Alum-treated archaeological wood

Characterization and re-conservation

Edited by Carola Häggström and Tom Sandström

R&D-publication from Swedish National Heritage Board

Swedish National Heritage Board
PO Box 5405, SE-114 84 Stockholm
Phone + 46 (0)8-5191 8000
Fax +46 (0)8-660 72 84
www.raa.se
registrator@raa.se

Authors: Carola Häggström and Tom Sandström, Swedish National Heritage Board;
Karin Lindahl, Acta Konserverings Centrum AB; Malin Sahlstedt, Swedish National
Maritime Museums; Emma Wikstad, Swedish Chemicals Agency
Cover: A wooden artefact from the Viking grave of Årby (left). Photo Acta Archaeologica.
The same object severely degraded today (right). © Swedish National Heritage Board.

ISBN 978-91-7209-667-7 (PDF)
ISBN 978-91-7209-668-4 (POD)

Contents

Preface

This research contributes to the field of conservation science and the publication focuses on how earlier methods for preserving wood using alum may lead to salt depositions which may cause serious decay on wood in museum collections. These are the results from a research project carried out in collaboration between the Swedish National Heritage Board and The Swedish History Museum. The Swedish National Heritage Board has a great interest and a long term engagement in the field of preservation of archaeological wood. The focus has been both research and method development where Sweden has been prolific. One of the reasons lies in the economic history of the country where forest has been a highly valued resource for industry both with regards to the building trade and for pulp and paper production which led to the method of polyethen glycol (PEG) for preserving wood. There are also other reasons why this area of research has developed, first of all the Baltic Sea provides excellent conditions for preserved wood, secondly this has meant the retrieval of a large number of wooden artefacts in need of treatment. The recent research has focused on the problem of damaging salt in organic materials. This project has dealt with the problem of alum as a conservation method which also will contribute to future research and method development. The facts and viewpoints presented in this publication represent the authors.

Lars Amréus
Director General

The research and development grant of the Swedish National Heritage Board is aimed towards gaining knowledge about heritage and the historical environment. The grant supports projects at the cross-section of cultural policy, the historical environment and various academic disciplines.

Abstract

Alum, with glycerol and various surface coatings, was routinely used during the early 1900's as a conservation treatment for archaeological wood to prevent shrinkage and to impart strength. A history of the method and its associated problems is outlined. A survey assessing the condition of alum-treated wood according to the presence or degree of salt precipitation, surface flaking, cracking and pulverization was undertaken on the archaeological collection of The Swedish History Museum in Stockholm. The majority of artefacts were found to exhibit on-going deterioration, loss of material, and a need for consolidation in the event of re-conservation. Alum-treated artefacts were generally found to be acidic with pH levels down to 1 or near 0. Of the artefacts surveyed, 5 % were found to be destroyed or beyond re-conservation. The fully hydrated state of alum was investigated in a climate chamber between 15 % and 85 % RH and 15 °C to 40 °C and found to be very stable. This suggested that acid hydrolysis rather than hydration pressure or salt crystallization is the main cause of deterioration. Artefacts were analyzed using SEM/EDS and FTIR for the presence of alum and other conservation materials such as glycerol, linseed oil, wax and shellac. Artefacts treated with alum and glycerol were found to be more degraded than artefacts treated with a coating such as linseed oil. Desalination in warm and cold water using two different consolidants; Paraloid® B-72 and Parylene N, and two types of physical supports; polyester wadding with polyethylene netting and polyether foam with polyolefin film, was tested followed by re-conservation using PEG 2000 and freeze drying. Surface pH was raised to weakly acidic or near neutral levels in all cases, and the weight of the artefacts was reduced by an average of 33 %. A higher degree of efficacy was noted with desalination at elevated temperature. A nation-wide survey was conducted to determine the quantity of artefacts treated with alum and the state of awareness, in Sweden, with regard to the alum method.

1 Introduction

For most of the former half of the 1900's, the so called alum method was routinely applied in Sweden to preserve waterlogged archaeological wood following excavation. Included in the alum-treated material from this time period are the wooden constructions and artefacts from the archaeologically significant sites of Bulverket, Käringsjön and Årby, the latter being material associated with one of the few excavated Viking Age boats in Sweden to date.

In connection with the opening of a Viking Age exhibition at The Swedish History Museum in Stockholm in 2001, displaying among other things the Årby material, conservators from the Swedish National Heritage Board found signs of notable deterioration on some of the objects. Although the problems associated with alum-treated wood were well known, the artefacts themselves had never been thoroughly investigated. To build knowledge about the original treatment and the subsequent deterioration that alum evidently had caused, and to seek methods to prevent or control that deterioration, the research project *Alum-treated archaeological wood – developing a rescue methodology for unique artefacts* was initiated as a joint project between the Swedish National Heritage Board and The Swedish History Museum in the autumn of 2002.

The purpose of the project has been to find solutions for the preservation of alum-treated archaeological wood in Sweden. Both active and preventive conservation measures have been investigated in order to develop recommendations for the treatment and preservation of these artefacts. By raising and sharing awareness and knowledge about alum-treated archaeological wood in Sweden, the project has aimed at preventing further loss of unique artefacts held in the national archaeological collections. Attention has in this way also been brought to wooden artefacts in general, an often overlooked and neglected part of the archaeological record.

In this report the different studies of the project are presented separately after an introductory background chapter. The studies include a survey assessing the present condition of a collection of alum-treated wooden artefacts in view of possible re-conservation treatment (chapter 3), an investigation into different variations in the alum treatment and consequent deterioration patterns on the artefacts (chapter 4), a pilot study on the re-conservation of a number of artefacts (chapter 5), an attempt at mapping the changes in alum at different temperature and relative humidity (RH) levels (chapter 6) and a nation-wide survey regarding the quantity and condition of potentially alum-treated artefacts in museum collections in Sweden (chapter 7). Dissemination of results, contact with other institutions and participation in various forums is described in the final chapter (chapter 8).

2 Background

2.1 The nature of waterlogged archaeological wood and certain properties of alum

A waterlogged environment is one of the few specific contexts in which wooden artefacts might survive over time. The supply of oxygen is limited and the microbiological activity from which wood will otherwise readily deteriorate is restricted, in wet environments such as lake sediments, peat bogs and compact archaeological culture layers below the ground water table. Under these conditions, the original shape and surface detail of waterlogged archaeological wooden artefacts may be preserved, seemingly unaltered.

Plate 1. The geologist Lennart von Post recovering house timbers during the excavations in 1923 of the prehistoric fortification, Bulverket, built on poles in the Tingstäde Träsk Lake on the island of Gotland, Sweden. The timbers were subsequently alum-conserved. Photo: Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

Wood degradation does however take place even in near anaerobic environments, and is in these cases most frequently caused by erosion bacteria.[1] Erosion bacteria mainly attack the cellulose rich part of the wood's cell walls, leaving behind a granular residue and a weakened lignin structure.[2] Artefact dimensions are intact only as long as water replaces lost material and completely fills up the cell structure of the wood, i.e. as long as the wood is in a waterlogged state. If dried, the wood suffers irreversible shrinkage with warping and cracking as a result, and subsequently irretrievable loss of archaeological information.[3]

In order to retain the integrity of waterlogged wooden artefacts upon drying, the water must be replaced with another substance. When the alum method was developed, it was hoped and believed that alum (potassium aluminium sulphate) had the properties required for such a substance.

Potassium aluminium sulphate is a double salt referring to its two positive ions of potassium (K) and aluminium (Al). It has been used for centuries and was in ancient Greece and Rome used medically as an astringent (Latin *alumen*, bitter salt). It has also been used in later times for bating textiles and tanning leather.[4] From 1861 and during the following 90 years, it was widely used for the conservation of excavated waterlogged archaeological wood in Scandinavia.

The most common form of alum is $KAl(SO_4)_2 \cdot 12H_2O$. It also exists without the 12 crystal waters: $KAl(SO_4)_2$. Some of their properties differ from one another. For example, whereas $KAl(SO_4)_2$ is a white hygroscopic powder, $KAl(SO_4)_2 \cdot 12H_2O$ consists of colourless crystals and decomposes slightly below 100 °C, i. e. the salt dissolves in its own crystal waters.[5] This latter fact was important for its use in the conservation of waterlogged wood as it enables the use of very high concentrations in water solution. A saturated solution of alum is however fairly acidic with a pH of approximately 3. This fact and the potential problem it may pose to the integrity of the wood has not adequately been investigated.

2.2 The alum method – a retrospective

In the mid-19th century it became necessary to find a suitable conservation method for waterlogged wood in connection with the recovery of large quantities of archaeological wooden finds in bogs in Denmark. Without treatment, the degraded wooden objects tended to shrink heavily, crack and distort on drying. In 1861 the Danish archaeologist C.F. Herbst introduced the alum method. The original method involved immersing the cleaned wet objects in a hot supersaturated solution of alum where they were boiled for two hours, sometimes repeatedly for large objects. After the objects had been dried they were given a protective coating by saturation of the object's surface with boiled linseed oil. After a second drying a coating of clear thin varnish was applied.[6] By substituting the water in the pores of the wood with alum, the method aimed at preventing shrinkage on drying and toward strengthening the material. The results were, at this time, found to be satisfactory. Objects treated in this way showed no change in shape or appearance according to Herbst.[7]

In order to improve the method so as to further prevent shrinkage while also retaining the fresh colour and shape of the wood, George Rosenberg, conservator at the National Museum in Denmark, modified the recipe in 1911 by including glycerol.[8] The pre-heated objects were placed in a solution of four parts by weight of alum, one part of glycerol and one of water, and were kept at a temperature of 92–94 °C for two to 30 hours depending on the size of the object. This was followed by one or several surface treatments, such as impregnation with melted beeswax, various types of oils, for example linseed oil, and coating with shellac or nitrocellulose varnishes.[9] Furthermore, several and very liberal coatings of glycerol were at times applied to the surfaces of objects to counteract shrinkage and the formation of cracks on drying.[10]

During a long period, until the late 1950's, large quantities of waterlogged wood were routinely conserved with the alum method in Scandinavia and in the Baltic States. In Sweden the first evidence of the method is from brief notes on a so called boiling list dating from 1925.[11] In the 1930's the method

Plate 2. The alum-boiler at the Museum of National Antiquities in Stockholm around 1950.
Photo: Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

seems to have developed into a large-scale operation at The Swedish History Museum in Stockholm. New laboratories were constructed and included two purpose-built alum-boilers, of which the longest was ten meters, built into the laboratory floor and heated by hot steam in copper pipes (see Plate 2).[12] The magnitude of the operation is evident from an order of 700 kg of alum and 120 kg of glycerol in 1937, confirming that at this time Rosenberg's method with glycerol was favoured.[13] However, the actual treatment records for the specific finds are rare and incomplete. There is essentially no information about the duration of the alum-boiling and scant information regarding surface treatments. From an article by the head of conservation at the time, Gillis Olsson, it is known that glycerol in combination with alum was in common use in Stockholm during the 1930's, however, the addition of glycerol is only mentioned in one case in the treatment records.[14]

The alum method has been used in other countries, for example in England and the U.S., but to a lesser extent.[15]

2.3 Early problems with the alum method

It was soon found that the alum method had several disadvantages. The Danish conservator Christensen reported in 1950 that the objects became extremely heavy, since they contained more alum than wood, but gained no strength. He describes the objects as brittle and unnaturally hard.[16] The shallow depth of penetration of alum, described by Christensen as only a few millimetres, stabilized the surface of the object only. Thus, the original shape was preserved, while the interior of the wood shrunk heavily during drying, thereby causing substantial internal cracking.[17]

When wood treated with alum in turn is subjected to fluctuations in relative humidity (RH) the results may be exceedingly destructive. The loss and regain of crystallisationwater is believed to cause physical disruption of the weakened cell structure of the wood. Alum is thought to dissolve and migrate in the wood at high RH levels and to re-crystallize when the structure falls again resulting in salt efflourescence and a breaking-up of the wood surface, eventually resulting in a total collapse and pulverization of the artefact. Given that it is highly hygroscopic, the addition of glycerol seems to aggravate this process.[18]

The surface treatments, initially intended to give protection to the artefacts, have also turned out to be permeable to humidity.[19] This means that instead of providing protection, the treatment creates a micro environment inside the artefact and additionally serves to effectively mask the true condition of the object underneath. Consequently, degradation processes invisible to the eye may continue inside a seemingly well preserved object, until a total rupture

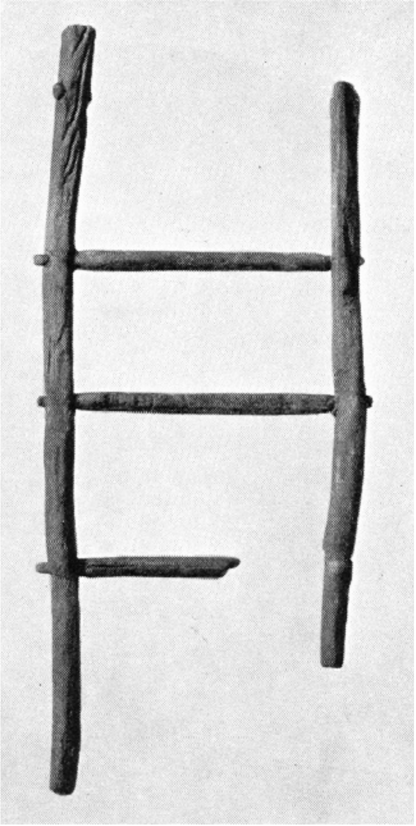


Plate 3. A wooden artefact from the Viking grave of Årby treated with alum and glycerol during the 1930's. The photo is taken shortly after the original alum-conservation. Photo originally published by Arbman, 1940. Reproduced with the permission from Acta Archaeologica.

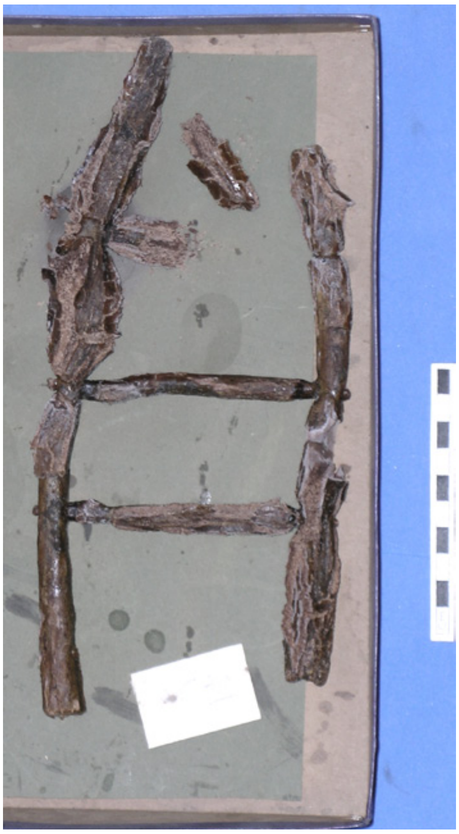


Plate 4. The same object severely degraded today. The hard shell of the surface has ruptured and the artefact has burst apart. Photo: Swedish National Heritage Board.

of the hard shell of the surface occurs. This happened with the Danish early Iron Age boat from Hjortspring where the hard shell broke open in areas and exposed an interior of pulverized wood.[20]

Another interesting point to note is that alum-conserved objects which have been stored under similar environmental conditions have often shown varying degrees of degradation. The explanation is assumed to be a balance between different factors such as the species of wood, the degree of degradation of the excavated wood and the amount of alum absorbed in the wood.[21]

Despite the drawbacks of the alum method, the lack of alternative satisfactory treatments meant that it remained in use until the end of the 1950's when new methods were developed and tried out.[22]

2.4 Previous research

Few investigations on alum-treated wood deal with the actual deterioration, such as how the salt interacts physically and chemically with the wood and the effects stemming from the fact that alum is an acidic salt. Primarily the focus has been on the conservation of waterlogged archaeological wood with alum – its history and the general problems it causes.

A brief account of the existing research might begin with Gunhild Kopperud's studies of the distribution of the alum in the wood cell-structure. Her investigation suggests that the alum is either evenly distributed or concentrated into clusters, as in the case of hardwoods where alum clusters tend to be attracted to the large vessels within the wood.[23] Moreover, chemical analyses indicate that aluminium ions may be chemically bonded to hydroxyl groups in the cell walls of the wood.[24]

The physical properties of degraded alum-treated wood, such as the strength, have been investigated on Norwegian material. In anticipation of a possible move to a new museum of the alum-conserved finds from the Oseberg Viking ship, strength tests were carried out on the wood. Bending strength and impact bending value were measured and the wood was found to have lost 95 % or more of its strength as compared to fresh wood.[25]

The sensitivity of alum-treated wood to high and fluctuating RH is often discussed in the conservation literature; however, actual recommendations regarding storage conditions, such as RH and temperature, vary. When such recommendations are suggested, the theory or study upon which they are based is not always accounted for. Previous environmental recommendations for alum/glycerol-treated material include slowly adjusting to a dry and stable environment, starting at 30–45 % RH, at a temperature of 15–20 °C, and gradually lowering the RH until the moisture content of the wood reaches about 8–10 %.[26] Another suggestion has been to simply store the material at a stable RH of 30–40 %.[27]

Studies of crystallisation properties of alum in both alum- and alum/glycerol-treated wood in fluctuating and stable RH were carried out by Kopperud in 1992.[28] Among other things, it was found that growth of crystals happened over time, the concentration of crystals tended to increase and that the crystals were inclined to grow together on the surface of the wood samples. Even at a high and stable RH (100 %), growth of crystals occurred. In alum/glycerol-treated wood, splitting caused by alum crystallization was found to occur in the longitudinal vessels in the interior of hard-woods.[29] At low levels of RH (15 %), the flexibility and strength of the wood decreased, possibly making it more sensitive to external physical forces, such as alum crystallization. Kopperud concludes without giving any specific values that alum- and alum/glycerol-treated wood should be kept in a stable environment within a medium range of RH.[30] A later study by Hutchings suggests further that alum-treated wood is extremely sensitive to small fluctuations in RH and that the wood will reach a new equilibrium moisture content in just over five hours when a rapid 10 % change in RH occurs, as compared to 42 days for PEG-treated wood[31].

2.5 Previous re-conservation attempts

Re-conservation of alum-treated archaeological wood has been attempted from time to time. The aim was to extract the alum and to replace it with an impregnant less susceptible to climate changes, and thus less destructive to the wood.

In 1964, attempts to re-conserve alum-treated wood were made at The Swedish History Museum in Stockholm. A collection of photographs was recently found at the museum showing alum-treated objects before and after re-treatment. On the reverse of the photographs were very brief notes in pencil regarding the treatment procedure. According to the notes the alum in the objects was washed out; however, neither the medium for extraction (presumably water) nor the procedure is described. The objects were then dehydrated in acetone and impregnated with polyester resin followed by cold-curing.[32] Examination and analysis with SEM-EDS of these objects as part of the condition survey that was carried out (see section 3) revealed extensive salt deposition from alum on the surface of these objects,indicating that the extraction of alum was unsuccessful. This was also demonstrated by the high initial conductivity values given by some of these objects that were included in the salt extraction process (see section 5). Furthermore, the condition survey showed the wood of these objects to be physically unstable with cracks and flaking surfaces in addition to a shiny plastic appearance.

In the 1970's, the Maritime Museum in Stockholm re-conserved a severely degraded and broken alum-treated pulley block made of birch. The alum was extracted by soaking in water which was repeatedly changed over four months. The water was subsequently exchanged for acetone which was then in turn exchanged for white spirit. Finally the block was impregnated with 100% paraffin wax and the pieces were joined together. The re-treatment was at the time considered successful.[33]

Extracting alum in water and replacing it with water soluble polyethylene glycol (PEG) is a method that has been used in Denmark and Latvia.[34] The severely degraded and fragmented alum/glycerol-treated Hjortspring boat and its related objects were re-treated at the National Museum in Denmark starting in the 1960's and completed in the 1980's. Pulverized areas were first consolidated with soluble nylon. The pieces were then placed in crates with a supportive packing consisting of cotton wool and mineral wool wrapped in gauze. Previous surface treatments, lacquers and beeswax, were removed with solvents. The alum was extracted in water at 90 °C for several months. The water was continuously changed and the process of alum extraction monitored by measuring conductivity and the presence of sulphates in the extraction liquid. The wood was subsequently fully impregnated with PEG 4000 at 55–65 °C, with a gradual increase of the concentration to approximately 96 % over a period of about five months and then air-dried. Finally, the pieces of wood were taken out of their packages, excess PEG was removed, the fragments reassembled and mounted for display.[35] Over the years, parts of the collection of alum-treated wood have been treated in a similar way at the National Museum in Denmark and at the National History Museum of Latvia.[36]

The National Museum in Denmark has also in recent years successfully used impregnation with PEG (2000 or 4000, up to 40 % in water) followed by vacuum freeze-drying for re-conservation of moderately deteriorated alum-treated wood. The alum has been extracted in water at 80 °C, and the process monitored with conductivity measurements and sulphate tests. The objects have been physically protected throughout the re-treatment by packing in polyether foam covered with a perforated heat-welded layer of polyolefin film. Surface treatments, for instance lacquers, have been found to loosen in the water and are then amenable to mechanical removal, at least to some extent, after the extraction and before PEG-impregnation. Finally, the excess water has been removed by vacuum freeze-drying.[37]

At the Canadian Conservation Institute a para-xylylene polymer, Parylene, has been applied to severely degraded alum-treated wood in order to consolidate its surface prior to salt extraction in water.[38] The great advantage of Parylene is that it forms a very even, transparent and thin layer. It conforms to irregularities in the surface and thus the appearance of the object, such as its colour, remains essentially unaltered.[39]

3 Condition survey of alum-treated wooden artefacts

3.1 Introduction

The Swedish History Museum in Stockholm holds the largest archaeological collection in Sweden and within it one of the largest national collections of wooden artefacts. Although problems associated with alum-treated wood have been well known at the museum, the artefacts themselves have never been thoroughly or systematically investigated. To specify the extent and condition of alum-treated wooden artefacts in the collection, a condition survey was carried out.

A classification model was developed, based on similar criteria as previous condition surveys on collections of alum-treated archaeological wood. The artefacts were condition assessed and, based on degree of degradation, categorized into different classes ranging from 1 to 5, representing a stable to a totally collapsed state.

Different sets of artefact data, such as pH and various signs of deterioration, were collected to be statistically evaluated and possible correlations between them investigated. Samples were taken from a number of artefacts to confirm presence of alum through SEM-EDS-analysis, and through FTIR-analysis to indicate presence of possible organic conservation substances, such as glycerol, linseed oil and beeswax. All artefacts were digitally photographed.

3.2 Locating the material group – archive and storage search

The archival records on archaeological excavations and conservation treatments (Antiquarian Topographical Archive, Swedish National Heritage Board) from the time period between 1900 and 1960 were surveyed to identify and locate whatever alum-treated archaeological wood was present in the collections of The Swedish History Museum, and if possible to specify its original treatments.

The earliest relevant documents are so called boiling lists, dating back to 1925. These show the weight changes of a number of wooden artefacts during drying and linseed oil impregnation following the treatment of alum-boiling. A coating of dilute crystal varnish is noted as the final treatment step.[40]

The conservation files from 1931-1958 hold most of the relevant documents. During this time period, treatment with alum seems to have been the standard conservation method for waterlogged wood, sometimes done as a mass treatment with hundreds of artefacts treated at a time. Post-treatments mentioned include linseed oil impregnation, oil and turpentine coating, linseed oil saturation and wax impregnation. The notes are brief and the actual alum-treatment only described as alum-boiling. The last document mentioning alum-boiling as a treatment method dates to 1947, however other sources suggest that the alum method was still in use in Sweden up to 1950.[41]

Through further study of archive and museum records, most of the alum-treated artefacts found in the documents could be physically located in two of The Swedish History Museums' different storage facilities. All of these artefacts were surveyed. In addition, all wooden artefacts excavated before 1966 in the central storage facility were examined, and those showing salt precipitation were collected and included in the survey. This was also done in a third storage facility. According to the current decision with regard to climate control, valid since January 1st 2001, the RH levels in the major storage facility should be controlled to 50 +/- 5 %; however measurements from July 2005 – July 2006 show RH and temperature variations between 31–54 % and 17–26 °C respectively.[42] RH and temperature measurements from the central storage facility during the same period varied between 43–50 % and 18–20 °C.[43] No information on the climate in the third storage facility or for the past yearly climate variations is available.

In all, 1474 artefacts from 27 different archaeological sites were included in the survey, providing a good representative sample of artefacts from the Stone and Iron ages as well as the medieval period. Geographically the sites were spread from the southern to the very northern parts of the country.

3.3 Deterioration categorization and data collection

A classification model to categorize the state of deterioration of the artefacts was formulated (see Table 1). Condition criteria were based on similar concepts as in previously carried out condition surveys on collections of alum-treated archaeological wooden artefacts.

In a condition survey including 225 wooden artefacts in the archaeological collections of the Colonial Williamsburg Foundation, Virginia, USA, the concepts of physical integrity, cohesiveness and surface interactions were used as criteria for condition assessment.[44] Physical integrity was used to refer to the physical structure of the wood. Signs of deterioration associated with physical integrity were identified as cracks and splits. Cohesiveness was used to refer to the micro-structural strength of the wood, i. e. the ability of the wood to hold together. Deterioration signs associated with cohesiveness were identified as flaking and splitting. Deterioration signs visible on the artefact surface, such as precipitation or distinct colour darkening, were classified as surface interactions.

Plate 5. Example of a class 2 artefact. The only visible sign of active deterioration is the salt precipitation on the surface; the arrows show where samples for chemical analysis have been taken. The dowel is from the Roman Iron Age (0–500 A.D.) site of Käringsjön in Halland. The specific treatment is unknown, but the presence of alum has been shown in SEM-analysis. Photo: Swedish National Heritage Board.

Plate 6. Example of a class 5 artefact, its original dimensions irreversibly lost. This small ladder from the Viking Age (800-1050 A.D.) burial site of Årby in Uppland, was alum-boiled, followed by a glycerol impregnation and an oil application. See footnote 41. Photo: Swedish National Heritage Board.

Class	State of deterioration	Signs of deterioration	Rescue measures
1	- Stable - Few signs of previous deterioration - No signs of active deterioration	- Salt precipitation	- Preventive measures
2	- Signs of previous and active deterioration, such as surface interactions and occasional cracks (see Plate 3)	- Salt precipitation - No or few (< 5)longitudinal and/or transversal cracks	- Active and preventive measures
3	- Signs of previous and active deterioration, such as surface interactions and cracking - Loss of surface material during handling	- Salt precipitation - Several (≥ 5) longitudinal and/or transversal cracks - Some (< 25 %) surface flaking or material loss	- Active and preventive measures - Surface consolidation and/or physical support prior to re-conservation treatment
4	- Signs of previous and active deterioration, such as surface interactions and cracking - Spontaneous loss of surface and/or bulk material	- Salt precipitation - Several (≥ 5) longitudinal and/or transversal cracks - Extensive (≥ 25 %) surface flaking or material loss	- Active and preventive measures - Consolidation and/or physical support prior to re-conservation
5	- Total destruction (see Plate 6)	- All above - Artefact collapse	- Beyond rescue

Table 1. Classification model to categorize the state of deterioration of the artefacts.

Condition assessment of 74 alum-treated archaeological wooden artefacts was recently done at the Viking Ship Museum in Oslo, Norway.[45] As the condition assessment was done in view of a potential move of the artefacts, this survey had a different focus; however, it deals with the same type of material, and physical integrity and cohesiveness served as criteria for condition evaluation here too. The presence of new cracks and the degree of pulverization were among the things examined for the categorization of artefacts into a five-grade condition scale.[46] A similar condition assessment was carried out on another 78 artefacts from the same collection in 2005 by conservators from Denmark and Sweden, using the same evaluation system and five-grade condition scale.[47]

The present survey focused similarly on condition assessment in view of potential action, in this case the possible need and potential for re-conservation treatment. The classification model (see Table 1), uses a five-grade scale, ranging from class 1, where no need for active measures is judged necessary, through classes 2, 3, and 4, where various degrees of consolidation or other physical support are suggested prior to re-conservation treatment, to class 5, representing artefacts that are totally collapsed and beyond possible conservation measures or rescue. Signs of deterioration are based on the concepts of physical integrity, cohesiveness and surface interactions. Preventive measures include adjustment, stabilisation and control of climate, regular condition checks, and a continuous increase and improvement of knowledge. Possible active measures include removal of alum through salt extraction in water, PEG-impregnation, and vacuum freeze-drying.

For documentation and for purposes of statistical analysis, an Access database was created. The data chosen to be recorded were:

- archaeological and museum data, such as site and location information, and artefact and accession numbers
- storage facility location
- number of parts or fragments (fragments or parts of artefacts clearly fitting together, were counted as one artefact; fragments or parts of artefacts lacking clear fitting were counted as separate artefacts, this to as far as possible avoid subjective interpretation)
- signs of deterioration:
  - longitudinal cracks: none, few (< 5), or several (≥ 5)
  - transversal cracks: none, few (< 5), or several (≥ 5)
  - splitting: yes or no
  - surface flaking in percentage of surface area: none, some (< 25 %), or extensive (≥ 25 %)
  - material pulverization: yes or no
  - salt precipitation: yes or no
  - class: 1 (stable) – 5 (totally collapsed), (see Table 1)
  - gluing: yes or no
  - general impression
- surface pH (indicator-strips, pH 0–14, Merck KGaA, 64271, Darmstadt, Germany; strips were moistened with water and pressed against the artefact surface)
- documented conservation treatment
- documented re-conservation treatment
- presence of alum and/or other compounds as shown in SEM-EDS-analysis
- indication of organic compounds present as shown in FTIR-analysis
- remarks

All artefacts were digitally photographed. Possible correlations between the different sets of data were examined, and basic statistics calculated.

