REBURIAL AND ANALYSES OF ARCHAEOLOGICAL REMAINS
Studies of the effect of reburial on archaeological materials performed in Marstrand, Sweden 2002-2005
THE RAAR PROJECT

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Summary

To protect the fragile and non-renewable archaeological heritage, non-destructive and non-intrusive conservation strategies, such as *in situ* preservation, are emphasised in the UNESCO convention from 2001 [1].Reburial can be seen as the other side of the coin in that it seeks to emulate a pre-excavation (*in situ*) environment that has been benign for the preservation of archaeological remains for centuries. Therefore, reburial and *in-situ* preservation of shipwrecks and other archaeological underwater sites represent a new field of interest that are being given increased attention. The approach offers the potential to understand and identify the processes of deterioration of archaeological materials in underwater environments. However, more importantly, it also offers the possibility to find methods of counteracting these processes and to create alternative storage options for preservation underwater archaeological heritage.

The extensive archaeological investigations and reburial of recovered archaeological artefacts that took place in Marstrand harbour during 1998 to 1999, was the catalyst for the international reburial research project 'Reburial and Analyses of Archaeological Remains' (RAAR), which started in 2001. The project is co-ordinated by The Bohus County Museum and Studio Västsvensk Konservering in Sweden and consists of six sub-projects co-ordinated in turn by museums and universities in Sweden, Denmark, Norway and Australia.

The general purpose of RAAR is to evaluate reburial as a method for long-term storage and preservation of waterlogged archaeological remains. Five sub-projects aim to investigate the effects of the burial environment in Marstrand harbour on a wide range of material types. These include organic material such as wood, textile, leather, bone, horn and antler and inorganic material such as silicates and metals. The stability of these, the most commonly encountered materials in archaeological excavations, has been studied, as well as packing and labelling materials. The sixth sub-project has monitored the reburial environment. The project is designed to last for 50 years and the following report discusses the findings of the first three-year burial phase of the project (2002-2005).

Based on the results from the first phase of the RAAR project some initial conclusions can be drawn and recommendations made from a degradation/preservation viewpoint. Despite the short burial period these first findings show that reburial could become a valid tool for heritage management, albeit its usefulness might be less general than previously assumed.

The importance is stressed of assessing the reburial site and the sediment/material used to determine whether the environment is likely to be conducive to preservation. In general, the lower the porosity and organic content the better it is for preservation of archaeological materials. *In situ* data logging and *ex situ* spot measurements complement each other as methods of assessing the environment. Measurements of turbidity in open water should be considered to assess the likelihood of scour around a site. Important parameters to monitor on a reburial site are dissolved oxygen, redox potential, sulphide and pH. Monitoring of sulphate, dissolved (and perhaps total) iron and *in situ* temperature would also assist in gaining overview of the likely on-going deterioration processes.

Based upon the results from RAAR thus far materials such as porcelain, stoneware, clay pipes and wood are likely to survive a long-term reburial, whereas glass and fibrous material should not be subjected to reburial. The exception could be tarred cordage recovered in large amounts, which, due to their physical bulk and the biocidal effect of the tar coating, will

survive for a longer period. Low-fired earthenware is unlikely to survive long-term exposure and should not be reburied. However, the resistance of earthenware to a marine environment varies, largely depending on the firing conditions during manufacture. The poor results for the very low-fired 'modern' earthenware samples after three years of reburial, cannot be stretched to issue a general recommendation against reburial of earthenware.

The initial study period has, however, not been long enough to enable conclusions to be drawn with regard to long-term reburial of soft and hard animal products. Based upon results thus far, it is believed that the six- and twelve-year retrievals will give more conclusive results for the leather samples, and the twelve- and twenty-four-year recoveries likewise for the bone, antler and horn samples. At this stage only short-term reburial can be recommended for recovered tanned leather artefacts and for recovered bone ecofacts. It is also too early in this reburial experiment to make any definitive statements regarding the long-term stability of the metal coupons in the Marstrand sediments (table 9).

As is well known, burial depths play an important role in preservation and it is generally considered that reburial at 50 centimetres create an anaerobic and preserving environment for archaeological artefacts. Current data however, indicates that increased reburial depth to greater than 65 centimetres is needed for metals and especially for ferrous alloys. It is likely that this depth would be beneficial for some of the other materials included in the study.

The impact of packing archaeological material prior to reburial is considered very important. Of the three packing systems investigated the Zip-lock® bags generally seemed to offer the best protection against degradation and/or infiltration of salts. Geotextile readily allows for free flow of the soluble salts but protects against direct influence of the burial sediment. Results indicate that the geotextile also offers protection from microorganisms within the sediment and isolates the material inside from some micro-structural alteration. It does not appear to protect against chemical alteration. Polyethylene netting offered the least protection and should be avoided.

Most of the synthetic packing materials tested seem very stable and could be used *in situ*ations when archaeological artefacts are to be reburied. Only the polyethylene netting should be avoided since it lost more than half of its strength during the *in situ* and laboratory exposure periods. To label finds the preferred option would be to use either prefabricated tags, like the so-called ‘ear-tags’ for livestock, or embossed polyethylene tags (table 8).

Reburial is also discussed from a curatorial point of view. Why and under what circumstances should we rebury? It is concluded that in the same way as traditional conservation and storage makes an object possible to study or exhibit, the reason to rebury an artefact is also to preserve it so that it can be accessed and used in the future. If there are no thoughts or ideas about future needs of an artefact or a collection, there is little point preserving it at all. It is desirable, indeed essential in some cases, that reburial time frames will be part of reburial procedures, i.e. depending on the materials to be reburied, a reburial program will be designed to last a certain number of years, decades or maybe even centuries. However, it should not be seen as the end solution.

A heritage institution could provide short- or long-term curation for its archaeological archive by using reburial depots provided they are used according to given restrictions. Obviously access for the public to the submerged archive will be strongly reduced. This disadvantage does have a time limit in accordance with the agreed-upon time frame for each depot Whether or not this is a drawback worth considering would have to be discussed for each reburial program.

Acknowledgements

The Reburial and Analyses of Archaeological Remains (RAAR) project was initiated thanks to funding from the National Heritage Board of Sweden, the Nordic Cultural Fund, Carl Jacob Lindebergs Fornminnesfond, and the County Board of Administration, Västra Götaland.

The National Heritage Board is the main sponsor of the project and has repeatedly provided funding during the initial three-year period. The project leaders and co-ordinators of the sub-projects wish to thank the National Heritage Board for its confidence in the project. We also wish to acknowledge project contact Kate Tronner at the National Heritage Board for her support during the whole period.

Each co-ordinating institute contributes to the funding of the project to varying degrees by providing work time for the co-ordinators, covering analytical costs, etc. This self-funding is quite substantial in some cases and the project is in great debt to these institutions. In particular the Western Australian Museum should be mentioned, since their contribution to the project has been fully covered by the museum.

Introduction

During the twentieth century advancement in technology led to increasing development and exploitation of the seabed. Inaccessible areas are now accessible; large scale coastal development; sub-sea development in the form of pipelines and cables; dredging and gravel extraction and the development of the aqua lung have led to the discovery of increasing numbers of shipwreck sites and other submerged or buried structures. While it is not possible to generalise about such sites, conditions often exist in these environments that favour the long-term preservation of archaeological materials. Valuable historical, social, economic, technological and scientific information may be gained by thorough archaeological investigation of underwater sites and following the excavation and recovery of artefacts from these preserving environments. The problem facing archaeologists, cultural resource managers and conservators in particular is how to deal with this rich and continuing source of cultural heritage material.

Once relevant information has been gained from surveyed sites or from excavated artefacts, decisions must be made regarding their immediate and long-term futures. Sites can be stabilised and left in-situ. The recovered artefacts can be left untreated and placed in appropriate long-term storage, reburied at their original excavation site or conserved followed by storage or display. In the worst case artefacts can be disposed of. Long-term storage may not initially involve the often-considerable costs associated with conservation treatment, but it is an option that is not without significant direct and indirect costs of its own. Storage of untreated artefacts will necessarily involve the provision of appropriate space for a separate storage facility, containers for artefacts, solutions to minimise artefact deterioration, environments that minimise photochemical and/or oxidative processes and staff to monitor the condition of artefacts while in storage. Large-scale conservation treatments of waterlogged archaeological materials are labour intensive and require the services of specialist personnel. In addition to the costs of treatments themselves, there may also be considerable expenses associated with post-conservation storage and display of treated artefacts, with controlled environments often being necessary to minimise post-treatment deterioration processes. The formation of acidic materials in the timbers of the *Vasa* and *Batavia* provide clear evidence of this latter necessity. [2,3]

Limited economical resources is generally the case regardless of whether an archaeological excavation is funded by research funds or by a developer in what is often called ‘contract archaeology’. Full conservation of all finds from an underwater excavation would often mean an unrealistic economic set back for the investigation as a whole and thereby also for the scientific quality of the work. It is therefore questionable whether the benefits of total conservation would be worth the cost from a research perspective. Hence with restricted possibilities, reburial seems a realistic option for (temporary) saving instead of discarding potentially important archaeological material.

The main criticism against reburying artefacts is that the method has not been satisfactorily evaluated. The method has been tried in Sweden and abroad, but few long-term evaluations have been carried out or published. The analyses that have been conducted have concentrated mainly on wooden material, to the neglect of a substantial part of the archaeological heritage.[1]

[1] See chapter Reburial of underwater archaeological artefacts - A brief history of the method for more information

A marine reburial seeks to emulate the depositional environment before it was disturbed by excavation and thereby create a storage area that has preservation capacities that can be compared with “normal” museum storage. Normally a trench is dug in the sea-bottom in which the finds are placed after documentation. Their positions are recorded and the trench is refilled with sediments or sand. In this way anaerobic storage conditions will develop. The practical problems involved and the preservation capacity of the method obviously raise many questions, both general and specific. First and foremost is obviously whether and how the method can be used in heritage management, especially when working with huge amount of archaeological materials.

In 1998 and 1999, extensive marine archaeological excavations were carried out in Marstrand harbour on the Swedish West Coast (figure 1). The two main archaeological investigations concerned cultural layers along the quay and the excavation of the 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. This eventually led to the international research project Reburial and Analyses of Archaeological Remains (RAAR). This report describes the result of the first three-year phase of the project.

Figure 1. The location of the small village Marstrand, in the archipelago north of Göteborg at the Swedish West Coast.

Historical background of RAAR

Short history of Marstrand

The island and town Marstrand is situated on the west coast of Sweden, approximately 40 km north of Göteborg (Gothenburg). According to the Norse Sagas, Marstrand functioned as a sheltered harbour in the Viking Age. The sagas also state that King Hakon of Norway founded the settlement in 1229. Its location in the archipelago indicates a community living on herring fisheries as well as being an anchorage for ships passing through the Skagerak. For centuries to follow it was a strategic and important trading place

Marstrand fell into Swedish hands in 1658 and was often used by the Swedish naval forces as an anchorage for convoys during the Great Northern War (1700-1721). This was the case in 1719 when the fleet was attacked by the Danish-Norwegian sea-hero Tordenskiold. After many years of warfare, the Swedish military was badly manned and morale was low due to the death of the Swedish King Carl XII. The ships in Marstrand were neither able to prevent Tordenskiold from landing artillery batteries on the islands surrounding the town, nor to stop his naval bombardment. As the siege proceeded a number of Swedish ships were captured or sunk. The decision was made to scuttle the fleet and retreat into the town citadel Karlsten.

Five frigates (among them the *Fredricus*), two galleys, one yacht and two fireships were scuttled and later depicted on a Danish chart showing Marstrand harbour (figure 2). A few of the ships were subsequently raised, but the frigates still remain at the bottom of the harbour. The citadel was given over to the Danes in exchange for the safe departure of its garrison. Later, however, the commander of the garrison was executed for his poor efforts in defending the town.

The remains from this battle, other sunken vessels and artefacts from the daily life of the inhabitants of Marstrand are still to be found buried in the sediments of the harbour.

Figure 2. Danish chart from the 18th century showing the Marstrand harbour under siege by the Danish navy in July 1719. The sunken Swedish man-of-wars are illustrated with upper parts of their masts above the sea level, among them the Fredricus as letter K. Archive: The Royal Library, Copenhagen, Denmark. No: XVIII 4.1. Marstrand C.

Archaeology and Reburial of Finds – the Marstrand Project

In the early 1990s it was noticed that houses along the quay in Marstrand were slowly collapsing (figure 3). It was then decided that the area of seabed closest to the quay had to be stabilised. This would affect the archaeological remains on the bottom and in the sediments.

Figure 3. The location of the small village Marstrand, in the archipelago north of Göteborg at the Swedish West Coast.

