, HDPE	x	x	x
Crate, pine	x		
Bag, PE	x	x	x
Net, PE	x	x	x
Sack, woven PP	x		
Geotextile, PP/PE	x	x	x
Geotextile, polyester	x	x	x
Tapaulin, synthetic rubber, EPDM	x		
Wadding, polyester	x		
Cord, polyester	x	x	x
Cord, PE	x	x	x
Cord, spun, PA	x	x	x
Yarn, PA	x	x	x
Prefabricated tag, polyether/ polyurethan	x	x	x
Tag, dymo ®, PE	x		
Tag, dymo ®, steel	x		
Marker, permanent ink on PE bag	x		
Marker, permanent ink, on PE tag	x		
Marker, permanent ink, OH, on PE-bag	x		
Marker, permanent ink, OH, on PE tag	x		
Pen, ball point, Archive proof on PE bag	x		
Pen, ball point, Archive proof on PE tag	x		
Pencil on PE -bag	x		
Pencil on PE-tag	x		

Three of the *in-situ* units will be retrieved during the first phase of the project, one each year. The samples will be inspected and documented. They will be photographed and examined with the aid of a microscope and preferably also with a SEM. Tensile strength will be tested after 3 years of exposure. This decision was taken after discussions with SP, the Swedish National Testing and Research Institute, on the basis that only one or two years of *in-situ* natural exposure was too short a period to observe any significant changes in the polymeric material. Therefore a tensile strength test was not considered worthwhile. The results will be reported each year.

.
Reburial is anticipated to last for an extended period; therefore, the packing and associated materials need to be able to survive for just as long. It is likely that the environment is harmless for the polymers, and that the mechanical properties of the materials in the first in-situ test units will not change much. Hence it is necessary to use experimental degrading techniques to determine the rate of degradation of the polymer material. The aim is to verify that no extensive degradation will take place and hopefully to establish relationships between temperatures and degradation times in this particular environment so that the rate of degradation and life span of a particular product can be estimated.

Ten different materials and products are being tested using experimental degrading techniques. The materials selected are presented in Table 6. The reason for not including all materials, as well as conducting experiments on certain materials only at one temperature, have mainly been economical, however previous research on polymeric materials have also been considered. Some polymers have been far more investigated than others, for instance polyethylene [10]. Two series of tests are planned.

Firstly, the aim is to investigate the chemical degradation of the samples. Samples of the selected materials have been placed in sediments taken from the reburial site in Marstrand, the degradation is accelerated by heating. Four of the ten selected materials are stored at three different temperatures, 50, 60 and $70^{\circ}C$, whereas the other six materials are stored only at $70^{\circ}C$ (Figures 13 a, b). By using higher temperatures the degradation of the material will be more rapid, which is needed if we are to see changes during the first phase of the project. A relationship can be established between degaration rates and temperatures (Arrhenius equation) and from that result it is (hopefully) possible to deduce degradation rates at lower temperatures for the different materials.

Figures 13 a and b. Degradation of test materials in Marstrand sediment at different temperatures.

The degradation will take place during a time span of 6 to 52 weeks depending on material (Table 7). No specific care has been taken to keep the sediments anoxic since the heating will change the microbiological activity. The tensile strength of each degradaded material will be tested, evaluated and reported.

Secondly, the aim is to assess the microbiological degradation on the same material. The samples are placed in sediments taken from Marstrand. In this case special care has been taken so that the sediments are kept as anaerobic as possible. The test units are kept in a fume cupboard of ambient room temperature and the time span is set to 1.5 years. The tensile strength of each degraded material will be tested, evaluated and reported (Figure 14).

Figure 14. Microbiological degradation of test materials.

The experimental degrading and tensile strength analyses are performed by the Swedish National Testing and Research Institute (SP).

Table 7. Eperimental degrading. Materials that will be tested for their mechanical properties after chemical degradation in Marstrand sediments.

Material	Temperature (°C)	Degradation time (weeks)
PE-net PE-bag PP/PE Geo-textile PE-cord	70	26
polyester cord PA-cord PA-yarn polyether/ polyurethane tag	70 60 50	6, 12, 20, 26 11, 20, 30, 39 13, 26, 39, 52
HDPE crate	70	26

Preliminary results
No major degradation seem to have occurred within most of the in-situ test samples after one year of exposure in the sediments in the Marstrand harbour.