3.4 Results and discussion

A total of 1474 artefacts from the collections of the National Museum of Antiquities were identified for the condition survey on the basis of available treatment documentation and appearance as possibly having been treated with alum. Samples were taken from selected and questionable artefacts for later analysis.

The condition survey served as an introduction to alum-treated archaeological wood as a material group. The surveyed artefacts were found to be made of different types of wood with different pre- and post-burial conditions, a variety of variously modified treatments including in some cases various re-conservation treatments, as well as different storage conditions. Given the lack of documentation and the scope of this survey, these factors were not analysed and are therefore expected to account for some degree of variance within the results. Although the sample group was found to be very heterogeneous, certain characteristic deterioration signs were evident and quantifiable. Similar to the results of other recent surveys on alum-treated wooden artefacts, these were salt precipitation, surface flaking, internal cracks and pulverization (see Plates 7, 8, 9 and 10).[48]

Both internal cracks and pulverization may go undiscovered on visual examination as there may be no sign on the artefact's surface. If the artefact is in parts, internal cracks will naturally show on the cross-section (see Plate 9), as will pulverization in any crack or split. However, if the artefact is in one piece, X-raying may be needed to discover internal cracks. A more subtle

Plate 7. Example of salt precipitation and cracking. Detail of oar handle from Jukkasjärvi in Lappland, dated to Scandinavian Bronze Age (1800–500 B.C.). The specific treatment is unknown, but the presence of alum has been shown in SEM-analysis. Photo: Swedish National Heritage Board.

Plate 8. Example of surface flaking. Surface detail of a plank from Bulverket on Gotland, dated to Scandinavian Iron Age (500 B.C.–1050 A.D.). The specific treatment is unknown, but the presence of alum has been shown in SEM-analysis, and archival material strongly suggests glycerol has been added in the treatment. Photo: Swedish National Heritage Board.

Plate 9. Cross-section of a trough in pieces, revealing internal cracks invisible on the surface. The trough is from the medieval site of Glimmingehus in Skåne, and treated with alum followed by an oil application. Photo: Swedish National Heritage Board.

Plate 10. Example of pulverization. The sticks are from the Viking Age (800–1050 A.D.) burial site of Årby in Uppland. A treatment of alum-boiling followed by glycerol impregnation and oil application is known from archive records. Photo: Swedish National Heritage Board.

way to detect these deterioration characteristics is by the hollow sound these artefacts typically give when tapped. Given the deceptive nature of this deterioration this means that in some cases, and for the purposes of this survey, artefacts may in fact be in a more deteriorated state than what has been visually determined.

The majority of the surveyed artefacts were on the basis of the observed physical deterioration signs found to be of class 3 and 4 (refer to Table 2), indicating on-going deterioration and loss of material, and the need for consolidation in the event of re-conservation. 5 % of the artefacts were considered be either destroyed or in a state of deterioration beyond which re-conservation could be considered possible (class 5). Less than 1 % was found to be stable (class 1).

Class	Number of artefacts	%
1	9	0,6
2	241	16,4
3	567	38,5
4	579	39,3
5	78	5,3
n	**1 474**	**100,0**

Table 2. Percentage of artefacts in each class where 1 represents a stable condition and 5 an artefact that is considered destroyed or beyond re-conservation.

pH	Number of artefacts	Average class	Salt efflorescence	Pulverization	Flaking	Cracking	
						longitudinal	perpendicular
0	1 %	3,6	93,8 %	68,8 %	31,3 %	81,3 %	56,3 %
1	18 %	3,9	100 %	83,9 %	64,6 %	90,6 %	60,2 %
2	28 %	3,4	98,8 %	45,4 %	47,2 %	85,9 %	47,6 %
3	33 %	3,2	97,5 %	26,4 %	47,6 %	77,1 %	53,2 %
4	9 %	2,9	95 %	20 %	37,1 %	75,4 %	63,2 %
5	3 %	3	92,9 %	7,1 %	27,4 %	89,3 %	58,3 %
6	3 %	3,6	84,4 %	57,8 %	50 %	95,6 %	85,6 %
7	5 %	2	5,8 %	1,4 %	0,7 %	50 %	23,9 %
Total artefacts	**n=1474 %**		**93,2 %**	**41 %**	**46,6 %**	**81,5 %**	**53,6 %**

Table 3. Average class and percentage of artefacts showing each of the observable signs of deterioration in relation to measured pH level.

There was only a weak relationship found between pH and class to indicate that acidity and visible deterioration are related. Many of the artefacts were nevertheless found to be very acidic with pH levels down to 1 and even 0 in a few cases (refer to Table 3). As many as 80 % of the artefacts were in fact found to have a pH level of 3 or below, which can be considered lower than normal regardless of wood species. All green wood is slightly acidic. Wood will also in time, to varying degrees, release acetyl groups in the form of acetic acid, which in turn decrease the pH below that of green wood.

Acid hydrolysis of wood is known to occur at low pH levels and can thus, in addition to the mechanical stress caused by alum crystallization, be a contributing factor to wood degradation. The chemical processes by which these very low pH levels arise, as seen in the wood in this study, and the chemical nature of any resulting deterioration within the wood, have not been fully investigated. Aluminium potassium sulphate will hydrolyze in water to give low pH levels. In this regard it is interesting to note that artefacts with a slightly moist or sticky surface, and presumably higher moisture content, have also been found to be very acidic.[52] Dissolution of the alum salt with fluctuating humidity and the presence of the hygroscopic ingredient glycerol in the conservation treatment would in turn be expected to exasperate the problem.

Similar results of very low pH on degraded artefacts were also found on alum-treated wood from Oseberg in Norway. In this case, with perhaps a more homogenous sample, artefacts in very good condition were found to have a pH of 3,5 or above, whereas artefacts in very poor condition were found to have a pH of 3,5 or below. A fairly wide range of pH values between 1,5 to 4,5 and 6 were in turn observed for artefacts classified as poor, and acceptable or good respectively.[53]

Higher levels of pH (6–7) were noted on 8 % of the artefacts. These higher levels, in excess of what one would expect in fresh wood of the same species and for alum-treated wood, may be explained by the fact that surface coatings of wax or other resins may in these cases have masked the true pH of the wood below. Artefacts with a surface pH of 7 were found to be in relatively good condition (an average class of 2) with little salt efflorescence, a negligible occurrence of pulverization and flaking, and a comparatively low occurrence of cracking. This is contrast, however, to artefacts with a surface pH of 6 which are in a very poor condition, more akin to artefacts with a very acidic surface. These artefacts also have much more salt efflorescence, often with a pulverized and flaking structure, and they are notably most prone to cracking. The relatively high degree of degradation seen in these artefacts may be due to the presence of a coating, acting to create a more humid micro-climate favouring degradation inside the artefact, and at the same time, as an inflexible shell making the artefact also more prone to cracking.

Nearly all artefacts (93 %), with the exception of artefacts having a pH of 7, showed some degree of efflorescence on the surface or within cracks. Pulverization of the wood structure was highest among artefacts with a pH of 0 to 1, and generally found to increase in relation to acidity. A similar trend was found for flaking, and as well for cracking, both longitudinally and perpendicularly to the wood grain. As mentioned, artefacts with a pH of 6 were anomalous in that they had a much higher than expected level of occurrence of pulverization, flaking and cracking. Artefacts at a pH of 0 on the other hand showed a somewhat lower occurrence for the same characteristics than what might be expected for a truly linear relationship. The reason for the latter in particular is unclear, but some degree of error might be expected due to the small sample size for this group.

Further analysis with more homogenous sample groups should provide clearer results. The condition survey work has nonetheless greatly increased the knowledge about alum-treated archaeological wood in general, and more specifically about its deterioration characteristics.

In connection with the condition survey work, test material for the re-conservation pilot study was chosen. A number of surveyed artefacts, representing different classes in need of active treatment, were selected (see further chapter 5).

4

Deterioration patterns for Alum Conserved Wood:

A comparison between alum based conservation treatments and the artefacts state of preservation

4.1 Introduction

The purpose of this study was to determine if there were differences in appearance or condition between groups of artefacts that could be related to the specific alum treatment that had been used. Chemical analysis using SEM-EDS and FTIR was carried out to confirm what little treatment information existed indicating that selected artefacts had been conserved with an alum based method, and more specifically to determine what materials had in fact been used. The results of this study may thus allow conservators to relate the appearance of the artefact to a specific alum treatment. Better identifcation and characterization of alum treated artefacts will in turn allow more specific steps to be taken to provide proper treatment and conditions for preservation.

4.2 Method

A survey was conducted at The Swedish History Museum in Stockholm to identify alum treated artefacts and to assess their condition (refer to chapter 3). Data from this survey was extracted in order to compare deterioration against type of treatment.

Three archaeological sites were chosen from this survey on the basis that they represented three distinct groups consisting of a large number of wooden artefacts believed to have been treated with alum. The groups were also chosen with the assumption that all artefacts from a single site would have been treated in a similar manner with respect to the addition of additives and coatings when conserved, and that such a selection would therefore represent a fairly homogenous sample. The three sites were Bulverket, Glimmingehus and Kärringsjön each with a total of 259, 240 and 202 artefacts respectively. Data representing visual and physical characteristics including pH, recorded in the survey for each of these artefacts, was assessed. A random selection of surface samples was in addition taken from the three groups for chemical analysis.

The surface samples from the artefacts were analyzed using SEM-EDS (Leo 1455Vp / Oxford instruments 7353) to identify the presence of alum. The samples were also analyzed using FT-IR spectroscopy (Perkin Elmer Spectrum One / Golden Gate ATR) to identify surface coatings and other additives, and to confirm the presence of alum.

The visual and physical characteristics assessed in the survey were compared between the three groups. These included the presence of salt efflorescence, flaking of the surface, cracking (both longitudinal and perpendicular) and pulverization of the wood structure. In addition, the general appearance of the artefacts, as noted in the survey, was also taken into consideration for comparison.

The pH of the surface as measured in the survey using wetted pH paper from Merck (universal indicator pH 0–14) was also compared between the three different groups. Average pH for each group was calculated as the mean value of each surface pH measurement.

The general condition of the artefacts was evaluated as the average of their numerical classification according to a scale of 1 to 5 (refer to section 3.3), representing a stable condition versus a condition of total collapse respectively.

4.3 Results

Three distinct groups could be identified through FT-IR analysis on the basis of the substances that had been used in the conservation treatment. The three groups as listed in table 4 consisted of artefacts treated with alum (refer to figure 1) and a surface coating of wax and or shellac (refer to figure 2 and 3), alum and linseed oil (refer to figure 4), and alum with glycerol (refer to figure 5).

Site	Alum	Linseed oil	Shellac / wax	Glycerol
Glimmingehus	yes	yes	no	no
Kärringsjön	yes	no	yes	no
Bulverket	yes	no	no	yes

Table 4. Substances found in each of the three sample groups following FT-IR analysis.

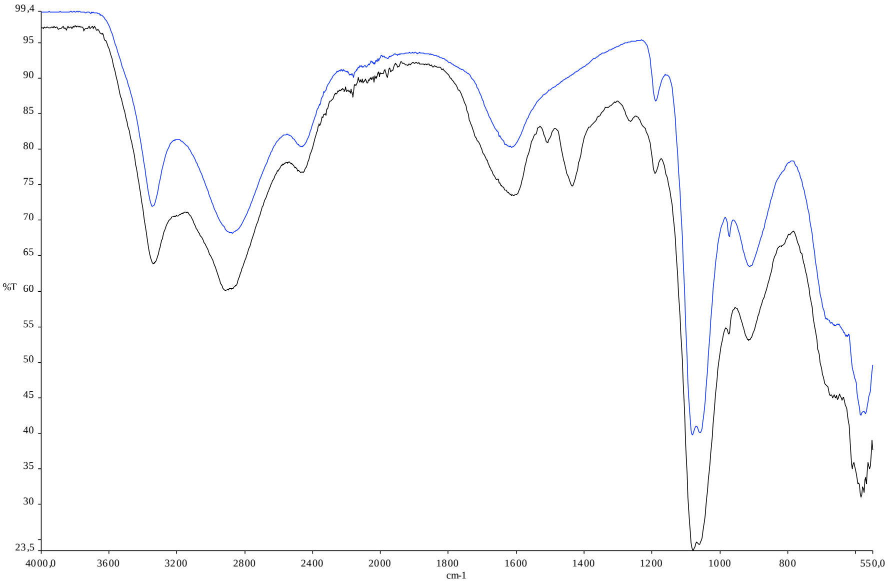


Figure 1. FT-IR spectra of wood sample (bottom) compared with reference spectra for $KAl(SO_4)_2 \cdot 12H_2O$ *(top blue).*

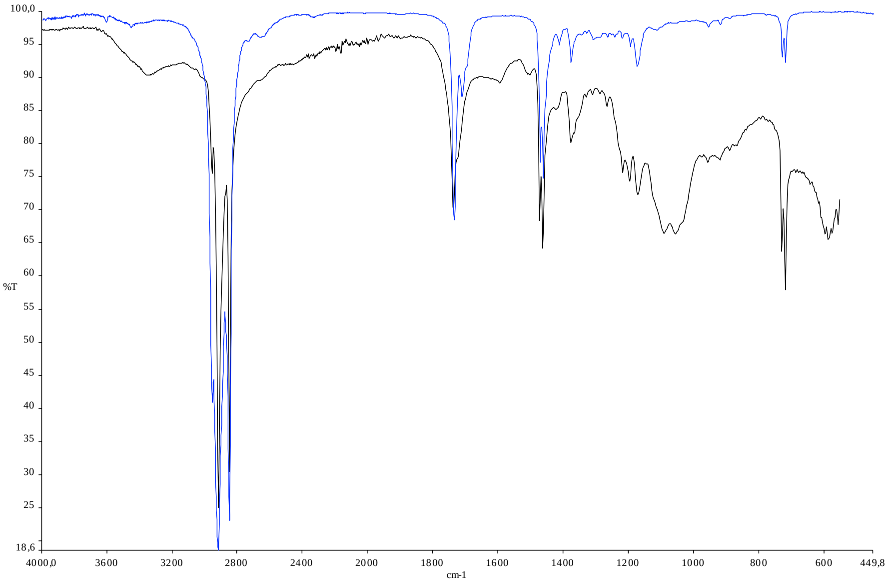


Figure 2. FT-IR spectra of wood sample from Kärringsjön (bottom) compared with reference spectra for bees wax (top blue).

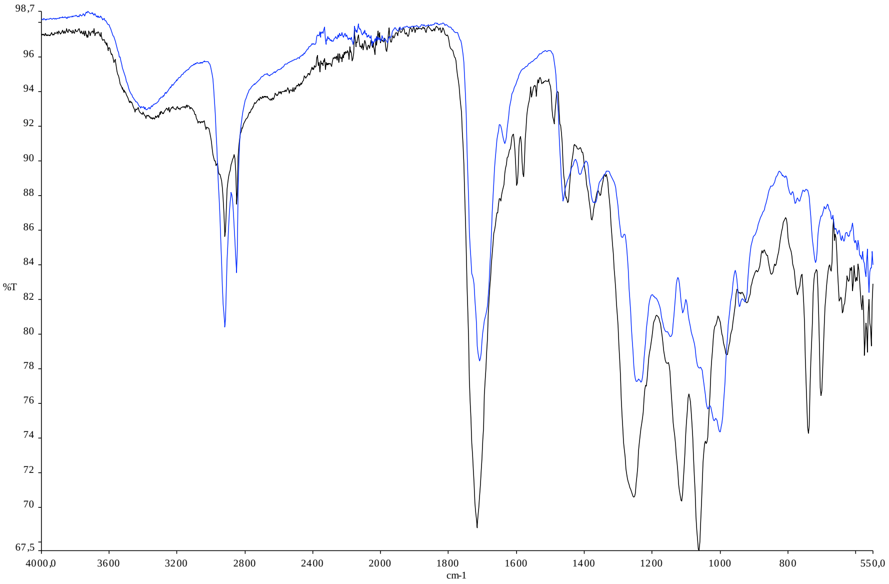


Figure 3. FT-IR spectra of wood sample from Kärringsjön (bottom) compared with reference spectra for shellac (top blue).

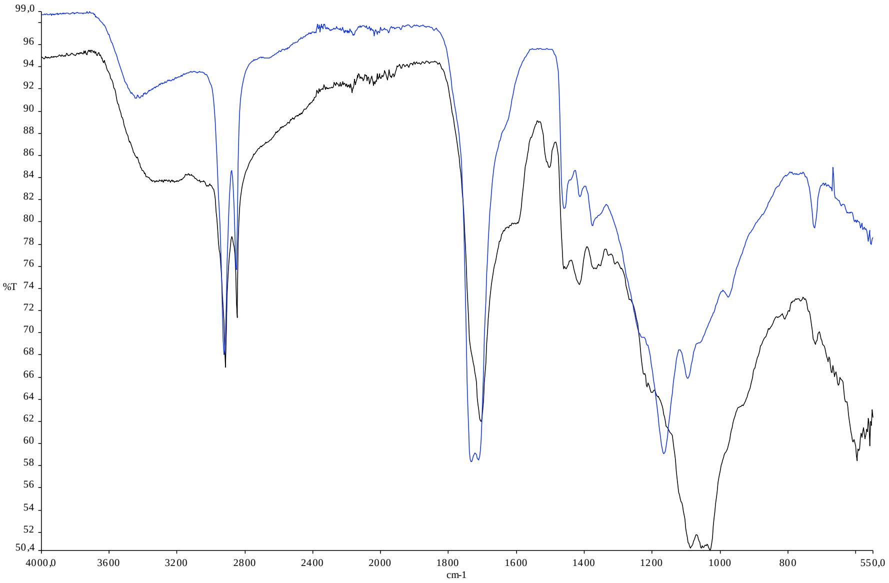


Figure 4. FT-IR spectra of wood sample from Glimmingehus (bottom) compared with reference spectra for linseed oil (top blue).

In terms of condition, alum artefacts treated with linseed oil and shellac and/or wax were both in a state of moderate deterioration characterized according to the ranking system by some cracking and loss of surface material during handling. Those treated with glycerol showed a fairly high degree of deterioration on the other hand, characterized by spontaneous loss of surface and bulk material. Table 5 summarizes the average condition and pH for each representative group of artefacts as well as the percentage of artefacts showing signs of salt efflorescence, pulverization, flaking, and cracking (longitudinal and perpendicular).

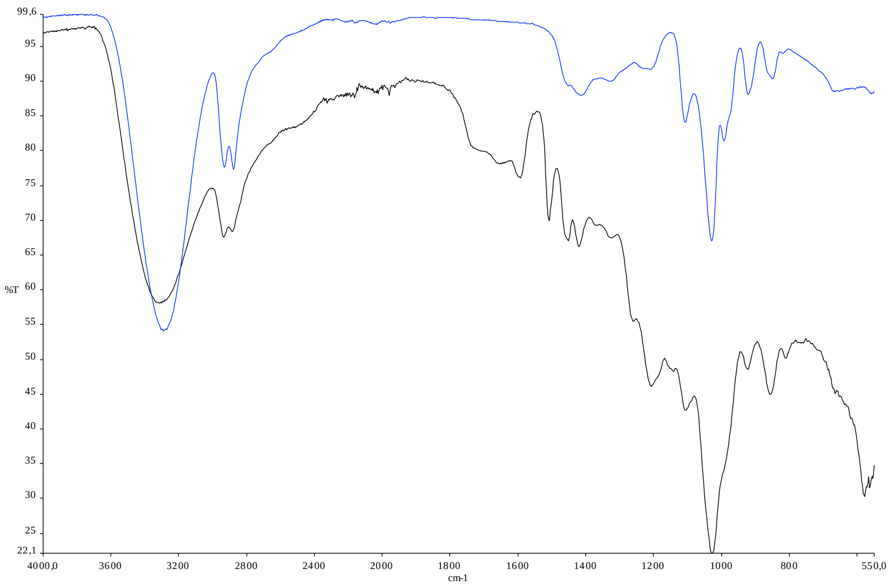


Figure 5. FT-IR spectra of wood sample from Bulverket (bottom) compared with reference spectra for glycerol (top blue).

Treatment	Average condition class 1–5	Salt efflorescence	Pulverization	Flaking	Cracking		pH
					longitudinal	perpendicular	
Linseed oil	2.7	95 %	4 %	52 %	83 %	73 %	2.8
Shellac, Wax	2.8	65 %	29 %	31 %	90 %	57 %	3.5
Glycerol	3.7	99 %	82 %	85 %	99 %	76 %	2.3

Table 5. A comparison of deterioration parameters for the three different alum treatments. The percentage values represent the number of artefacts showing signs of a given condition.

The detail and terminology used in descriptive comments for each artefact was not all together consistant throughout the survey. Some characteristics were not evaluated in all cases, and the comments made rather reflect what was considered most pronounced for each artefact. Some typical differences are however discernible, in relation to treatment, between the general appearance of the artefacts (refer to table 6). Those artefacts treated with linseed oil typically had a saturated appearance whereas artefacts treated with glycerol were typically characterized as dry and powdery and not as dark in appearance as those treated with linseed oil or wax and/or shellac. Artefacts with surface treatments consisting of various wax and shellac coatings varied in their appearance and were described as dry or saturated, sticky, and waxy.

Appearance	**Linseed oil**	**Wax and/or shellac**	**Glycerol**
Saturated / partly saturated	87.5 % (210)	27.2 % (55)	3.9 % (10)
Dark	77.9 % (77.9)	54.4 % (110)	10.4 % (27)
Medium dark	0.4 % (1)		15.1 % (39)
Light	0.4 % (1)		12.0 % (31)
Orange / red-brown	6.2 % (22)		
Waxy		47.5 % (96)	
Shiny, plastic, lacquered		2.5 % (5)	0.4 % (1)
Dull/ partly dull (matt)		3.0 % (6)	
Dry	6.2 % (22)	40.0 % (82)	79.9 % (207)
Moist			5.0 % (13)
Sticky	4.6 % (11)	13.4 % (27)	
Well preserved / stable			1.9 % (5)
Somewhat powdery		0.5 % (1)	
Powdery	2.5 % (6)	16.3 % (33)	58.7 % (152)
Falling apart			3.5 % (9)
Total collapse			1.5 % (4)

Table 6. A comparison of descriptions (percentage and total number of artefacts with observed appearance) relating the appearance of the three different alum treatments.

4.4 Discussion

The results show that the artefacts can be characterized according to the alum-method (additives used in combination with alum) that was used for the conservation treatment. Artefacts treated with just alum and variously coated with shellac and/or wax have either a shiny surface or a dull darkened saturated appearance (refer to plate 11). They may be dry and sometimes crumbly or alternatively sticky to the touch. The varying feel of the surface is presumably associated with either the use of lacquer or wax. The outer layer can often be quite hard and intact, but in most cases there is some longitudinal cracking. There is comparatively less salt efflorescence, presumably because the outer coating depending on its nature, may in certain cases act as a barrier. These artefacts are generally very brittle. The intact appearance of the surface is often misleading. Inner pulverization is often visible where there is a crack or a break (refer to plate 12), and sometimes all that exists is an outer crust with a pulverized interior.

The surface pH for artefacts coated with shellac and/or wax is higher, with an average pH of 4 and sometimes even near neutral. But this can also be misleading given that the interior will often be quite acidic in those areas where there is access for analysis through points of breakage.

Plate 11. Alum with a surface coating of shellac and/or wax. The artefact appears to be in good condition but may be severely deteriorated below the surface. Photo: Sara Kusmin, The Swedish History Museum, Stockholm.

Plate 12. Alum with a surface coating of shellac and/or wax. Although the surface is hard the artefact is quite brittle and will easily break. Photo: Swedish National Heritage Board.

Plate 13. Alum with linseed oil. The surface is typically dark and saturated in appearance, and in this case, with areas of dry powdery wood. Photo:*Swedish National Heritage Board.*

Plate 14.) Alum with linseed oil. Cross-section of a trough revealing internal cracks and voids not visible on the surface. Photo: Swedish National Heritage Board.

Plate 15. Alum with glycerol. A high degree of surface flaking and salt efflorescence is visible on the surface. Photo: Swedish National Heritage Board.

Plate 16. Alum with glycerol. The wood is dry and powdery to the point where the object is falling apart. Photo: Swedish National Heritage Board.

Those artefacts treated with alum followed by immersion or a surface application of linseed oil generally have a darkened, partially or fully saturated appearance, sometimes with an orange surface colouration (refer to plate 13). Salt efflorescence on the surface was typical and most often there was both longitudinal and perpendicular cracking present (refer to plate 14). There was very little structural pulverization. In this regard the linseed oil seems to have a consolidating effect and may also be effective as a barrier. The surface pH is somewhat less acidic with an average value of pH 3.

Artefacts treated with alum in combination with glycerol were found to be in the worst condition. The artefacts are characterized by salt efflorescence on the surface and there is a high degree of structural pulverization of the wood (refer to plate 15). Flaking predominates and cracking, particularly in the longitudinal direction is present. The objects are as a result very friable (refer to plate 16) and it has been noted that deterioration will in extreme cases reduce the artefact to powder. The artefacts tend to have a dry powdery appearance but may also feel moist to the touch. The artefacts were examined at different times and in some cases at different locations which may account for differences in the perceived dry or moist feel of the surface. The surface is very acidic with pH levels of 2 and even approaching 0 with pH paper.

It can be concluded that it was possible to correlate specific deterioration signs with specific variations in the alum treatment and to some degree, the pH level on the surface of the artefact. The results provide some useful information for identifying alum treated artefacts in collections and provide some assistance in evaluating their condition.

5 Re-conservation of alum-treated wood – a pilot study

5.1 Introduction

Re-conservation of alum-treated wood has in recent years not been attempted in Sweden. The purpose of the re-conservation pilot study was therefore to test materials and methods for re-conservation of alum-treated artefacts. Artefacts representing different degrees of degradation, i.e. class 2, 3, and 4 according to the condition survey classification, are included in the study (see section 3.3).

The reasons for re-conservation can be several. The main reason is to remove alum and related acidic species in order to avoid potential mechanical damage due to changes in hydration state or crystallization, and to raise the pH of the wood so as to limit the potential for further chemical deterioration. Removal of alum, and also additives such as glycerol, are also expected to reduce the sensitivity of the artefacts to environmental factors, such as the level of RH and its degree of fluctuation. Furthermore, it is desirable to make artefacts which have already undergone severe degradation due to alum less vulnerable, so that they can be handled, studied, displayed, and used as museum objects, without the risk of further damage. In addition there may be aesthetical reasons.

The re-conservation pilot study is divided into three stages. Stage 1 deals with the extraction of alum in water; the extraction process is studied and extraction rates in water at two different temperatures are compared. In stage 2 the re-treatment continues by substituting another impregnate for the alum and in stage 3 the wood is dried. The methods used in stages 2 and 3, i.e. PEG-impregnation followed by water removal using vacuum freeze-drying, are widely and successfully used in the conservation of freshly excavated archaeological wood. As previously described, these methods have also been used for re-treatment of alum-treated wood in Denmark.

When the cohesive properties of the alum-treated wood are reduced, such as for artefacts of classes 2, 3 and 4 in the condition survey, the wood will not permit soaking in water or re-impregnation and freeze-drying without risk of material loss. Therefore, four different physical supports and consolidants have been applied to the artefacts. Their permeability to water and alum, as well as in stage 2 to PEG 2000, was tested and evaluated. Their ability to consolidate and support the degraded wood during all stages was assessed at the end of the re-treatment process.

5.2 Materials and equipment

5.2.1 Sample material

A set of 29 archaeological artefacts previously treated with alum from the collection of The Swedish History Museum was chosen as sample material. The selection was done in conjunction with the condition survey when objects were assessed and classified. The artefacts for the study were primarily chosen on the basis of their numerical classification. The artefacts that were selected were all from classes 2, 3 and 4, since these all have signs of previous and active deterioration and are judged to need, and to be able to withstand, active measures (i.e. re-conservation). Size was also a criterion for selection. Small to medium sized objects were chosen for practical reasons and to give a more uniform sample group for purposes of comparison. Some factors that were already known were not taken into consideration, for example, object type, dating, archaeological site or original conservation treatment; moreover, many factors were quite simply unknown and were thus exempt from consideration.

5.2.2 Documentation

Detailed documentation was carried out on each artefact and is presented in Table 4. The artefacts were weighed and digitally photographed in high resolution from two to four different angels depending on the shape of the object. Data on surface pH and class were collected from the condition survey data base.

Given the lack of any written documentation regarding conservation with alum for many of the objects chosen for the re-conservation study, material samples from each artefact were analyzed using SEM-EDS (Leo 1455Vp / Oxford instruments 7353) to confirm that these artefacts had been treated with alum. The presence of K, Al and S were used as an indication of alum. K, Al and S were found in all wood and/or salt samples for all of the 29 objects.

To investigate the possible presence of other conservation materials, such as glycerol, linseed oil and wax, artefact samples were analysed with a Fourier Transform Infrared Spectroscope (FTIR, PerkinElmer, Spectrum One). The presence of alum was confirmed for most artefacts, 24 out of 29. Glycerol was found in 13 out of 14 artefacts from the archaeological site of Bulverket. Glycerol was also found in one case from the archaeological site of Glimmingehus, a collection of artefacts of which no prior knowledge of glycerol being used in the conservation treatment existed. This gives further evidence for the large-scale use of alum and glycerol first indicated by archival material[54]. Other materials found were wax and wax emulsion (see further section 4.3).