An extensive under water archaeological project was therefore undertaken. The project, called the "Marstrand project”, was managed by Andreas Olsson (Bohus County Museum, BM) with Inger Nyström Godfrey (Studio Västsvensk Konservering, SVK) responsible for conservation issues. Before the final investigations were launched a pre-disturbance, investigation started in 1997, with the general aim to assess the scope and likely archaeological scientific value of the final investigation and to address issues like extent and costs. [4,5]

The pre-disturbance investigation resulted in two final archaeological investigations being carried out during 1998 and 1999. These two archaeological excavations focussed on extensive cultural layers along the quay and the excavation of the18th century frigate, the *Fredricus.* [6,7,8]. During the pre-disturbance investigation it was found that the favourable preservation conditions in the harbour would result in a large number of finds and the cost for conservation and future storage were considered unrealistic. This raised questions concerning alternative methods for preserving the recovered cultural heritage. Since reburial had been used for shipwrecks and timbers with seemingly good results [9,10] it was decided that following documentation 85-90 % of the finds would be reburied in the harbour. The decision was taken by the County administration.

Two reburial trenches were dug in close proximity to the excavation site; one for metals only (predominantly iron) and one for all other materials. The trenches were large enough for the objects to be placed in one layer. In total the excavations yielded about 12.000 artefacts and, after thorough documentation, approximately 10.300 of these were reburied in the sediments (figure 4). Criteria for evaluation of the artefacts were established and teams (consisting of archaeologists and conservators) decided what should be conserved and what should be reburied. Artefacts of all sizes and materials were reburied, even though the dominating materials were different types of wood, glass, ceramic and iron. Due to ecological consequences it was prohibited to bury lead objects in the sediments. Small finds were packed individually in labelled plastic crates of high-density polyethylene. Different groups of materials were kept separate. Large objects were packed individually and labelled. The reburied artefacts were registered in a database and their reburial location plotted on plans of the trenches. The situation was far from ideal and with limited time and money the packing (bags, nets, etc.) and labelling materials were reuse of those used during the excavations. [11,12]

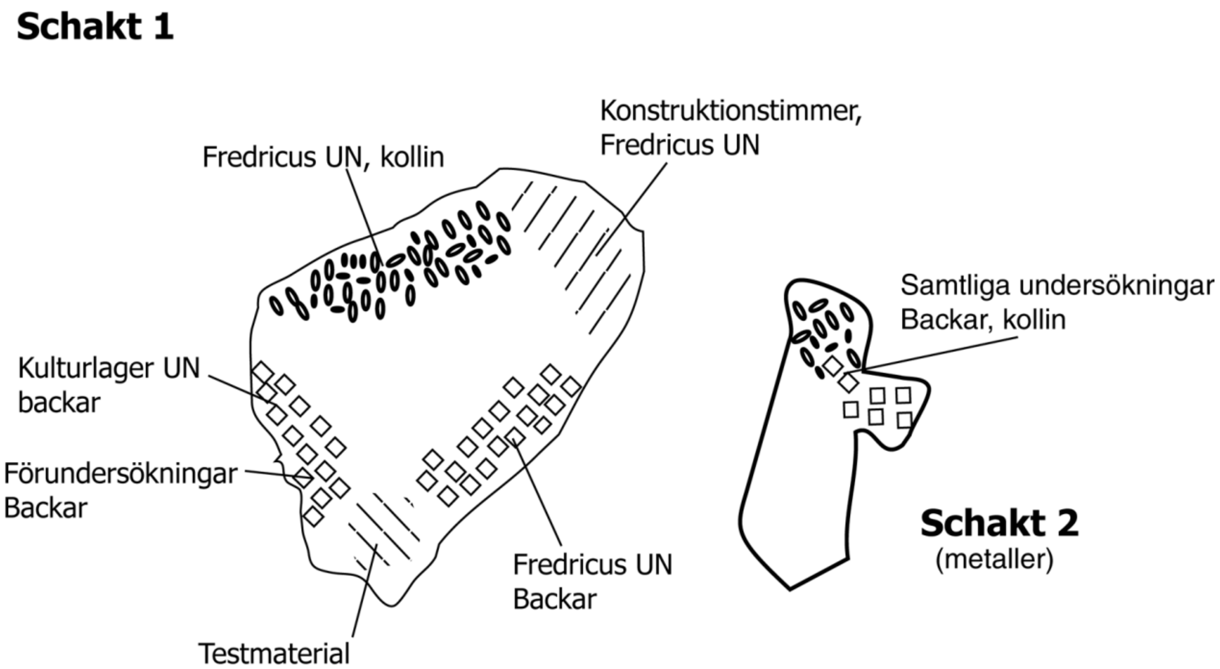

Figure 4. Plan of the two reburial trenches and the distribution of the reburied artefacts from the archaeological excavation in Marstrand harbour. Illustration: Andreas Olsson, Bohus County Museum.

The finds were covered with at least 50 centimetres of clay and silt from the area. Previous analyses of the sediment close to *Fredricus* showed a neutral pH, a reducing environment below 50 centimetre and a low water content (33%). [13] Although finds have been reburied in the past [14], the reburial at Marstrand is the first methodical reburial accomplished in Sweden. Others have since followed. [15]

During the reburial process it became obvious that many questions were unanswered. What materials should one avoid reburying? Would different ways of packing finds better prevent degradation? What materials or products would be most suitable for labelling and packing finds so that they could be kept separate or in groups making them more readily identified when or if they were to be retrieved at a later stage. As the archaeological project had neither the competence nor the means to answer these questions so the idea of launching a reburial research project studying the above-mentioned issues was raised.
According to the Swedish heritage legislation the economic responsibility of the developer stops after excavation and conservation. After this the long-term responsibility for preservation of cultural heritage falls on museum and state authorities. Since reburial has not previously been used in a methodical fashion in Sweden, questions of ownership, responsibility and other legal and practical implications were raised. It was therefore decided to hold two seminars on the reburial subject. The first seminar addressed the scientific aspects of the method and aimed at setting up a long-term research project at the reburial site in Marstrand. This subsequently became the RAAR project. The second seminar focused on the administrative and jurisdictional status of a reburial site. The two seminars, funded by the Swedish National Heritage Board, were held in 2001. [16]

Figure 5. Participants of the first reburial seminar in Marstrand 2001. Back row from left: Elizabeth Peacock, Thomas Bergstrand, Charlotte Björdal, Tomas Nilsson, Tomas Areslätt. Front row from left: Inger Nyström Godfrey, Inger Hall-Roth, Carola Bohm, Sara Wranne, Andreas Olsson. Photo: Staffan von Arbin, Bohus County Museum.

Reburial of underwater archaeological artefacts - A brief history of the method

Archaeological finds, especially from waterlogged sites, have been cared for in various ways. Reburial in depots is one of them. Early depots in Sweden can, for instance, be found outside Stockholm where finds from three wrecks were reburied during the 1960s and 70s.[2] However, as in many cases, the level of documentation and control were limited or non-existent. [17] During recent years reburials have taken place at three archaeological excavations in Sweden: the "Marstrand project", mentioned above and the excavations of the East India-man *Götheborg* and the Danish man of war *Stora Sofia*. In all cases, a selection of the material found has been conserved and the rest has either been reburied or discarded. Selections were based on certain criteria that considered scientific, technical and economic factors. [18, 19]

Reburial was first reported in 1979 [20]. It has since been applied in numerous contexts [21-25], but it is only in recent years that the technique has been seen as an increasingly attractive alternative for the long-term preservation of excavated archaeological artefacts. Despite the fact that work still needs to be done to determine its effectiveness and reliability, reburial is appealing for a number of reasons. Studies have shown that covering wood with a shallow layer of sand, for example, is sufficient to prevent attack by marine borers while burial to depths of only 50 cm significantly reduces the extent of microbiological activity. [26] A properly planned reburial could provide a storage option for archaeological material in a similar or improved environment to that which was responsible for its preservation in the first place. Reburial is a technique that should involve minimal continuing maintenance costs and allow access, albeit somewhat limited, to the reburied materials should that be necessary in the future. As for land-based storage, monitoring of the underwater reburial site is critical however, if the success or otherwise of the preservation strategy is to be ascertained. [27,28].

Due to the fact that the major part of all ship remains until the early 20th century is wood, this material has been the one most frequently studied. Authors associated with this report have discussed the effect of factors such as sediment chemistry and depth of burial on ship remains and other archaeological artefacts. [29-31]

One of the major threats to sites *in situ* or re-buried artefacts is that of scour; the removal of sediments surrounding a site through tidal, wind or vessel generated currents. This can lead to exposure of structure, which can subsequently be attacked by biological organisms or the more aggressive chemical processes that operate in oxygenated seawater.
To prevent physical, chemical and biological degradation of wreck and reburial sites physical protection such as sandbags, different types of sediment (e.g. clay, sand, gravel) geotextiles and sea grass mats have been used. New remediation strategies to contain sediments within a reburial site by using a chemically and environmentally inert interlocking plastic ‘crash barrier’ have been tested with positive results. [32]

While many reburial studies have involved shipwreck remains, in particular hull remnants, very few have examined the impacts of reburial on metal structures, metal artefacts and small artefacts of varying material types. Even fewer have monitored the environment of the site and the efficacy of reburial. These are critical aspects of any reburial. [33]

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2 The Jutholm wreck, *Neptunus* and *Två Lejon*

Jurisdiction and heritage management - The Swedish situation

The Heritage Conservation Act is the core legislation for the preservation of Sweden's historic environment. The act protects place names, ancient remains, archaeological finds, historic buildings, ecclesiastical monuments and the export of antiquities.

In the Heritage Conservation Act [3] reburial is not mentioned as an alternative preservation strategy for heritage management. However, due to extensive contract underwater archaeological investigations during the last ten years, reburial is now on the agenda. Increasing professionalism in underwater archaeology and infrastructure investments have been the driving force behind the search for new solutions in handling and preserving large volumes of waterlogged archaeological finds.

Within the framework of RAAR a seminar was held in 2001 to consider how reburial could be implemented within current heritage legislation. [34] The question was again raised in 2005 when the National Heritage Board (RAÄ) and the National Maritime Museum (SMM) in Sweden initiated an investigation on reburial. The focus was on curatorial issues including responsibilities, legal status, costs and other heritage related consequences. The overall conclusion was that reburial should only be used for finds of high historic value that due to various circumstances could not be conserved. In this sense reburial is not considered to be an end solution, rather it is temporary storage until more favourable conditions permit retrieval and conservation. The investigation highlights some important factors, which hopefully will be accepted as guidelines in the near future.

In short, the following are stated in the RAÄ/SMM report. [35]

- The cost of reburial will be less than for conventional conservation, while the cost for management and use will be more.

- Since reburial depots are not protected by the Heritage Conservation Act, some other form of legal protection needs to be applied, e.g. regulations in planning instruments, land encumbered with an easement etc.

- An important question is that of responsibility. Who is responsible for the reburied ship remains and artefacts and what does the responsibility entail? According to existing legislation the museum responsible for the excavated finds is also responsible for the reburial depot, since this storage is considered equivalent to normal land based museum storage.[4] However, the developer of a site should be held partly responsible for costs involved in constructing the depot.

- Access to the finds for the public and for research is severely reduced. To a certain extent thorough documentation and a well-defined selection of finds that are not reburied can counteract this.

- There are no accepted guidelines as to what should and should not be reburied. Thus far reburials in Sweden have been selected primarily when conservation costs have been seen to be unreasonable in relation to the cultural and historical values of the finds.

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[3] Lag (1988:950) om kulturminnen m.m.

[4] Responsible museums can be The National Historic Museum or more often the regional museum in question.

Reburial and Analyses of Archaeological Remains -The RAAR Project

Objectives

The general purpose of the project "Reburial and Analyses of Archaeological Remains" (RAAR) is to evaluate reburial as an alternative method for long term storage and preservation of waterlogged archaeological remains.

The study aims to determine the effects of the burial environment in Marstrand on a wide range of material types. These are organic materials (e.g. wood, textile and leather) as well as inorganic materials such as silicates and metals. The stability of these, the most commonly encountered materials on archaeological excavations, has been studied, as well as that of packing and labelling materials. Understanding the degradation patterns of packing and labelling materials is important, since it affects the ability to identify artefacts at a later stage. The different material groups were divided into sub-projects, each with its own specific objectives. These objectives together with the materials and methods of analyses are described in the sub-project reports.[5]

The project concurrently monitors and assesses the burial environment in Marstrand with the aim to complement the studies on materials and to discuss important physical and chemical criteria necessary for a reburial environment. The environmental sub-project aims as well to develop methods to assess and monitor the reburial environment.

It is the scope of the study to provide, where possible, guidelines for the material types that can safely be reburied in environments similar to the one at Marstrand and those that should not be reburied. Hopefully, this wide-ranging study will provide valuable information linking environmental parameters and degradation of the included materials. Studying the environmental parameters and the degradation of test materials will also provide insight into the preservation status of the reburied archaeological artefacts from the Marstrand project.