All pre-stamped or pre-fabricated labels are perfectly readable after one year of exposure. Apart from the steel labels, which are slightly tarnished, no traces of degradation are visible. However, small changes have taken place in the written material, e.g. text written with markers and a ball-point pen. The degradation that is noted as colour changes, bleaching and blurred contours and when written on a shiny surface the text can be partially chafed. (Figures 15 a, b)
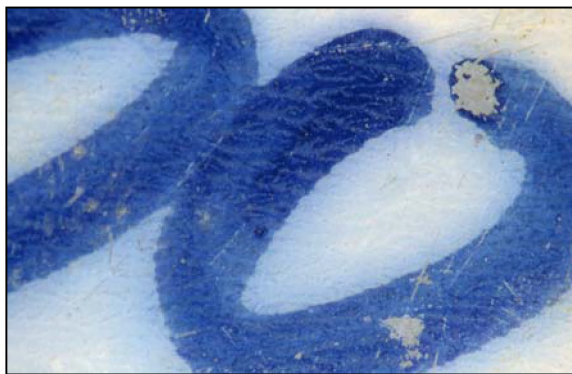
Figures 15 a and b. Permanent Marker OH. Close-up on writing on PE-bag after one year of exposure (left) and on reference sample (right)

The experimental degrading tests have so far shown only minor changes in the physical properties of the tested material, but no conclusions could be made at this early stage. (Figures 16 a, b)
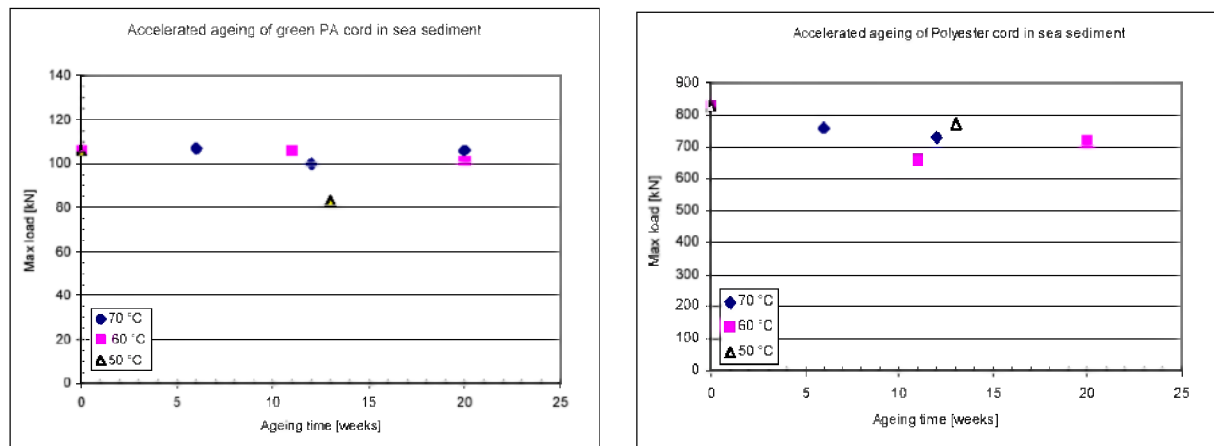
Figures 16 a and b. Graph showing the tensile strength of polyamide yarn (left) and polyester cord (right) degaraded in sea sediment at different temperatures.

The environment of the re-burial site.
This sixth sub-project measures environmental parameters at the burial site. The premise for reburial as a valid method of preserving archaeological artefacts is that it seeks to emulate the conditions of the pre-excavated environment. That archaeological finds in marine sediments are well preserved is primarily attributed to reduced levels of oxygen. Parameters, which give a good indication of these conditions, are dissolved oxygen, sulphide, pH and redox potential. By measuring these parameters at the reburial site and comparing them with a 'control' undisturbed area it will be possible to determine whether or not the reburial site does emulate the pre-excavated environment. Furthermore, it should be possible to correlate the aforementioned parameters with the measured deterioration of the control materials placed in the various reburial trenches. Through such a correlation it will be possible to evaluate the use of reburial as a valid method of preserving archaeological remains.

The aims of this sub-project are:
- To test, develop and compare different equipment to accurately measure parameters within the reburial trench and thus develop standard methodologies for assigning the preservation qualities of the environment.
- To obtain background data on the environment of undisturbed sediments around the reburial trench in Marstrand.
- To assess how quickly the environment within the reburial trench comes to emulate undisturbed sediments within Marstrand.
- To use this data to support data analysis of the other subgroups´ projects.