Plate 17. Alum-treated wooden sticks from Kärringsjön. Photo: Swedish National Heritage Board.

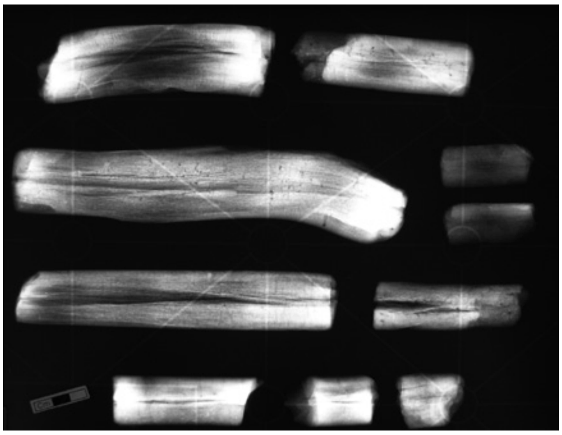


Plate 18. Radiograph of the same artefacts showing alum in a greater concentration at the cross-cut ends of the wood (lighter areas) as well as hidden internal cracks along the grain of the wood. The white regular lines originate from the film cassette. Photo: Swedish National Heritage Board.

All objects were also X-rayed to reveal information, if possible, on depth of penetration of alum in the wood, internal condition of the artefacts and hidden features, such as joints (Philips Mobile Surgical X-ray Unit XG 4002, BV 21-S; film: Agfa Curix Ortho HT-G, Medical X-ray film, size 350 x 430 mm; exposures: 40 kV and between 1,2-20 seconds depending on the thickness of the artefact). Generally, with X-radiography it proved to be difficult to determine the depth of penetration and exact location of alum in the wood as X-radiographs are two-dimensional images of three-dimensional objects. However, it clearly showed that the alum was often in greater concentration in the cross-cut end of the wood where it would have had the easiest entrance into the wood structure (see Plates 17 and 18). Furthermore, the X-radiography revealed details such as internal cracks and voids as well as invisible joints.

5.2.3 Physical supports and consolidants

Two types of physical supports were tested on artefacts of classes 2, 3 and 4. These were intended to support the artefacts during the entire re-treatment and were removed after the completion of the freeze-drying stage.

The first type consisted of plain polyester wadding (Ohlssons Tyger & Stuvar AB, Sveav. 34, 11134, Stockholm, Sweden) covered by a tube-shaped polyethylene netting (R.W. Nissen AB, Box 124, 74623, Bålsta, Sweden). The artefacts were individually wrapped in the polyester and then covered by the polyethylene netting which was tied at both ends. This type of support resulted in a fairly

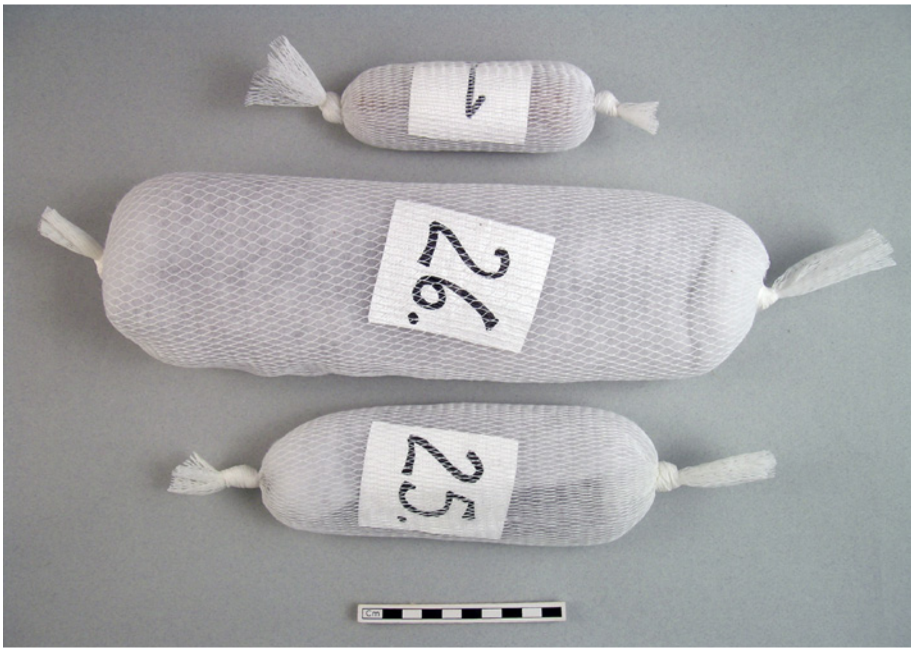


Plate 19. Artefacts supported by polyester wadding and polyethylene netting. Photo: Swedish National Heritage Board.

Plate 20. Making a supportive package of polyether foam and polyolefin film around an artefact. The polyolefin film is heat-sealed with a soldering iron. Photo: Swedish National Heritage Board.

Plate 21. Artefacts supported by polyether foam and polyolefin film. Photo: Swedish National Heritage Board.

loose package (see Plate 19). The method has been used successfully for the support of freshly excavated archaeological material during PEG and freeze-drying treatment at the Swedish National Heritage Board.

The second type of physical support consisted of polyether foam (thickness 5 mm, Special-plast Produktions AB, Gillinge, 18691, Vallentuna, Sweden) and perforated polyolefin film (Cryovac 570Y, with 28 holes per cm2, diameter of holes 0,76 mm, Gemmer Emballage ApS, Biltoftvej 1, 6800, Varde, Denmark). Each artefact was wrapped tightly in polyether foam and subsequently wrapped in the polyolefin film. The polyolefin film was heat-sealed with a soldering iron with a small flat tip (Weller® digital soldering station, WSD 81, working temperature set at 160 °C, Cooper Tools GmbH, Carl-

Benz-Str. 2, 74345, Besigheim, Germany). The result was a tight support-package which followed the shape of the object closely (see plates 20 and 21). This method has successfully been used in the conservation of moderately deteriorated alum-treated wood at the National Museum in Denmark, and the application of the polyolefin film has been described by Lilja Jensen et al.[55]

Two types of consolidants were tested, Paraloid® B-72 and Parylene N. Surface consolidation was applied on class 4 artefacts which had salt precipitation, several (≥ 5) longitudinal and/or transversal cracks and extensive (≥ 25 %) surface flaking or material loss. The consolidants were intended to be left on the surface after completion of the freeze-drying stage and thus their chemical long-term stability was regarded as being of great significance. Reversibility was considered of less importance since the artefacts were deteriorated to such a degree that removal of the consolidant after PEG-impregnation and freeze-drying was judged as impossible without the risk of further damage. The aim was to consolidate the surface of the artefact only in order to retain the surface morphology and shape of the object during the entire re-treatment. Paraloid® B-72 is a co-polymer of ethyl methacrylate and methylacrylate with a glass transition temperature (Tg) of 40 °C.[56] It was chosen because it is well known and widely used by conservators and because it has long-term chemical stability (classified as a Feller Class A material - a standard of stability).[57] Furthermore, Paraloid® B-72 has been tested and proven to be successful as a consolidant during desalination of salt-laden ceramics by Paterakis. Her study showed that Paraloid® B-72 as a consolidant had little effect on the rate of desalination.[58]

A 10 % (w/v) solution of Paraloid® B-72 (Preben Munch-Nielsen, Jernbane Allé 55, 3060, Espergaerde, Denmark) in ethanol:acetone (4:1) was applied to the artefacts. The artefacts were immersed in the solution for approximately five seconds which was judged to be the necessary time for the consolidant to cover the walls of the pores, the open cracks and the loose fragments within the surface-layer of the degraded wood. The depth of penetration of the consolidant was not measured. After consolidation the artefacts were air-dried.

Parylene is the generic name for members of a polymer series. Parylene N is poly-para-xylylene. Parylene C is modified by the substitution of one chlorine atom, Parylene D by the substitution of two chlorine atoms. All three of them are extremely stable polymers, e.g. insoluble in all organic solvents up to 150 °C; the substitution of chlorine enhances the stability and decreases the pore size. When it comes to reversibility Parylene C can be dissolved in chloronaphtalene at 175 °C and Parylene N at the boiling point of chloronaphtalene, 225 °C, i.e. they are in practice irreversible.[59] Since the consolidant needs to be permeable to dissolved alum and PEG, Parylene N, the type with the largest pore sizes, was chosen.

The application of Parylene involves special equipment including oven heating and a vacuum chamber. In short the process starts with a vaporization of the solid dimer at ca 150 °C. This dimer is then cleaved into very reactive monomers at ca 680 °C. The monomers are transported in gas phase to the vacuum chamber where they, at room temperature, form a very thin polymer layer on the object. The thickness of the layer is controllable from a minimum thickness of approximately 1 µm.[60]

Three different thicknesses, 1, 10 and 17 µm, were tested. Two artefacts, in good condition, were included in the study without any physical support or consolidant.

5.3 Experimental

5.3.1 Alum extraction

As the first step of the re-treatment process, the destructive alum must be removed from the artefacts. The artefacts were put through a salt extraction process in water purified by reversed osmosis (RO-water). In the salt extraction process, the permeability of the different supports and consolidants was demonstrated and, by dividing the selected artefacts into two groups – one to be desalinated at room temperature (15 artefacts) and one to be desalinated at approximately 50 °C (13 artefacts) – the effect of water temperature on the salt extraction rate was investigated. The different classes and combinations of physical support or consolidation were all represented in both groups (see Table 7). Of the 29 artefacts selected, one was set aside to serve as a reference sample (artefact ID no. 19).

The artefacts were put into individual salt extraction baths, using beakers and containers of glass, stainless steel and polypropylene. Beaker and container sizes were chosen so as to fit the artefact sizes as closely as possible.

The salt extraction in heated water was similarly carried out in individual baths. The artefact beakers were placed in a larger water tank provided with a heat-controlling pump, Circulator HAAKE DC30/DL30 (Thermo Electron GmbH, D-76227 Karlsruhe, Germany), which circulated the heated water around all of the individual beakers containing the artefacts. The temperature of the water in the beakers was 1–2 °C below the temperature of the circulating water, which was set to 50 °C.

After between six or seven months in the salt extraction baths some of the artefacts were still floating. To ensure that the artefacts were free from inner voids with possible salt deposits, an attempt to completely waterlog floating artefacts was made by putting the extraction baths under vacuum. It was possible to achieve a waterlogged state for nine of the eleven floating artefacts put under vacuum (ID nos. 3, 4, 7, 13, 20, 21, 23, 24, 26, 27 and 28). Time

Artefact data		Physical support/ consolidant					Salt extraction in RO-water	
Artefact id number	Class	None	Polyester wadding and poly-ethylene netting	Polyether foam and perforated polyolefin	Surface consolidation: Paraloid® B-7210 % (w/v) in ethanol: acetone (4:1)	Surface consolidation: Parylene N different thicknesses	Room temperature	48 ° C
10	2	X					X	
29	2	X						X
2	2		X				X	
1	2		X					X
23	2			X			X	
28	2			X				X
9	3		X				X	
25	3		X					X
24	3			X			X	
21	3			X			X	
3	3			X			X	
8	3			X				X
27	4		X				X	
4	4		X				X	
12	4		X					X
26	4		X					X
5	4			X			X	
17	4			X			X	
13	4			X			X	
11	4			X				X
7	4			X				X
20	4			X				X
18	4				X		X	
22	4				X		X	
6	4				X			X
16	4					2 x 0.5 µ	X	
14	4					10 µ		X
15	4					17 µ		X

Table 7. Artefact combinations of physical supports or consolidants and water temperatures during salt extraction.

under vacuum varied between 30 minutes on one occasion for some artefacts, to as long as 90 minutes on repeated occasions for others. The pressure varied from 107 to 80 mbar (Edwards High Vacuum Pump, model E1M5). Artefact ID nos. 3 and 27 were not waterlogged despite several attempts at a pressure of 80 mbar for 60 minutes. In order to keep the floating artefacts immersed during the alum extraction as well as the following PEG-impregnation, these baths were covered with polypropylene lids, and weighed down by sand bags.

To monitor the salt extraction process, the conductivity of the extraction water was measured. Conductivity was measured using a 644 Conductometer (Metrohm Ltd., CH-9100, Switzerland) from samples taken on average every second week before each water-change. The pH in each bath was also measured in connection with the water-changes. The same kind of pH-strips as in the condition survey were used, i.e. indicator-strips, pH 0–14 (Merck KGaA, 64271, Darmstadt, Germany).

As a reference, the pH and conductivity of the RO-water from the tap was measured at each water-change. The pH was at all times 5, while the conductivity varied between 4.9–7.9 µS/cm, giving a mean value of 6.1 µS/cm.

In cases of salt extraction of ceramics, the figure ≤ 150 µS/cm has been given as an acceptable concentration of soluble salts in the final extraction bath, and used as an indication for the completion of the extraction process.[61] This is considered to be a lower limit for ceramics given that over-washing may weaken the structure as soluble compounds leach out.[62] In the present case the level was set substantially lower. The artefacts were judged to be desalinated when conductivity in the extraction bath was ≤ 50 µS/cm on three successive occasions.

In order to identify what was being extracted other than alum, 13 samples of the residues from the evaporated first extraction bath were sent to STFI-Packforsk AB for analyses. The evaporated residues chosen were from the baths of artefacts with ID nos. 3, 4, 8, 9, 12, 14, 15, 16, 18, 21, 22, 24 and 25. At STFI-Packforsk AB the residues were analyzed using pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS) (see appendix 4, 5 and 6).

5.3.2 PEG-impregnation

The next step in the re-conservation process of the previously alum conserved artefacts following the completion of the desalination treatment was impregnation with polyethylene glycol (PEG) followed by vacuum freeze-drying. This method was chosen given today's extensive experience with the method and the good results attained with newly excavated archaeological waterlogged wood.

A single mixture high molecular impregnation using PEG 2000 was selected for the treatment. The reason for this was in part due to the very degraded condition of the wood and the need for a high degree of structural support and filling of voids which can only be achieved using high molecular PEG. Studies of PEG freezing properties have furthermore shown that the freeze drying unit to be used (Martin Christ, Delta WS24, with a minimum chamber wall temperature of -35 °C) will give better results with a high molecular PEG. The temperature during freeze drying should not be above the minimum eutectic temperature which for PEG 2000 is approximately -30 °C, in order to insure that both PEG and water remain in a solid phase during the entire sublimation process so that the cell structure of the wood does not collapse.[63]

Since the artefacts were generally very degraded it was also decided to use a very high final concentration of 40 % weight/volume (w/v) solution of PEG and water. The concentration was started at 10 % (w/v) and increased by 15 percent increments up to the final concentration of 40 % (w/v) PEG 2000[64].

The objects were divided and placed into one of two vats of either small or large objects respectively based on their relative thickness. The thickest object in each group was then used to calculate the impregnation time required for each group according to Jensen.[65] This model takes a number of variables into account including the final concentration of PEG in the impregnation bath, the density of the wood, the relationship between object width and length, the relative diffusion coefficient and the temperature. Since it was not possible to measure the unknown density of the alum conserved artefacts, density values for moderate (≈ 0.35 g/cm^3) to above moderately deteriorated (≈ 0.1g/cm^3) wood was used. Two sets of alternate impregnation times were accordingly calculated for each group and where the values differed markedly the longer time was selected to ensure as complete an impregnation as possible.

Artefacts that had not been tagged already were placed in plastic netting (polyethylene tube netting, RW Nissen AB, box 124, 74623, Bålsta) together with a numbered tag. In those cases where an artefact was deemed to require support a sheet of fluted plastic (polypropylene co-polymer, Eqpack AB, Box 577, 631 08 Eskilstuna) was cut accordingly and inserted into the netting. Impregnation was carried out in a dark refrigerated room (ca +5 °C) using plastic vats with lids in order to minimize microbial growth.

Artefacts having a thickness greater than 4 cm were impregnated together in vat 1, and those that were smaller were impregnated together in vat 2. The largest artefact in vat 1 was number 5 which had both a thickness and a width of 9 cm. The calculated impregnation time for this artefact was 24.6 months. The artefacts in vat 1 included numbers; 2, 3, 4, 5, 7, 9, 10, 14, 15, 16, 17, 18, 20, 26 and 27. The smaller artefacts were placed in vat 2, the largest of these being number 11, which had both a thickness and a width of 3 cm. The calculated impregnation time for this artefact was 3.4 months. The artefacts placed in vat 2 included numbers 1, 6, 8, 11, 12, 13, 21, 22, 23, 24, 25, 28 and 29.

5.3.3 Vacuum freeze-drying

When impregnation in a vat reached completion the artefacts were removed and the excess PEG solution was allowed to run off. Freeze drying was then carried out in two separate runs for the small and large artefacts respectively.

The artefacts in their packaging were placed directly on the shelf inside the chamber of the freeze dryer (Martin Christ, Delta WS24) which had been set at -40 °C to allow for an initial freezing period of at least three days (chamber wall temperature circa -35 °C) before sublimation was initiated. Representative artefacts were placed on the digital scales inside the chamber to monitor the progress of the freeze drying process. Weight stabilization was reached after a period of three months for the small artefacts and after three and a half months for the large artefacts. The vacuum pump was at this point turned off and the temperature was raised stepwise to 0 °C while the vacuum was retained in the system. Once 0 °C was reached the cooling was turned off. When the chamber had reached room temperature air was allowed into the chamber. The temperature during the freeze drying process varied between -25 to -30 °C as measured on the chamber wall. A maximum pressure of 0.025 mbar was registered at the beginning of the freeze drying process, decreasing successively down to 0.0007 mbar towards the end of the process.

The support packaging in those cases where it had been used was cut open and peeled away following completion of freeze drying. Artefacts having a large amount of excess PEG on the surface were carefully cleaned with a soft brush and/or ethanol before being evaluated. For a more detailed account of the conservation steps following freeze drying refer to appendix 3, *After treatment*.

5.4 Evaluation

The artefacts were documented after re-conservation in the same manner as before treatment by weighing, digital photo and X-ray imaging.

Following this the artefacts were then evaluated through a number of steps. First they were evaluated in terms of condition and the presence of damage and then classified. Any possible changes that may have occurred during the treatment were then documented. From this data conclusions were then drawn with regard to desalination, impregnation with PEG and freeze drying as a viable and appropriate method for re-conservation of alum treated wood. The support materials and consolidants were evaluated in terms of their ability to physically stabilize the artefacts through all the steps of the re-conservation process as well as to their permeability to alum, PEG and water.

5.4.1 Condition survey comparison before and after re-conservation

The artefacts were documented after re-conservation in the same manner as before treatment (refer to table 1). This was done without reference to the previous results from the condition survey before re-conservation. The physical integrity, cohesion and surface interaction was described with respect to the presence and number of cracks in different directions, breaks, surface flaking, pulverization, salt efflorescence (visual inspection) and surface pH (indicator-strips, pH 0–14, Merck). On the basis of this data the artefacts were then classified according to the same system as before treatment (from a scale of 1 to 5 representing a stable condition to one of total collapse). Comparisons were then made with the results from before treatment in terms of damage, condition and class (refer to appendix 1 *Condition survey comparison before and after re-conservation*)

5.4.2 Effects on artefacts

The second step of the evaluation involved documenting any changes to the artefacts that may have occurred as a result of the re-conservation process. The archaeological artefacts used as sample material were not homogenous but rather differed in terms of size, thickness, artefact type and site context etc. A number of parameters were also unknown including wood species, original state of preservation, exact method of original alum treatment, amount of alum originally in the artefact, the original dimensions of the artefact, etc. No real quantifiable measurements of variables before and after conservation were therefore attempted other than weight. Any changes that may have occurred during re-conservation were instead determined by visual inspection and comparison with photographs taken before re-conservation

Dimensional changes such as shrinkage or warping were noted and described. Other changes in terms of structural cohesion were also documented in terms of how well the artefact had held together during the re-conservation process. The *number of larger pieces detached from the artefact* was documented and defined as the number of pieces that became detached during the re-conservation process. This included both new breaks and old glue joints that came undone during the treatment. Changes in terms of the artefacts surface stability such as flaking were noted. Any negative effects to the artefact caused by the support or consolidation material used were documented. In this case even changes to the material itself were noted. Colour changes were described and a general comment describing the overall impression of the artefact was made. From the results the artefacts were then ranked, from A to C as follows, with respect to the how successful the re-conservation treatment was deemed to be in each case.

A. Re-conservation treatment successful
   No negative comments. All values good
B. Re-conservation treatment acceptable
   No notable dimensional changes or marks caused by the support material or consolidant. Structural cohesion unchanged with no loss of material. Small changes not affecting the visual experience of the artefact or its information value accepted (including for example minor detachment of surface flakes that can be glued back in place).
C. Re-conservation treatment not acceptable
   Major irreversible changes affecting the artefacts integrity. The visual experience of the artefact and /or its information value have been altered (i.e. the form and/or appearance has changed dramatically and irreversibly) (refer to appendix 2 *Effects on Artefacts*)

5.5 Results

5.5.1 Results salt extraction

All but three artefacts were desalinated according to set criteria, i.e. conductivity in the extraction bath was ≤ 50 µS/cm for three consecutive measurements. In baths with artefacts no. 7 (heated), 9 (un-heated) and 22 (un-heated), the conductivity remained at approximately 140, 70 and 60 µS/cm respectively for up to eight water-changes over a period of several months. It was decided that after a total of 442, 508 and 494 days respectively, the salt extraction would be stopped for these artefacts even though desalination according to set criteria had not quite been accomplished. Data for these artefacts were nonetheless included when comparing un-heated and heated baths.

A comparison was made between un-heated and heated baths in terms of the number of days as well as the number of water-changes required to reach completion of salt extraction. At variable room temperature the desalination process required on average 320 days and 23 water-changes to reach completion, whereas the process required on average 258 days and 19 water-changes to reach completion at 48 °C. It can thus be said that heating the extraction baths can reduce the extraction duration with 19 % and the water-changes with 17 %. In addition to the rate of extraction being higher with warm water, it also appears that more salt is able to be extracted with the use of heated water baths for desalination (refer to figure 6).

Naturally, many factors other than the extraction water temperature influence the salt extraction process and its rate. Other factors that influence the rate and success of the process are the purity of the extraction water, how often water-changes are carried out, the thickness and volume of the artefact,

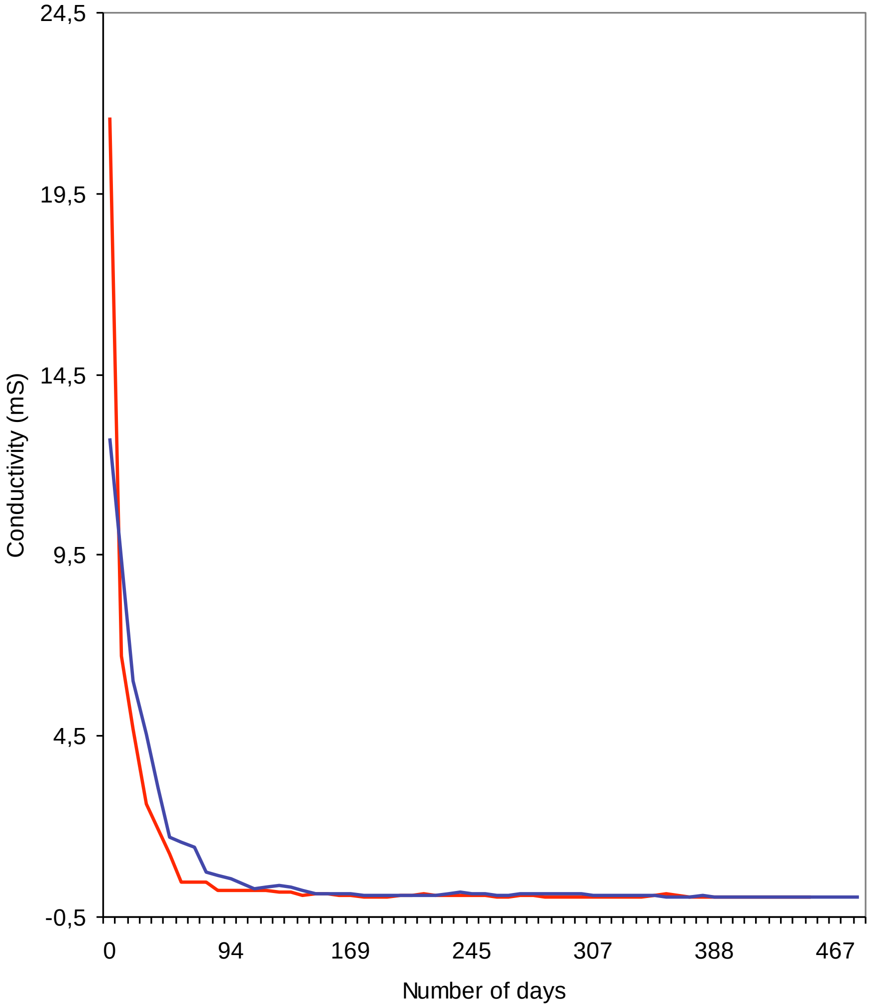


Figure 6. Comparison of the average conductivity curves for artefacts desalinated in water at room temperature (blue) and artefacts desalinated in warm water at approx. 48 °C (high steep curve in red) indicating that extraction in warm water is more effective.

the amount of alum and other water soluble compounds in the wood, the porosity of the wood which in turn is dependent on the wood species and the state of deterioration of the wood, and the permeability of possible surface treatments and physical supports or consolidants.

Yet another obvious aspect of the process is the influence of microbial activity. Although this aspect will not be studied here, it should be noted that micro-biological growth was evident and extensive in baths at room temperature, whereas no activity visible to the eye was found in the heated baths.

The Py-GC/MS analysis of residues from the 13 evaporated extraction baths, done at STFI-Packforsk AB (appendix 4, 5 and 6), found sulphates, most probably from alum, in all 13 cases, and glycerol in 11 cases. The fact that Py-GC/MS is more sensitive to small amounts of materials, together with the fact that the samples used here were more concentrated, explain why glycerol was found in three cases where it was not detected by FTIR. Of note is that glycerol was found in some if not all samples from the archaeological sites of Mora Äng, Käringsjön and Glimmingehus, materials not previously known to have been treated with glycerol, again adding to the picture of a large-scale use of alum with the addition of glycerol.

The fatty acids found in the samples from artefact ID no. 8 and 9 are likely oxidation products from vegetal oil originally applied after the alum-treatment, but may also originate from the wood. The fragments of carbohydrates found in all samples most likely come from degraded wood

5.5.2 Results; physical supports and consolidants

Paraloid B-72 failed as a consolidant when used in the heated bath extraction process at a temperature of approximately 48 °C. The artefact consolidated with Paraloid B-72 (artefact ID no. 6) started to fall apart after two weeks and was completely destroyed and beyond rescue after 44 weeks in the heated bath.

The failure of the consolidant, Paraloid B-72, is most likely explained by its glass transition temperature (T_g) which is 40 °C, and thus lower than the temperature of the heated extraction water. Therefore, if Paraloid B-72 is to be used as a consolidant during salt extraction at elevated temperatures, it is obviously important to set the temperature below 40 °C. The artefacts consolidated with Paraloid B-72 in water at room temperature, artefacts no. 18 and 22, were intact despite the loss of some minute fragments.

The Py-GC/MS analysis of residues from the 13 evaporated extraction baths done at STFI-Packforsk AB (appendix 4, 5 and 6) found high concentrations of dimethylphthalate in samples from artefact no. 21 and 22 and small amounts in the sample from artefact no. 25. Dimethylphthalate is a well known substance often used as a plasticizer in polymeric materials. It is likely to derive from the polyester resin that is known to have been applied to these three artefacts in a previous attempt at re-conservation in 1964.[66] Furthermore, dimethylphthalate in very small amounts was also found in one other sample, from artefact no. 24, which had not been polyester-treated in the 1960's. When in such small amounts, dimethylphthalate may originate from the polymeric materials used as physical support or from the container used in the re-conservation attempt. Dimethylphtalate is not a reactive compound, and is not likely to cause any degrading action in the wood in such small amounts.

It can be noted that in seven out of eight cases, in heated as well as un-heated baths, samples from artefacts supported by both polyether foam/polyolefin film and polyester wadding/polyethylene netting show no significant amounts of compounds likely to originate from these materials. Likewise, samples from artefacts consolidated by Paraloid B-72 show no traces of the consolidant in significant amounts, nor do any samples from artefacts consolidated with Parylene N show any traces of compounds originating from Parylene N.

To what degree the permeability of the various supports and consolidants may differ will not be studied here; it can simply be stated that all physical supports and consolidants tested are clearly permeable to the ions of the alum salt in water solution.

5.5.3 Results; condition survey comparison before and after re-conservation

It is difficult to draw any definite conclusions with regard to differences between the types of damage observed, such as the number of cracks or breaks before and after re-conservation, given the small sample size. Certain trends are however discernible.

The number of cracks for the majority of the 28 artefacts included in the study remained the same (46 %) or appeared to decrease (36 %) after re-conservation. In those cases where the number of longitudinal or transverse cracks increased (18 %) no correlation was found with the temperature of the desalination bath. There is also no correlation between the type of support material or consolidant and an increase in the number of cracks. Those artefacts consolidated with Paraloid B-72 or Parylene N did not, however, exhibit any increase in cracking.