Main objectives

- **Evaluate reburial as a method for preserving wet archaeological remains**
- **Determine the effects of the burial environment on a range of material types**
- **Gain information about the preservation status of the reburied archaeological artefacts**

Partners, time frame & funding

The project is divided into six sub-projects, each one with its own co-ordinator (table 1). For obvious reasons a study like this has to be conducted by people with different expertise within the conservation field. Initially the project had purely a Nordic base, but from 2003 it also included Australia.

[5] See Appendices

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, (RAÄ)
Metals	Vicki Richards & Ian MacLeod	Western Australian Museum, Fremantle, Australia,(WAM)
Wood	Charlotte Björdal & Thomas Nilsson	Swedish University of Agricultural Science, Uppsala, Sweden, (SLU)
Other organic material	Elizabeth Peacock	The Norwegian University of Science and Technology, Trondheim, Norway, (NTNU)
Packing and labelling materials	Inger Nyström Godfrey	Studio Västsvensk Konservering, Göteborg, Sweden, (SVK)
Environmental monitoring	David Gregory	The National Museum of Denmark, Brede, Denmark, (NM)

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	This document finalises the first phase
2	2008 & 2014	
3	2026 & 2050	

The RAAR project could be undertaken thanks to funding from the National Heritage Board in Sweden, the Nordic Cultural Fund, Carl Jacob Lindebergs Fornminnesfond, and the County Board of Administration, Västra Götaland.

The project received funds of 1.950.000 SEK, with the National Heritage Board as the main fund provider. Each co-ordinating institution has contributed to funding the project in varying degrees by providing work time for the co-ordinators, covering analytical costs, etc. This self-funding is quite substantial in some cases and the project is in great debt to these institutions.

The reburial site

During the excavation season in 1999 two trenches were dug in the harbour of Marstrand, on the opposite side of the *Fredricus* wreck, for the reburial of recovered artefacts that were not prioritised for conservation (figure 6). One trench was intended for metal objects, the bulk consisting of iron artefacts, and one trench was used for organic materials and silicates. The trenches were irregular in shape but measured approximately 15 x 5 metres (metal trench) and 25 x 20 metres (all other materials). The depth varied from 1 to 2.5 metres. The trenches were large enough for the objects and crates to be placed in one single layer.

Known advantages of the reburial site are:

- Easy access at reburials and future controls.
- Under surveillance 24 hours per day because of proximity of ferry employees.
- Environmental conditions are similar to the archaeological site
- Anchorage and diving is prohibited in the area.
- No cultural layers had been registered.

Known disadvantages are:

- The harbour is busy, especially during the summer season, which could petrol and oil contamination. There could be other disturbances caused by currents from the ferry and passing boats.
- If the prohibition of anchorage and diving is not followed and the surveillance is ineffective, the reburial site is an easy target.

Designated areas within the reburial trenches were used for the research project. One reason for using the same trenches was that it simplified the positioning of sample units, since the trenches had already been measured and fixed points were marked in the trenches.

Figure 6. View of the reburial site at the jetty. Photo: Inger Nyström Godfrey, Studio Västsvensk Konservering.

Materials, Deposition and Retrieval of Samples

In order to have enough identical samples to determine the effects of the burial environment on material commonly found archaeological excavations and to study initial deterioration mechanisms of these material types, the samples included in most of the sub-projects are mainly of modern origin. Their deterioration will therefore not, simulate exactly that of already degraded archaeological artefacts of similar material type such as those recovered from a marine burial environment.

All samples have been buried in unused sections of the two trenches previously dug for the archaeological finds (figure 7). All the sample units, except for the metals, were buried in September 2002. The metals samples were buried one year later in September 2003. This delay was necessary when the first co-ordinating institute for the metals sub-project withdrew from the project. The new co-ordinating institute for metals, the Western Australian Museum, was unable to start until 2003.

Most material test units were mounted in perforated crates, except the wood and metal samples, which were mounted vertically on racks and poles (figures 8 & 9). The crates are all covered with approximately 50 centimetres of clay and silt from the surrounding area, while the wood and metal samples 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 metal samples are positioned in the metal trench in two parallel rows and the other units are placed in defined areas based on the year of their retrieval. These areas are approximately $1x1.5m^2$

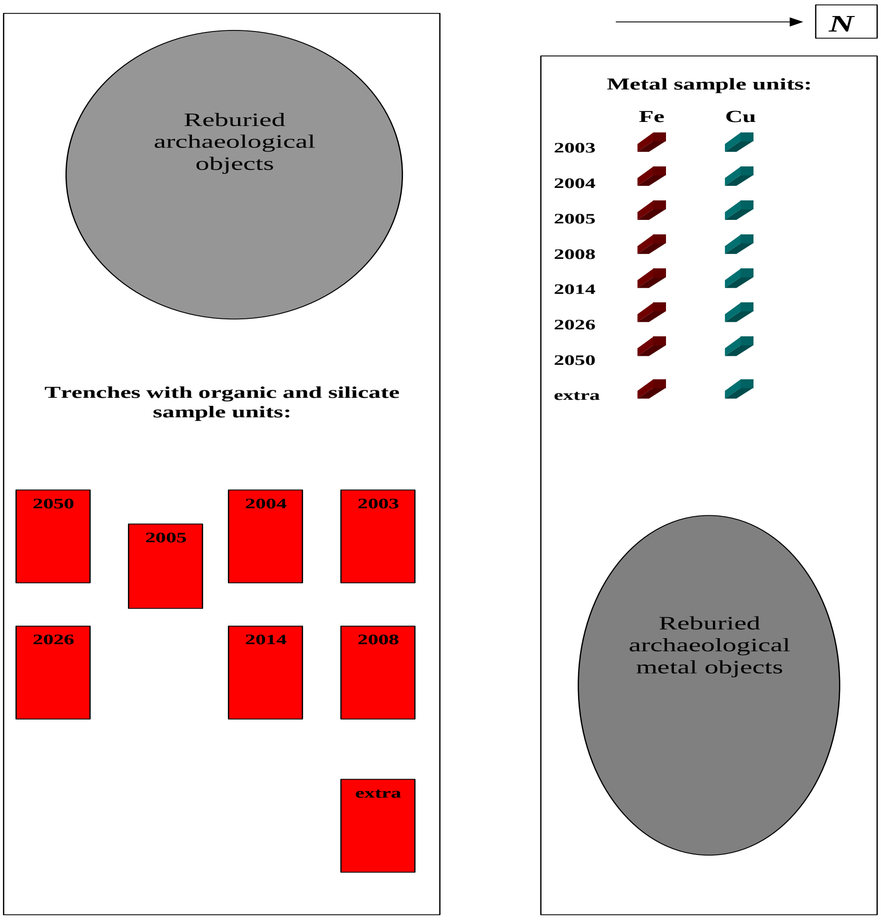

Figure 7. Schematic distribution plan of the buried material test samples in the two trenches. Illustration: Inger Nyström Godfrey, Studio Västsvensk Konservering.

Figure 8. Test rack with overgrown wood samples. Photo: Thomas Bergstrand, Bohus County Museum.

Figure 9. Metal samples mounted on a rod exposed above the sea bed. Photo: Jens Lindström, Bohus County Museum.

Samples were retrieved annually for the first 3 years (figure 10). While the intent was to retrieve samples every 12 months, the sample units were actually retrieved after 12, 23 and 37 months respectively. The samples were packed and transported according to instructions provided by the sub-project co-ordinators (figures 11-14). During and in between retrievals, sediment cores were taken and data collected from the datalogger (figures 15, 16, Table 3). Thomas Bergstrand (BM) and Inger Nyström Godfrey (SVK) were responsible for all field activities while David Gregory from the National museum in Denmark was responsible for collecting the environmental data (figure 17).

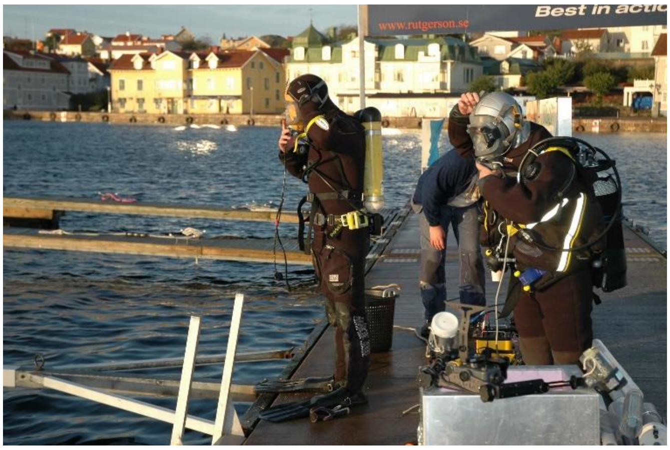

Figure 10. Divers are ready to retrieve samples from the reburial site. Photo: Vicki Richards, Western Australian Museum.

Figure 11 & 12. After retrieval. The top sediment in the crates was excavated before transportation to the laboratory. After retrieval. Crate packed and ready for transportation.Photo: Vicki Richards, Western Australian Museum.

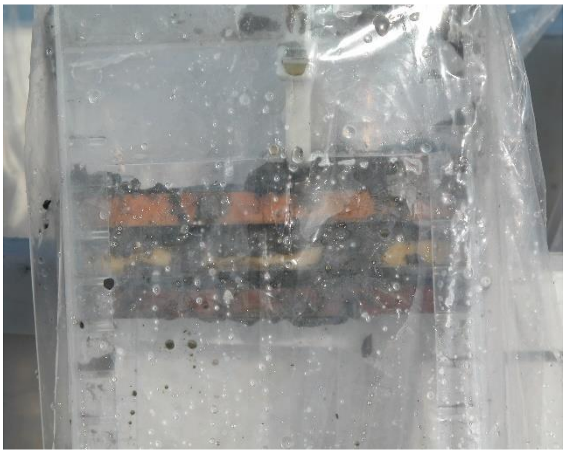

Figure 13 & 14. After retrieval. Wood samples ready for transportation to the laboratory. Photo: Vicki Richards, Western Australian Museum.

After retrieval. Metal samples were vacuum packed before transportation to Australia. Photo: Ebba Samuelsson, Studio Västsvensk Konservering.

Figure 15. Data logger in working position. The logger is fixed above the sea bed while the most of the sensors are placed inside dipwells down into the sediments. Photo: Jens Lindström, Bohus County Museum.

Figure 16. Coffee on the jetty during fieldwork, from the left: Staffan von Arbin, Thomas Bergstrand, Inger Nyström Godfrey and Eva Ernfridsson. Photo: Inger Nyström Godfrey, Studio Västsvensk Konservering

Figure 17. Downloading data from the data logger used in the Environmental monitoring subproject. Kristiane Straetkvern, David Gregory and Thomas Bergstrand enjoying the evening sun at Ingers' place. Photo: Inger Nyström Godfrey, Studio Västsvensk Konservering.

Underwater photographs and video sequences were taken before sample units were lifted to document the situation on the seabed. This was particularly important for the wood and metals sub-projects since these each had one set of samples above the seabed. In April 2004 it was noticed that the sediments had compacted since the start of the project. This left some of the wood sample units more exposed than was intended.[6] Sediments were added where needed in August 2004.

Due to a misunderstanding about which area was to be retrieved, samples from the wrong area were lifted in 2005. Instead of the samples from the 2005 retrieval area, samples from the 2050 retrieval area were lifted. However, this is not important for the results, since every retrieval area contains the same samples.

Table 3. Field activities

Date	**Burial of samples**	**Retrieval crates**	**Retrieval wood**	**Retrieval metal**	**Data-logger**	**Sediment cores NM**	**Sediment cores WAM**
2002-09-01	All samples, except metals						
2003-03-18/20			T1: 6 months		Deployed	X	
2003-07-20					Retrieval of data		
2003-09-30	Metal samples	T1:1	T1:1				X
2004-04-22					Deployed	X	X
2004-08-23		T1:2	T1:5[7]	T2:1	Retrieval of data	X	X
2004-12-06					Retrieval of data	X	X not analysed
2005-05-18					Retrieval of data	X	
2005-10-21		T1:7	T1:7	T2:2	Retrieval of data	X	X not analysed
2005-04-04						X	

Communication

The RAAR-project and all results have continuously been presented in various fora. Since the start in 2002 the main communication channel has been, and still is, the project website (http://www.svk.com/reburial/index.htm). Here all essentials about the project are described as well as publications of the most recent results and fieldwork activities. The website will be kept open in its present state at least until the second phase of the project is accomplished in 2008/2009. It will be possible to download this report from the website during this period.

Beside the website presentations have been given at conferences and seminars. One of the more extensive paper were presented at the ICOM CC-WOAM conferense in Copenhagen 2004, and was held by Inger Nyström Godfrey on behalf of the participants of the project.