Materials and methods
The monitoring of the environment is conducted in three ways, including spot measurements and long-term monitoring. The spot measurement system, which is used, is a series of microelectrodes to measure, dissolved oxygen, pH, redox potential, and sulphide content of the sediment. The system uses standard microelectrodes made by the Danish micro sensor manufacturer Unisense, who has been working with the National Museum of Denmark to develop a meter and measuring system which can be used directly underwater /in situ.
For shallow depths (1-10cm) this can be done in situ within the sediment. For greater depths (10 - 60cm) a series of core samples must be taken and the microelectrodes can then be used to determine the aforementioned parameters on the surface (Figure 17). One core is taken in the reburial trench and another core is taken adjacent to the reburial trench, and serves as a "control" of what the surrounding undisturbed sediments are like; just the kinds of conditions we want to re-establish within the reburial trench.

In order to record long term changes, a datalogger, under development by Eauxsys UK limited, that measures the same parameters has been placed in the reburial trench and data are logged daily (Figure 18). Parameters measured using this system include dissolved oxygen, pH, redox potential, temperature and pressure (in order to measure depth). The advantage of this system is that it can take measurements at regular intervals (we opted for every second hour) over several months. The sensors themselves are placed within water-permeable plastic tubes, that are buried 50cm below the surface of the sediment. The idea being that pore water from the sediment establishes an equilibrium which is then measured by the sensors.
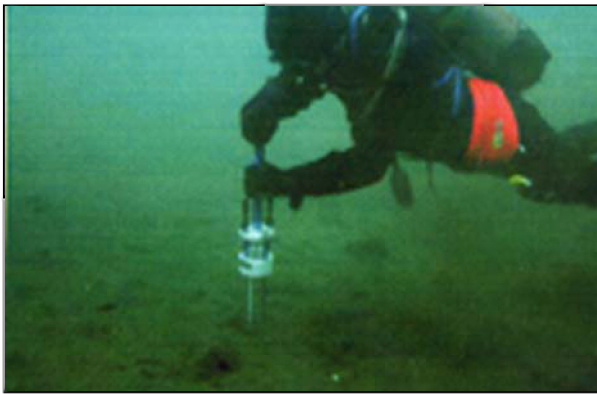
Figure 17. The corer in use
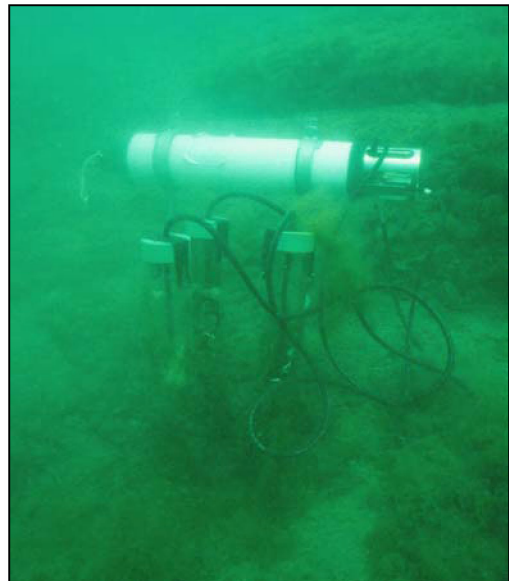
Figure 18. The datalogger in-situ

It was envisaged that the reburial site would be visited during the spring, summer autumn and winter in the initial phase of the reburial so as to record the initial changes in the reburial environment and also any seasonal fluctuations. Results from the in situ measurements are obtained in real time and require little post-processing. Core samples are analysed at the Conservation Department of the National Museum of Denmark. The data from the data logger is collected every three months and processed at the Conservation Department on the National Museum of Denmark.

The first monitoring of the site began later than originally planned. Due to the hard winter in Marstrand 2002/2003 it was not possible to get to the site until March 2003. In March, spot measurements were taken and the datalogger installed. The logger was retrieved in July 2003 and data was downloaded. After the first period of monitoring problems were encountered with the datalogger, which had to be returned to the manufacturer and be re-furbished. By the time this was completed and it had been further checked and tested in Denmark, it was not possible to replace the logger until the Spring of 2004. It is still the intention to collect data over a year using the datalogger to elucidate seasonal changes in the seabed. During the second visit to the site in April 2004 new spot measurements were also collected .

Problems encountered
The micro sensors are extremely fragile due to their very fine diameter. Two sensors were broken during testing, so it was decided to measure within sediment cores on the surface. At present new sensors are being tested which have been installed within a hypodermic syringe for prorection. It is hoped to test the system in situ during the next visit.