With regard to surface interactions it was found that the degree of surface flaking for 75 % of the artefacts remained the same or decreased. In the case of the remaining seven artefacts (25 %) surface flaking was found to have increased. There was no correlation found between surface flaking and the support materials or consolidants tested or between surface flaking and the temperature of the desalination bath, except for the fact that both Parylene N and Paraloid B-72 were found to decrease the amount of surface flaking. This indicates that despite the small sample size, the two consolidants tested are able to consolidate previously flaking surfaces.

In the case of surface pulverization it was found to be absent in all cases where it had been noted before re-conservation indicating that PEG has a stabilizing or consolidating function on the surface. The common and aesthetically disfiguring salt efflorescence visible on the surface before re-conservation was also removed after desalination. Those artefacts treated with Parylene did however exhibit some crystal efflorescence that appeared to be under the surface of the parylene.

The generally low pH values measured on the surface of the artefacts before re-conservation climbed to weakly acidic or neutral levels after re-conservation indicating that the acidic compounds were removed from the surface

Plate 22. Artefact no. 13, before re-conservation. Photo: Swedish National Heritage Board.

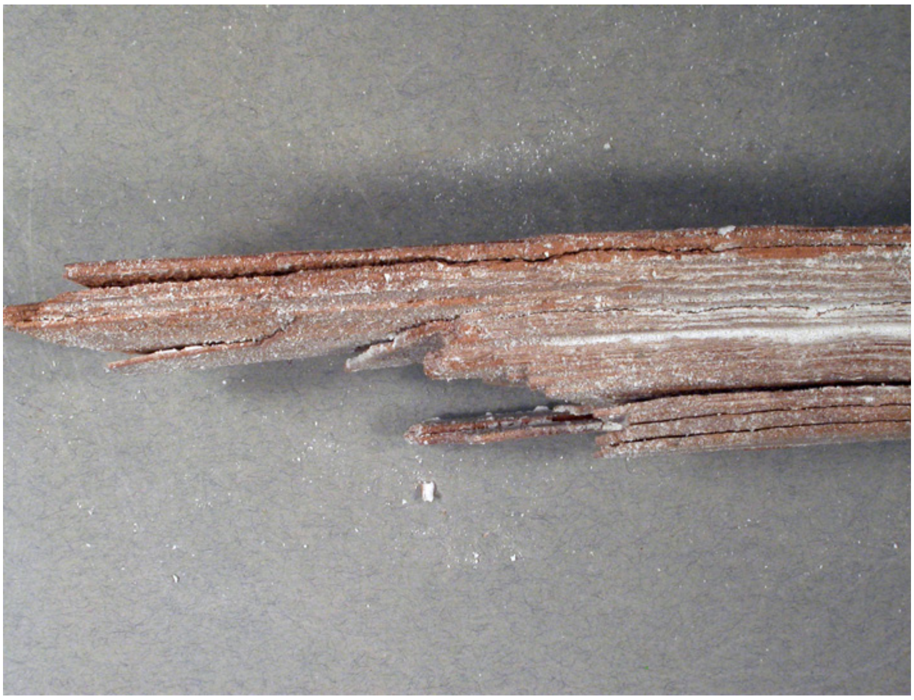


Plate 23. Artefact no. 13, detail after freeze drying. New longitudinal cracks have developed after re-conservation. The artefact was given a support using polyether foam and polyolefin film and desalinated at room temperature. The white surface deposit is excess PEG 2000 which has not yet been removed. Photo: Swedish National Heritage Board.

Plate 24. Artefact no. 6, before re-conservation. Photo: Swedish National Heritage Board.

Plate 25. Artefact no. 6, after freeze drying. Stabilization with Paraloid B-72 in warm water was not successful as a means of retaining physical stability during desalination. The artefact fell apart and sections were pulverized beyond rescue. The white surface deposit is excess PEG 2000 which has not yet been removed. Photo: Swedish National Heritage Board.

after desalination. The pH of artefact no. 7 which was covered by a coating of wax (as identified by FTIR analysis) in contrast increased only to a pH of 4 as measured on the surface of the wax. The wax in this case also changed to an opaque white appearance following re-conservation.

The number of artefacts with breaks (yes/no) remained the same (82 %) for the majority of the artefacts after re-conservation. However, in the case of five artefacts (no. 6, 7, 8, 27 and 28) breaks did occur during re-conservation. Artefact no. 6 in fact fell apart during desalination. This artefact had been consolidated with 10 % Paraloid B-72 and desalinated in warm water. The reasons why this artefact fell apart is discussed in section 5.5.2. Artefacts no. 7, 8 and 28 developed new breaks with detached pieces being stuck to the packing material (polyether foam). These artefacts were similarly desalinated in warm water and it would seem that the higher temperature has a tendency to soften old surface treatments and consolidants which get stuck in the polyether foam in turn resulting in detachment when the support material is finally removed from the artefact.

A few artefacts that had previously been repaired lost adhesion due to the old glue joints caming apart during desalination. This was expected and the artefacts were subsequently re-glued as a final step in the re-conservation process.

Comparing changes in condition as represented by class (1 = stable condition, 5 = total collapse), between artefacts before and after re-conservation, it can be seen that the majority of the artefacts have in fact moved up to a higher class (50 %) or remained the same (39 %) after re-conservation. Only three artefacts have been classified lower after re-conservation. Due to the small sample size it is not possible to make any conclusions with regards to the effect of support material, consolidation and/or temperature differences during desalination.

Comparing class before and after re-conservation was however found to be a somewhat misleading means of assessment. This is shown by the fact that the artefact (no. 6) that completely fell apart as a result of re-conservation was actually assigned a higher class after treatment. The reason for this is that classification was based only on damage that could be attributed to alum induced deterioration (refer to classification model to categorize the state of deterioration, section 3.3). The presence of damage such as breaks could not, with certainty, be attributed to alum and was therefore not factored into the classification, and also only evaluated in terms of either yes or no. Artefact no. 6 which did not have any breaks before re-conservation but which developed breaks after re-conservation was given a higher class after re-conservation because symptoms attributable to alum deterioration were determined to have diminished.

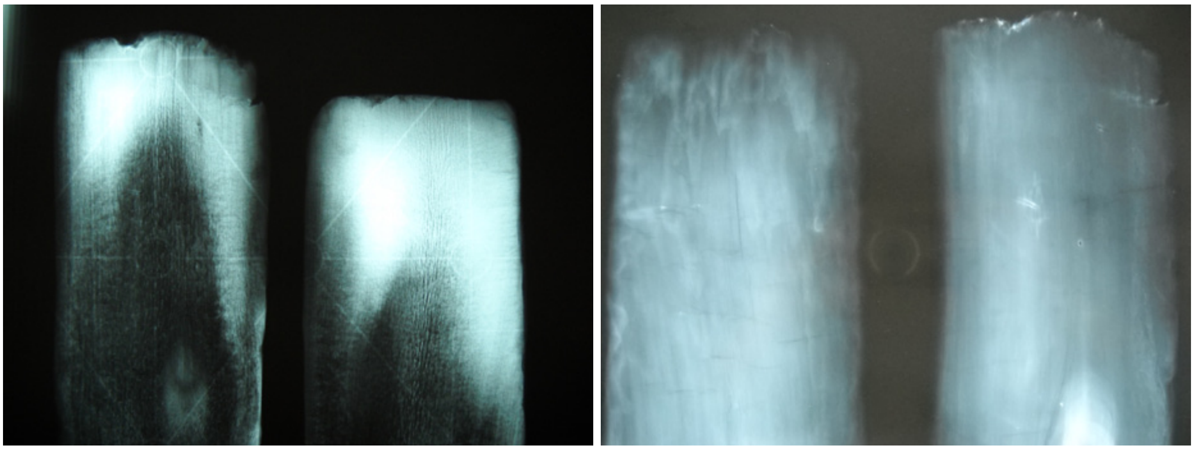


Plate 26. Radiograph of the same artefacts before (left) and after (right) desalination and re-conservation. The salt concentration (bright areas) at the ends of the artifact are no longer present and the wood shows a relatively even attenuation throughout the structure.
Photo: Swedish National Heritage Board.

5.5.4 Results; effects on objects

Comparing the changes that have occurred during re-conservation it can be noted that all artefacts decreased drastically by 8–59 % in terms of weight (it was not possible to weigh artefact no. 6 due to the fact that it had fallen apart). The average weight decrease was found to be 33 %. Comparison of the radiographs before and after re-conservation also show that the concentration of alum visible as bright areas at the cross-cut ends of the artefacts are no longer present and that the structure of the wood shows a more even x-ray attenuation indicating that the alum has been removed and replaced by PEG (refer to plate 26).

The majority of material removed from the artefacts is assumed to be alum. Analysis of the desalination water does however indicate that other water soluble products such as glycerol and fragmented carbohydrates were also removed (refer to appendix 2, Effects on artefacts and appendix 4,5 and 6 analyses made by STFI-Packforsk). The average weight loss for artefacts desalinated in warm water (38 %) is higher compared to those in water at room temperature (29 %) which would seem to indicate that desalination was more effective in warm water. Quantitative or qualitative analysis of the total amount of all products removed was not carried out. The sample size was also determined to be too small to draw any conclusions with regard to any possible relationship between the support material or consolidant and weight loss during desalination.

The majority (89 %) of the artefacts were determined to have retained their original shape in comparison to pictures taken before re-conservation. Three artefacts however show some change of form, such as shrinkage or deformation. It was not possible to see any relationship between changes in form and support material or consolidant used and/or temperature during desali-

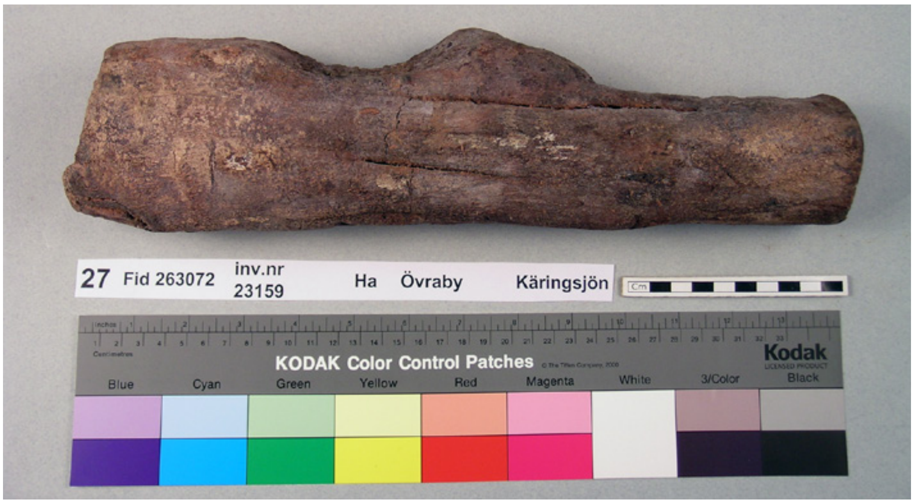


Plate 27. Artefact no. 27, before re-conservation. Radiograph showing the presence of large inner voids. Photo: Swedish National Heritage Board.

Plate 28. Artefact no. 27, immediately following freeze drying. The support material consisting of netting and polyester wadding has not sufficiently stabilized the artefact during re-conservation. The artefact has deformed and broken apart. Photo: Swedish National Heritage Board.

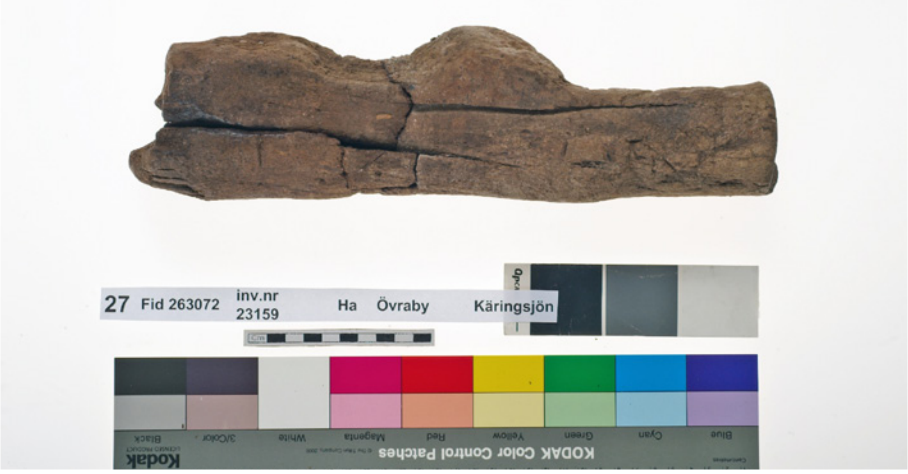


Plate 29. Artefact no. 27, after re-conservation and regluing. The artefact is irreversibly changed. Photo: Swedish National Heritage Board.

nation. The changes in form that were noted seem rather to be related to the artefacts condition and or earlier conservation. One of the artefacts (no. 27) that deformed had, for example, large inner voids visible with X-ray examination that more than likely resulted in collapse and deformation when the artefact was desalinated. Another artefact (no. 28) had several old glue joints and infills at the joints that dissolved during desalination in warm water and caused an overall bending of the artefact.

A total of eight artefacts (29 %), not considering those that have come apart due to the failure of old glue joints, have to some degree fallen apart during re-conservation. One of these artefacts, as already stated, is no. 6 which was consolidated with Paraloid B-72 and which fell apart during desalination in warm water as discussed in section 5.5.2. The other seven artefacts failed after being treated with a support consisting of either polyether foam/polyolefin film or polyester wadding/polyethylene netting and desalinated in water that was either heated or at room temperature and show no correlation to their varying treatments.

Some loss of material (small fragments) from the surface is evident on sixteen (57 %) of the twenty-eight artefacts as a result of the re-conservation process. The majority of the material is wood, in some cases likely integrated with substances such as oil or wax that may have been applied as a surface treatment. The majority of these artefacts (81 %) were however exhibiting ongoing surface flaking even prior to re-conservation. Of those artefacts exhibiting surface flaking prior to re-conservation only those treated with Parylene N did not exhibit any further loss. There was no loss of material from those artefacts treated without any support material. This applies to only two artefacts but these were in good condition (class 2) without surface flaking before re-conservation. The results show no correlation between surface flaking and water temperature during desalination.

Some of the artefacts with surface flaking exhibited a loss of material even before re-conservation was initiated. In terms of ranking (A to C) those artefacts that had surface flaking prior to re-conservation, given that no other factors were negative and the overall impression was good, were given a ranking of A (successful re-conservation). Those artefacts that had an increased level of flaking were given a ranking of B (acceptable re-conservation) if the other requirements for a B ranking were satisfied. An increase in flaking has thus been regarded as acceptable given the possibility to consolidate the surface and/or reattach flakes as a final step in the treatment.

A change in colour has to some degree been noted for twenty (71 %) of the twenty-eight artefacts when their appearance was compared to the photographs taken before re-conservation. Colour change has not however been

Plate 30. Support material used to encapsulate artefact no. 23 showing black spots on the interior surface that was in contact with the wood. The white substance is crystallized PEG 2000. Photo: Swedish National Heritage Board.

Plate 31. Artefact no. 8, after re-conservation using warm water for desalination. Fragments from the surface have adhered to the polyether foam and detached from the artefact when the foam was removed. Photo: Swedish National Heritage Board.

Plate 32. Artefact no. 13, after re-conservation using water at room temperature for desalination. Fragments from the surface have adhered to the polyether foam and detached from the artefact when the foam was removed. Photo: Swedish National Heritage Board.

taken into consideration in the evaluation. The colour as judged from the photographs was hard to assess. Some artefacts have become lighter whereas others have become darker. Some artefacts have as a result gained a more wood-like appearance in comparison to their appearance before re-conservation. Moreover what colour the artefacts may have had at the time of excavation is not known.

Considering the possible negative effects that may have arisen as a result of the support or conservation material it can be concluded that black spots have appeared in some cases on both the polyether foam and the polyester wadding that was desalinated in water at room temperature. The black spots are likely to have been caused by microbial growth during the desalination and/or impregnation stage. No attempt has been made to identify any potential microorganisms. The reason why spots were only found on the polyetherfoam at room temperature and not in the case where the water was heated is probably due to the organisms temperature range for growth and reproduction being exceeded in the latter case. Although it can not be ruled out, no negative effect on the actual artefact has been found as a result of biological activity.

It was also noted that flakes from the surface of some artefacts adhered to the inside of the support material and to a varying degree detached when it was removed. This was observed for seven of the twelve artefacts with a support material of polyether foam with polyolefin film, and three of the eight artefacts with a support material of polyester wadding with polyethylene netting.

With respect to Parylene it can be concluded that it has resulted in a visible and undesirable surface appearance. All three of the artefacts treated with Parylene N have a gray plastic like appearance that no longer resembles wood. The artefact (no. 15) that was treated with the thickest coating (17 µm) was also determined to have the most plastic like appearance of the three. Of the three artefacts treated with Paraloid B-72 one was found to have a somewhat shinier surface after treatment, as compared to before treatment, but this was deemed to be acceptable.

In a number of cases where the polyether foam support material was subjected to warm water desalination it appears that the foam material has also deteriorated chemically giving the foam a hardened feel and notably darker appearance. It is likely that the elevated temperature has accelerated the deterioration of the foam and it is not inconceivable that some resulting degradation products may have diffused into the wood as a result.

An account of the ranking results (from A to C) of the artefacts indicating the level of success of the re-conservation treatments shows that eight artefacts (29 %) out of twenty-eight have been given a ranking of A (successful re-conservation). Eleven (39 %) have been given a ranking B (acceptable

Plate 33. Artefact no. 29, before re-conservation. Photo: Swedish National Heritage Board.

Plate 34. Artefact no. 29, after freeze drying. Photo: Swedish National Heritage Board.

Plate 35. Artefact no. 29, after re-conservation and removal of excess PEG from the surface. The artefact has been re-conserved without any support or consolidation and has received a ranking of A (successful re-conservation). Note that the artefact was also in a good condition before re-conservation. Photo: Swedish National Heritage Board.

Plate 36. Artefact no. 23, before re-conservation. Photo: Swedish National Heritage Board.

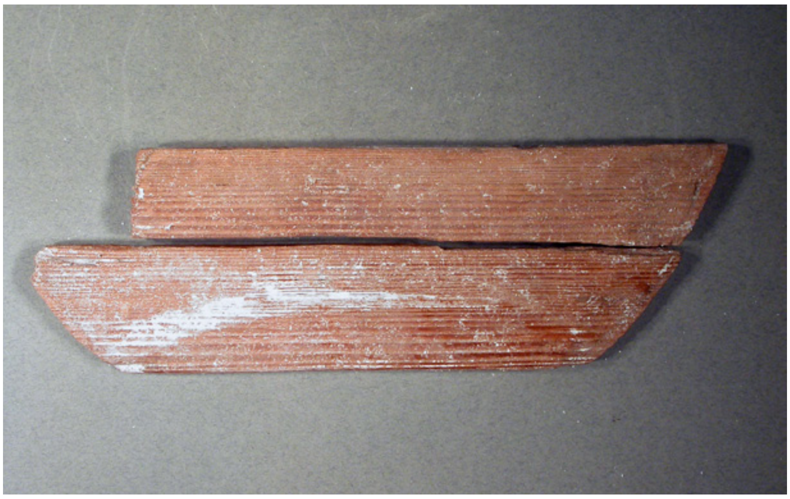


Plate 37. Artefact no. 23, after freeze drying. Photo: Swedish National Heritage Board.

Plate 38. Artefact no. 23, after re-conservation, removal of excess PEG from the surface and re-gluing with a resulting rank of A (successful re-conservation). The artefact was desalinated in water at room temperature with a support of polyether foam and polyolefin film. Photo: Swedish National Heritage Board.

re-conservation) whereas nine artefacts (32 %) have been given a ranking of C (not acceptable re-conservation).

There was no correlation found between the ranking of the artefacts and the temperature of desalination treatment. With the exception of treatment with Parylene N, which resulted in a ranking of C due to the plastic appearance of the artefacts, there is also no correlation between the different consolidants and support materials used and the resulting ranking of the artefacts. It is however notable that the two artefacts re-conserved without the use of any support material or consolidation were ranked as A.

All of the artefacts have also received additional treatment before and after the ranking was carried out. The removal of excess PEG from the surface of the artefacts has been done using various methods including cleaning with ethanol and/or careful melting with a hot air gun. A number of artefacts have also been glued in order to repair both old and new breaks, and in some cases treated to consolidate the surface, see appendix 3, after treatment.

	Classification according to deterioration		
Rankgroup	**Class 2**	**Class 3**	**Class 4**
A Successfull re-conservation	🟥 🟦🟦 🟧🟧		🟥 🟦 🟩
B Acceptable re-conservation		🟥🟥🟥 🟦🟦	🟥🟥🟥🟥 🟦 🟩
C Not acceptable re-conservation	🟥	🟥	🟥 🟦🟦 🟩 ⬛⬛⬛

Table 8. Relationship between the artefacts state of deterioration and result of re-conservation. For definition of classes see classification model to categorize the state of deterioration of the artefact (section 3.3; table 1) and for definitions of conservation results see section 5.4.2.

🟥 Polyether foam and perforated polyolefinfilm
🟦 Polyester wadding with polyethylene netting
🟧 No physical support or consolidant
🟩 Paraloid® B-72
⬛ Parylene N

A correlation can be seen between the condition of the artefact before re-conservation according to the classification scale of 1 to 5, see section 5.4.2.and the success of the re-conservation treatment (ranking A to C). A higher number of artefacts in good condition also have a ranking of A (successful re-conservation) after re-conservation whereas artefacts in a lesser condition more often have a ranking of B or C after re-conservation. This in itself is not surprising but rather indicates that the methods tested are less than ideal for artefacts with more serious deterioration.

5.5.5 Practical experience gained from the study

When handling the artefacts in a waterlogged state during the desalination and impregnation steps it was found that some of the larger and or longer artefacts were not able to structurally carry their own increased weight. This implies a risk to the structural integrity of the artefact when it is repeatedly transferred between water changes during desalination. This type of damage could be minimized by using rigid support plates under the artefacts during desalination, impregnation and freeze drying.

One artefact (no. 26) which was treated using a support of polyester wadding and polyethylene netting was entirely coated with polyester fibres after re-conservation. This particular artefact, which was desalinated with warm water, had previously been conserved with an application of wax (identified by FTIR), which softened during desalination adhering the polyester fibres to the surface. Even though it was possible to remove the fibres without damaging the artefact the process was very time consuming. This exemplifies the possible negative side effects that may result with desalination in warm water when earlier conservation treatments are unknown, particularly treatments involving surface applications.

5.6 Discussion

The results of the study indicate that desalination of alum conserved artefacts in warm water (48–50 °C) reduces the time required for desalination by 19 % compared to water at room temperature. A higher temperature can however have a certain negative effect on polyether foam in terms of accelerating deterioration. It can also affect previous conservation materials such as surface treatments and adhesives potentially causing damage to the artefact. Removal of support packaging for example may result in the removal of surface flakes that have adhered to it. Since desalination at room temperature was found to be successful it may be considered preferential even though it takes longer. Desalination at room temperature may also be considered of advantage since it requires no special equipment or energy for heating. Time consuming steps

Plate 39. Artefact no. 26, after freeze drying and opening of the support encapsulation. White polyester wadding fibres cover the surface of the artefact. Photo: Swedish National Heritage Board.

Plate 40. Artefact no. 26, after re-conservation. The white fibres were removed mechanically and with the help of ethanol requiring a significant amount of effort and time. Photo: Swedish National Heritage Board.

to remove fibres that may adhere to the surface when using warm water are also minimized.

The study has shown that successful re-conservation results can be obtained following desalination through impregnation with PEG followed by freeze drying.

The results show that the support materials and consolidants can provide sufficient protection during re-conservation to keep flaking surfaces in place and prevent structural damage. All of the support materials and consolidants that were tested were permeable to water through all stages of desalination, impregnation and freeze drying. The ions from the alum salt in water solution were also found to be able to pass through all of the support materials and consolidants tested. The degree to which alum has been completely removed from the artefacts was not evaluated in this study. It would be desirable to take future samples from the artefacts to analyze the relative content of alum left in the wood. Particularly in the case of those artefacts consolidated with Parylene where there appears to be crystals present under the Parylene coating.

Furthermore, the results suggest that PEG is able to pass through all of the support materials and consolidants tested. An insufficient PEG-impregnation would have been discernible from the artefacts by signs of shrinkage, deformation or crack development. The majority of artefacts however show no signs of shrinkage or deformation after re-conservation. The typical pattern of multiple cracks across the grain that is common in the case of insufficient PEG impregnation is also not present. The distribution of PEG in the wood was, however, not investigated.

All of the support materials and consolidants were found to be able to physically stabilize the artefacts during re-conservation. Parylene N was found to be the best in this respect. The results, however, vary depending in part due to the varying nature of the artefacts with regard to, for example, degree of deterioration.

Some negative results and tendencies have, however, been noted with some of the examined support/consolidation materials. Polyether foam has first of all, to a higher degree than the other materials, a tendency to pull away the surface of the wood, when the support material is removed after freeze-drying.

Paraloid B-72 failed totally to stabilize one of the objects (no. 6), which had been desalinated in warm water, probably due to the desalination temperature being above the glass transition temperature for Paraloid B-72. Another object, consolidated with Paraloid B-72, turned white (object no. 22). In this case the white colour is not caused by PEG residues, but seems to originate from the various materials on the surface of the object, such as the Paraloid B-72 that was applied as a consolidant, the polyester originating from an earlier re-conservation or the wax originally used for treating the surface. The reason for this colour change is unknown, but it cannot be ruled out that the consolidant has absorbed water and then whitened, a phenomenon known from the desalination of ceramics and archaeological iron, that have been consolidated or glued with Paraloid B-72. Usually the white colour fades with drying or can be removed by a light spraying with acetone or ethanol. In this case the white appearance vanished before assessment, in conjunction with the removal of excess PEG from the surface with ethanol. The object was thus ranked as A (successful re-conservation). The third object tested with Paraloid B-72 (no. 18), was ranked as B (acceptable conservation). Its original shape was preserved and the flaking surface had for the most part been consolidated during the treatment, leaving the surface with only a very slight gloss. In general the suitability of Paraloid B-72 as a consolidant in the re-conservation of degraded alum-treated archaeological wood should be further investigated and tested on a larger amount of objects.

The use of Parylene N has resulted in a grey plastic-like look, noteable on all of the three objects tested, that has been judged as considerable and as having irreversible changed the appearance of the objects. These objects were as a result given a ranking of C (not acceptable). The fact that the process of applying Parylene N to wood is at best difficult to reverse and quite resource demanding, makes it less suitable as a consolidant. On the other hand, Parylene N turned out to have the best capacity to physically stabilize the objects during re-conservation, which, as a very last resort, could make it a possible consolidant for very degraded alum-treated wood.

Looking at both the positive and negative results of the evaluation of the various support/consolidation materials used in the re-conservation process, the two objects which were re-conserved with no support/consolidation at all, were the most successful (rank A, successful re-conservation). The explanation for this is most likely that both objects were in a good condition already from the start (class 2). Polyester wadding combined with polyethylene netting and polyether foam with polyolefin film had similar results, 75 % of the tested objects in both groups were given a ranking of A or B. Since polyether foam combined with polyolefin film showed more of a tendency to adhere to the surface of the artefact resulting in a greater loss of flakes from sensitive surfaces, the first combination seems to be the better alternative. The fact that the results vary somewhat, reflects the heterogenous nature of archaeological objects and the difficulty encountered when using such a test material with a limited number of samples.

The results from the chemical analyses of the residues from the evaporation of the desalination water indicate that the polyester impregnation of some of the objects during re-conservation in 1964 caused the emission of dimethylepthalates (a common plasticising agent). If foreign materials, such as consolidants, with unknown side-effects are to be used on artefacts, they should first be tested for stability with regard to the release of possibly harmful substances.

The extensive weight loss of the objects during re-conservation should be expected to reduce the risk of mechanical damage, provided that the PEG is sufficiently able to consolidate the inner structure of the wood without any loss of strength. A lighter object carries its own weight more easily, which also leads to less stress on glue joints. The objects become less sensitive to handling and may need less supporting measures for instance during transport and on exhibition display. Whether the PEG preserves or affects the strength of the wood, still remains to be investigated.

The pH-values on the surface of the objects had risen to near neutral levels. However, it cannot be ruled out that the wood is more acidic further below the surface. More investigations are needed to explain the reasons for the low pH-values and the effect this may have on alum-conserved wood.

The vacuum treatment applied to floating objects during the desalination process in order to achieve a waterlogged state (see section 5.3.1) has not been included as a factor in the assessment of the re-conservation procedure. The results, however, indicate that this treatment might have had some effect. Comparing the ranking (A–C) of the eleven vacuum treated objects it can be noted that the majority (91 %) of these objects were given a ranking of only B (six) or C (four). The vacuum treatment is likely to mechanically stress deteriorated waterlogged wooden objects, as air bubbles permeate out via cracks in the wood and through the fragile surface, and should preferably be avoided.

The result of this study and the experiences gained, demonstrate many of the practical difficulties facing the conservator in connection with the re-conservation of archaeological objects. The nature of earlier conservation materials, such as consolidants and other substances applied as surface treatments, adhesives and fillings, are often unknown and conservation documentation insufficient or even absent. Moreover it is often difficult to evaluate how earlier conservation materials may react during the re-conservation process. When choosing a re-conservation method, where the end result is uncertain, an assessment should be done to weigh the possible risks against the possible benefits or effects of treating or not treating an artefact.