[6] Wood samples in T1:2, T1:4, T1:7 and T1:extra were not fully covered due to compacting sediments.
[7] Wood samples in T1:2 were found to be slightly exposed when the site was visited. Samples were instead taken from another annual area, T1:5. The wood samples in T1:2 are still in place and sediments were added in August 2004.

[36]. Later on the same year, the project was presented by a poster at a conference in London, UK, called: *Sustaining Europe's Cultural Heritage: From research to policy*.

In May 2006 a seminar with all the participants of the RAAR project was held at Studio Västsvensk konservering in Göteborg. At the seminar the co-ordinators and sub-project co-ordinators were able to present and debate each other's results, draw conclusions and discuss the second phase of the project (figure 18). T

Figure 18. The participants of the RAAR-project gather at the seminar in May 2006 held at Studio Västsvensk Konservering.

Experimental and results – Summaries of the sub-project reports

Environmental Monitoring

Introduction

A program of environmental monitoring was carried out in the main reburial trench (trench 1) between 2003 and 2006. Other sub projects researchers sought to analyse the deterioration of a range of modern materials and archaeological materials, which had been reburied in Marstrand harbour. To complement these results, the monitoring program aimed to assess the reburial environment. That archaeological finds in marine sediments are well preserved is primarily attributed to reduced levels of oxygen that is to say anoxic conditions. However, even under these conditions the presence and activity of anaerobic microorganisms will still cause the deterioration of archaeological materials albeit at a slow rate. The aims of the monitoring program were threefold:

- Develop methods to assess and monitor the reburial environment
- Assess the deterioration processes (aerobic / anaerobic) ongoing in the reburial environment
- Based on the results of the monitoring give an estimate of ongoing deterioration in the reburial trench.

This short report is a summary of the sub project and the reader is referred to Appendix 1 for more detailed information.

Processes in marine sediments and rationale for the monitoring program

Nearly all biogeochemical processes in young sediments (i.e. during early diagenesis) are directly or indirectly connected with the degradation of organic matter. Organic matter may be produced by algae and other organisms in open water, which subsequently sinks to the seabed and becomes incorporated within the sediment. It may also be the remains of plant material such as eelgrass or seaweed or, as in the case of Marstrand, shipwreck material deposited within the sediment.

The utilisation of the organic matter by organisms within sediments involves oxidation – reduction (Redox) reactions. These reactions follow a well-documented succession with various chemical species being utilised based on the amount of energy they yield. From the pool of potential electron acceptors, the microbial community selects the one that maximises energy yield from the available substrate. This is partly due to metabolic regulation within a single population and in part due to the competition between several populations with diverse metabolic capabilities. In marine sediments, the sequence of electron acceptor utilisation can be observed spatially in horizontal layers of increasing depth. In typical coastal marine sediment, only the first few millimetres of the sediment are oxygenated, though bioturbation by invertebrates may extend this oxygenated zone downward. For a few centimetres under the oxygenated zone, nitrate serves as the electron acceptor followed by manganese and iron oxides. Below this, sulphate is the principle electron acceptor. Methanogenesis, is usually confined to the sulphate depleted deeper sediment layers, though the generated methane may diffuse upward into the zone of sulphate reduction

Thus, the deterioration of organic matter still occurs in anoxic environments due to the activity of anaerobic organisms, albeit at a slower rate. Bearing in mind, it was not possible within this project to tailor a monitoring program for all the various materials encountered on the site and used in the reburial experiment, it was decided to analyse the sediments used in the reburial project for: their anoxicity; the predominant biogeochemical processes ongoing; and assess whether the depth of burial of ca. 50cm was deep enough to make sure that ongoing decomposition was at as slow a rate as possible.

Methods

The monitoring of the environment was carried out in two ways: *In situ* using a data logger, with sensors placed within dip wells to record long term variations in open seawater and within the sediment. *Ex situ* and in the laboratory by taking spot measurements in sediment cores (*ex situ*) taken from the reburial mound and an "undisturbed" area close to the reburial trench. Following an initial period of method development, data was collected between 2004 and 2006, which would show any seasonal variations.

The data logger was deployed on four occasions between the following periods:

- 22nd April 2004 to 23rd August 2004
- 24th August 2004 to 6th December 2004
- 7th December 2004 to 18th May 2005
- 19th May 2005 to 21st October 2005

Sediment core samples were taken on the: 24th August 2004; 7th December 2004; 19th May 2005; 21st October 2005 and 4th April 2006.

Table 4 shows which parameters were measured on these occasions.

Table 4: Parameters measured in the monitoring program.

Parameters	*In situ (Data logger)*	Ex situ *(Sediment cores)*
In open water		
Temperature	✓	✗
Water depth	✓	✗
In sediment		
Redox potential	✓	✓
Dissolved oxygen	✗	✓
pH	✓	✓
Sulphide	✗	✓
Sulphate	✗	✓[1]
Dissolved iron	✗	✓[1]
Porosity of sediment	✗	✓
Organic content of sediment	✗	✓

Redox potential, pH, Dissolved oxygen, and sulphide were all measured using microelectrodes. Porosity and organic content were determined on samples of sediment from the cores.

[1] Sulphate and dissolved iron were only measured on the cores in April 2006 to compare and confirm previous analyses.

Results

Measurements in the sediments from the reburial trench show that:

- The dissolved oxygen content can be seen to be suboxic (0.1 – 0.3 mg dm^{-3}) after the first few centimetres within the cores and thereafter they are bordering on anoxic (<0.01 mg dm^{-3}).
- Sediments were strongly reducing with potentials between –160 to –250mV (vs SHE).
- The predominant processes ongoing in the sediments are sulphate reducing – especially at the depths where archaeological material has been reburied.
- Seasonal variations were seen
- The reburial sediments are primarily of a sandy nature (by observation), with an organic matter content of <5%.
- From the set of core data collected in April of 2006, it is apparent that there is still sulphate available for deterioration of organic matter. However, an initial model shows that this equates to a turnover of organic matter of 0.004g of organic matter per cm^2 of sediment per year (or 0.4g per 100 years). This equates to the organic content of sediment 6 cm below where sulphate has been presently measured. This is worth examining further and will be achieved by taking sediment cores that go deeper than the 50cm depth of burial and confirming how much sulphate is present. However, under all circumstances the future rate of deterioration of artefacts in the main reburial trench will be at a very slow rate.

Lessons learned

In situ data logging and *ex situ* spot measurements complement each other as methods of assessing the environment. The data logger did not function perfectly, yet as a general method should be persevered with – not necessarily at Marstrand but when considering other sites to be preserved *in situ*. Measurements of turbidity in open water should be considered as a means to assess the likelihood of scour around a site.

The use of the sediment samples gave a wide range of information both on the structure and nature of the sediments and, from the parameters measured within the pore water, the general processes ongoing in the sediment. Perhaps a different method of taking the sediment cores should be developed to enable deeper cores to be taken and also to ease the analysis within the laboratory. The parameters measured for the majority of the monitoring programs (dissolved oxygen, redox potential, sulphide, and pH) were useful to get a general idea of the processes ongoing but these should be supplemented in the future with measurements of sulphate, dissolved (and perhaps total) iron and *in situ* temperature. However, prior to any reburial, the type of sediment /material used should be assessed to see whether it is likely to be conducive to preservation – i.e in terms of its porosity and organic content, which will have an effect on the rates of microbial activity**.**

Conclusions

The main reburial mound appears to have good preservation conditions for the reburied artefacts. However, following the seminar held in Göteborg in May, it was apparent that the main reburial trench may not necessarily reflect the conditions in the metal trench (trench 2) where the metal sub project has reburied their experimental materials. A future phase of fieldwork in late 2006 or early 2007 will take further sediment cores to obtain information specifically about these areas.

Metals

The aim of the metals sub-project is to investigate the corrosion of metals buried in the marine environment. The corrosion of reburied and exposed modern metal coupons will be examined and compared over time. This study will ascertain the effect of reburial on the deterioration of archaeological metals commonly found on underwater cultural heritage sites and assist in evaluating the effectiveness of reburial as a long-term *in-situ* preservation strategy for metallic archaeological remains.

The samples units consisted of prefabricated proprietary metal coupons of known metal composition mounted utilising high-density polyethylene (HDPE) materials. The metal coupons deployed in the experiment were ferrous alloys: duplicate coupons of cast iron and mild steel and one standard Defence Science and Technology Organisation (DSTO) copper steel coupon and copper alloys: duplicate coupons of brass, copper and bronze. The ferrous and copper alloys were mounted separately to minimise galvanic and proximity corrosion. Each sample unit consisted of three sets of duplicate metal coupons mounted at three different depth intervals (totally exposed above the sediment, just below the sediment and buried 50cm in the sediment) on the HDPE rod (figure 19).

The fourteen copper (7) and ferrous (7) alloy sample units were buried in Marstrand Harbour, Sweden on 30 September 2003 in two rows separated by a distance of approximately 3m with about 1-2m between each sample unit. The wood, other organics, ceramics/silicates and polymer sample units were buried in September the previous year and the environmental monitoring began in March 2003.

The first sets of metal sample units (copper and ferrous alloys) were retrieved on 24 August 2004 after 1 year on-site and the second sets were retrieved on 21 October 2005 after 2 years on-site. The sample units were documented *in-situ* prior to any physical disturbance. Each sample unit was then removed by physically extracting the rods from the sediment and the corrosion potentials (E_{corr}) of each coupon measured *in-situ* on the seabed prior to recovery. Immediately after recovery the sample units were photographed, prepared for transport and then sent to the conservation laboratories in Fremantle, Western Australia. On arrival the metal coupons were documented, one of the duplicate coupons stripped of all corrosion products and the other left unstripped in preparation for scanning electron microscopy/electron dispersive x-ray analysis (SEM/EDAX). Digital electron micrographs (SEM) and energy dispersive x-ray analyses (EDX) were collected as the primary data.

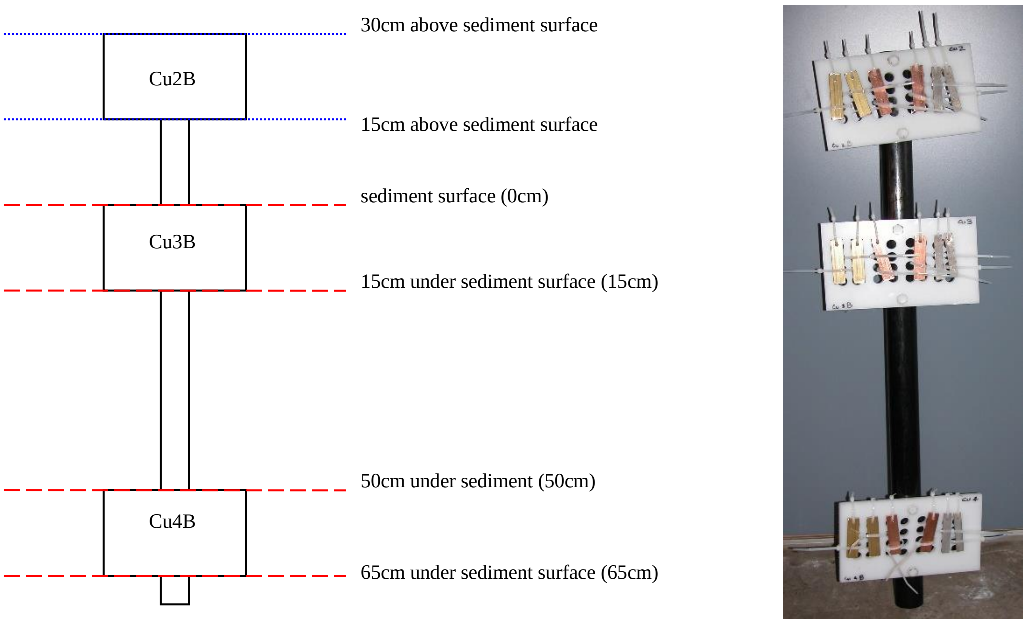

Figure 19. Schematic diagram and the completed copper alloy coupon support plate arrangement on rod 1 retrieved in 2004.

In addition, sediment core samples were collected from the reburial trench on 30 September 2003, 22 April and 24 August 2004. Additional control core samples were collected from an undisturbed area in April and August 2004. The core samples were sent to the Chemistry Centre of Western Australia where they were analysed for particle size distribution, moisture loss at 105ºC and weight loss on ignition at 550ºC and 1050ºC.

The results of the metal sample analyses, the effect of the reburial environment on the extent of deterioration after these two retrieval periods and the results of some physical analyses of sediment cores are summarised below. The full report is reproduced in Appendix 2.