It has been decided to continue measuring within sediment cores rather than directly *in situ*. Although the robustness of the microelectrodes in a hypodermic needle is drastically improved there is a problem of "carry over" and the sensors becoming clogged when measuring. To ensure that reliable results are obtained the sensor tip is gently cleaned inbetween measurements to ensure that there is no residue from previous measurements. This is not possible using a diver operated system *in situ*. Furthermore, as discussed *in situ* measurements only yield results down to 10cm below the surface of the sediment whereas the processes ongoing down to 50cm below the sediment surface are of more interest.

The life of a sensor in a specific environment is not known. After three months there was a dramatic decrease in the pH measured with the datalogger. Following discussion with the manufacturer it transpires that the pH sensor, along with the redox sensor, has a finite operating life time which is about 3 months continual use. The redox potential measured by the datalogger is far lower than the redox potential measured by the microelectrodes. This big difference makes assessment difficult since an error of equipment maybe responsible for one or both results. Questions have also been raised about whether the pore water in the permeable tubes is representative of the water in the sediments. Experiments are currently ongoing to assess the porosity and permeability of the sediment in Marstrand to ascertain whether this is a real problem

Preliminary results
The preliminary results are based on the results from the data from 2003. The level of dissolved oxygen within the reburial trench were already almost at the detection limits of both sets of equipment (Figures 19 a, b). Interestingly, the core samples of both undisturbed sediment and sediment used in the reburial showed less than 1mg / litre. This would imply that even when sediments have been used for reburial an anoxic environment is re-established very quickly. The results from the microelectrodes are to be trusted far more than the data logger data. This is because the type of sensor used on the data logger is of a Clarke type, which actually utilises any dissolved oxygen present. For optimal results there should be constant circulation around the sensor – if there is not any available, dissolved oxygen will be used by the sensor and a zero reading will be given. This is not necessarily representative of the environment.
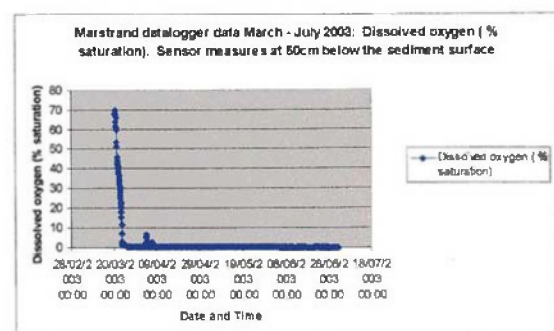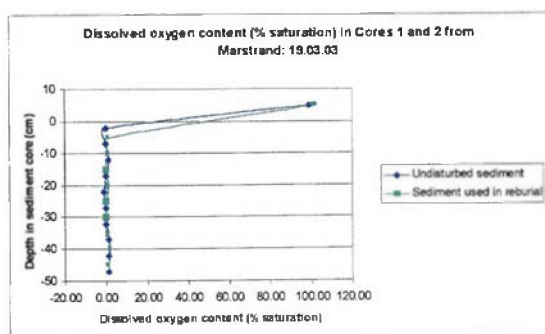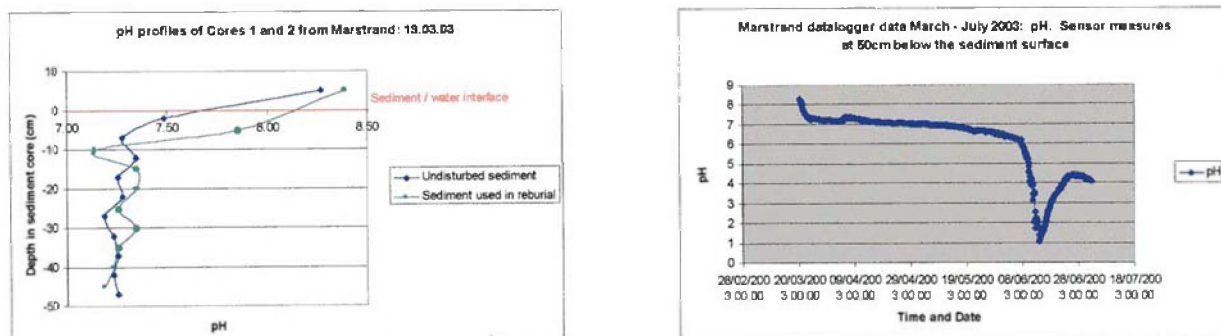

Figures 19 a and b. Dissolved oxygen content (% saturation) of sedimentd cores (left) and in-situ in the reburial trench monitored by the datalogger (right).