5.7 Conclusions

It is difficult to draw definitive conclusions from the results of this study, since the investigated objects were few and of great diversity. The results do show that it is possible to re-conserve alum-treated wooden objects in various stages of degradation, and with the possible addition of unknown treatments (such as impregnation with glycerol, oil or wax) by desalination in water, followed by PEG-impregnation and vacuum freeze-drying. The support material combinations most frequently associated with a successful re-conservation (A ranking), are polyester wadding with polythene netting (three out of eight) and polyether foam with polyolefin film (two out of eight). It should, however, be noted that two of the eight most successful cases included objects, which were in such good condition that they were treated without any support material at all.

Furthermore, the results indicate that raising the temperature of the desalination bath might be harmful to both objects and support material and hence that this method should be used with some caution.

In spite of some objects having undergone changes during re-conservation, e.g. partial loss of surface layer, most of the objects are probably in a better state in terms of their future preservation after removal of alum. The objects should have become less sensitive to changes in relative humidity. Moreover, the risk of mechanical damage, e.g. during handling, should have been reduced as a result of the objects having become much lighter. The raising of the objects surface pH to near neutral levels should also be beneficial.

This study should be regarded as a pilot study which has generated practical experience and knowledge and the results can be seen as a general guide for the practicing conservator. It should be of help in future studies looking at the re-conservation of alum-treated wood. It would be desirable that a more extensive study be carried out on a larger and more standardized test material. It could be designed either as a test of the more successful support materials and consolidants used in this study, or as a further study including a wider range of support materials and consolidants. An extensive re-conservation treatment always involves an act of major interference and strain on a degraded wooden object. The potential risk of damage should always be weighed against the advantages of, for example, obtaining objects more physically stable and less sensitive to climatic factors. Bearing in mind all the negative and degrading properties associated with alum salt, the objects in this study should have gained a longer life.

5.8 Summary

The purpose of this study has been to test possible materials and methods for the re-conservation of alum treated archaeological wooden artefacts.

The study was comprised of a selection of twenty-nine alum treated artefacts in varying states of deterioration including one artefact which served as a reference. The artefacts varied in terms of where they were found, type, age and what additives in addition to alum that they had been treated with. A number of properties such as wood species and degree of deterioration were also unknown. Chemical analysis using SEM-EDS and FTIR was undertaken to identify unknown additives such as glycerol, linseed oil and/or wax, and also to confirm the presence of alum, since little documentation with regard to the original conservation treatments, was available.

The artefacts were treated by a three step conservation process consisting of desalination using water to remove alum, PEG impregnation and vacuum freeze drying. Desalination was carried out using RO-water comparing the rate of desalination at room temperature and with heating to 48–50 °C. The desalination process was in each case monitored in terms of conductivity and pH. Samples of the desalination residue after evaporation was analysed using Py-GC/MS to investigate what products were being extracted from the artefacts.

Two different physical supports and two consolidants were tested and evaluated in the re-conservation study. The physical supports consisted of polyester wadding with polyethylene netting and polyether foam with polyolefin film. The consolidants were Paraloid B-72 and Parylene N. The materials were evaluated in terms of their ability to support and consolidate the deteriorated structure of the artefacts during the three steps of the re-conservation process. In addition, the permeability of the different materials to water, alum and PEG 2000 was also evaluated

An analysis of the results was carried out in several steps and is presented in this report. The first step of the analysis describes the damage and general condition of the artefacts with respect to physical integrity, cohesion and surface interaction, as well as surface pH. A comparison was made between damage documented before re-conservation and damage that occurred after re-conservation. The second step of the analysis deals with a documentation of any changes that occurred during the re-conservation process, such as deformations, colour change, changes in weight and any effects caused by the consolidant or support material. The artefacts were also X-rayed and compared in terms of changes observable before and after re-conservation. Based on the results the objects were then ranked (A to C) in terms of the determined success of the re-conservation with A, B and C corresponding to successful, acceptable and not acceptable respectively.

The results from the desalination study indicated that desalination at a warm temperature (ca 48–50 °C) reduced the time required for desalination by 19 % and the number of water changes by 17 % compared to desalination at room temperature. Paraloid® B-72 was however found to fail as a consolidant when desalination was carried out in warm water likely due to the temperature of the water being in excess of the glass transition temperature (Tg) for this consolidant. All of the support materials and consolidants that were tested were found to be permeable to alum ions in water solution. Significant amounts of microbial growth were observed in the desalination baths at room temperature. Microbial growth was in comparison not observed in the warm baths.

The final results indicate that desalination of alum in water followed by PEG impregnation and vacuum freeze drying will give successful results for alum conserved archaeological wood in varying degrees of deterioration. The majority of artefacts were found to have a lesser or equal degree of damage compared to before re-conservation. Treatment with either Paraloid® B-72 or Parylene N was found to minimize the occurrence of surface flaking to a higher degree than what was achieved with the other support materials or consolidants tested. In general, 89 % of the artefacts were found to have retained their shape as compared to before re-conservation. Weakly acidic or near neutral surface pH levels, instead of the very low pH levels measureable before treatment, were attained for all of the artefacts. The weight of artefacts was also markedly reduced by an average of 33 %. The weight loss for the larger artefacts was higher for those artefacts that had been desalinated in warm water suggesting a higher degree of efficacy with desalination at elevated temperature.

Surface adhesion to the support material and a resulting loss of surface flakes when the material was removed was noted for artefacts with support material consisting of polyether foam with polyolefin film and polyester wadding with polyethylene netting. Those artefacts treated with Parylene N developed a grey plastic like surface appearance that was deemed unsatisfactory. There was no clear indication of any damage being caused to the artefacts as a result of desalination at elevated temperature. The polyether foam was however found to show signs of accelerated aging as a result of the warmer desalination water. Overall, 68 % of the artefacts were ranked as A (successful) or B (acceptable) with respect to the success of the re-conservation treatment. The remaining 32 % were considered as not acceptable (C). All of the consolidants and support materials were found to physically stabilize the artefacts during re-conservation. Those artefacts treated with Parylene N were however found to have changed significantly and irreversibly in terms of appearance.

The varying range within the results reflects the heterogeneous nature of the archaeological artefacts comprising the test material of the study. The practical experience gained from this study is presented in the report together with a discussion regarding the pros and cons associated with the different consolidants and support materials as well as the risks and possible gains associated with a re-conservation effort. The results can be seen as general guidelines for the conservator and will hopefully be of benefit for future studies relating to re-conservation methods for alum conserved wood.

6 The capacity of alum to bind and release crystal water with changing climatic conditions

6.1 Introduction

The aim of this experiment was to investigate if the number of bound crystal waters in alum change with variations in relative humidity and/or temperature by monitoring weight change in samples of alum. It is often stated that the wood degradation caused by alum, is due to the effect of alum taking up and releasing crystal water. The resulting cyclical increase and decrease in the size of the salt with fluctuations in temperature and relative humidity, is believed to cause the rupture and collapse of the wood structure typically associated with alum deterioration. No evidence for this process has been shown experimentally and a search of the literature has only shown data for water-free alum; $KAl(SO_4)_2$ (white hygroscopic powder), and the fully hydrated state; $KAl(SO_4)_2 \cdot 12\ H_2O$ (transparent).[67] In an essay by Kopperud at the School of Conservation in Copenhagen it is claimed that alum salts with other numbers of crystal water exist but there is no data given to support this statement.[68]

6.2 Method

With a change of temperature and/or relative humidity it would be expected that the weight of the alum salt would either, increase, decrease or remain unchanged. For this reason a comparison of stabilized values for the weight of alum at different temperature and relative humidity-combinations was carried out.

Samples of alum were prepared using aluminium potassium sulphate dodecahydrate (Merck 1.01047.1000). Since $KAl(SO_4)_2$ is very hygroscopic the content of the alum container was approximated to be $KAl(SO_4)_2 \cdot 12\ H_2O$, as also indicated on the container. The percentage change in weight required to indicate a loss of one water molecule from the fully hydrated state of alum was calculated as 3.80 % according to the following calculations:

$KAl(SO_4)_2 \cdot 12\ H_2O$ has a molar mass of 39,10 + 26,98 + 2 * (32,06 + 4 * 16,00) + 12 * (16,00 + 2 * 1,01) = 474,4 g/mole.

H_2O has a molar mass of 16.00 + 2 * 1,01 = 18,02 g/mole.

Therefore 18.02 / 474,4 = 3.80% of 1 $KAl(SO_4)_2 \cdot 12\ H_2O$.

The percentage change in weight required to indicate a gain of one water molecule by the water free state of alum was calculated as 6,98 % according to the following calculations:

$KAl(SO_4)_2$ has a molar mass of 39,10 + 26,98 + 2 * (32,06 + 4 * 16,00) = 258,2 g/mole.

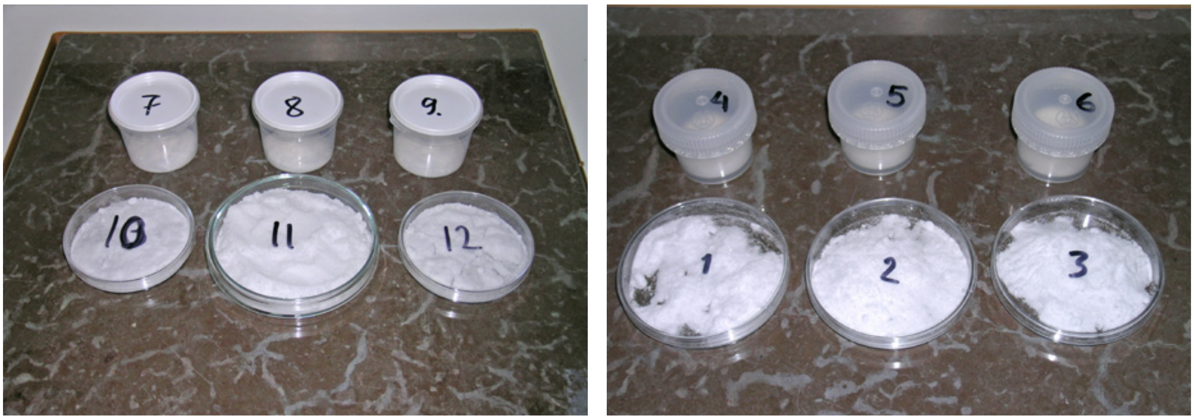
H_2O has a molar mass of 16,00 + 2 * 1,01 = 18,02 g/mole.

Therefore 18,02 / 258,2 = 6,98 % of 1 $KAl(SO_4)_2$.

The type of container used for the experiment was based on the premise that the greater surface area afforded by a low and wide container would more readily allow water to be given off or absorbed by the alum. The container also required a tight fitting lid to provide a good seal for when the container was taken out for weighing to avoid weight change due to the salt absorbing or giving off moisture outside the climate chamber. It was also of importance that the same lid was used each time the container was weighed in order to control for slight variations in weight between the different lids. Four different types of containers were used in the experiment, the first and second being shallow and wide with a non-tight fitting lid and the third and fourth being narrower and deeper with tight fitting lids. Samples 1–3 and 10 and 12 consisted of plastic Petri plates (diameter 9 cm and height without lid 1.3 cm). Sample 11 consisted of a larger glass Petri dish with lid (diameter 11 cm, height without lid 2.2 cm). Samples 4–6 consisted of plastic PET containers with screw- top lids (Nalgene; diameter 4 cm at bottom and 4.4 cm at rim, height without lid 4.3 cm). Samples 7–9 consisted of plastic PET containers with plastic pop-on lids (diameter 5.5 cm at the bottom and 6.2 cm at the rim, height without lid 5 cm).

It should be noted however, that all the molecules will probably not loose or gain crystal water to the same extent, since diffusion through the salt, down to the bottom of the container, has to take place. Thus it is doubtful if the number of crystal waters will be the same at the bottom of the container as at the surface.

The samples were exposed to different combinations of temperature and relative humidity using two climate chambers (WTC Binder KBF-115 and KBF-240). Two different chambers were used in order to accommodate all of the samples. Step intervals of 20 % were chosen for the assessment of the effect of relative humidity giving steps of 15 %, 35 %, 55 %, and 75 % toward an upper RH of 85 %. Temperature was in turn assessed in steps of 15 °C, 20 °C, 30 °C, and 40 °C. The investigation was carried out within the temperature and relative humidity constraints of the climate chambers. Table 9



Plates 41 and 42.
Three different containers were used in the experiment having either a large surface area or a tight fitting lid.
Photo: Swedish National Heritage Board.

illustrates the experimental matrix as well as the limits marked as "X" indicating RH and temperature combinations which the climate chamber is unable to achieve.

In order to prevent contamination of the samples and any erroneous influence on the weight, the containers were handled with gloves and placed on clean aluminium foil when outside the climate chamber. The lids were put on inside the climate chamber to minimize the risk of the climate outside the chamber influencing the sample. Those containers with less tightly sealed lids were taken out one at a time.

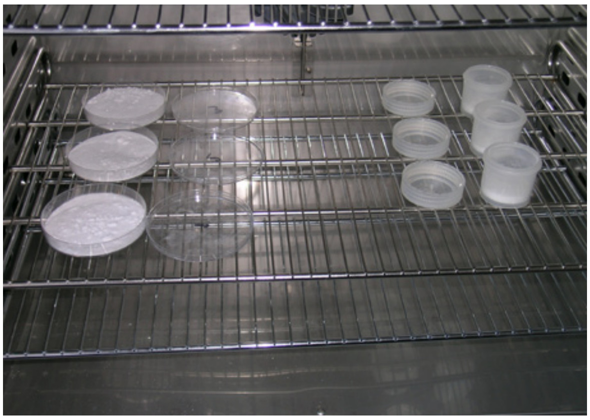
The temperature and RH setting was changed to the next step when the weight had remained the same after three consecutive weight determinations. Weighing was initially done twice a week with intervals up to one month between some measurements.

Table 9. Matrix illustrating the relative humidity and temperature values compared in the study ("X" indicates combinations that were not assessed given that they fell outside the limits of the climate chamber used).

	15 °C	**20 °C**	**30 °C**	**40 °C**
85 %				X
75 %				
55 %				
35 %				
15 %	X	X		

Table 10. Steps 1 through 12 for the variation of temperature and RH in the small climate chamber containing samples 1 to 6.

	15 °C	**20 °C**	**30 °C**	**40 °C**
85 %			5	X
75 %		12	6	4
55 %		11	7	3
35 %		10	8	2
15 %	X	X	9	1



Plates 43 and 44 (above left and right). Placement of samples 1 to 6 in the small climate chamber.
Photo: Swedish National Heritage Board.

Plate 45 (left). Placement of samples 7 to 12 in the large climate chamber.
Photo: Swedish National Heritage Board.

Samples 1 to 6 were placed in the small climate chamber in opened containers together with their respective lids. The samples were initially placed on shelves at different levels within the chamber (Plate 43), but were later shifted to the same shelf (Plate 44).

The temperature and RH levels were varied according to the matrix in table 10 starting with step 1 at 15 % RH and 40 °C and ending with step 12 at 75 % RH and 20 °C.

Samples 7 to 12 were placed in the large climate chamber in opened containers together with their respective lids. The temperature and RH levels were varied according to the matrix in table 11 starting with step 1 at 85 % RH and 15 °C and ending with step 11 at 55 % RH and 30 °C.

Samples 1, 2, 3, 10 and 12 were removed from the study during the experiment. The Petri dish containers used for these samples were of the low and wide plastic type and it was found early on in the experiment that the alum grains had a tendency to migrate out. The alum grains were found to adhere to the inside of the lid, probably due to static electricity, and were subsequently lost when the container was opened and closed. The alum grains also seemed

	15 °C	20 °C	30 °C	40 °C
85 %	1	8	9	X
75 %	2	7	10	
55 %	3	6	11	
35 %	4	5		
15 %	X	X		

Table 11. Steps 1 through 11 for the variation of temperature and RH in the large climate chamber containing samples 7 to 12.

to move out of the low containers as a result of the air currents produced by the fan in the climate chamber. These particular samples were as a result consistently found to loose weight even when they were expected to gain weight.

6.3 Results and Discussion

The weights of the alum samples did not change significantly within the range of relative humidity and temperature investigated. Relative humidity and temperature varied between 15 % and 85 %, and 15 °C to 40 °C, respectively. No change in weight was larger than 1 w%, even after five month intervals between 15 % and 85 % RH, and such a small variation cannot be seen as evidence for an uptake or release of crystal water by the alum salt.

The results from this study show that alum keeps a firm hold of its crystal waters and confirms that it is a very hygroscopic salt, which easily binds its twelve crystal waters. The statement concerning the capacity of alum to exist in a varied number of crystal water states in a wood matrix is therefore questionable and the results appear to challenge the notion that alum is very sensitive to normal variations of relative humidity encountered in a museum.

How alum reacts upon heating and treatment during initial impregnation into an archaeological wood matrix, as well as the effect of aging and interaction with other agents and products needs to be considered further in order to explain why alum treated wood has been found to be sensitive to changes in climate. The more temperature and RH sensitive components are likely the products added as part of the treatment, such as glycerol, or reaction products present in the wood as a consequence of the alum treatment, rather than the alum itself.

7 Nation wide survey of archaeological alum-treated wooden artefacts

7.1 Introduction

A nation wide survey was undertaken in the form of a questionnaire that was sent to a total of 50 Swedish museums. The aim of the questionnaire was to establish the approximate quantity and condition of archaeological alum-treated artefacts on display or in storage in the museums throughout the country. The purpose of the survey was also to gain some idea as to the extent of the need for preventive or remedial measures and to raise awareness within the museum sector for the problems and risks associated with these artefacts and the alum treatment.

7.2 Method

The questionnaire was sent to the 51 museums listed below. The museums considered for the survey were identified from the listings available through Museifönstret (www.museifonstret.se), a data base comprising circa 400 Swedish museums. The selection of the museums included in the survey was made by first identifying those larger institutions, including county or provincial museums, city or larger town museums and national museums, with Swedish archaeological artefacts in their collections. The second stage involved identifying other potential collections of alum-treated artefacts among the smaller town museums and other more local museums. These were contacted by telephone and those with archaeological wooden artefacts in their collections were included in the survey.

The digital-based questionnaire was formulated at the Swedish National Heritage Board using the software Apsis Survey Pro. The questionnaire was preceded by a letter that was sent by e-mail to each museum, presenting a short introduction to the project and describing the purpose of the survey. A selection of pictures showing various typical symptoms of deterioration were included as an aid for identifying and describing the condition of any alum treated wood. The letter also contained a link to the home page for the project and included a short historical description of the alum method.

The questionnaire was addressed to a specific individual at each museum, often the person in charge of the collections, and was open to the respondent for a period of four weeks. After three weeks a reminder was sent out. A final reminder was sent to those who had not yet answered the questionnaire after the fourth week. All the answers were dealt with anonymously. At the end of the survey it was also possible to indicate if the institution wanted to be contacted by a conservator for more information or consultation.

Museums

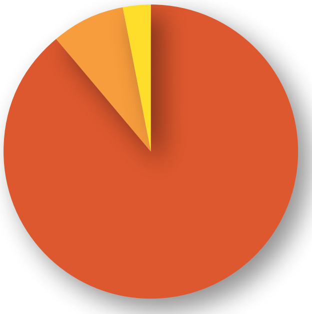
Ajtte
Blekinge museum
Bohusläns museum
Dalarnas museum
Enköpings museum
Eskilstuna stadsmuseum
Gustavianum
Göteborgs stadsmuseum
Helsingborgs museer, Kulturmagasinet
Hälsinglands museum
Jamtli
Jönköpings läns museum
Kalmar läns museum
Kulturen i Lund
Köpings museum
Landskrona museum
LUHM
Länsmuseet Gävleborg
Länsmuseet Halmstad
Länsmuseet på Gotland
Länsmuseet Varberg
Länsmuseet Västernorrland
Lödöse museum
Malmö museer
Norrbottens museum
Norrköpings stadsmuseum
Regionmuseet i Kristianstad
Sigtuna museum
Sjöfartsmuseet i Göteborg
Sjöhistoriska museet
Skellefteå museum
Smålands museum
Statens historiska museum
Stockholms läns museum
Stockholms stadsmuseum
Södermanlands museum
Sövde stadsmuseum
Trelleborgs museum
Upplandsmuseet
Vasamuseet
Värmlands museum
Västerbottens museum
Västmanlands läns museum
Västra Götalands museum
Örebro läns museum
Östergötlands läns museum
Sundsvalls museum
Sölvesborgs museum
Ystads stadsmuseum

7.3 Results

The response value was 70% (36 respondents out of 51 answered) which may be considered high. It was assumed that those who did not answer did not have any alum-treated wood in their collections or alternatively did not have the time or the expertise to answer the questionnaire.

The beginning of the questionnaire contained three questions formulated to determine which of the museums were likely to have alum-conserved wood. The respondents were first asked if they had archaeological wood and secondly if they had alum-treated archaeological wood. Those that responded with a yes or that indicated that they were not sure to the first two questions were allowed to proceed in the questionnaire. Those that responded with a no were excluded from the rest of the questionnaire. The third question was based on the time period that the alum method was in use. Those that responded that they only had archaeological wood from before 1900 or after 1970 were thereby also excluded from the rest of the survey.

1) Do you have archaeological wood in your collections?



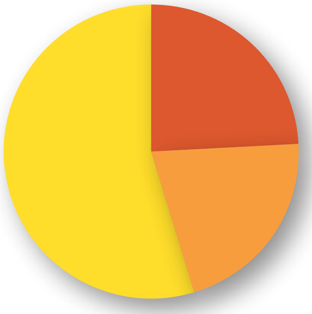
36 responses

🟥 Yes: 88.9 % (32 respondents)

🟧 No: 8.3 % (3 respondents)

🟨 Do not know: 2.8 % (1 respondent)

2) Do you have alum-conserved wood in your collections?



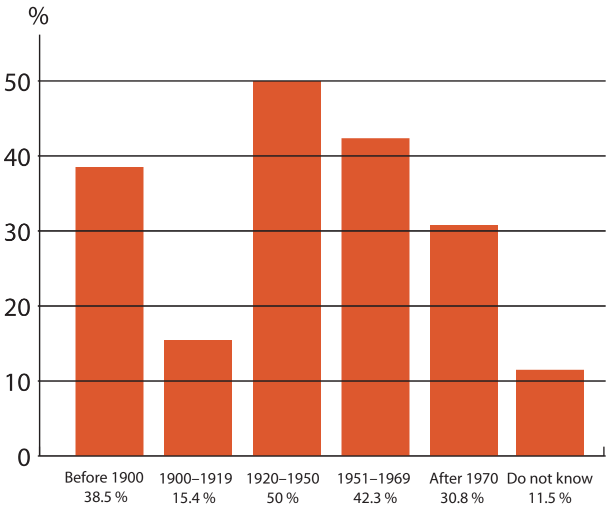
The 33 remaining respondents answered

🟥 Yes: 24.2 % (8 respondents)

🟧 No: 21.2 % (7 respondents)

🟨 Do not know: 54.5 % (18 respondents)

3) During which period/periods did you acquire the archaeological wood?



The 26 remaining
respondents answered

Before 1900:
38.5 % (10 respondents)

1900–1919:
15.4 % (4 respondents)

1920–1950:
50 % (13 respondents)

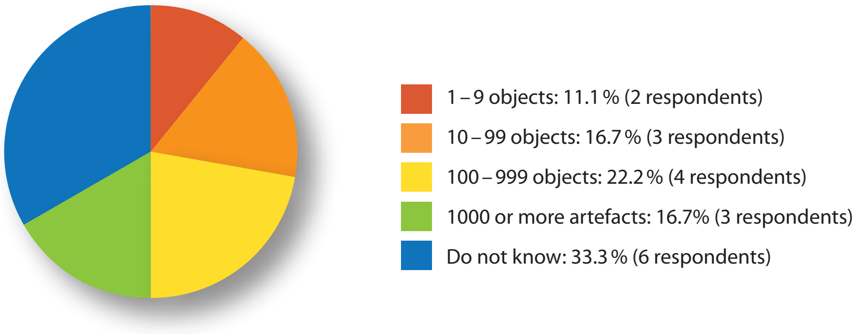
1951–1969:
42.3 % (11 respondents)

After 1970:
30.8 % (8 respondents)

Do not know:
11.5 % (3 respondents)

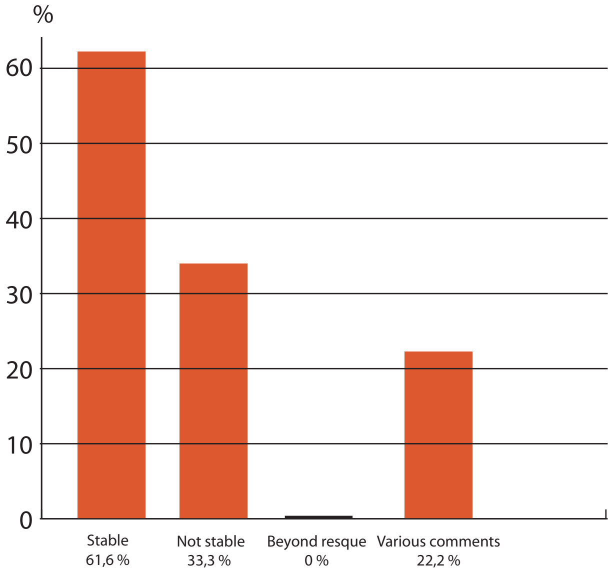
A total of 13 respondents from the remaining 26 indicated that their collections included archaeological wood acquired during the period 1920–1950. Those that stated that their collections included only archaeological wood acquired before 1900 and/or after 1970, when presumably no conservation treatment with alum took place, were excluded from the rest of the questionnaire. Eighteen respondents in addition to the 13 proceeded to answer question four given that a number of respondents also had artefacts between 1900 and 1969 and due to the fact that 3 respondents indicated that they did not know.

4) Approximately how many archaeological wooden artefacts acquired during the period 1920–1950 do you have in your collections?



The remaining 18 respondents were asked to estimate the approximate number of archaeological wooden artefacts acquired during the period 1920–1950 in their respective collections. The minimum total number of artefacts for the 18 museums corresponds to 3432 as calculated by adding together the lower interval values for each pie segment. The total real value is however difficult to estimate from the questionnaire given that three museums indicated that they had more than 1000 artefacts from the time period when alum conservation was most predominant and as many as six were not able to give an estimate.

5) How would you describe the condition of your archaeological wooden artefacts in general?

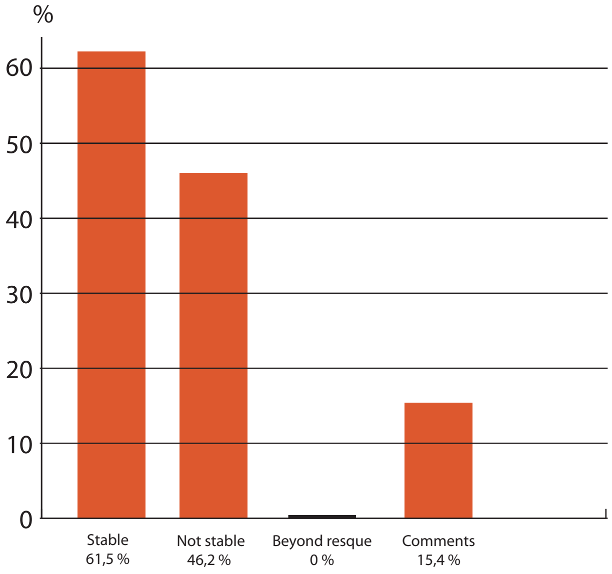


The remaining 18 respondents answered:

Stable: 61.1 %
Not stable: 33.3 %
Various comments: 22.2 %
- No inventory has been carried out
- It varies. Mostly OK
- Concerning the alum-conserved wood. We have no real control
- In general it looks flaky

No one, however, has described the wood as being "beyond rescue".

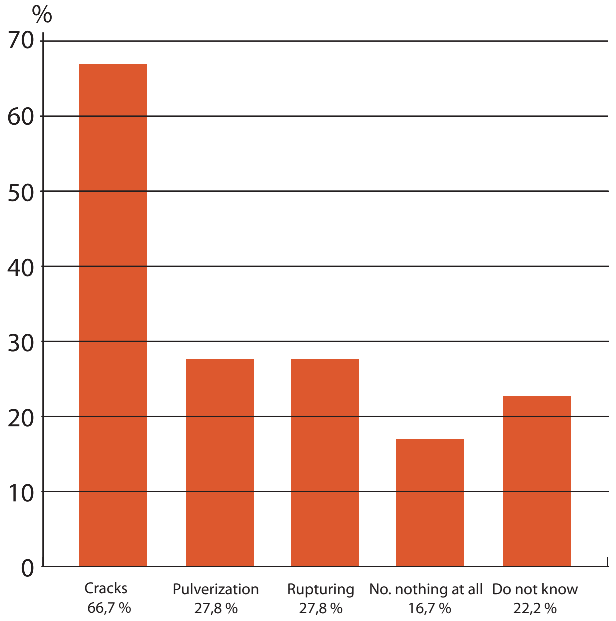
6) How would you describe the over-all condition of the archaeological wooden objects acquired during the period 1920–1950?



13 respondents:
Stable: 61.5 %
Not stable: 46.2 %
Beyond rescue: 0 %
Comments: 15.4 %

The majority of respondents (61.5 %) consider their archaeological wood from the period where the alum conservation method predominated (1920-1950) as stable. Another 46.2 % on the other hand considered them to be "not stable". Compared with the 33.3 % stating "not stable" in the previous question for the "condition of all archaeological wooden artefacts in general" it can be concluded that artefacts from this time period are accordingly rated as somewhat more unstable.