- The basic experimental design was very sound; however, some minor problems were encountered with differential aeration corrosion occurring on some coupons caused by the cable ties and the flow holes in the support plates. These effects were, however, minimal and very localised and did not affect the overall corrosion of the coupons.
- The manner in which metals are packed for reburial is extremely important.
- Metals of significantly different composition must be separated, however even artefacts of similar composition should be physically separated in some way (e.g. geotextile barrier) to minimise direct contact with other artefacts.
- Copper alloy artefacts recovered from a saline environment should always be stored wet.
- All metal artefacts should be stored in a similar environment to that from which they had been recovered (e.g. deoxygenated environments if the artefact is recovered from under the sediment) if further analysis of the corrosion product layer and underlying residual metal is to be undertaken.
- It is vitally important that metals are reburied to depths where there is no chance of partial exposure to the aerobic marine environment through sediment movement due to strong wave action or currents.

- It is very important to fully understand the physico-chemical and biological nature of the local sedimentary environment prior to deployment of any reburial strategy.
- The resistance of a metal to initial corrosion is very much dependent on the initial composition, the metallurgical structure and the method of manufacture of the parent metal.
- The metal coupons are still in the initial stages of corrosion without encapsulation by concretion, but the corrosion mechanisms are slowly beginning to stabilise after two years.
- The metal coupons do not accurately reflect the corrosion behaviour of historic metals after two years of immersion.
- The extent of corrosion of all metal coupons decreased significantly once the coupons were buried, even at very shallow depths and this protective effect increased with increasing burial depth.
- Metals, especially ferrous alloys require burial depths greater than 65cm in very poorly sorted, mobile clay sediments that contain high levels of moisture, organics and anaerobic bacteria deep into the sediment column.

In conclusion, it is still too early in this reburial experiment to make any definitive statements regarding the long-term stability of the metal coupons with respect to reburial depth and to extrapolate this to historic metals. Therefore, it is of paramount importance that this project continues so as much information as possible regarding the corrosion processes of these metal coupons can be obtained. This information, in conjunction with analysis of actual shipwreck artefacts, will allow the evaluation of the long-term effectiveness of reburial as a means of *in-situ* preservation for archaeological remains.

Silicates

In this subproject, investigations have been carried out to determine the effects of reburial in Marstrand harbour on a variety of glass and ceramic samples. Artefacts of this material category, recovered from marine archaeological sites, may be found in relatively good condition even after many centuries in the underwater environment. This applies in particular to high-fired ceramic wares such as porcelain and stoneware. They might, therefore, be considered as potential candidates for reburial without seriously endangering their long-term survival. This report covers the analysis of samples retrieved from the reburial site over three consecutive years: 2003, 2004 and 2005 – Phase I of this 50-year project. In view of the relatively short time span involved, only tentative conclusions and recommendations are offered.

The samples that have been used in this study are authentic archaeological shards from previous excavations at Marstrand, as well as ‘modern’ and model samples. The archaeological samples are earthenware, stoneware, flintware, clay pipes and two different types of glass: colourless potash glass and green bottle glass. The ‘modern equivalents’ are earthenware, stoneware, flintware, porcelain and two types of model glass: 1) an unstable composition with high potassium, high calcium content 2) a stable soda glass. For each material category, three different packing regimes have been tested: sealed Zip-lock® bags, permeable PE netting and semi-permeable geotextile fabric.

Upon retrieval, each sample was photographed, examined visually, under optical microscope, analyzed with SEM/EDS (energy dispersive spectrometry) and, where relevant, weighed. Conclusions have been drawn, based on a synthesis of these data.

As expected, the archaeological samples proved difficult to interpret and to assess the observed changes. Of the 'modern' materials, the model glass samples exhibited the most obvious alterations. The unstable glass experienced strong discolouration and severe loss of surface material, with the formation of a silica-rich gel layer that grew ever deeper over the three-year burial period. Packing in Zip-lock® bags dramatically repressed the depletion of alkali ions, thus offering protection, but promoted biological growth. Loss of alkali, again increasing with the time of exposure, was registered also on the model soda glass. Some surface exfoliation appeared on the colourless archaeological table glass and, much more extensively, on the green bottle glass. The bottle glass was, however, severely deteriorated even before reburial and the evidence of any alterations over the three-year period, is feeble. The ceramic samples displayed extreme variations of status. The 'modern', very low-fired earthenware had seriously disintegrated after three years of exposure, whereas the porcelain and 'modern' stoneware revealed no pronounced alterations, neither visible nor chemically detectable. On all other ceramic samples, visible alterations were generally very limited, but they had all absorbed chlorine and sulphur.

In view of these results, reburial cannot be recommended for any type of glass. For the majority of porous ceramic wares it is highly questionable if the intentional exposure to the stresses imposed by salt migration can be justified. Very low-fired earthenware is unlikely to survive long-term exposure in a marine environment, but if it should, it is highly unsuitable for reburial. High-fired ceramic wares, such as porcelain, stoneware and clay pipes, are sometimes found in large quantities on marine archaeological sites. These material categories are highly stable and might thus be considered for reburial. Problems with over-glaze decoration and gilding on porcelain as well as salt infiltration in clay pipes and less high-fired stoneware, cannot be overlooked, however. The strongest objection would be that of the limited access for study and research of an archaeological archive submerged in the seabed. In addition, conservation processes, primarily desalination, are not necessarily cost-prohibitive for these material types.

Of the three packing systems investigated, the Zip-lock® bags generally seemed to offer the best protection against degradation and/or infiltration of salts, but the nature and potential effects of the observed biological growth, is poorly understood. Geotextile readily allows for free flow of the soluble salts but protects against direct influence of the burial sediment. PE netting offered the least protection and should be avoided.

The observations made hitherto in this sub-project leave many questions unanswered, as well as giving rise to new ones. Questions to focus on for future retrievals should, among others be:

- What are the implications of the biological growth observed in Zip-lock® bags?
- Does the material, if undisturbed, reach a state of equilibrium with its environment?
- Does the rate of deterioration, seen particularly on the model glass, abate?
- Is the discolouration, seen on some samples, exacerbating future conservation needs?

A summary of the results after three years of burial is presented in table-form below (Table 5 & 6). The full report may be found as Appendix 3 in this volume.

Table 5: Glass

Archaeological samples		**Model samples**	
Clear table glass	Bottle glass, green	Soda glass	Potash glass
Thin iridescent surface layers with reduced alkali levels. Surface exfoliation One sample in Zip-lock® bag broken	Thick silica-rich surface layers with areas of elevated NaCl, S, Fe Heavy surface exfoliation No clear difference between re-buried sample and reference	Accelerating depletion of Na	Depletion of alkali components in surface layers Severe disintegration and loss of surface Zip-lock® bag represses leaching, but promotes biological growth Discolouration of weathered layers

Table 6. Ceramics

Archaeological samples				**Modern samples**			
Porous			Non-porous	Porous		Non-porous	
Earthenware, lead glazed	Flintware, lead glazed	Clay pipes	Stoneware, salt glazed	Earthenware, low-fired	Flintware, lead glazed	Stoneware, feldspatic glaze	Porcelain, feldspatic glaze
No visible alteration Absorption of NaCl, S	No visible alteration Absorption of NaCl, S	Often black-stained in wet condition Absorption of NaCl, S, Fe	No visible alteration Traces of NaCl, S	Severe disintegration Absorbed NaCl, S	No visible alteration Absorption of NaCl	No alteration	No alteration

Wood

The aim of this study was to investigate the wood degradation processes on sound wood samples buried in the reburial trench in Marstrand harbour. Observations were carried out at different depths in the sediment and applied on different wood species.

Due to inherent differences in durability, several wood species were tested. Oak heartwood, pine sapwood and birch were chosen. The test samples were mounted on a plastic rack of 70 cm in length and inserted vertically in the reburial trench. Three group of samples were located respectively 5 centimetres above seabed, 10 centimetres below seabed, and 42 centimetres below seabed. Three racks were retrieved at intervals of six, twelve, twenty-four and thirty-six months. Remaining racks were left in place for long term observations.

After retrievals, the wood samples were examined in order to localise marine borers on the surface and interiour. Secondly, thin sections were cut by hand with a razor blade and examined in light microscope, where the microbial degradation was determined, and the depth of decay measured.

Results
Data obtained from the examination of wood samples exposed at different depths in the seabed during a period of 3 years gave detailed information on the initial and further development of microbial decay throughout the experimental period.

Teredo and Limnoria
Observations after 12 months revealed that all wood samples exposed above the seabed were attacked by *Teredo* (Appendix 4, table 1). The decay was not visible on the wood surface itself but was seen after the wood was split into two halves (Appendix 4, figs 3 a, b). After 36 months, degradation was so extensive that all wood samples above seabed were totally decomposed and no longer present in the racks. No attack by *Teredo* was found in wood exposed in the sediment. *Limnoria* was found in association with *Teredo*. Small holes were observed in the wood surface. The effect of *Limnoria* was seemingly limited but also difficult to estimate due to the aggressive decay by *Teredo* in the same wood samples.

Microorganisms
Soft rot was present in all wood samples situated above seabed and at a depth of 10 cm in the sediment. However, the activity was significantly lower in the sediment. Decay was intensified with time (Appendix 4, table 2).

Tunnelling bacteria was found to degrade wood samples both above the seabed and in sediment, 10 cm beneath the seabed (Appendix 4, table 3). Due to the severe degradation by *Teredo* with time, decay by tunnelling bacteria was difficult to observe in the already heavily degraded wood samples later on.

Erosion bacteria were not observed in wood exposed above the seabed (Appendix 4, table 4), but were present within the sediment and most active at the depth of 42 cm. It was the only micro-organism active at the depth of 42 cm.

Decay rate
Decay proceeded with time, and by the end of the experiment (36 months) the decay zone in all samples was measured to millimetre levels, in order to obtain information on the total decay in relation to wood species and depth of exposure, disregarding the type of wood degraders present. The results are shown in Appendix 4, table 5.

Wood species
The three different wood species; birch, oak and pine were found to have different durabilities to the decay forms present in marine environment, both above and beneath the seabed.

Depth of burial
There was a significant decrease in decay related to the depth of burial. Above the seabed all wood species were degraded rapidly, primarily by marine borers and secondly by microorganisms. Ten centimetres below seabed, degradation declined significantly. When exposed in sediment at a depth of 42 cm, erosion bacteria were the only active wood degraders.

Time
As time proceeded, decay developed, and attack became more intense both above seabed and in sediment.

Discussion and conclusions

Reburial by means of sediment cover of shipwreck structures on the seabed, is a simple, useful and effective method for decreasing wood degradation. Results from this study verify the fact that wooden structures degrade very fast above the sediment in saline seawater. For the small wood samples used in this experiment, 3 years of exposure resulted in total disintegration by marine borers. For timber of larger dimensions, decay may take more years, but the overall degradation process is still very fast. Throughout history decay and degradation have been the ultimate destiny of many shipwrecks.

Most shipwrecks are made from oak. This wood species is more resistant to marine borers compared to pine and birch. At 42 centimetres below the seabed, oak is slowly degraded by erosion bacteria. While pine proved to be slightly more durable in this study, the high variability between samples suggests that future studies should use a larger number of samples.

Wood located in sediments is protected from marine borers. Here the decay is strictly related to the presence of microorganisms and the influence of environmental conditions. Both soft rot (SR), tunnelling bacteria (TB) and erosion bacteria (EB) were found in the upper layers (10 cm below the seabed), whereas only EB were active at the lower level (42 centimetres below the seabed). It is known that the oxygen concentrations in sediments decrease rapidly with depth. Beneath the first few centimetre's conditions become increasingly more anaerobic. It is known from other studies that EB are the main degraders of waterlogged archaeological wood under near anaerobic conditions. Hence, they are, not unexpectedly, predominantly found in the low-oxygen areas of the sediment. [37-40]

SR and TB are faster wood degraders than EB and cause more damage to the wood structure and surface layers, where unique tool marks and ornamentation is located. Consequently, this allows us to recommend a reburial depth of at least 50 cm. Future studies should investigate the effect of even thicker sediment layers in order to find the optimal depth of burial.

Removal of sediments by strong water movements will expose wood to fast degradation. Conditions at proposed reburial sites should be carefully examined therefore, to ensure that sediment removal is unlikely. Otherwise long-term preservation may be compromised.

A final conclusion is that the technique used in this study, where sound wood samples were exposed at the shipwreck site, was most successful in identifying marine borers and all the microbial decay forms. The technique also made it possible to quantify decay over time. Future and more detailed studies are required to enable us to extrapolate data for much longer periods.

Organic material other than wood - Textile, Leather, Antler, Horn and Bone

Aim

The aim of the organic materials subproject is to evaluate the effect of burial in a marine environment on the more sensitive non-wood organic materials that make up the marine archaeological record and to make recommendations concerning the use of similar environments for long-term storage of recovered artefacts made of these materials. Furthermore, characterisation of the nature and rate of deterioration of these materials will add to the current body of knowledge regarding degradation pathways in the marine environment. The marine sediment environment of the harbour at Marstrand, Sweden provides the field laboratory in which this research is being carried out.