The pH using the micro sensors (Figure.20a) showed a decrease from approximately 8.30 at the water sediment interface to between 7.2 and 7.3 from 10cm down to 50cm within both undisturbed sediment and sediment used in the reburial. These results indicate that the environment is almost of neutral pH. The datalogger (Figure 20 b) showed significantly different

results with increasing time. However, the results are questionable; a pH of 1 is highly unlikely. When the datalogger was retrieved it was noticed that the sensor itself needed replacing.

Figures 20 a and b. pH profiles of the sediment cores (left) and in-situ in the reburial trench, monitored by the datalogger (right).

Redox potential measurements using the microsensors (Figure. 21 a) show that, as with the pH, there is a steady decrease in the potential from oxidising, in the open seawater, to a more reducing environment (approximately -100mV versus S.H.E) at 50cm below the surface. At present we can say that the more reducing the environment the better for the reburied artefacts. However, in the future these results will be interpreted with the pH data and results from the other subprojects to give a more detailed idea of the processes occuring in the sediment. As with the pH results it is interesting that there is very little difference between undisturbed sediment and sediment used in the reburial. Measurements using the datalogger also show that the environment is reducing. However, there is a large difference between the meassurments using the two types of equipment. As can be seen in Figure 21 b the potential stabilised between -300 and -400mV which is significantly more reducing than the potential measured with the micro sensors. As with the pH sensor, problems were encountered with the redox sensor after the datalogger was taken up in July and is being investigated. However, what also needs to be examined is that the redox measurements with the micro sensors were taken after 15 minutes stabilisation time. As can be seen from the data logger data, it took over two days before stable readings were obtained. This is one of the very interesting aspects of the project comparing and contrasting different methodologies. As the old adage goes, you can tell what the time is if you have one watch but what is it when you have two watches?
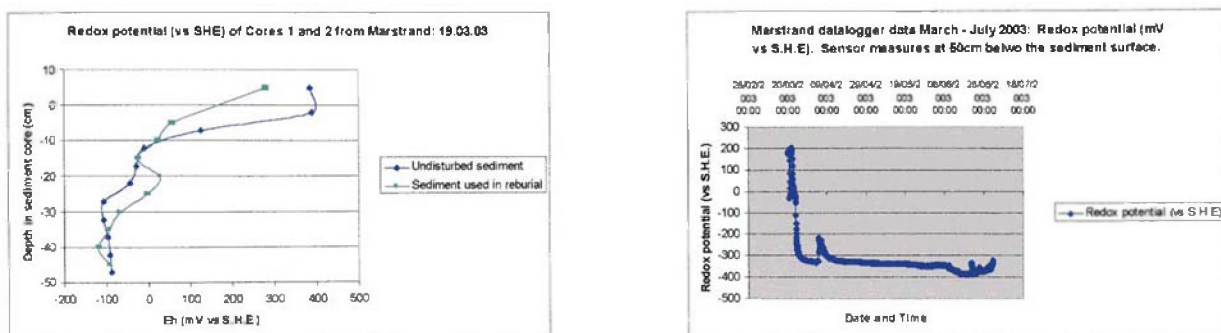
Figures 21 a and b. Redox potential profiles from sediment cores (left) and monitored in the reburial trench with the datalogger (right).

Total sulphide measurements with the micro sensors show a significant amount of sulphide present in the sediment indicating reducing conditions (Figure 22). Interestingly more is seen in the undisturbed sediments. This supports the dissolved oxygen and redox potential measurements by the other micro sensors, which reflect the ideal conditions for the action of sulphate reduction

by sulphate reducing bacteria which yield sulphide. If the potentials by the datalogger are correct we could expect that methanogenesis is part of the ongoing process within the sediment. This may well be the case but at present we have no means of testing this.
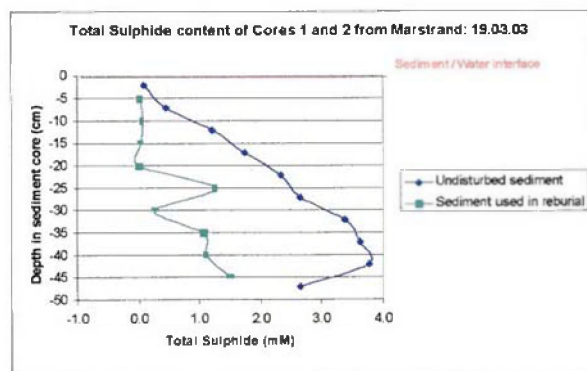

Figure 22. The total sulphide content of sediment cores.