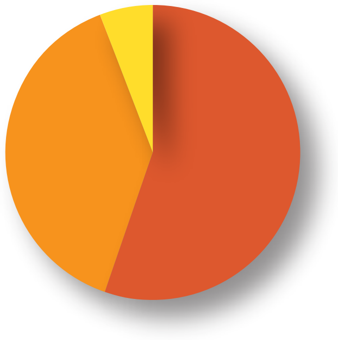
7) Do the archaeological wooden objects acquired during the period 1920–1950 show any of the following traits?



18 respondents:
Cracks: 66.7 %
Pulverization: 27.8 %
Rupturing: 27.8 %
No. nothing at all: 16.7 %
Do not know: 22.2 %

It was possible to indicate the presence of more than one type of damage within the overall collection in question. Relatively few artefacts (16.7 %) were perceived as being without any type of damage. This question does not allow for any quantitative evaluation since the answer only indicates the presence of damage not the number of artefacts affected.

8) Do you keep your archaeological wood in climate controlled storage areas?



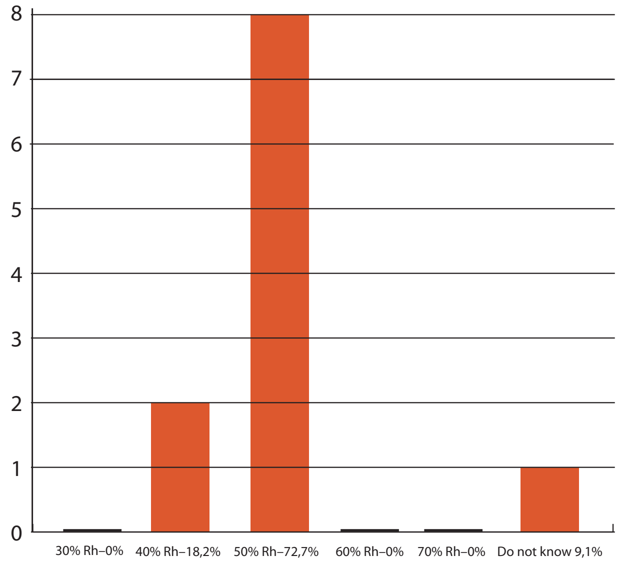
18 respondents:

🟥 Yes: 55. 6 % (10 respondents)

🟧 No: 38.9 % (7 respondents)

🟨 Do not know: 5. 6 % (1 respondent)

9) What is the average relative humidity in the storage area where most of the archaeological wooden artefacts are kept?



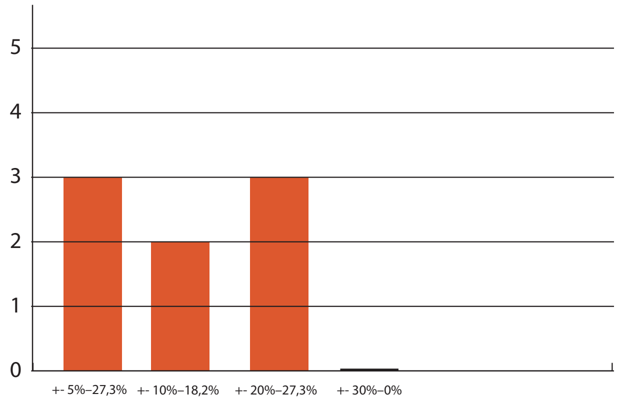
11 respondents

40 % – 18.2 %
(2 respondents)

50 % – 72.7 %
(8 respondents)

Do not know: 9.1 %
(1 respondent)

10) How much does the relative humidity vary throughout the year in the storage area where most of the archaeological wooden artefacts are kept?



11 respondents

+/-5 % – 27.3 %
(3 respondents)

+/-10 % – 18.2 %
(2 respondents)

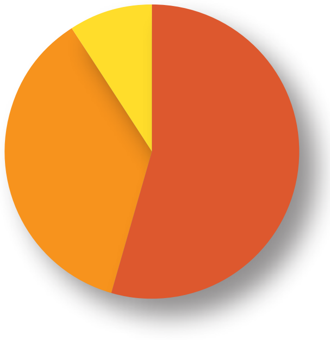
+/- 20 % – 27.3 %
(3 respondents)

+/-30 % – 0 %
Do not know
27. 3 % (3 respondents)

The yearly range in relative humidity varied between a very acceptable low level for 27 % of the storage areas to fairly high unsatisfactory level for another 27 % of the respondents. It is also notable that as many as 27 % of the respondents did not know how much the relative humidity varied.

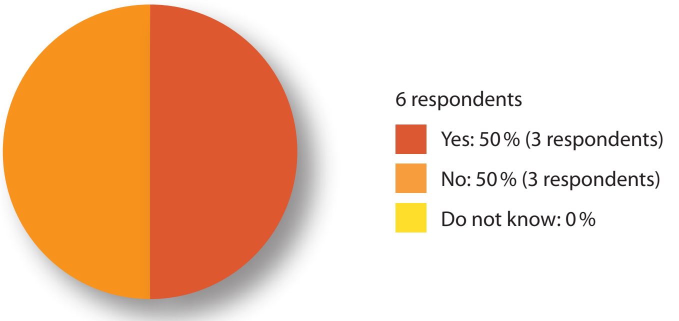
The survey also looked at the correlation between the answers to the questions regarding the general stability of the archaeological wood (stable or not stable) and whether collections were kept in climate controlled areas or not.

11 a) Is your archaeological wood kept in a climate-controlled storage area?
Response as given by those that responded stable in reference to the general stability to their archaeological wooden artefacts?



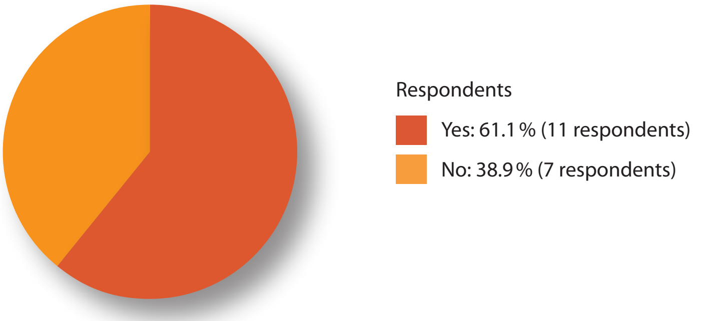
11 respondents
🟥 Yes: 54. 5 % (6 respondents)
🟧 No: 36.4 % (4 respondents)
🟨 Do not know: 9.1 % (1 respondent)

11 b) Is your archaeological wood kept in a climate-controlled storage area?
Response as given by those that responded unstable in reference to the general stability to their archaeological wooden artefacts?



A somewhat greater percentage of those who answered that their archaeological wood artefacts were "stable" also stored their archaeological wood in climate controlled storage areas.

12) Are you already familiar with the problems connected with alum-conserved archaeological wood?



Eleven of the 18 respondents answered that they were already familliar with the problems assciated with alum-treated wood.

The final question posed in the survey asked if the museum would like to be contacted by a conservator from the Swedish National Heritage Board regarding alum-treated wood and the difficulties associated with it. Seven respondents stated that they were interest in such contact. Four respondents, in spite of not being familiar with the problems inherent to alum-treated wood, indicated that they were not interested.

7.4 Summery and conclusion

The percentage of recipients that responded to the questionnaire was 70 % (36 out of 51 recipients). In spite of the high percentage of answers, the number might still be considered too small for a general assessment. Certain tendencies can however be discerned. It may be concluded that there exists some awareness of the problems regarding alum-conserved wood. Out of 33 respondents, 8 state that they possess alum-treated wood in their collections, 7 claim that they do not, and 18 indicate that they do not know. The fact that as many as 18 respondents state that they do not know, suggests also some degree of uncertainty in terms of having the necessary ability to recognize alum-treated wood. With regard to the question concerning the general assessment of the condition of the archaeological wood, 61.1% answered “stable”, while 33.3 % indicated “not stable”. None of the respondents judged any artefacts in their collections as “beyond rescue”. These results, it should be noted, depend on the respondent’s level of knowledge for evaluating the collections and how comprehensive such a survey or assessment has been.

Taking into consideration the storage and general preservation conditions for the collections it can be noted that those who answered “stable” with reference to the general assessment of the condition of the archaeological wood, more often seem to be keeping the wood in climate controlled storage areas.

An estimate from the survey of the number of possible alum-conserved artefacts yields at least 3432 artefacts, or 4945 artefacts when applying a mean value per segment. Since the second largest segment represents 1000 or more objects, the total number of artefacts is likely to be much higher.

One of the main purposes with this survey was to draw the attention of the museums to the problems connected with alum-conserved wood. Of the 36 museums which chose to participate, 18 remained at the end. Out of those, 61 % stated that they know about the alum problem and 39 % that they do not know. The questionnaire included photographs of damaged wooden objects, which will now hopefully make it easier for museums to recognize alum-treated wood in their collections so that care can be taken for proper storage, and so that artefacts in need of re-conservation can be identified. It is obvious that museums in general are in a great need of more information on this subject and that it is important to develop guide-lines for identifying alum treated artefacts, and for providing proper storage.

8 Presentations

8.1 Oral presentations

- March 25, 2004. Project presented to STFI and Trätek.
- December, 2005. Project presented to the staff of the Vasa Museum.
- June, 2006. Information presented to 150 museum visitors during two days at The Swedish History Museum in connection with the inventory of objects from the Årby grave within the Viking exhibition.
- September 11–13, 2006. Paper (Saving alum-treated archaeological wood – report form a research project underway) presented at the Alum Meeting of the 3rd Triennial Conservation Conference at Northumbria University, New Castle.
- November, 2006. Presentation given at the SVK (Studio of the Western Sweden Conservators Trust) conference, Fynden i fokus (Finds in Focus), Gothenburg.
- September, 2008. Poster and pamphlet presented at the ICOM-CC conference, 15th Triennial Meeting in New Delhi, India. Results were presented from evaluation of chemical analysis data and the correlation between pH and deterioration with other added conservation materials in addition to alum.
- April 24–25, 2009. Project presented at the Scandinavian Alum Seminar at the Museum of Cultural History, University of Oslo together with colleagues from the National Museum of Denmark and the Technical University of Denmark.
- The progress of the project has been presented internally at both the National Heritage Board of Sweden and The Swedish History Museum.
- Under its duration the project has been presented at several occasions in connection with educational visits to various conservation laboratories.

8.2 Periodicals

- *Object of the Month*, Museum of National Antiquities, June 2004, by Ulrik Skans.

8.3 Poster and other printed matter

Poster and a brochure presented at the ICOM-CC conference, 15th Triennial Meeting in New Delhi, India, September 2008. Results were presented from evaluation of chemical analysis data and the correlation between pH and deterioration with other added conservation materials in addition to alum

The off-print of *Saving Alum-treated Archaeological Wood – Report from a Research Project Underway* was distributed at the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam and at the conference *Fynden i fokus (Finds in Focus)* at SVK, Studio of the Western Sweden Conservators Trust, in Gothenburg 2006.

8.4 Digital publications

A progress report (*Saving alum-treated archeological wood. Report from a research project underway, 2006*) of the project is published on the home page of the Swedish National Heritage Board where a description of the project is also available.

A short description of the project from 2004 is presented at the home page of Para Tech Coating: http://www.hpetch.se.web2.shared.songnetworks.se/paratech/riksantikvariet/index.html.

8.5 International contacts, meetings and educational visits

- May 2003. Visit to the Museum of Cultural History, University of Oslo and the Viking Ship Museum to discuss alum deterioration and to look at alum-treated objects from the Oseberg ship. Plans were discussed for future cooperation with archaeological conservators Nancy Child and Susan Braovac and chemist Evabeth Aastrup involved in an on-going project looking at similar problems with alum.
- January 2004, educational visit to conservator Kristiane Straetkvern at the Conservation Department in the National Museum of Denmark.
- March 25th 2004, meeting with STFI and TRÄTEK (Swedish Institute for Wood Technology Research).
- May 2004, Stockholm was visited by two conservators from the University Museum of Cultural Heritage in Oslo for exchange of experiences related to problems with alum-treated wood.
- June 2004. ICOM-CC, WOAM conference in Copenhagen. Four project members took part in a meeting with conservators from the National Museum of Denmark and the University Museum of Cultural Heritage in Oslo, concerning a future joint Scandinavian project regarding archaeological alum-treated wood.

- 2005. Meeting with archaeological conservator Emily Williams, Colonial Williamsburg Foundation, Virginia, USA, for the purpose of exchanging knowledge and experience concerning the classification of alum conserved woood, and for establishing a future network for information and cooperation.
- April 2009. Meeting regarding the alum problems in Oslo with participants from University of Oslo, the National Museum of Denmark and the Technical Museum of Denmark.
- June 2009, meeting with STFI and TRÄTEK (Swedish Institute for Wood Technology Research) concerning possible future cooperation.
- Exchange of knowledge and experience via e-mail with David Grattan, Senior Conservation Scientist, Canadian Conservation Institute (CCI), Canada and archaeological conservator Clifford Cook, Parks Canada, Canada.

8.6 Workshops

- September 21, 2006. Workshop on desalination and freeze-drying with representatives from the Vasa Museum.
- November 17, 2008. Workshop for the evaluation of re-conservation results for Vat 2, small objects, with present and previous project members.
- September 29th 2009, Workshop for the evaluation of re-conservation results for Vat 1, large objects, with present and previous project members.

8.7 Participation in courses and conferences

- November 2003. Participation by three project members at the conference; Archaeological Conservation in Gothenburg, organized by Studio of the Western Sweden Conservators Trust (SVK).
- June 2004. Participation by four project members at the 9th ICOM Group on Wet Organic Archaeological Materials, Copenhagen. Plans for a joint Scandinavian project looking at archaeological alum-treated wood was presented and discussed at the National Museum of Copenhagen.
- Autumn 2004. Three project members attended a course dealing with PEG (polyethylene glycol) impregnation and freeze-drying of waterlogged organic material, led by Senior Researcher Poul Jensen, Conservation Department of the National Museum of Denmark and Conservator Lars Møller Andersen, Viborg Amts Konserveringsværksted (Viborg County Conservation Laboratory), Denmark.
- Spring 2005. Three project members attended the course Wood Chemistry and Wood Biotechnics at KTH (Royal Institute of Technology), department of Fibre and Polymer Technology.

- 2005. Participation at the conference, The Conservation of Archaeological Materials: Current Trends and Future Directions at Colonial Williamsburg Foundation, USA.
- May 9–11, 2007. Participation at the Salt Damage Congress in Ghent, Belgium.
- September 10–15, 2007. Participation at the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam.
- September 19, 2008. Presentation at the ICOM-CC, 15th triennial conference in New Delhi.
- October 7–10, 2009. International Conference on Wooden Cultural Heritage, COST (European Cooperation in Science and Technology), Action IE-0601 Wood Science for Conservation of Cultural Heritage. Co-author (Tom Sandström) to article *The Use of an Electric Field for the Removal of Alum from Treated Wooden Objects,* Iben Christensen et al.
- November 16–20, 2009. Participation by one member at the International Training School on Advanced Radiographic Methods in Wood Research, (ADRAM-09) COST-Action IE-0601 at the Paul Scherrer Institute (PSI), Switzerland. Analyses of wood samples and presentation of the project.

8.8 Questionnaire

A survey was formulated and sent to 51 Swedish museums with questions concerning quantity and condition of archaeological alum-treated wood.

9 Acknowledgements

The authors wish to thank Ulf Lindborg, D. Tech and former Head of the Conservation Department at the Swedish National Heritage Board, for advice and support in connection with the initiation of the project; Annica Ewing, Senior Curator, and Ulrik Skans, Senior Conservator, at The Swedish History Museum in Stockholm for their enthusiasm, interest and valuable information and participation; The Swedish History Museum in Stockholm for supplying the project with the archaeological material necessary for the re-conservation pilot study; and the Research & Development Programme at the Swedish National Heritage Board for financial support. Special thanks also to Anders Nord and Kate Tronner for help with FTIR analysis and to Eva Christensson and Maria Rossipal for valuable assistance with the text.

10 References

10.1 Bibliographic references

Eds: Alkærsig, Ole, Garff, Jan & Lundbæk, Morten; Jespersen, Kirsten, *Jord- og Vandfundet Træ*, Bevarings Håndbogen, Statens Museumsnævn, Copenhagen, pp 128–134, 1986.

Arbman, Holger, *The Årby-Fund*, Acta Archaeologica, Vol. XI, Copenhagen, pp 43–101, 1940.

Björdahl, C. G., *Waterlogged Archaeological Wood, Biodegradation and its implications for conservation*, Swedish University of Agricultural Sciences, Uppsala, 2000.

Braovac, S., *An evaluation of the Condition of the Viking Age Collections at the Viking Ship Museum, part I: Objects on display in the Fourth Wing*, unpublished, 2001; a summarized version published in: Alf Bøe (ed.), Viking Ship Seminar, University of Oslo, Oslo, pp 59–68, 2002.

Ed: Bøe, Alf; Bonde, Niels, Hoffman, Per & Schwab, Eckhart, *Report on the Strength Tests Performed on Wood Samples from the Gokstad Ship and Boats, and from the Oseberg Finds Complex; and Some Observations on Strakes from the Gokstad, Oseberg, and Tune Ship*, Viking Ship Seminar, University of Oslo, Oslo, pp 71–85, 2002

Canadian Conservation Institute (CCI) Homepage, Amazing Facts, Preserving My Heritage, The Parylene Project, An Update, available at http://www.cci-icc.gc.ca/publications/cidb/view-document_e.aspx?Document_ID=105 (2006-05-10).

Christensen, B. Brorson, *Om Konservering af Mosefundne Trægenstande*, Aarbøger for Nordisk Oldkyndighed og Historie 1950, Nordisk Forlag, Copenhagen, pp 22–55, 1951.

Christensen, B. Brorson, *The Conservation of Waterlogged Wood in the National Museum of Denmark*, The National Museum of Denmark, Copenhagen, 1970.

Cronyn, J. M., *The Elements of Archaeological Conservation*, Routledge, London, 1990.

Eds: Crumlin- Pedesen, Ole & Trakadas, Athena; Bojesen-Koefoed, Inger, M., Stief, Maj & Sørensen, John, N., *Hjortspring, a Pre-Roman Iron-Age Warship in Context, Ships and Boats of the North*, Vol. V, The Viking Ship Museum, Roskilde, pp 44-53, 2003.

Eaton, John, W. *The Preservation of Wood by the Alum Process*, Florida Anthropologist, Vol. V, No. 4, pp 115–117, 1962.

Ed: Fjæstad, Monika; Björdal, Charlotte, *Tidens Tand*, Swedish National Heritage Board, Stockholm, pp 113–127, 1999.

Grattan, David, W. & Bilz, Malcom, *The Thermal Aging of Parylene and the Effect of Antioxidant*, Studies in Conservation 36, pp 44–52, 1991.

Greenwood, N. N. & Earnshaw, A., *Chemistry of the Elements* 2nd Edition, Butterworth-Heinemann, Oxford, 1997.

Ed: Grimshaw, Kirsten; Grattan, David, W., *Parylene at the Canadian Conservation Institute- An Initial Survey of Some Applications*, Preprints ICOM Committee for Conservation Conference 9th Triennial Meeting, ICOM-CC, Los Angeles, pp 551–556, 1990.

Ed: Grosso, Gerald H.; Barkman, G. Lars; Bengtsson, Sven; Håfors, Birgitta & Lundvall, Bo, *Processing Waterlogged Wood*, Pacific Northwest Wet Site Wood Conservation Conference, Vol. I, Neah Bay, Washington, pp 17–23, 1976.

Herbst, Christian Fredrik, *Om Bevaring av Træ fundne i Törvemoser*, Antikvarisk Tidskrift 1858–1860, pp 174–176, 1861.

Horie, C.V., *Materials for Conservation*, Butterworth-Heinemann, Oxford, 1987.

HP Etch Homepage, Para Tech Coating Scandinavia AB, What is Parylene, Update Apr. 2004. Tillgänglig på http://www.hpetch.se/paratech/whatis.html (2006-08-29)

Hutchings Jeremy, The properties of Alum. Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam pp 589–614, 2009.

Hägg, Gunnar, *Allmän och oorganisk kemi*, Almqvist & Wiksell, Uppsala, 1989.

Jensen, Jørgen; Nørlem, Sørensen, John; Rieck, Flemming & Steif, Aistrup, Maj, *Hjortspringbåden genopstillet*, Nationalmuseets Arbejdsmark 1989, Nyt Nordisk Forlag Arnold Busck A/S, Copenhagen, pp 101–113,1989.

Jensen, Poul., Frysetørring, Imprægnering af vanddrukkent træ med PEG, Grafiske metoder til beregning af imprægneringstider, Kurskompendium från Frystorkningskurs 1–3 nov. 2005, arrangerat av Studio Västsvensk Konservering, Göteborg, unpublished.

Kopperud, Gunhild, K., *Alunkonservering av Vasstrukkent Tre*, BSc Thesis, The School of Conservation, The Royal Danish Academy of Fine Arts, Copenhagen, 1992.

Ed: in chief: Lide, David R., *Handbook of Chemistry and Physics*, CRC Press, Boca Raton, 1998–1999.

Moss, A.A. *The Presevation of a Saxon Bronze-Bound Wooden Bucket with Iron Handle*, Museums Journal, Vol. 52, pp 175-177, 1952.

Olsson, Gillis, *Om Konservering av Träföremål*, Emil Kihlströms Tryckeri A-B, Stockholm, 1934.

Paterakis, A. Boccia, *The Deterioration of Ceramics by Soluble Salts and Methods for Monitoring their Removal*, Recent Advances in the Conservation and Analysis of Artefacts, pp 67-72, 1987.

Ed: Paterakis, Alice, Boccia; Paterakis, Alice, Boccia *The Desalination of Consolidated Ceramics*, Glass, Ceramics and Related Materials, Interim Meeting of the ICOM-CC Working Group, EVTEK, Vantaa, pp144-153, 1998.

Ringgaard, Maj, *Hjortspringfundet - Historien om den Gamle Konservator Gustav Rosenbergs Utgravnings- og Konserveringsmetoder*, Meddelelser om Konservering, IIC Nordic Group, pp111-121,1989.

Rosenberg, George, A. *The Preservation of Antiquities of Organic Material*, The Museums Journal, Vol. 33, pp 432-437, 1934.

Eds: Rowell, Roger M. & Barbour, James; Peterson, Curtis, E. *New Directions in the Conservation of Archaeological Wood*, Archaeological Wood; Properties, Chemistry and Preservation, American Chemical Society, Washington DC, pp 433-449, 1990.

Eds: Roy, Ashok & Smith, Perry; Lilja Jensen, Eva, Salomonsen, Eva & Strætkvern, Kristiane, *From a Waterlogged Site to the Archaeologist's Desk- New Packing Methods with a Minimum of Handling*, Preprints Archaeological Conservation and its Consequences, Copenhagen 1996, IIC, London, pp 89-93, 1996.

Sandström, T. & Straetkvern, K., *Gjennomgang av utvalgte alunkonserverte gjenstander i magasin VHS,* Vikingeskibsmuseet, Bygdøy, 2005, unpublished.

Specialty Coating Systems (SCS) Homepage, Parylene Knowledge, Specifications & Properties, Update Oct. 2003, Tillgänglig på

<http://www.scscoatings.com/parylene_knowledge/specifications.cfm (2006-08-29)

Wilson, K., *Survey of an Archaeological Wood Collection*, Colonial Williamsburg Foundation Virginia, 1999, unpublished.

10.2 Archival references

Aktiebolaget Alfort & Cronholm, Tender of 700 kg alum and 120 kg glycerine, Stockholm, 21 April 1937, to The Museum of National Antiquities, Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

Aktiebolaget Wilhelm Becker, Tender of 700 kg alum and 120 kg glycerine, Stockholm, 21 April 1937, to The Museum of National Antiquities, Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

Konserveringsmissiven 1931–1958, Archival boxes BI: 1–5, Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

Kungliga Byggnadsstyrelsen , P.M. över leverans och uppsättning av alunkokare, urlakningsapparat, 2 st. paraffinkokare för kokrum nr 38 samt destillationsapparat uti konserveringsflygeln vid statens hisoriska museum, 1936, Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

Lagergren, Nils, Photographs in black and white with pencil notes on the re-treatment of alum conserved wood from Ha. Övreby sn., Kärringsjön and Up. Lagga sn**.,** Mora Äng, 1964, The Museum of National Antiquities, Stockholm.

Lindahl, Karin & Ozola, Ieva, Unpublished report: Rapport gällande bistånd till konservering av museiföremål i Riga, Lettland, Swedish National Heritage Board, Diarienummer 819-1824-1995, 1995.

Tekniska avdelningen, The Museum of National Antiquities, Boiling list, Diarienummer 1642/25, Gödåker, 1925, Antiquarian Topographical Archive, Swedish National Heritage Board, Stockholm.

10.3 Verbal information/Correspondence

Bojesen-Koefoed, Inger, M. & Strætkvern, Kristiane, archaeological conservators, verbal communication on visit to The National Museum of Denmark, January 2004.

Gaismina, Sarmite, Director of the Conservation Centre of the History Museum of Latvia, personal correspondence, 1998.

Gaismina, Sarmite, Director of the Conservation Centre of the History Museum of Latvia, personal correspondence, 2003.

Skans, Ulrik, Senior Conservator at the National Antiquities Museum in Sweden, e-mail correspondence, 2006.

Jensen, Poul, Senior Scientist at the National Museum of Denmark, e-mail correspondence, 2006.