Methodology

Samples have been drawn from modern materials of vegetable-tanned leather, undyed and dyed (madder, indigo and weld) woven wool fabric (vadmel), raw (grey) woven linen fabric, undyed woven silk fabric, hemp rope, tarred/treated cotton fishing net, antler, horn, and fresh 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. One sample of each material was sewn into a nylon open mesh envelope, and half of these envelopes were further enclosed in envelopes made of a non-woven geotextile fabric. One set of geotextile-covered and uncovered samples was laced side-by-side with nylon cord in the bottom of a perforated plastic tray (figure 20). In this manner, for each tray one set of sample materials would be directly exposed to the harbour sediment, while the other was protected from direct contact with sediment, although still exposed to the chemistry and hydrology of the burial location.

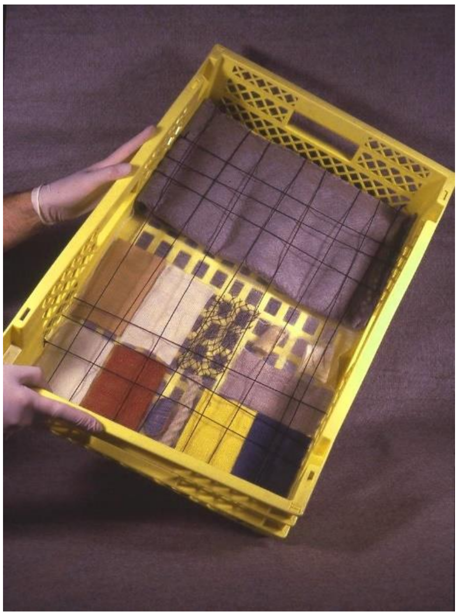

Figure 20. The sample unit with one uncovered and one covered set of samples before burial in September 2002 in the harbour at Marstrand.

In September 2002 seven trays were deposited in the project trench in Marstrand harbour for later retrieval over the predetermined 50-year project period (i.e., following burial for 1, 2, 3, 6, 12, 24 and 48 years). The trench was subsequently backfilled with circa 50 cm of excavated sediment. No sample sets were deposited on the surface of the harbour bed or with a shallower sediment backfill. One set of control samples and all retrieved samples are stored in darkness at constant temperature and relative humidity in the climate-controlled museum stores at Vitenskapsmuseum, Norwegian University of Science and Technology. The following results, conclusions and guidelines are based on the recovered 1-, 2- and 3-year sets of samples.

Results

Fibre-based materials

The non-wood organic materials can be divided into three groups: hard animal tissues (bone, antler and horn), soft animal tissues (leather), and fibre technologies (fabrics, rope and net).

The fibre-based materials were more severely affected by burial in the sediment at Marstrand than the other non-wood organic materials investigated. Samples that were directly exposed to the marine sediment were substantially more affected by burial-induced degradation than those in the non-woven geotextile envelopes. This difference in preservation/deterioration between the covered and uncovered samples increased with increasing burial time.

Visual inspection of the textile samples revealed that the silk fabric and tarred/treated cotton fishing net were the least affected by burial and that the linen fabric and rope the most affected. The latter illustrate a breakdown of substance, being reduced to10% of their pre-burial weight. The silk and net did not show gross signs of structural breakdown until following three-years' burial. It is obvious that the net pre-treatment had a biocidal effect and reduces hydrolysis. The wool samples exhibited both a wide variation in and extensive changes to the samples. These changes in colour, physical integrity, density, and surface characteristics were not consistent between the undyed and dyed materials. The pre-burial colours of the dyed fabric are strong. It is readily apparent that in some instance's dyestuffs, in particular madder and less so weld, conferred a deterring effect on the deterioration of the dyed wool fibres in the burial environment at Marstrand.

Leather

Preservation of the soft animal tissue - vegetable-tanned leather - was much better than the textile materials and slightly less than the bone, antler and horn. Visual inspection of the leather samples revealed minimal change after burial in the marine sediment. Samples are complete with physical integrity preserved. Visually the change in colour, which is darker, was similar for both the covered and uncovered samples for each retrieval year. Upon closer inspection of the microstructure of the grain surfaces, damage is evident. By two-years there is a general etching of the surface and exposure of subsurface collagen fibres. Evidence has not been found for microbial degradation. However, the pH of the surrounding sediment is above the recommended 4-6 pH range for leather indicating that it may undergo alkaline hydrolysis.

Bone, antler and horn

The hard animal tissues, bone, antler and horn, are much more robust than the leather, textiles and cordage with which they were deposited. Being mineralised tissues, the bone and antler survived better than the purely organic horn samples. On visual inspection of the hard tissue samples there appeared to be little change after burial in marine sediments for the bone and antler. The surfaces of the bone samples were slightly darker and the antler samples perhaps more so because of the greater porosity and higher collagen content compared to fresh bone. The horn however exhibited a higher propensity for shrinkage and cracking after burial, particularly the samples directly exposed to the sediment. It is clear that there are diagenetic changes to both the major and minor elements in all of the skeletal materials examined and that these are sometimes accompanied by microstructural changes. The higher levels of elemental uptake measured in the uncovered samples suggests that intimate contact with the sediment is an important factor in diagenetic change.

The histological analyses show no obvious evidence for microbiological destruction of the hard animal tissues, although chemical evidence suggests some anaerobic microbial activity in the burial environment. The outer surfaces and microstructure of the horn samples show deterioration that is seemingly independent of whether the samples were covered with the geotextile of not. This suggests a chemical hydrolysis mechanism for the degradation rather than attack by microorganisms. After three years of burial the uncovered samples of bone and possibly horn show evidence of surface attack by small invertebrates.

Conclusion

The materials included in this study are modern in origin, and thus at the outset do not simulate burial-degraded archaeological artefacts of similar materials or artefacts recovered from a marine burial environment. For these materials the study is of burial rather than reburial. Moreover, the sample materials were not packed in polyethylene or similar slow-biodegradable packaging film to protect them from interaction with the surrounding sediment solution and sediment. Artefacts of these materials selected for deposit in a marine archive would undoubtedly be packaged prior to deposition. Therefore, these results reflect degradation to non-protected materials and to materials once the protective packaging fails either through leakage or failure of the packaging material itself.

All the non-wood materials included in this study exhibited degradation as the result of one- to three-years burial in 50 cm of sediment in Marstrand harbour. In this three-year timeframe there was no indication that the degradation was levelling off to establish an equilibrium state. Results indicate that the geotextile envelope offers protection from microorganisms within the sediment and isolates the material inside from some micro-structural alteration. The envelope does not appear to protect against chemical alteration.

One aim of this investigation has been to assist in evaluating the technique of reburial in the marine environment as an alternative to traditional museum storage for marine archaeological finds. The Phase I three-year burial period has been sufficient to be able to draw conclusions for the fibre-based materials included in the study. This initial study period has not been long enough to be able to draw conclusions with regard to recommendations for or against long-term reburial for the soft and hard animal products. Based upon results thus far, the six- and twelve-year retrievals will be important determinants for the leather samples, the twelve- and twenty-four-year recoveries likewise for the bone, antler and horn samples.

Guidelines

Fibre-based materials

Finds of the more perishable organic materials, especially fibre-based ones such as textile fabrics, basketry and rope make up a small percent of total recovered artefacts both in number of items and in physical bulk. Being a rarer category of find they are usually given a higher priority, and it is less likely that such finds would be selected for reburial. The exception could be in instances where large volumes of similar rope/cables, nets and sails are recovered, in which case representative samples are likely to be conserved with the remaining finds reburied. Regardless, fibre materials are demanding in that their conservation is labour-intensive and therefore costly. In a water-degraded condition their polymer substance is highly degraded, and their physical structure disintegrated. Frequently in an attempt to preserve physical integrity such artefacts must be recovered together with their surrounding sediment matrix as block lifts. Once documented, analysed and accessioned into an archive, these artefacts are not likely to be robust enough to survive the reburial process. Finds of basketry, nets and rope/cables also fall into this category.

Based upon the Phase I results for the modern fibre-based materials investigated, buried at a depth of 50 cm in harbour sediment, reburial cannot be recommended for recovered fibre artefacts. The exception is tarred cables recovered in massive amounts, which due to their physical bulk and the biocidal effect of the tar coating will survive for a longer period. It is advised that such material be packaged in materials recommended by the polymer subproject, and buried at a depth greater than 50 cm.

Leather

Finds of leather can make up a sizeable portion of non-wood organic artefacts recovered from a marine site. It is possible that following full documentation leather artefacts may be selected for reburial in a marine environment. Based upon the Phase I results for the modern vegetable-tanned leather buried at a depth of 50 cm in harbour sediment, short-term reburial can be recommended for recovered tanned leather artefacts. It is advised that such material be packaged in materials recommended by the polymer subproject, and buried at a depth greater than 50 cm.

Bone, antler and horn

The marine reburial of skeletal material poses several potential problems. Human skeletal remains require specialised handling and disposal protocols because of the obvious culturally sensitive nature of the material. It is highly unlikely that reburial at sea is suggested for human remains unless this involves returning bones to a recognised war grave. Horn and antler are such rare finds in marine archaeological sites that it is very unlikely that any finds made of these materials or worked bone would be selected for reburial. Only animal bones are likely to be selected for reburial/disposal at sea.

Based upon the Phase I results for the modern hard animal products investigated, buried at a depth of 50 cm in harbour sediment, short-term reburial can be recommended for recovered bone ecofacts. It is advised that such material be packaged in materials recommended by the polymer subproject, and buried at a depth greater than 50 cm.

It must be noted that recovered marine archaeological organic materials routinely undergo desalination at an early stage of post-excavation finds processing. It is important that the use of this method be re-evaluated in circumstances in which finds may be selected for later reburial in a saline marine environment.

Packing and labelling material

Introduction

In archaeology a range of modern products are used to separate, mark and support archaeological objects during an excavation. These products are often polymeric in nature. As reburial of archaeological material is anticipated to last for an extended period, the packing and labelling materials need to be able to survive for just as long. Consequently, the durability of these products is of great importance. Although reburial environments are likely to be benign for the preservation of polymer material, present knowledge of their long-term stability is limited. Better knowledge of the most suitable products and materials to use will not only improve the quality of cultural heritage management but will also improve the efficiency of the work that is to be conducted. The correct material can be used, and unknown or problematic material can be avoided from the start of an excavation.

Aim

The objectives of this sub-project are to investigate how a reburial environment will affect the mechanical properties of some relevant packing products/materials and also to determine the readability of a number of labelling materials subjected to a marine sediment environment.

The materials chosen in the investigation are products that are commonly used to separate, mark and support artefacts during underwater archaeological excavations. The study compares and assesses the usefulness of these materials in relation to reburials.

Materials and method
The study includes a variety of products and materials (table 7), mainly of polymeric origin, including polyethylene (PE), polypropylene (PP), polyester, polyamide or nylon (PA) and polyether/polyurethane. Stainless steel labels have also been included and compared with polyvinyl chloride (PVC) labels. Samples of pinewood, to imitate a pine container, were also tested and compared to a PE container.

Four different types of pens have been used on two different supports. Two different brands of permanent marking pens, one is especially designed for writing on overhead plastic sheets, a ball-point pen with archival proof ink and a pencil have been tested. All text has been written both on polyethylene bags and on polyethylene tags.

The products can be placed in the following groups according to their uses.[8]

- Materials to separate objects (crates/containers, bags, nets and sacks).
- Materials for tying or attaching labels to object (different kind of cords).
- Materials for support and protection, e.g. wadding, geo-textile and synthetic rubber tarpaulin.
- Materials to identify objects, e.g. tags with embossed or prefabricated numbers, but also identities written with pencil, permanent markers and an archival proof ballpoint pen.

It is likely that the reburial environment will have little effect on the polymers and that the mechanical properties of the materials buried in the first phase in-situ units will not change much. Hence it was necessary to also use accelerated ageing techniques to determine the rate of degradation of the polymer materials.

The test materials were exposed in three different environments in order to evaluate their long-term properties (table 7)

- *In-situ* in the actual sediments in the harbour under the same conditions as during a normal reburial (referred to as “in-situ exposure”).
- Accelerated ageing in sea sediment at various temperatures 50, 60 and 70 ±2 º C has been performed in order to evaluate the long-term effect of the chemical matters in the sediment (referred to as “chemical degradation”)
- Exposure in the marine sediment at room temperature (23 ±2 º C) in an isolated anaerobic system including the presence of microorganisms (referred to as “biological degradation”).

After retrieval from the burial environment samples were inspected and documented. They were photographed and examined under the microscope. The written, prefabricated or embossed labelling material were also investigated using colourimetric analyses. The mechanical strength of the in-situ samples from the third retrieval (after 3 years of exposure) and the experimentally degraded samples were tested and compared with reference samples (appendix 6, table 2).