Future work

Future work is to validate the efficacy of using dipwells for the dataloggers. This is being addressed through a series of laboratory experiments to be conducted at the National Museum of Denmark. A complete year of data will be logged using the datalogger. Ideally two years will be collected but this is depending upon funding. When possible sediment cores will be taken representative of the seasons of the year. Following the collection of one year of datalogger data the results will be analysed in terms of their effects on the materials present in the re-burial mound to ascertain if there is a correlation between the environment and the observed patterns of deterioration.

5. Preliminary results

It seems the reburial sediments in Marstrand become anoxic quickly, which is the condition towards which reburials in general are aiming. The pH is neutral and following the anoxic condition there is a high degree of sulphide. This result is of course positive and promising. However, there are still questions and concerns about how different materials behave in this specific environment and also how parameters, like sulphide, affect the degradation of materials.

After one year of exposure in the sediments a degradation of the most sensitive materials, notably textiles of a vegetable origin like hemp rope and linen, could clearly be noticed. More robust materials like wood, leather, bone, etc are less affected. The depth at which the materials are buried matters, as are shown in the wood sub-project. The decrease of oxygen with depth also decreases the species of fungi and bacteria found, and at 50 cm only erosion bacteria seem able to attack wood. As expected no changes could be seen in the cearmic material whereas some of the glass samples show signs of degradation and leaching of alkali components. Apart from colour changes of written text, the packing and marking materials have not undergone any noticeable damage during one year of exposure. The experimental degradation tests remains to be finished and evaluated.

It seems that protection like different packing regimes or for that matter also tarring offer a considerable improvement of the preservation of different material. How long the protection lasts cannot be stated at this early stage, however.

The project "Reburial and Analyses of Archaeological Remains " (RAAR) is still in its infancy so no definite conclusions can, or should, be drawn yet. In the autumn of 2004 the retrieval of the second lot of samples will be accomplished and sent to each co-ordinator for analyses and

evaluation. The results will be available during 2005 at our website:
www.svk.com/reburial/index.htm

Acknowledgement

References

1. Bergstrand, T. (2002) In-situ preservation and re-burial, methods to handle ship remains in the archipelago of Göteborg. In P. Hoffmann, J.A. Spriggs, T. Grant, C. Cook & A. Recht (eds), *Proceedings of the 8th ICOM Group on Wet Organic Archaeological Materials Conference*, Stockholm 11-15 June 2001, International Council of Museums (ICOM), Committee for Conservation Working Group on Wet Organic Archaeological Materials, Bremerhaven, pp. 155-166.

2. & 3. Nyström, I. (2002) Preventive conservation and re-burial of archaeological objects. In P. Hoffmann, J.A. Spriggs, T. Grant, C. Cook & A. Recht (eds), *Proceedings of the 8th ICOM Group on Wet Organic Archaeological Materials Conference*, Stockholm 11-15 June 2001, International Council of Museums (ICOM), Committee for Conservation Working Group on Wet Organic Archaeological Materials, Bremerhaven, pp167-174.

4. Bergstrand, T. & Nyström, I. (2001) Återdeponering av arkeologiska fynd – en metod? Bohusläns Museum Rapport 2001: 32.

5. Återdeponeringsprojektet/Glas och keramik. Rekommendationer för analysarbetet, utarbetade av Anders G. Nord och Kate Tronner, 1 juni 2004. Internal report, National Heritage Board, Stockholm (Unpublished)

6. Peacock, E.E. (in press). Moseforsøg – two generations of bog burial studies. Interim textile results. In: *Report from the 8th NESAT Symposium*. Lodz: Polish Academy of Sciences.

7. Peacock, E.E. (1998). Moselik på kunstig vis, *SPOR* **26**, 49-51.

8. Evershed, R.P. (1992) Chemical investigation of a bog body adipocere. *Archaeometry*, **34**(2), 253-265.

9. Turner-Walker, G. & Syversen, U. (2002) Quantifying histological changes in archaeological bones using BSE-SEM image analysis. *Archaeometry* **44**(3), 161-168.

10. Ignazy Jakubowicz, The Swedish National Testing and Research Institute, Borås. Personal comment.