Notes

1. Björdahl, 2000, pp 30–31
2. Björdahl, 2000, pp 31–32
3. Björdahl, 2000, p 28. Cronyn, 1990, p 254
4. Greenwood & Earnshaw, 1997, p 216. Hägg, 1989, p 612
5. Handbook of Chemistry and Physics, 1999, pp 4–77
6. Christensen, 1970, pp 13–14. Herbst, 1861, pp 174–175
7. Herbst, 1861, p 175
8. Christensen, 1970, p 17
9. Rosenberg, 1934, pp 432–435. Christensen, 1950, pp 28–29
10. Christensen, 1970, pp 19–20
11. Tekniska avdelningen, The Museum of National Antiquities, 1925, Boiling list
12. Kungliga Byggnadsstyrelsen, 1936, P.M.
13. Aktiebolaget Wilhelm Becker, 1937, Tender of 700 kg alum and 120 kg glycerine. Aktiebolaget Alfort & Cronholm, 1937, Tender of 700 kg alum and 120 kg glycerine. Olsson, 1934, pp 4–5
14. Olsson, 1934, p 4
15. Moss, 1952, p 53. Eaton, 1962, p 116. Wilson, 1999
16. Christensen, 1950, p 30
17. Christensen, 1970, p 16
18. Christensen, 1970, p 20. Peterson, 1990, p 442, in: Rowell et al. (eds.)
19. Christensen, 1970, p 20
20. Ringaard, 1989, pp 118–120
21. Christensen, 1970, p 16
22. Christensen, 1970
23. Kopperud, 1992, p 97, 104, 109, 123
24. Kopperud, 1992, p 132
25. Bonde et al., 2002, pp 71–85, in: Bøe, A. (ed.)
26. Jespersen, 1986, p 130, in: Alkærsig et al. (eds.)
27. Björdahl, 1999, p 125, in: Fjæstad, M. (ed.), chapter: Trämaterial– historiskt och arkeologiskt.
28. Kopperud, 1992
29. Kopperud, 1992, pp 130–131
30. Kopperud, 1992, p 134
31. Hutchings, 2009
32. Lagergren, 1964
33. Barkman, 1976, p 19, in: Grosso, G. H. (ed.)
34. Bojesen-Koefoed & Straetkvern, 2004. Lindahl & Ozola, 1995. Gaismina, 1998 & 2003
35. Bojesen-Koefoed et al., 2003, p 44, in: Crumlin– Pedesen et al.(eds.), chapter: New Conservation and Display. Jensen et al., 1989, pp 102–103
36. Bojesen-Koefoed & Straetkvern, 2004. Lindahl & Ozola, 1995. Gaismina, 1998 & 2003
37. Bojesen-Koefoed & Straetkvern, 2004
38. Canadian Conservation Institute, 2006
39. Grattan, 1990, p 551, in: Grimshaw, K. (ed.). Grattan & Bilz, 1991, p 44
40. Tekniska avdelningen, The Museum of National Antiquities, 1925, Boiling list
41. Christensen, 1950, p 29. Konserveringsmissiven 1931 – 1958, Archival boxes BI: 1–5
42. Skans, 2006
43. Ibid

44. Wilson, 1999, p 3
45. Braovac, 2001, p 24
46. Braovac, 2001, p 25
47. Sandström & Straetkvern, 2005
48. Wilson, 1999, pp 6–7. Braovac, 2001, pp 18–19. Sandström & Straetkvern, 2005 pp 5–7
49. Aktiebolaget Alfort & Cronholm, 1937. Aktiebolaget Wilhelm Becker, 1937.
50. Konserveringsmissiven 1931 – 1958, Archival boxes BI: 1–5
51. Ibid
52. Sandström & Straetkvern, 2005, p 7
53. Ibid
54. Aktiebolaget Wilhelm Becker, 1937, Tender of 700 kg alum and 120 kg glycerine Aktiebolaget Alfort & Cronholm, 1937, Tender of 700 kg alum and 120 kg glycerine
55. Bojesen–Koefoed & Straetkvern, 2004. Lilja Jensen et al., 1996, pp 90–91, in: Roy et al. (eds.)
56. Horie, 1987, p 107
57. Horie, 1987, p 106
58. Paterakis, 1998, pp 150–151, in: Paterakis A. B. (ed.)
59. Specialty Coating Systems, 2006
60. HP Etch, 2006
61. Paterakis, 1987, p 71
62. Paterakis, 1987, p 72
63. Jensen & Schnell, 2004, in: Hoffman et al. (eds.)
64. Jensen, 2006
65. Jensen, 2005
66. Lagergren, 1964
67. Handbook of Chemistry and Physics, 79th edition, 1998–1999
68. Kopperud, Gunhild (1992) Alunkonservering. Undersøkelse av materiale fra Viemose-, Hjortespring– og Osebergfunde

11

Appendix 1–8

Appendix 1

Condition survey comparison before and after re-conservation

No	**1**	**2**	**3**	**4**	**5**
Fid No.	262855	262856	118012	262857	262858
SHM No.	-99	-99	22028	-99	-99
Province	Gotland	Gotland	Skåne	Gotland	Gotland
Parish	Tingstäde	Tingstäde	Vallby	Tingstäde	Tingstäde
Site	Bulverket	Bulverket	Glimmingehus	Bulverket	Bulverket
Object	Dowel	Board	Trough	Stick	Log
Original alum conservation from written records	No information	No information	Alum- boiling	No information	No information
Result SEM	Alum	Alum	Alum	Alum	Alum
Result FTIR	Alum + glycerol	Alum + glycerol	Alum	Alum + glycerol	Alum + glycerol
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyethylene netting/polyester wadding + heated water	Polyethylene netting/polyester wadding + room temperature water	Polyolefin film/polyether foam + room temperature water	Polyethylene netting/polyester wadding + room temperature water	Polyolefin film/polyether foam + room temperature water
Vacuum treatment in connection with alum extraction	No	No	Yes, parts of	yes	No
Analyzed elements from the first extraction bath	Analysis not carried out	Analysis not carried out	Sulphate + carbohydrates	glycerol + sulphate + butandiol + carbohydrates (fragments of)	Analysis not carried out
Longitudinal cracks, condition survey, before re-conservation	Few	Few	Several	Several	Several
Longitudinal cracks after re-conservation	Several	Several	Several	Several	Several
Transversal cracks, condition survey, before re-conservation	Few	Few	Few	Several	Few
Transversal cracks after re-conservation	None	Several	Several	Several	Several
Break, condition survey, before re-conservation	No	Yes	Yes	Yes	No
Break, after re-conservation	No	Yes	Yes	Yes	No
Flaking surface, condition survey, before re-conservation	None	None	None	Extensive	Some
Flaking surface after re-conservation	None	Some	Some	Extensive	Some
Pulverization, condition survey, before re-conservation	No	No	No	Yes	Yes
Pulverization after re-conservation	No	No	No	No	No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes	Yes	Yes
Salt precipitation after re-conservation	No	No	No	No	No
Class, condition survey, before re-conservation	2	2	3	4	4
Class after re-conservation	3	3	3	4	3
General impression, condition survey, before re-conservation	Dry, crumbly	Dry, well preserved	Very dark	Dry, crumbly	Dry, crumbly
General impression after re-conservation	Good	Very good	Good	Not so good, surface unstable	Not so good
pH-value, surface, condition survey, before re-conservation	3	4	1	2	2
pH-value, surface, after re-conservation, RO-water (tap water)	5(7)	5 (7)	5 (7)	6 (7)	5 (7)

Appendix 1

Condition survey comparison before and after re-conservation

No	6	7	8	9	10
Fid No.	262859	262861	263053	263054	263055
SHM No.	23159	21107	22028	22028	22028
Province	Halland	Lappland	Skåne	Skåne	Skåne
Parish	Övraby	Jukkasjärvi	Vallby	Vallby	Vallby
Site	Käringsjön	Valkijärvi	Glimmingehus	Glimmingehus	Glimmingehus
Object	Handle	Oar handle	Dowel	Plank	Corf
Original alum conservation from written records	No information	No information	Alum-boiling, oil impregnation	Alum-boiling, oil impregnation	Alum- boiling
Result SEM	Alum	Alum	Alum	Alum	Alum
Result FTIR	alum + wax emulsion	Alum + wax emulsion	No analysis carried out	Alum	Alum + glycerol
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/ room temperature water	Paraloid B72 10% in ethanol (w/v) + heated water	Polyolefin film/ polyether foam + heatedwater	Polyolefin film/polyether foam + heated water	Polyethylene netting/ polyester wadding + room temperature water	No support + room temperature water
Vacuum treatment in connection with alum extraction	No	Yes	No	No	No
Analyzed elements from the first extraction bath	Analysis not carried out	Analysis not carried out	Glycerol + sulphate + carbohydrates + organic diacids (C8, C9)	Glycerol + sulphate + fatty acids + carbohydrates (fragments of)	Analysis not carried out
Longitudinal cracks, condition survey, before re-conservation	Several	Several	Few	Few	None
Longitudinal cracks after re-conservation	Few	Few	Several	Several	None
Transversal cracks, condition survey, before re-conservation	Few	None	Few	Several	None
Transversal cracks after re-conservation	None	None	Few	Several	Several
Break, condition survey, before re-conservation	No	No	No	No	No
Break, after re-conservation	Yes	Yes, small piece has become detached	Yes, small piece has become detached	No	No
Flaking surface, condition survey, before re-conservation	Some	Some	Some	Some	None
Flaking surface after re-conservation	None	Some	Some	Some	None
Pulverization, condition survey, before re-conservation	Yes	Yes	No	No	No
Pulverization after re-conservation	No	No	No	No	No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes	Yes	Yes
Salt precipitation after re-conservation	No	No	No	No	No
Class, condition survey, before re-conservation	4 (mean value)	4	3	3	1
Class after re-conservation	2	3	3	3	3
General impression, condition survey, before re-conservation	Dry, crumbly	Very dark, waxy surface	Very dark	Very dark	Very dark
General impression after re-conservation	Not so good	Surface has turned white	Not so good, support material discoloured, dark, degraded	Flakes stuck in support material	Very good
pH-value, surface, condition survey, before re-conservation	1 (mean value)	3	3	3	3
pH-value, surface, after re-conservation, RO-water (tap water)	5 (7)	4 (7)	5 (7)	5 (7)	5 (7)

Appendix 1

Condition survey comparison before and after re-conservation

No	11	12	13	14	15
Fid No.	263056	263057	263058	263059	263060
SHM No.	-99	-99	-99	-99	-99
Province	Gotland	Gotland	Gotland	Gotland	Gotland
Parish	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde
Site	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket
Object	Dowel	Stick	Plank	Part of stick	Part of stick
Original alum conservation from written records	No information	No information	No information	No information	No information
Result SEM	Alum	Alum	Alum	Alum	Alum
Result FTIR	Alum + glycerol	Alum + glycerol	Alum + glycerol	Alum + glycerol	Alum + glycerol
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyolefin film/polyether foam + heated water	Polyethylene netting/polyester wadding + heated water	Polyolefin film/polyether foam + room temperature water	N Parylene 10 µ + heatedwater	N Parylene 17 µ + heated water
Vacuum treatment in connection with alum extraction	No	No	Yes	No	No
Analyzed elements from the first extraction bath	Analysis not carried out	Glycerol + sulphate + carbohydrates	Analysis not carried out	Glycerol + sulphate + carbohydrates	Glycerol + sulphate + carbohydrates
Longitudinal cracks, condition survey, before re-conservation	Several	Few	Several	Several	Several
Longitudinal cracks after re-conservation	Several	None	Several	Several	Several
Transversal cracks, condition survey, before re-conservation	Few	Few	Few	Several	Several
Transversal cracks after re-conservation	Few	None	None	None	Several
Break, condition survey, before re-conservation	No	No	No	No	No
Break, after re-conservation	No	No	No	No	No
Flaking surface, condition survey, before re-conservation	Some	Some	Extensive	Extensive	Extensive
Flaking surface after re-conservation	Some	None	Some	None	None
Pulverization, condition survey, before re-conservation	Yes	Yes	Yes	Yes	Yes
Pulverization after re-conservation	No	No	No	No	No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes	Yes	Yes
Salt precipitation after re-conservation	No	No	No	Difficult to assess, salt crystals might sit under the Parylene layer	Difficult to assess, salt crystals might sit under the Parylene layer
Class, condition survey, before re-conservation	4	4	4	4	4
Class after re-conservation	3	1	3	3	3
General impression, condition survey, before re-conservation	Dry, crumbly	Dry, crumbly	Dry, crumbly	Dry, crumbly	Dry, crumbly
General impression after re-conservation	Good	Very good	Not so good, support material discoloured, dark patches	Stable, well preserved shape, whitish grey, plastic-like surface	Stable, well preserved shape, whitish grey, plastic-like surface
pH-value, surface, condition survey, before re-conservation	1	2	1	2	2
pH-value, surface, after re-conservation, RO-water (tap water)	5 (7)	5 (7)	5 (7)	5 (7)	5 (7)

Appendix 1

Condition survey comparison before and after re-conservation

No	**16**	**17**	**18**	**19**	**20**
Fid No.	263061	263062	263063	263064	263065
SHM No.	-99	-99	-99	-99	-99
Province	Gotland	Gotland	Gotland	Gotland	Gotland
Parish	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde
Site	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket
Object	Part of stick	Part of stick	Part of stick	Part of stick	log with dowel
Original alum conservation from written records	No information	No information	No information	No information	no information
Result SEM	Alum	Alum	Alum	Alum	alum
Result FTIR	Alum + glycerol	Alum + glycerol	Alum + glycerol	Alum + glycerol	alum
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	N Parylene 1 µ + room temperature water	Polyolefin film/polyether foam + room temperature water	Paraloid B72 10% in ethanol (w/v) + room temperature water	Referens	polyolefin film/polyether foam + heated water
Vacuum treatment in connection with alum extraction	No	No	No		Yes
Analyzed elements from the first extraction bath	Glycerol + sulphate + carbohydrates	Analysis not carried out	Glycerol + sulphate + carbohydrates		Analysis not carried out
Longitudinal cracks, condition survey, before re-conservation	Several	Several	Several		Several
Longitudinal cracks after re-conservation	Few	Several	Few		Few
Transversal cracks, condition survey, before re-conservation	Several	Several	Several		Few
Transversal cracks after re-conservation	Several	Several	Several		Few
Break, condition survey, before re-conservation	No	No	No		No
Break, after re-conservation	No	No	No		No
Flaking surface, condition survey, before re-conservation	Extensive	Extensive	Extensive		Yes
Flaking surface after re-conservation	None	Some	None		Yes
Pulverization, condition survey, before re-conservation	Yes	Yes	Yes		Yes
Pulverization after re-conservation	No	No	No		No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes		Yes
Salt precipitation after re-conservation	Difficult to assess, salt crystals might sit under the Parylene layer	No	No		No
Class, condition survey, before re-conservation	4	4	4		4
Class after re-conservation	3	3	3		4
General impression, condition survey, before re-conservation	Dry, crumbly	Dry, crumbly	Dry, crumbly		Dry, crumbly
General impression after re-conservation	Stable, well preserved shape, whitish grey, plastic-like surface	Very good	_		Good but crumbly. One small fragment detached
pH-value, surface, condition survey, before re-conservation	2	2	2		1
pH-value, surface, after re-conservation, RO-water (tap water)	5 (7)	6 (7)	5 (7)		5 (7)

Appendix 1

Condition survey comparison before and after re-conservation

No	**21**	**22**	**23**	**24**
Fid No.	263066	263067	263068	362395
SHM No.	22289	22289	22028	23159
Province	Uppland	Uppland	Skåne	Halland
Parish	Lagga	Lagga	Vallby	Övraby
Site	Mora Äng	Mora Äng	Glimmingehus	Käringsjön
Object	Stick	Un-identified	Cask head	Handle
Original alum conservation from written records	Alum-boiling, beeswax impregnation	Alum-boiling, beeswax impregnation	Alum-boiling, oil impregnation	No information
Result SEM	Alum	Alum	Alum	Alum
Result FTIR	No analysis carried out	Wax	Alum	Alum + wax
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	No	No
Re-conservation: combination of support/consolidants and heated/ room temperature water	Polyolefin film/polyether foam + room temperature water	Paraloid B72 10% in ethanol (w/v) + room temperature water	Polyolefin film/polyether foam + room temperature water	Polyolefin film/polyether foam + room temperature water
Vacuum treatment in connection with alum extraction	Yes	No	Yes	Yes
Analyzed elements from the first extraction bath	Glycerol + sulphate + low molecular acid (fumaric acid) + dimethyl phtalate + carbohydrates (fragments of)	Glycerol + sulphate + low molecular acid (fumaric acid) + dimethyl phtalate	Analysis not carried out	Glycerol + sulphate + dimethyl phtalate + carbohydrates (fragments of)
Longitudinal cracks, condition survey, before re-conservation	Several	Several	Few	Several
Longitudinal cracks after re-conservation	Few	None	None	Few
Transversal cracks, condition survey, before re-conservation	Few	Few	None	None
Transversal cracks after re-conservation	Few	None	None	None
Break, condition survey, before re-conservation	Yes	Yes	Yes	No
Break, after re-conservation	Yes	Yes	Yes	No
Flaking surface, condition survey, before re-conservation	None	Some	None	None
Flaking surface after re-conservation	Some	None	None	Some
Pulverization, condition survey, before re-conservation	No	Yes	No	No
Pulverization after re-conservation	No	No	No	No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes	Yes
Salt precipitation after re-conservation	No	No	No	No
Class, condition survey, before re-conservation	3	4	2	3
Class after re-conservation	3	1	1	3
General impression, condition survey, before re-conservation	Very dark	Very dark	Very dark	Dark, waxy
General impression after re-conservation	Not so good, support material with black spots, mould? some flakes stuck in support material	Very good	Very good, black markings on support material, post-microbial activity?	Good, small fragments stuck in support material
pH-value, surface, condition survey, before re-conservation	3	3	2	2
pH-value, surface, after re-conservation, RO-water (tap water)	5 (7)	5 (7)	5 (7)	5 (7)

Appendix 1

Condition survey comparison before and after re-conservation

	25	26	27	28	29
Fid No.	272166	263071	263072	271780	272172
SHM No.	23159	23159	23159	23159	23159
Province	Halland	Halland	Halland	Halland	Halland
Parish	Övraby	Övraby	Övraby	Övraby	Övraby
Site	Käringsjön	Käringsjön	Käringsjön	Käringsjön	Käringsjön
Object	Un-identified	Stick	Log	Distaff	Un-identified
Original alum conservation from written records	No information	No information	No information	No information	No information
Result SEM	Alum	Alum	Alum	Alum	Alum
Result FTIR	Wax	Alum + wax	Alum + wax	No analysis carried out	Wax
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyethylene netting/polyester wadding +heatedwater	Polyethylene netting/polyester wadding +heated water	Polyethylene netting/polyester wadding room temperature water	Polyolefin film/polyether foam + heated water	No support + heated water
Vacuum treatment in connection with alum extraction	No	Yes	Yes	Yes	No
Analyzed elements from the first extraction bath	Sulphate + traces of dimethyl phtalate + carbohydrates	Analysis not carried out	Analysis not carried out	Analysis not carried out	Analysis not carried out
Longitudinal cracks, condition survey, before re-conservation	None	Several	Several	Few	None
Longitudinal cracks after re-conservation	None	None	Few	Few	None
Transversal cracks, condition survey, before re-conservation	Several	Few	Several	None	Few
Transversal cracks after re-conservation	Few	Few	None	Few	Few
Break, condition survey, before re-conservation	Yes	Yes	No	No	No
Break, after re-conservation	Yes	Yes	Yes	Yes, some new, some in old glue lines	No
Flaking surface, condition survey, before re-conservation	None	None	Some	None	None
Flaking surface after re-conservation	Some	Some	Extensive	None	None
Pulverization, condition survey, before re-conservation	No	Yes	Yes	No	No
Pulverization after re-conservation	No	No	No	No	No
Salt precipitation, condition survey, before re-conservation	Yes	Yes	Yes	Yes	Yes
Salt precipitation after re-conservation	No	No	No	No	No
Class, condition survey, before re-conservation	3	4	4	2	2
Class after re-conservation	3	3	4	2	2
General impression, condition survey, before re-conservation	Dark, waxy	Dry, crumbly, sticky	Dry, crumbly, sticky	Dark, dull	
General impression after re-conservation	Good	Light patches, due to whitening of surface wax, otherwise good	Not so good	Support material discoloured	Very good
pH-value, surface, condition survey, before re-conservation	3	2	2	2	2
pH-value, surface, after re-conservation, RO-water (tap water)	5 (7)	5 (7)	5 (7)	5 (7)	5 (7)

Appendix 2

Effects on artefacts

No	1	2	3	4	5	6
Fid No.	262855	262856	118012	262857	262858	262859
SHM No.	-99	-99	22028	-99	-99	23159
Province	Gotland	Gotland	Skåne	Gotland	Gotland	Halland
Parish	Tingstäde	Tingstäde	Vallby	Tingstäde	Tingstäde	Övraby
Site	Bulverket	Bulverket	Glimmingehus	Bulverket	Bulverket	Käringsjön
Object	Dowel	Board	Trough	Stick	Log	Handle
Original alum conservation from written records	No information	No information	Alum-boiling	No information	No information	No information
Vacuum treatment in connection with alum extraction	No	No	Yes, partly	Yes	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyethylene netting/polyester wadding + heated water	Polyethylene netting/polyester wadding + room temperature water	Polyolefin film/ polyether foam + room temperature water	Polyethylene netting/polyester wadding + room temperature water	Polyolefin film/ polyether foam + room temperature water	Paraloid B72 10% in ethanol (w/v) + heated water
Analyzed elements from the first extraction bath	Analysis not carried out	Analysis not carried out	Sulphate + cabohydrates	Glycerol + sulphate + butandiol + carbohydrates (fragments)	Analysis not carried out	Analysis not carried out
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No	No
Dry weight (g) before re-conservation	60.0	2240.0	3155.0	662.0	1827.0	453.0
Dry weight (g) after re-conservation and removal of PEG from surface (reduction of weight)	50.3 (16 %)	2042.0 (9%)	2385.2 (24%)	506.6 (23%)	1520.1 (17%)	Object disintegrated, not possible to weigh
Comparison with photo, what has happened in the re-conservation process?	The wedged-in piece of wood seems to have loosened slightly			Small surface fragments stick to the support material	Small surface fragments stick to the support material, a few more new cracks across the fibres	Seperated into pieces
Number of larger unattached parts	0	0	6, some of them as a result of old glue joints breaking up	2	0	Many (more than 10)
Small fragments	No	Yes	Yes	Yes	Yes	Yes
Change of colour	No	Slightly darker	Possibly less red	Darker	Slightly darker	No
Detrimental influence of support material/ consolidants during re-conservation	No	No	No	No	No	No
Change of shape	No	No	No	No	No	Cannot be assessed, due to total disintegration
General impression	Good	Very good	Good, pieces have broken off, probably due to handling during desalination	Not so good	Not so good	Not so good
Overall impression of re-conservation: Classification A-Approved	A	A				
Overall impression of re-conservation: Classification B-Acceptable			B		B	
Overall impression of re-conservation: Classification C-Not acceptable				C		C

Appendix 2

Effects on artefacts

No	7	8	9	10	11	12
Fid No.	262861	263053	263054	263055	263056	263057
SHM No.	21107	22028	22028	22028	-99	-99
Province	Lappland	Skåne	Skåne	Skåne	Gotland	Gotland
Parish	Jukkasjärvi	Vallby	Vallby	Vallby	Tingstäde	Tingstäde
Site	Valkijärvi	Glimmingehus	Glimmingehus	Glimmingehus	Bulverket	Bulverket
Object	Oar handle	Dowel	Plank	Corf	Dowel	Stick
Original alum conservation from written records	No information	Alum-boiling, oil-impregnation	Alum-boiling, oilimpregnation	Alum-boiling	No information	No information
Vacuum treatment in connection with alum extraction	Yes	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyolefin film/ polyether foam + heated water	Polyolefin film/ polyether foam + heated water	Polyethylene netting/ polyester wadding + room temperature water	No support + room temperature water	Polyolefin film/ polyether foam + heated water	Polyethylene netting/polyester wadding + heated water
Analyzed elements from the first extraction bath	Analysis not carried out	Glycerol + sulphate + carbohydrates + organic diacids (C8, C9)	Glycerol + sulphate + fatty acids + carbohydrates (fragments)	Analysis not carried out	Analysis not carried out	Glycerol + sulphate + carbohydrates
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No	No
Dry weight (g) before re-conservation	627.0	22.5	1213.9	296.2	86.9	23.4
Dry weight (g) after re-conservation and removal of PEG from surface (reduction of weight)	439.5 (30 %)	17.8 (21%)	1119.1 (8 %)	262.8 (11%)	61.2 (29 %)	13.6 (42 %)
Comparison with photo, what has happened in the re-conservation process?	The wax has melted in the heated water bath and got stuck to the support material, the colour of the wax has changed to a substantially lighter shade	Small surface fragments have separated and stick to the support material	Small surface fragments stick to the support material		Possibly some new surface cracks	Small surface fragments stick to the support material
Number of larger unattached parts	1	3	0	0	0	0
Small fragments	Yes	Yes	Yes	Yes	Yes	Yes
Change of colour	Lighter	Less orange	Slightly less red	Slightly lighter	No	No
Detrimental influence of support material/ consolidants during re-conservation	No	No	No	No	No	No
Change of shape	No	No	No	No	No	No
General impression	Good, apart from the light wax on the surface	Not so good, support material has discoloured, darkened, degraded	Very good	Very good	Good	Very good
Overall impression of re-conservation: Classification A-Approved				A	A	A
Overall impression of re-conservation: Classification B-Acceptable	B		B			
Overall impression of re-conservation: Classification C-Not acceptable		C				

Appendix 2

Effects on artefacts

No	13	14	15	16	17	18
Fid No.	263058	263059	263060	263061	263062	263063
SHM No.	-99	-99	-99	-99	-99	-99
Province	Gotland	Gotland	Gotland	Gotland	Gotland	Gotland
Parish	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde
Site	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket
Object	Plank	Part of stick	Part of stick	Part of stick	Part of stick	Part of stick
Original alum conservation from written records	No information	No information	No information	No information	No information	No information
Vacuum treatment in connection with alum extraction	Yes	No	No	No	No	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyolefin film/polyether foam + room temperature water	N Parylene 10 µ + heated water	N Parylene 17 µ +heated water	N Parylene 1 µ + room temperature water	polyolefin film/ polyether foam + room temperature water	Paraloid B72 10% in ethanol (w/v) + room temperature water
Analyzed elements from the first extraction bath	Analysis not carried out	Glycerol + sulphate + carbohydrates	Glycerol + sulphate + carbohydrates	Glycerol + sulphate + carbohydrates	analysis not carried out	glycerol + sulphate + carbohydrates
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	No	No	No	No	No
Dry weight (g) before re-conservation	169.9	141.2	236.8	192.6	181.0	100.0
Dry weight (g) after re-conservation and removal of PEG from surface (reduction of weight)	99.1 (42%)	103.0 (27 %)	162.4 (31%)	152.1 (21%)	126.1 (30%)	69 (31%)
Comparison with photo, what has happened in the re-conservation process?	Possibly colour change and encreased layering					Cracks only faintly visible
Number of larger unattached parts	0	0	0	0	0	0
Small fragments	Yes	No	No	No	Yes	Yes
Change of colour	Yes, partly because large areas of the surface had stuck to the support material	Yes, greyish white plastic-like surface,	Yes, greyish white plastic-like surface,	Yes, greyish white plastic-like surface,	More natural-looking, no surface salt	More natural-looking, no surface salt, slightly plastic-like to the touch
Detrimental influence of support material/ consolidants during re-conservation	No	Paralene visible	Paralene visible	Paralene visible	No	Slightly shiny surface (Paraloid B72)
Change of shape	Shrinkage	No	No	No	No	No
General impression	Not so good, support material with dark stains	Not so good	Not so good	Not so good, grey	Very good	Good
Overall impression of re-conservation: Classification A-Approved						
Overall impression of re-conservation: Classification B-Acceptable					B	B
Overall impression of re-conservation: Classification C-Not acceptable	C	C	C	C		

Appendix 2

Effects on artefacts

No	**19**	**20**	**21**	**22**	**23**
Fid No.	263064	263065	263066	263067	263068
SHM No.	-99	-99	22289	22289	22028
Province	Gotland	Gotland	Uppland	Uppland	Skåne
Parish	Tingstäde	Tingstäde	Lagga	Lagga	Vallby
Site	Bulverket	Bulverket	Mora Äng	Mora Äng	Glimmingehus
Object	Part of stick	Log with dowel	Stick	Un-identified	Cask head
Original alum conservation from written records	Reference	no information	alum-boiling and impregnation with beeswax	alum-boiling and impregnation with beeswax	alum-boiling, oil-impregnation
Vacuum treatment in connection with alum extraction	Reference	Yes	Yes	No	Yes
Re-conservation: combination of support/consolidants and heated/room temperature water	Reference	Polyolefin film/ polyether foamt + heated water	polyolefin film/polyether foam + room temperature water	Paraloid B72 10% in ethanol (w/v) room temperature water	Polyolefin film/polyether foam + room temperature water
Analyzed elements from the first extraction bath	Reference	Analysis not carried out	Glycerol + sulphate + low molecular acid (fumaric acid) + dimethyl phtalate + carbohydrates (fragments)	Glycerol + sulphate + low molecular acid (fumaric acid) + dimethyl phtalate	Analysis not carried out
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	Reference	No	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	No
Dry weight (g) before re-conservation	Ref 87.1 (- crumbs in plastic bag)	893.8	25.6	76.0	141.8
Dry weight (g) after re-conservation and removal of PEG from surface (reduction of weight)	Ref 87.7	474.8 (47%)	12.9 (50%)	55.8 (27%)	81.9 (42%)
Comparison with photo, what has happened in the re-conservation process?	Reference		The previously existing crack might have widened slightly	Unchanged, but the surface is markedly duller	Nothing
Number of larger unattached parts	Reference	0	0	0	0
Small fragments	Reference	Yes	Yes	No	No
Change of colour	Reference	Slightly darker	Slightly lighter	Slightly lighter, white	Possibly lighter, more natural-looking, more orange before
Detrimental influence of support material/ consolidants during re-conservation	Reference	No	No	No	No
Change of shape	Reference	No	No	No	No
General impression	Reference	Good, but crumbling	Not so good, support material with black spots, mould? Some flakes have stuck to the support material	Very good	Very good, black marks on the support material, microbial activity?
Overall impression of re-conservation: Classification A-Approved	Reference			A	A
Overall impression of re-conservation: Classification B-Acceptable	Reference	B	B		
Overall impression of re-conservation: Classification C-Not acceptable	Reference				

Appendix 2

Effects on artefacts

No	**24**	**25**	**26**	**27**	**28**	**29**
Fid No.	362395	272166	263071	263072	271780	272172
SHM No.	23159	23159	23159	23159	23159	23159
Province	Halland	Halland	Halland	Halland	Halland	Halland
Parish	Övraby	Övraby	Övraby	Övraby	Övraby	Övraby
Site	Käringsjön	Käringsjön	Käringsjön	Käringsjön	Käringsjön	Käringsjön
Object	Handle	Un-identified	Stick	Log	Distaff	Un-identified
Original alum conservation from written records	No information	No information	No information	No information	No information	No information
Vacuum treatment in connection with alum extraction	Yes	No	Yes	Yes	Yes	No
Re-conservation: combination of support/consolidants and heated/room temperature water	Polyolefin film/polyether foam + room temperature water	Polyethylene netting/polyester wadding + heated water	Polyethylene netting/polyester wadding + heated water	Polyethylene netting/polyester wadding + room temperature water	Polyolefin film/polyether foamt + heated water	No support + heated water
Analyzed elements from the first extraction bath	Glycerol + sulphate + dimethyl phtalate + carbohydrates (fragments)	Sulphate + traces of dimethyl phtalate + carbohydrates	Analysis not carried out	Analysis not carried out	Analysis not carried out	Analysis not carried out
Re-conservation 1964, Lagergren, Technical Department, Museum of National Antiquities	No	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	Alum desalination and polyester impregnation	No	No
Dry weight (g) before re-conservation	172.5	90.5	544.4	878.7	33.3	30.0
Dry weight (g) after re-conservation and removal of PEG from surface (reduction of weight)	82.6 (52%)	44.1 (51%)	334.8 (39 %)	489.3 (44 %)	13.8 (59 %)	12.4 (59 %)
Comparison with photo, what has happened in the re-conservation process?	Nothing	A glue joint has broken, whereby a fragment has come off	The wax turned lighter and melted in the heated waterbath making the support material stick to the surface, leaving the object fluffy with polyester wadding	Object collapsed and broke into many parts, deformed, new fractures show large interior cavities	Broken glue joints, support material has penetrated cavities, leaving the object partly stuck to it probably several new cracks; old glue joints have broken up	Nothing
Number of larger unattached parts	0	1 (glue joint)	0	5		0
Small fragments	Yes	Yes	No	Yes	No	No
Change of colour	One end is lighter	Lighter	Object turned much lighter due to the wax	Less red, whitish, due to the wax	No	No
Detrimental influence of support material/consolidants during re-conservation	No	Polyesterfibres caught in the wood	No	No	No	No
Change of shape	No	No	No	Substantial	Slightly bent	No
General impression	Good, fragments have become attached to the support material	Good	Good	Not so good	Support material discoloured	Very good
Overall impression of re-conservation: Classification A-Approved						A
Overall impression of re-conservation: Classification B-Acceptable	B	B	B			
Overall impression of re-conservation: Classification C-Not acceptable				C	C	

Appendix 3

After treatment

Post treatment	Removal of excess PEG with ethanol	Heat treatment	Attachment of parts and consolidation of surface flakes	Other
1	x		x	
2	x			
3	x		x	
4	x		x	
5	x		x	
6	x		x	
7	x		x	
8	x	x	x	
9	x			
10	x			
11	x	x		
12	x	x		
13	x		x	
14	x			
15	x			
16	x			
17	x			
18	x			
20	x			
21	x	x	x	
22	x		x	
23	x	x	x	
24	x	x		
25	x		x	
26	x			bark loose
27	x		x	
28	x		x	
29	x	x		

RAPPORT

Uppdragnr: 2005-0384 Inkom: 2005-11-15 Ert beställ.nr.: Antal prov: 4	Riksantikvarieämbetet Box 5405 114 84 Stockholm Er ref.: Emma Wikstad

Analys av indunstat lakvatten från alunbehandlat trä

Provtyp

Fyra prover som består av material från indunstat lakvatten från arkeologiskt alunbehandlat trä. Proverna är märkta Nr 4, Nr 9, Nr 21 och Nr 24.