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[8] For a complete list of materials, data and suppliers see Appendix 6.

The mechanical strength of all material was evaluated by tensile testing, except for the wood material, which was evaluated by three-point bending. Tensile stress, tensile strain and max load for various products were measured according to ISO standards.

Sample ID	***Product***	**Material**	**Abbreviation**	**Burial environment/Degrading techniques**		
				In-Situ	***Chemical degradation in lab***	***Bio-degradation in lab***
A	Crate	Polyethylene	HDPE	X		
B	Crate	Pine		X		
C	Bag	Polyethylene	LDPE	X	X	X
D	Net	Polyethylene	PE	X	X	
E	Sack, woven	Polypropylene	PP	X		
F	Geotextile	Polyethylene/ Polypropylene	PP/PE	X	X	
G	Geotextile	Polyester		X		
H	Tapaulin	Synthetic rubber	EPDM	X	X	X
I	Wadding	Polyester		X		
J	Cord	Polyester		X	X	X
K	Cord	Polyethylene	PE	X	X	X
L	Cord, spun	Polyamide	PA	X	X	X
M	Yarn	Polyamide	PA	X	X	X
N	Tag, prefabricated	Polyether/ Polyurethane	PETR/PUR	X	X	X
O	Tag, dymo ®	Polyvinyl chloride	PVC	X		
P	Tag, dymo ®	Steel		X		
Q:1	Marker	Permanent ink on PE bag		X		
Q:2	Marker	Permanent ink on PE tag		X		
R:1	Marker for OH	Permanent ink on PE bag		X		
R:2	Marker for OH	Permanent ink on PE tag		X		
S:1	Pen, ball point	Archival proof ink on PE bag		X		
S:2	Pen, ball point	Archival proof ink on PE tag		X		
T:1	Pencil	Graphite on PE -bag		X		
T:2	Pencil	Graphite on PE-tag		X		

Table 7. The materials and burial environment chosen in the study.

Discussion and conclusions

This first preliminary study on packing and labelling material investigated products that have been used primarily in archaeological and reburial contexts. It is important that these products are easily available and not too expensive, which was the case with most of the studied products.

When commercial products are studied a few problems arise. One is that the complete content of a specific product can be difficult to obtain because of trade secrets. Therefore, only the main ingredient(s), the base material, of each product can be given in a study like this. The fact that additives, such as plasticisers and colours, are mixed with base materials complicates the interpretation of degradation analyses. Processes such as the extraction of additives in different environments may affect the mechanical properties in various ways. Different products made of the same base material are likely to have different additives, which may cause them to degrade differently. Hence conclusions from the analyses in this study are valid primarily for the tested products and to a lesser extent for the base materials.

Packing material
Most of the polymer materials tested seem very stable and could be used *in situ*ations when archaeological artefacts are to be reburied. However, for the materials that were not experimentally aged in the laboratory (HDPE crate, PP sack, polyester geotextile and wadding), these are tentative findings, since only three years have passed since the materials were buried in Marstrand harbour. For the materials that were experimentally aged in the laboratory the result is more reliable. Table 8 summarizes the results and evaluations of the stability of the tested materials

One of the materials that showed a significant change was the pinewood. Despite the relatively short term of three-year in-situ exposure this material decreased its strength at break point by at least 25 %. The other crate material tested, high-density polyethylene (HDPE), seemed unaffected by the in-situ exposure and seems a good choice to use in a reburial situation.

The polyethylene net also showed big changes both after exposure to chemical degradation in the laboratory and after three years *in-situ* exposure in marine sediment. This constitutes a problem since the packing/separation functions of a net in reburial situations are very important. A possibility would of course be to use a PE net with coarser, stronger strings or using nets made from other material, such as polyester. If any of these options are not possible in a reburial situation, it would be wise to use PE nets with the similar properties as the one tested only with lighter artefacts.

The PE net lost almost two thirds of its initial strength during the testing period, whereas the strengths of the PE bag and PE cord were unchanged, primarily because of the dimensions and forms of the products. Production technique is also important, since a material can be produced to be strong in one direction and weaker in others.

The interpretation of the tensile tests on the polyamide products (a cord and a yarn) has been slightly difficult. Although polyamide is known to be a very strong and durable material, often used in marine environments (e.g. Kevlar sails) little is known about the degradation processes in an anaerobic environment. [41]

The strength of the polyamide products is still very good, but changes have taken place in the samples exposed to anaerobic environments; *in-situ* in the Marstrand sediment and experimentally aged biologically in the laboratory. On the other hand, the samples aged chemically at three different heat and time regimes did not alter significantly. This means that the products have good stability against oxidation processes. It is also likely that degradation processes in the two anaerobic environments have stabilised, since there is little difference in mechanical strength between the *in-situ* samples and the laboratory biologically aged samples. Future analyses of buried polyamide samples will hopefully give more conclusive results and until more is known polyamide products should be used with caution in anaerobic reburial environments.

The other cord materials tested, polyethylene and polyester, were unaffected by the different environments and could be used in reburial situations.

Labelling material
After three years, buried in the sediments at Marstrand, all labels were easily readable with the naked eye. Ocular inspection and chromaticity readings confirm, however, that written

text with the black marker[9] (R) and the blue archival proof pen[10] (S) had changed (table 8, 12 in Appendix 6). The total colour differences, ΔE, are considerable and consistent on both the polyethylene bags and tags. The black marker text (R) has changed colour to blue. Although the changes in the blue archival ink text were less easily detectable to the eye, a light tinge of green was noted.

Even though the samples have only been exposed to the sediment for a very short period the changes that occurred in the tested writing materials are substantial enough to make a few recommendations. Markers must be of good permanent quality and not made for writing on over-heads, as for the one tested. The marker that was stable over the test period was “Edding 404, permanent marker”, but it is likely that other brands would have similar quality markers that could be used.

As the archival ink pen tested (BIC svenskt arkiv) showed signs of degradation in this particular environment it is not suitable for anaerobic clay sediments. Another reason to avoid this pen is the fineness of the tip of the pen, which makes the lines very thin and therefore also more difficult to read if the ink fade and changes in colour. As expected, the pencil writing did not change at all. Using a pencil for labelling artefacts is therefore safe.

Although the prefabricated embossed labels (“ear tags”) and the Dymo labels all look good after three years the stainless steel Dymo labels had begun to tarnish and it is likely that they would continue to do so, eventually leading to problems with identification. These findings confirm those of previous studies that showed that stainless steel corrodes in anaerobic environments due the action of the sulphate reducing bacteria, conditions which flourish in anaerobic environments like those in Marstrand. [42]

It therefore seems a better choice to use the PVC Dymo labels or the prefabricated embossed tags, so called “ear-tags”, to label artefacts that will be buried in sediments. Note, however that there are at least two different types of “ear-tags”, the one tested in this study with numbers pressed into the base material and one with numbers printed on the surface with laser additive colour. The embossed type is preferable to use since the laser tags have not been tested in reburial sediment, but also because problems with vanishing numbers have been noticed within the farming community. [43]. Using the prefabricated “ear tags” tags offers a better ergonomic work situation, since it causes less strain on staff in charge of labelling a big collection, a factor worth taking into account as well.

[9] Stabilo OHpen Universal
[10] Svenskt arkiv

Table 8. The evaluation of the packing and marking materials tested in the subproject are based on the tentative findings from in-situ burial and experimental degradation in the laboratory. Materials useful for reburial of archaeological artefacts are indicated with plus (+) and materials that should be avoided are indicated with minus (-)

Sample ID	***Product***	**Material**	**Usefulness for reburials Tentative findings drawn from in-situ degraded samples**	**Usefulness for reburials Findings drawn from in-situ and experimental degrading of samples**
A	Crate	Polyethylene	+	
B	Crate	Pine	-	
C	Bag	Polyethylene	+	+
D	Net	Polyethylene	-	-
E	Sack, woven	Polypropylene	+	
F	Geotextile	Polyethylene/ Polypropylene	+	+
G	Geotextile	Polyester	+	
H	Tapaulin	Synthetic rubber	+	+
I	Wadding	Polyester	Not yet tested	Not yet tested
J	Cord	Polyester	+	+
K	Cord	Polyethylene	+	+
L	Cord, spun	Polyamide	+/-	+/-
M	Yarn	Polyamide	+/-	+/-
N	Tag, prefabricated	Polyether/ Polyurethane	+	+
O	Tag, dymo ®	Polyvinyl chloride	+	
P	Tag, dymo ®	Stainless steel	+/-	
Q	Marker	Permanent ink	+	
R	Marker for OH	Permanent ink	-	
S	Pen, ball point	Archival proof ink	-	
T	Pencil	Graphite	+	

Discussion and Conclusions

The usefulness of reburial for heritage management

Archaeological heritage is a fragile and non-renewable resource; therefore, the archaeological community has moved away from relying solely on traditional excavation methods towards a strategy of *in situ* preservation of this cultural resource. [44] Further, the UNESCO convention from 2001 emphasises that the choice of conservation strategies to be deployed should be achieved through non-destructive, non-intrusive survey rather than excavation. Only if a site is threatened by development, land-use change, looting or natural deterioration should excavation be carried out. Sites not under threat may be investigated to elucidate scientific problems. The convention states that the archaeological record, including *in situ* or removed cultural heritage and supporting documentation, must be deposited in an institution that can provide for public access and permanent curation of the archive. If these directives are to be followed can reburial be used as a tool for cultural heritage management?

The focus of the Marstrand reburial project has been to address the question of whether reburial can provide acceptable and protective long-term storage for some material types commonly found at archaeological sites. Moreover, this project briefly discusses under what circumstances and for what reasons archaeological finds could be reburied when their long-term preservation in such an environment could be recommended.

Findings from the RAAR project

If any form of reburial (or for that matter *in situ* stabilisation) is to be successful, the primary aim should be to understand the agents of deterioration on a site or of an artefact and develop and implement strategies to mitigate for them. As discussed, sites that are buried tend to be well preserved due to the limited oxygen, which minimises deterioration, by micro-and macro organisms.

Prior to any reburial, the type of sediment /material used should be assessed to see whether it is likely to be conducive to preservation. Porosity and organic content in particular will have an effect on the rates of microbial activity**.** The lower the porosity and organic content the better it is for preservation of archaeological materials.

The Marstrand reburial is in seawater sediment. The difference between reburial storage in salt and freshwater sediments has not been studied as part of the Marstrand reburial project. However, based on what is known about the effect of salt on different material, it is expected that reburial storage in fresh water is likely to be as good, if not better than reburial in sea sediments.

The degradation processes have not yet stabilised for many of the tested materials and future analyses will be needed to draw final conclusions about reburial as a preservation strategy. Therefore, it is of paramount importance that this project continues so that as much information as possible can be obtained regarding the degradation processes of the tested materials. This information, in conjunction with analyses of actual shipwreck artefacts, will allow evaluation of the long-term effectiveness of reburial as a preferred means of preservation for archaeological remains.

Based on the results from the first phase of the Marstrand reburial project however, some initial conclusions can be drawn, and recommendations made from a degradation/preservation viewpoint. The recommendations are summarised below and in Table 9. Selection criteria from a curatorial point of view are still to follow, but from conservation perspective reburial seems a valid tool for heritage management to use, albeit its usefulness might be less general than previously assumed. This first and highly important condition to establish the usefulness of reburial as a preservation method for heritage maintenance is thereby fulfilled and the focus can be set on *why* archaeological finds should be reburied. If we use reburial as a way of preserving artefacts for the future what role will they eventually play? How and when will they be used?
In summary:

- The main reburial trench in Marstrand appears to have generally good preservation conditions for the reburied artefacts and the material samples. The reburial sediments are primarily of a sandy nature, with an organic matter content of <5%. At the depths were the artefacts and most of the material samples are buried (~ 50 cm) the sediments are anoxic and strongly reducing with the predominant ongoing process being sulphate reducing.
- Important parameters to measure on reburial site include dissolved oxygen, redox potential, sulphide, and pH. These and measurements of sulphate, dissolved (and perhaps total) iron and *in situ* temperature will give an indication of on-going processes.
- Although it is still too early in this reburial experiment to make definitive statements regarding the long-term stability of the metal coupons with respect to reburial depth, it is clear that corrosion is reduced as depth increases and that metals, particularly ferrous metals, require burial to depths greater than 65 cm.
- Reburial cannot be recommended for any type of glass.
- Low-fired earthenware is unlikely to survive long-term exposure and should not be reburied. However, the resistance of earthenware to a marine environment varies, largely depending on the firing conditions during manufacture. The poor results for the very low-fired 'modern' earthenware samples after three years of reburial, cannot be stretched to issue a general recommendation against reburial of earthenware.
- High-fired ceramic wares, such as porcelain, stoneware and also clay pipes are highly stable and should survive reburial processes but consideration should still be given to the problems of over-glaze decoration and gilding on porcelain and salt infiltration in clay pipes and less high-fired stoneware.
- Reburial is a simple, useful, and effective method for decreasing wood degradation. Wooden structures above the sediment, in saline seawater degrade very fast.
- Of birch, oak and pine samples tested, birch was the least durable towards most types of decay, oak was more resistant to marine borers than either birch or pine while pine was slightly more durable to erosion bacteria than oak at depths of 42 cm.
- While a depth of at least 50 cm is recommended for wooden artefacts, studies should examine the effects of burial at even greater depths.
- Burial is not recommended for fibre artefacts, with the possible exception of large tarred cables/ropes, if similar representative samples are conserved.
- Although longer burial times are needed before firm recommendations can be made regarding reburial of soft and hard animal products like leather, bone, antler and horn, only short-term reburial, at depths greater than 50 cm, should be considered for leather and bone artefacts.

- A general viewpoint is that reburial should be avoided if artefacts have decorative surfaces or show traces of production or wear.
- Although most of the synthetic packing materials appeared stable, these results are only tentative and need to be confirmed in the next phase of the project.
- Of the packing materials, the Zip-lock® bags generally seemed to offer the best protection against degradation and/or infiltration of salts; geotextile readily allows for free flow of the soluble salts, but protects against direct influence of the burial sediment, possibly offers some protection from microorganisms within the sediment and isolates the material inside from some micro-structural alteration but does not appear to protect against chemical alteration; polyethylene netting offers the least protection and should be avoided.
- Appropriate containers for groups of finds include high-density polyethylene crates, polyethylene bags, polypropylene sacks and geotextile envelopes, with the former the most highly recommended.
- Polyethylene and polyester cords are suitable to tie and secure artefacts and labels while polyamide cord and yarn still requires further testing before it can be recommended.
- Preferred options for identifying finds include the use of prefabricated tags (live stock 'ear tags'), embossed PVC labels (eg Dymo® labels), pencils or black permanent markers. Ballpoint pens, even those labelled, as 'archival' should not be used.

Table. 9. Recommendations on materials suited for reburials

Material	**Long-term reburial possible**	**Short-term reburial possible**	**Reburial not recommended**	**No conclusive findings after 2-3 years**
Metals				x
Porcelain	x			
Stone ware	x			
Clay pipes	x			
Earthen ware, low-fired				x
Glass			x	
Wood	x			
Fibre artefacts			x	
Tanned leather		x		x
Animal bones		x		x
Antler		x		x
Horn				x

Consequences for heritage management

The archaeological heritage is a record of past human activities and should be kept for future studies and interpretation on behalf of and for the benefit of present and future generations. [45] When it comes to handling and protecting the physical cultural heritage, national bodies of heritage institutions and administrations have different tools to manage, preserve and maintain sites and finds.

An archaeological excavation implies making a selection of evidence to be documented and preserved at the cost of losing other information and possibly even total destruction of a site.

All *in-situ* heritage remains are legally protected by the Swedish Heritage Act, no matter their importance for future research. Once excavated from the site however, that general protection is lost and the find is subjected to an evaluation that might result in conservation, reburial or destruction. Therefore, *in situ* preservation is favourable also from a jurisdictional point of view. This is not always a possible path and excavation is sometimes necessary.

For excavated sites and artefacts, the most common and traditional method has been and still is to conserve and store the objects in museum archives or place on exhibitions. In some cases, disposal is used as a method of managing artefacts. It is however, only applied when the artefacts are considered of no value and its use follows a thorough documentation of the finds. Reburial has recently been implemented abroad and in Sweden as an alternative and less expensive preservation strategy for archaeological artefacts. In Sweden it is not yet an officially recognised conservation strategy. The Swedish Heritage Act and its guidelines do not mention reburial as a preservation method for artefacts; therefore, neither guidelines nor maintenance protocols for its use exist. Despite the legal situation there are still three ways of dealing with physical finds from an excavation; conservation, reburial and disposal.

Reburied artefacts are not to be forgotten in the sediments nor should reburial be chosen instead of conscious disposal of artefacts that have been evaluated as of no use on, for example, e.g. scientific, emotional or aesthetic grounds. In the same way as traditional conservation and storage preserves an object for study or exhibition purposes, artefact reburial is also designed to preserve it so that it can be accessed and used in the future. If there are no thoughts or ideas about future needs or use of an artefact or a collection, there seems little point preserving it at all. This might lead to some problems, since it would perhaps be easy to use reburial as an "artefact dump" when the decision to discard is difficult or controversial. However, it is important to make a clear distinction between reburial and discarding.

A reburial is considered less expensive than traditional conservation and storage, mainly because there is no active conservation cost involved and possibly also less cost for "housing"[11] the collection. However, there are definitely costs involved in setting up the reburial depot and maintaining it. To put it crudely, artefacts chosen for reburial should be worth this investment. For this and other reasons a reburial needs to be thoroughly considered and planned.

It is possible and maybe even likely that stipulated time frames will be part of reburial procedures, i.e. depending on the materials to be reburied, a reburial program will be designed to last a certain number of years, decades or maybe even centuries. It should not however, become the end solution. Reburial could be used as short-term storage while waiting for funding to cover conservation and traditional storage or in-depth analyses. It could also be a preferred option for long-term storage if analytical or investigative methods at hand are not optimal or if artefacts or collections are to be kept in a 'capsule' awaiting future questions, improved analytical techniques and/or the development of more suitable conservation treatments. As with time frames, future intentions with regard to reburied artefacts or collections of artefacts should be stated before a reburial is commenced to force creative thinking and planning as well as to prevent creation of a 'reburial dump'. The idea that a reburial exists within a specified time frame is consistent with results of the physical preservation of material in anaerobic sediments. Neither analytical results nor any scientists

[11] The cost involved for using, leasing, buying etc would differ between countries and between sites within a country.

would guarantee an unlimited preservation time for any type of material in anaerobic marine sediments or for that matter in most environments.

Following the above discussion, a heritage institution could provide short- or long-term curation for its archaeological archive by using reburial depots provided they are used within the given stipulations. However, access for the public to the submerged archive will be considerably restricted. This disadvantage does have a time limit in accordance with the agreed-upon time frame for each depot. Whether or not this is a drawback worth considering would have to be discussed for each reburial program.

The influence of reburial on planning and logistics of an archaeological investigation

The use of reburials in heritage management stresses the importance of planning and logistics during an archaeological investigation and underlines the importance of pre-investigation analyses. Pre-investigations should lead to in a better understanding of the volume and characteristics of the finds anticipated for the final investigation and therefore also for any subsequent reburial. Reburials can produce improvements in the handling of finds and planning of archaeological projects.

Some post excavation conservation treatments, desalination processes for example, start immediately after finds are retrieved from a site. It is important that the use of desalination and possibly other treatment methods are re-evaluated in circumstances in which finds may be considered for later reburial in a saline marine environment.

The use of reburial also put focus on basic values involved in choosing what will remain as cultural heritage. Selection always has to be made, but it is the statement *why* in that process that will make the difference between a justified or an arbitrary choice. Who is making the choice and what are the values that guide the categories of artefacts that will be saved for posterity and what categories that are disqualified?

Criteria for conservation, reburial and disposal have been discussed before [11] and should continue to be discussed on different levels; national, regional and before and during each individual investigation. Without discussing criteria or decision making in any depth, the experience from the Marstrand project is that it is important that a group of specialists evaluate and discuss the artefacts before final decision are taken on conservation, reburial or disposal. The final decision on any of the options available is difficult to take before the excavation is finished and there is a more complete picture of what the excavation has yielded. This has, if nothing else, a logistical impact on the excavation and has to be planned for before the excavation starts.

Reburial depots

Parallel to the RAAR project there has been a discussion in Sweden on how reburial depots are best maintained and supervised. Large-scale regional or national depots have considerable advantages over smaller local or site related depots both from economic and qualitative points of view. The establishment of a depot is often expensive and implies geo-chemical and other analyses of the sediments to assure its suitability. The excavation of the sediments and the use of the property require legal permits, of which the latter may be an easement.

As the removal of sediments by strong water movements could expose artefacts to rapid degradation, control must be maintained at archaeological/reburial sites in order to observe and ensure long-term preservation. Surveillance would consist primarily of regular observations of the reburial site and recurrent sediment and water analyses.

In situ data logging and *ex situ* spot measurements complement each other as methods of assessing the environment and measurements of turbidity in open water should be considered as a possible means to assess the likelihood of scour around a site.

Consequences for the reburied artefacts from the Marstrand excavations in 1998 to 1999

The bulk of the artefacts reburied in 1998 and 1999 consists of a variety of ceramic and glass finds, a large number of wooden artefacts as well as wrought and cast-iron objects. A smaller number of leather and tarred rope fragments were also deposited as well as a few non-ferrous material objects. The main reburial mound appears to have what is generally thought to be good preservation conditions with an anaerobic and reducing environment. When the reburial was decided there was neither a time frame on the storage nor any specific plans with the reburied artefacts. It was and is considered as long-term storage with reduced access but is still a better option than discarding all of the finds.

In retrospect, with the results from the reburial research project available, some of the material groups, such as the glass and possibly parts of the earthenware material should not have been reburied. It would perhaps also have been wise not to rebury the leather artefacts. Future findings of the metal sub-project will hopefully provide information about likely deterioration of the reburied metals. The stoneware, porcelain and wooden artefacts, however, should remain well preserved.

There is also a problem with regards to packing material and labelling of the artefacts. Some heavy objects were packed in polyethylene netting, often to keep an identifying label in place. The fact that the PE net lost so much of its initial strength after only three years in the reburial environment is problematic. Labelling protocols were also inadequate with different markers, pens, pencils and Dymo® labels used. There is unfortunately a high risk that identities will have been lost after what is now eight years in the sediments.

Evaluation of the first phase of the RAAR project

It may seem simple to deploy material samples, retrieve them regularly and after analyses give straightforward answers about the effectiveness of reburials for heritage management. The RAAR project has in most ways performed well beyond expectation, due to the competence and ambition of the participants. The few problems that have arisen have been mostly of a technical nature and difficult to anticipate.

Some problems concern the sediment analyses in Marstrand harbour. The sediments in the metal trench (T2) had accumulated naturally since 1998 when the trench was dug. When the metal samples where to be buried in 2003 it seemed simplest to just push them into place in the unconsolidated sediment instead of shovelling sediments around and on top of them as had been done with all the other samples in trench 1 (T1). This however, resulted in sediments with different water contents covering the metal, a different situation to that of the other samples. The sediment investigation made by RAAR included the analyses of a whole range of parameters (particle size distribution, water content, organic content, siliceous content, redox potential, pH, dissolved oxygen, sulphide content etc) in undisturbed and disturbed sediments. Similar sets of analyses have not been made to compare trench 1 and 2 since the differences in water content were first realised. This discrepancy will be corrected in the second phase of the project.

Degradation outcomes of the RAAR project are highly environmentally specific; it has been proposed that even more detailed characterisation of the Marstrand sediments be undertaken in a future phase of the project.

The first phase of the project found that microbiological activity still affected the samples at 50 cm depth. It was therefore concluded that exposure of samples at levels deeper than 50 cm would have been useful. The metal, wood and environmental monitoring sub projects especially would have benefited from measurements taken at 1-meter depth. The possibility of depositing new samples in connection with the next retrieval in 2008 is being examined.

Although the handling and transport of the recovered samples has generally been smooth and with good results, some difficulties have been encountered. For instance, even though oxygen scavengers were used, it was not possible to keep the metal samples oxygen free from the retrieval in Marstrand until their arrival in Australia. The old packing regimes will be reviewed and improved before the next retrieval.

Finally, one can conclude that there has been a need for more frequent information exchange between the project participants. A more established forum for exchange of results and experiences would have contributed to better outcomes. Annual work seminars were in the initial RAAR project plan, but unfortunately could not be realised due to lack of funding.

Future

The initial findings from phase 1 have revealed many interesting and some unpredicted results and have in general, so far fulfilled the objectives of the project. However, three years of exposure in the sediments of Marstrand is an insufficient period of time for changes to take place in many of the buried material samples. Conclusions are therefore pending. Further analyses and more in-depth studies over a longer period of time is of great importance before the suitability of reburial as a tool for heritage management can be confirmed or denied. All of the sub projects have also stressed the importance of future analyses planned for phase 2.

The participating institutions have all announced their initial willingness to continue with phase 2, which include retrievals in year 2008 and 2014. The realisation of phase 2 will also provide an opportunity to compensate for former oversights and to deal with new questions. Present problems, such as the need for better sediment analyses in both reburial trenches, improved routines for packing and transportation of metal samples and possible burial of new samples at a greater depth in the sediments can be addressed. The willingness and determination of all of the participants to continue the study is high and all are optimistic that the project managers will find the funds to enable the next phase to proceed.

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