Metoder

Karakteriseringen av det organiska innehållet utfördes med pyrolys-gaskromatografi-masspektrometri (Py-GC/MS). Resultatet erhålls i form av ett s.k. pyrogram med intensiteten av pyrolysprodukterna avsatt mot tiden (i sek). Masspektra (MS) upptas, vilket möjliggör en tolkning av strukturtyper.

Vissa pyrolysprodukter är svåra att kromatografera på GC-kolonnen, t.ex. syror. För att få dem mera lättflyktiga kan man metylera dem direkt på pyrolysblecket genom tillsats av tetrametyl-ammoniumhydroxid (TMAH).

Bestämning av totalt organiskt kol (TOC) i vattenprov innefattar två analyser. Det organiska kolet i provet oxideras till koldioxid genom förbränning medan återstoden (oorganiska kolet) reduceras genom surgörning. Den bildade koldioxiden detekteras därefter spektrofotometriskt. TOC-värdet beräknas som differensen mellan det totala kolinnehållet och det oorganiska kolinnehållet.

Stockholm, 1 december 2005
STFI-Packforsk AB / Kemisk analys

Tfn.: 08-67 67 000/445
Anders Reimann
Analysansvarig
Telefax: 08-10 83 40
e-mail: anders.reimann@stfi.se

Frågeställning

De fyra proverna ska enligt överenskommelse analyseras med avseende på TOC, glödrest (askhalt) samt pyrolys-gaskromatografi-masspektrometri (Py-GC/MS).

Resultat

Proverna torkades över natt vid ca 50 °C innan analys.
I tabellen nedan visas resultaten för glödrestbestämningen (askhalten) samt totalt organiskt kol (TOC) för de fyra proverna. Glödrestbestämningen ger en mycket grov uppfattning om mängden oorganiskt material i proverna. Mängden aska varierar mellan 24–38 % för proverna. Under glödrestbestämningen oxideras vissa oorganiska salter vid den höga temperaturen och minskar därmed i vikt. Avgång av eventuellt kristallvatten i saltet ger också en viktminskning. Som framgår uppvisade ren alun endast en askhalt på 31 %.

Halten organiskt kol (TOC) är låg i samtliga prover. Halten organiskt kol varierar från 1,3 % (prov Nr 24) till 9,3 % (prov Nr 21). Inget oorganiskt kol (karbonat) kan påvisas i något av proven. Sammantaget visar dessa båda analyser att de fyra proverna huvudsakligen består av oorganiskt material.

Prov	Nr 4	Nr 9	Nr 21	Nr 24	Alun-ref.
Glödrest (askhalt)	24 %	29 %	24 %	38 %	31 %
TOC	89 mg/g	34 mg/g	93 mg/g	13 mg/g	-

Tabell 1: Glödrestbestämning (askhalt) och totalt organiskt kol (TOC).

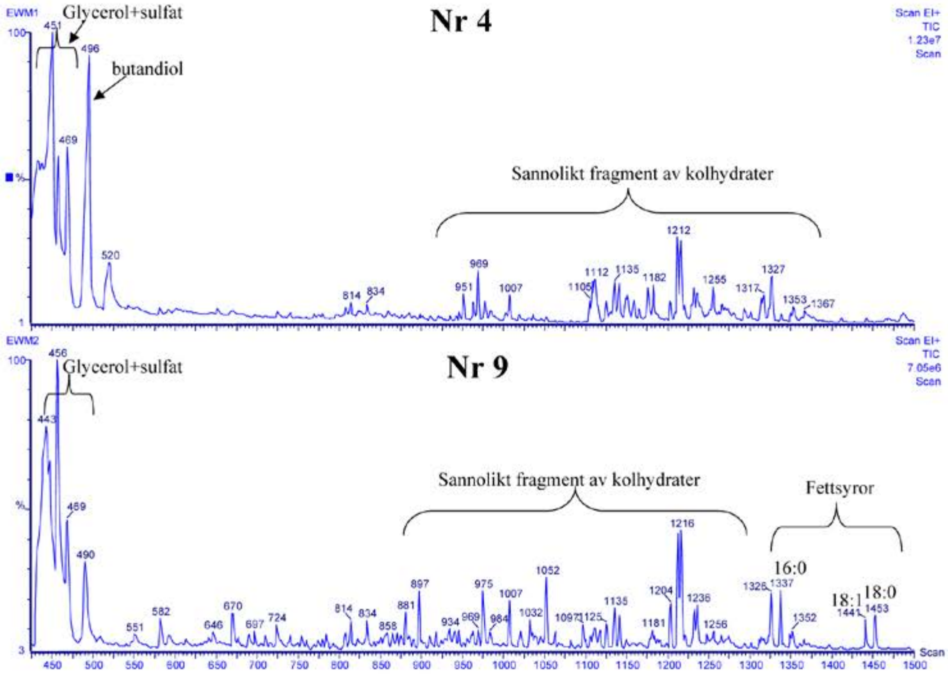
De fyra proverna analyserades med pyrolys, både med och utan metylering (TMAH). I *figur 1 och 2* visas ett erhållet representativt pyrogram för varje prov. Pyrogrammen ger en god uppfattning om den organiska sammansättningen samt de ingående komponenternas relativa mängder.

Prov ”Nr 4”: Linolja, fotogen, vax, polyeten, polyester och polypropylen bedöms som relativt enkla att identifiera med Py-GC/MS. Ingen av dessa komponenter kan dock påvisas i provet i signifikanta mängder. I pyrogrammet syns ett antal pyrolysprodukter, vilka utifrån masspektra tolkats till fragment av kolhydrater eller nedbrutna lågmolekylära kolhydrater. I början av pyrogrammet syns glycerol i ganska hög halt samt en dialkohol (troligen butandiol). Sulfat finns också i provet, vilken troligen kommer från alun.

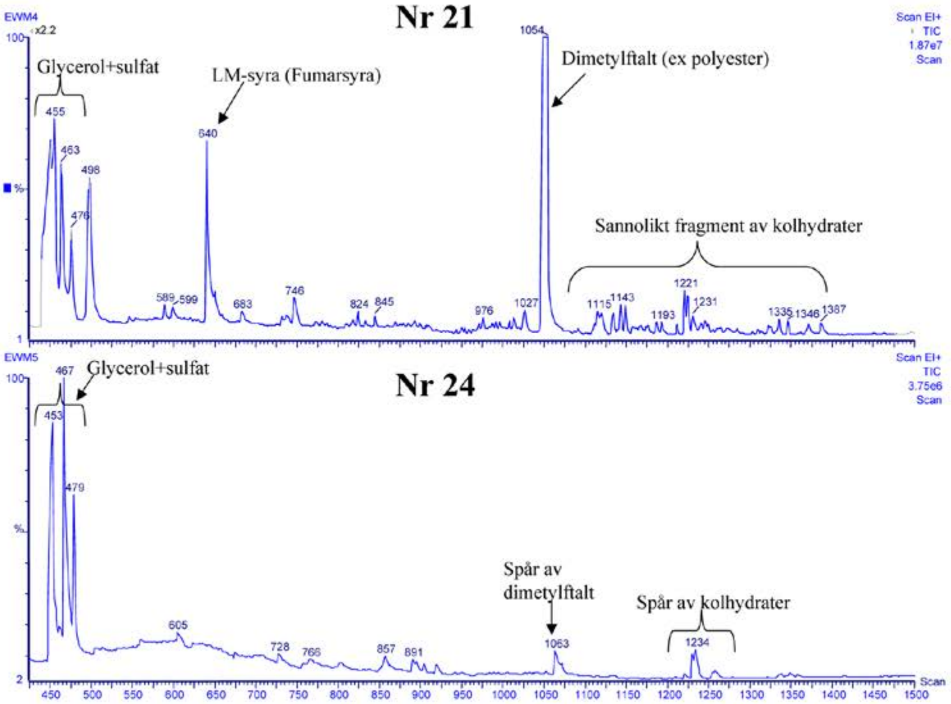
Prov ”Nr 9”: utöver pyrolysprodukter från nedbrutna kolhydrater, glycerol och sulfat (likt Nr 4) finns även en del fettsyror i provet. Fettsyror betecknas ofta med antalet kolatomer: antal dubbelbindningar och produkterna från t.ex. palmitinsyra och oljesyra har därför märkts 16:0 och 18:1 i pyrogrammet. Fettsyrorna kan komma från t.ex. linolja, vegetabilisk olja eller från extraktivämnen i veden.

<u>Prov ”Nr 21”:</u> Den dominerande organiska produkten i provet utgörs av dimetylftalat, vilken är en vanlig mjukgörare. Den utgör också huvudkomponenten i vissa polyesterplaster. Dess ursprung i provet är därför sannolikt polyesterbehandlingen. I provet finns också glycerol, sulfat och nedbrutna kolhydrater i ungefär samma mängder som i proverna Nr 4 och Nr 9. En lågmolekylär syra (sannolikt fumarsyra) kan också påvisas i provet.

<u>Prov ”Nr 24”:</u> Detta prov innehåller mycket låga halter av organiska komponenter. I provet kan endast lite glycerol, sulfat samt spår av dimetylftalat och spår av kolhydrater identifieras. Dimetylftalaten (mjukgörare) kan komma från någon av plasterna som givit stöd åt föremålet under urlakningen.



Figur 1: Pyrogram av proverna ”Nr 4” och ”Nr 9”. Analyserna är utförda med metylering (TMAH).



Figur 2: Pyrogram av proverna "Nr 21" och "Nr 24". Analyserna är utförda med metylering (TMAH).

STFI-PACKFORSK

RAPPORT

Uppdragnr: 2006-0459
Inkom: 2006-11-06
Ert beställ.nr.:
Antal prov: 7

Riksantikvarieämbetet
Box 5405
114 84 Stockholm

Er ref.: Emma Wikstad

Analys av indunstat lakvatten från arkeologiskt trä

Provtyp

Sju prover som består av material från indunstat lakvatten från arkeologiskt alunbehandlat trä. Proverna är märkta Nr 3, Nr 8, Nr 12, Nr 14, Nr 15, Nr 16 och Nr 25.

Metoder

Karakteriseringen av det organiska innehållet utfördes med pyrolys-gaskromatografi-masspektrometri (Py-GC/MS). Resultatet erhålls i form av ett s.k. pyrogram med intensiteten av pyrolysprodukterna avsatt mot tiden (i sek). Masspektra (MS) upptas, vilket möjliggör en tolkning av strukturtyper.

Vissa pyrolysprodukter är svåra att kromatografera på GC-kolonnen, t.ex. syror. För att få dem mera lättflyktiga kan man metylera dem direkt på pyrolysblecket genom tillsats av tetrametyl-ammoniumhydroxid (TMAH).

Bestämning av totalt organiskt kol (TOC) i vattenprov innefattar två analyser. Det organiska kolet i provet oxideras till koldioxid genom förbränning medan återstoden (oorganiska kolet) reduceras genom surgörning. Den bildade koldioxiden detekteras därefter spektrofotometriskt. TOC-värdet beräknas som differensen mellan det totala kolinnehållet och det oorganiska kolinnehållet.

Stockholm, 15 december 2006
STFI-Packforsk AB / Kemisk analys

Anders Reimann
Analysansvarig

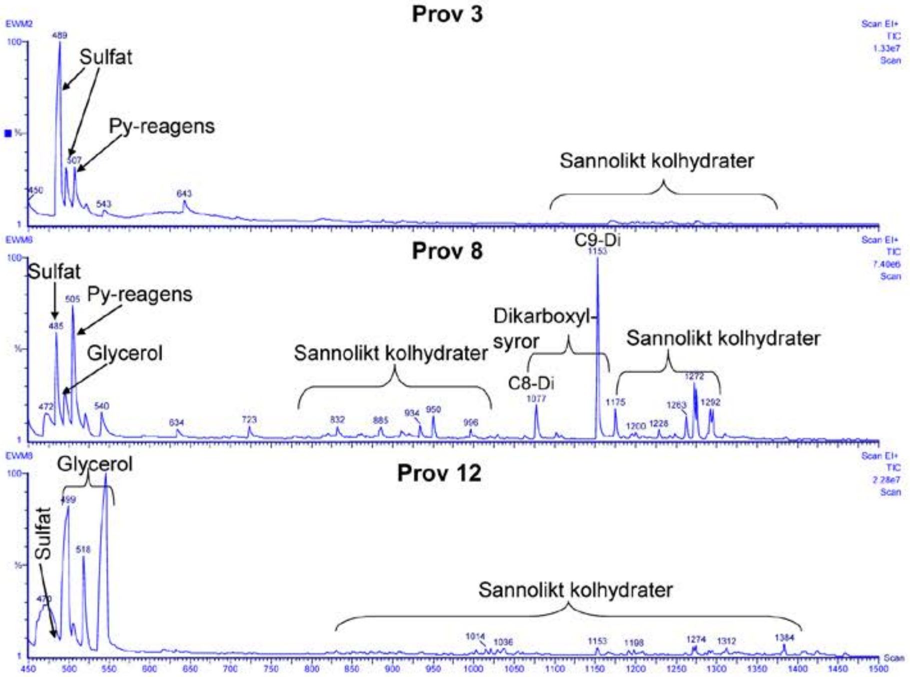
Tfn.: 08-67 67 000/445
Telefax: 08-10 83 40
e-mail: anders.reimann@stfi.se

Frågeställning

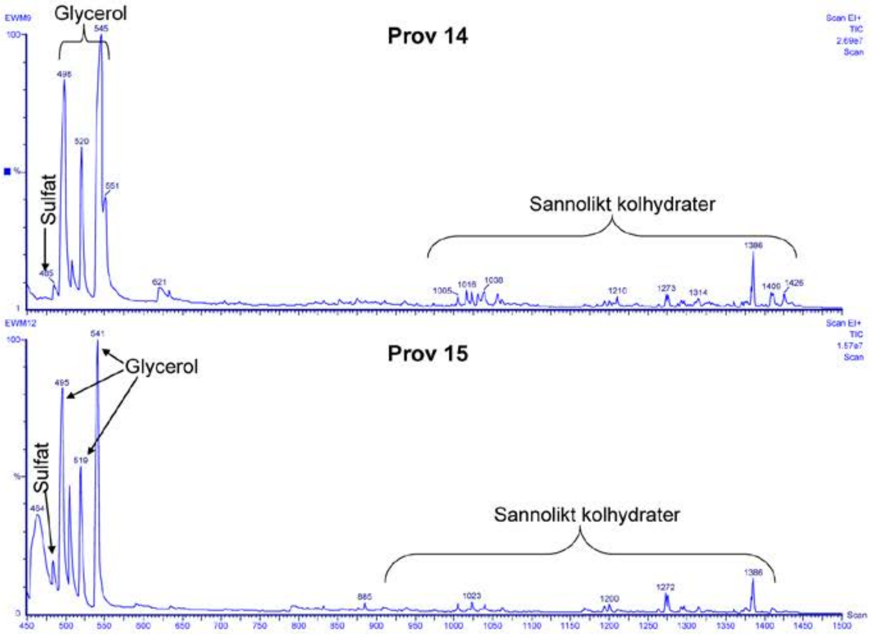
De sju proverna ska enligt överenskommelse analyseras med avseende på TOC, glödrest (askhalt) samt pyrolys-gaskromatografi/masspektrometri (Py-GC/MS).

Resultat

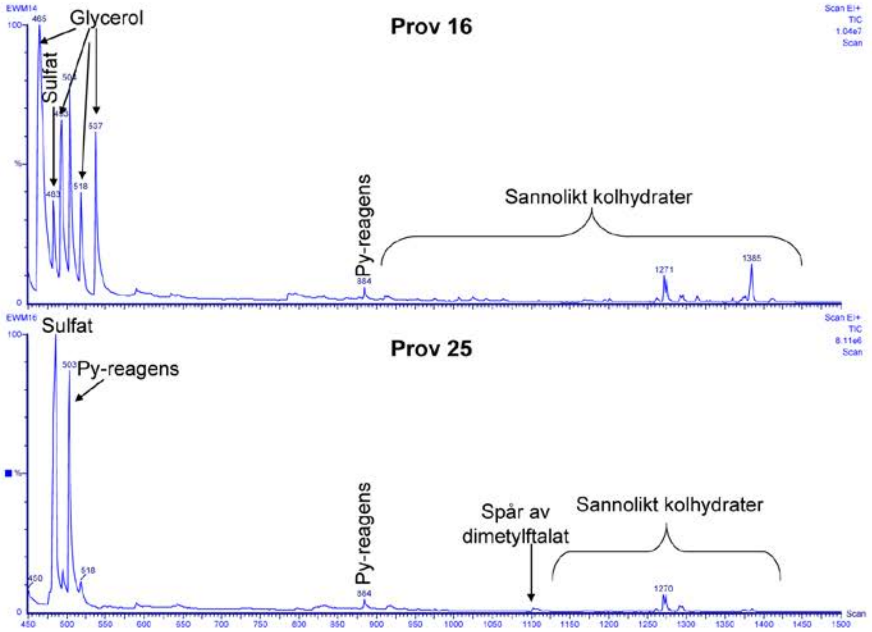
De sju proverna analyserades med pyrolys, både med och utan metylering (TMAH). I *figur 1, 2 och 3* visas ett erhållet representativt pyrogram för varje prov. Pyrogrammen ger en god uppfattning om den organiska sammansättningen samt de ingående komponenternas relativa mängder.



Figur 1: Pyrogram av proverna Nr 3, Nr 8 och Nr 12. Analyserna är utförda med metylering (TMAH).



Figur 2: Pyrogram av proverna Nr 14 och Nr 15. Analyserna är utförda med metylering (TMAH).



Figur 3: Pyrogram av proverna Nr 16 och Nr 25. Analyserna är utförda med metylering (TMAH).

Prov ”Nr 3”: De material av polyeter och polyolefin som givit stöd åt föremålet under urlakningen bedöms som relativt enkla att identifiera med Py-GC/MS. Ingen av dessa material kan dock påvisas i provet i signifikanta mängder. I provet syns endast hög halt av sulfat, vilken troligen kommer från alun samt en mindre mängd produkter, vilka tolkats som nedbrutna kolhydrater.

Prov ”Nr 8”: Detta prov innehåller höga halter av två dikarboxylsyror med 8 respektive 10 kolatomer. Deras ursprung är osäker, men de två syrorna är t.ex. normalt förekommande nebrytningsprodukter från oxidation av vegetabilisk olja. Utöver dikarboxylsyrorna innehåller provet sulfat (troligen från alun), en mindre mängd glycerol samt en del produkter vilka tolkats som nedbrutna kolhydrater. Inga komponenter från de plaster som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet i signifikanta mängder.

Prov ”Nr 12”: Den dominerande organiska produkten i provet utgörs av glycerol. I provet finns även en del sulfat (alun) samt en mindre mängd produkter vilka tolkats som nedbrutna kolhydrater. Inga komponenter från de plaster som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet i signifikanta mängder.

Prov ”Nr 14”: Detta prov har en mycket liknande sammansättning av komponenter som prov 12. I provet finns höga halter av glycerol som utgör den dominerande organiska komponenten. I provet finns även en del sulfat (alun) samt en mindre mängd produkter vilka tolkats som nedbrutna kolhydrater. Inga komponenter från de material som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet i signifikanta mängder.

Prov ”Nr 15”: Detta prov har en mycket liknande sammansättning av komponenter som proverna 12 och 14. Det material som givit stöd åt föremålet under urlakningen har inte kunnat påvisas i provet i signifikanta mängder. Den dominerande organiska komponenten i provet utgörs även här av glycerol. I provet finns även en del sulfat (alun) samt en mindre mängd produkter vilka tolkats som nedbrutna kolhydrater.

Prov ”Nr 16”: Även detta prov har en mycket liknande sammansättning av komponenter som proverna 12, 14 och 15. Den dominerande organiska produkten i provet utgörs av glycerol. I provet finns även en del sulfat (alun) samt en mindre mängd produkter vilka tolkats som nedbrutna kolhydrater. Inga komponenter från de material som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet i signifikanta mängder.

Prov ”Nr 25”: Den dominerande komponenten i provet utgörs av sulfat, vilken troligen kommer från alun. I provet finns även spår av dimetylftalat, vilken är en vanlig mjukgörare. Den utgör också huvudkomponenten i vissa polyesterplaster, varför den troligen kommer från provets polyesterbehandling. Liksom i de övriga proverna finns även i detta prov en mindre mängd produkter vilka tolkats som nedbrutna kolhydrater.

Appendix 5

I *tabell 1* visas resultat för glödrestbestämning, totalt organiskt kol (TOC) och totalt oorganiskt kol (TIC) för de sju proverna. Proverna torkades över natt vid ca 50 °C innan dessa analyser utfördes. Glödrestbestämningen ger en grov uppfattning om mängden oorganiskt material i proverna. Mängden glödrest (aska) varierar mellan 22–50 % för proverna. Vid glödrestbestämningen oxideras vissa oorganiska salter vid den höga temperaturen och minskar därmed i vikt. Avgång av eventuellt kristallvatten i saltet ger också en viktminskning. Som framgår uppvisade ren alun endast en askhalt på 31 % (uppdrag 2005-0384).

Tabell 1: Glödrestbestämning (askhalt), totalt organiskt kol (TOC) samt totalt oorganiskt kol (TIC).

Prov	**Nr 3**	**Nr 8**	**Nr 12**	**Nr 14**	**Nr 15**	**Nr 16**	**Nr 25**	**Alun-ref.**
Glödrest	36 %	24 %	23 %	22 %	22 %	24 %	50 %	31 %
TOC (mg/g)	17	159	149	86	72	70	13	-
TIC (mg/g)	0	0	0	0	0	0	0	-

Halten organiskt kol (TOC) är varierande och ganska låg i samtliga prover. Halten organiskt kol varierar från 1,3 % (prov Nr 25) till 16 % (prov Nr 8). Inget oorganiskt kol (TIC = karbonat) kan påvisas i något av proven. Sammantaget visar TOC och glödresten att de sju proverna domineras av oorganiskt material.

Noterbart är också att proverna Nr 3 och Nr 25 uppvisade högre glödrest och lägre TOC än övriga prover. I dessa två prover kunde heller ingen glycerol påvisas. Det är därför troligt att glycerol utgör en betydande del av de övriga provernas organiska material.

STFI-PACKFORSK

RAPPORT

Uppdragnr: 2007-0093
Inkom: 2007-02-14
Ert beställ.nr.:
Antal prov: 2

Riksantikvarieämbetet
Box 5405
114 84 Stockholm

Er ref.: Emma Wikstad

Analys av indunstat lakvatten från arkeologiskt trä

Provtyp

Två prover som består av material från indunstat lakvatten från arkeologiskt alunbehandlat trä. Proverna är märkta Nr 18 och Nr 22.

Metoder

Karakteriseringen av det organiska innehållet utfördes med pyrolys-gaskromatografi-masspektrometri (Py-GC/MS). Resultatet erhålls i form av ett s.k. pyrogram med intensiteten av pyrolysprodukterna avsatt mot tiden (i sek). Masspektra (MS) upptas, vilket möjliggör en tolkning av strukturtyper.

Vissa pyrolysprodukter är svåra att kromatografera på GC-kolonnen, t.ex. syror. För att få dem mera lättflyktiga kan man metylera dem direkt på pyrolysblecket genom tillsats av tetrametyl-ammoniumhydroxid (TMAH).

Bestämning av totalt organiskt kol (TOC) i vattenprov innefattar två analyser. Det organiska kolet i provet oxideras till koldioxid genom förbränning medan återstoden (oorganiska kolet) reduceras genom surgörning. Den bildade koldioxiden detekteras därefter spektrofotometriskt. TOC-värdet beräknas som differensen mellan det totala kolinnehållet och det oorganiska kolinnehållet.

Stockholm, 5 mars 2007
STFI-Packforsk AB / Kemisk analys

Anders Reimann
Analysansvarig

Tfn.: 08-67 67 000/445
Telefax: 08-10 83 40
e-mail: anders.reimann@stfi.se

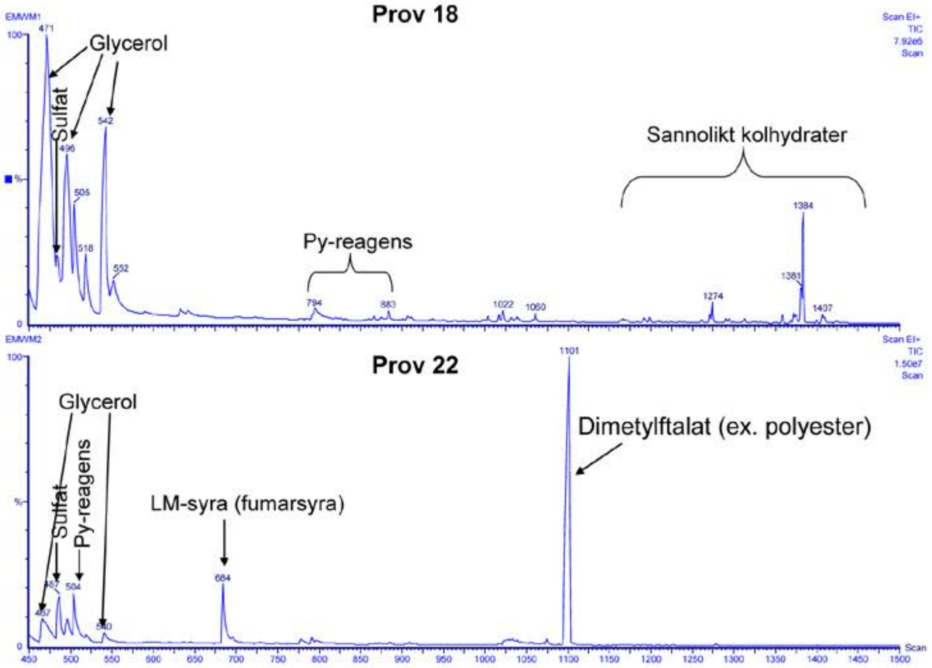
RAPPORT 2007-0093

Frågeställning

De två proverna ska enligt överenskommelse analyseras med avseende på TOC, glödrest (askhalt) samt pyrolys-gaskromatografi/masspektrometri (Py-GC/MS).

Resultat

Proverna analyserades med pyrolys, både med och utan metylering (TMAH). I *figur 1* visas ett erhållet representativt pyrogram för de två proverna. Pyrogrammen ger en god uppfattning om den organiska sammansättningen samt de ingående komponenternas relativa mängder.



Figur 1: Pyrogram av proverna Nr 18 och Nr 22. Analyserna är utförda med metylering (TMAH).

Prov ”Nr 18”: Enligt uppgift har provet sannolikt konserverats genom alunkokning. Analysresultaten visade på höga halter av glycerol samt en del sulfat, vilken troligen kommer från alun. En del föreningar vilka tolkats som nedbrutna kolhydrater finns också i lakvattnet, vilket framgår av pyrogrammet. Inga föreningar från det material ”Paraloid B72” som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet.

Prov ”Nr 22”: Provet har enligt uppgift konserverats genom alunkokning, bivaximpregnering samt eventuellt polyesterimpregnering. Analysresultaten visade att den dominerande organiska föreningen i detta lakvattenprov utgörs utav dimetylftalat. Denna förening utgör huvudkomponenten i vissa polyesterplaster t.ex. PET (polyetylentereftalat). Det är därför sannolikt en polyesterbehandling som är ursprunget till föreningen. I provet finns även betydande mängder sulfat (alun) och glycerol. En lågmolekylär syra i höga halter (sannolikt fumarsyra) kan också påvisas i provet, vilket framgår av pyrogrammet. Inga föreningar från det material ”Paraloid B72” som givit stöd åt föremålet under urlakningen har kunnat påvisas i provet. Provet har en kemisk sammansättning som mycket liknar det tidigare analyserade lakvattenprovet ”Nr 21” (uppdrag 2005-0384).

I *tabell 1* visas resultat för glödrestbestämning, totalt organiskt kol (TOC) och totalt oorganiskt kol (TIC) för proverna. Proverna torkades över natt vid ca 50 °C innan dessa analyser utfördes. Glödrestbestämningen ger en grov uppfattning om mängden oorganiskt material. Vid glödrestbestämningen oxideras även vissa oorganiska salter vid den höga temperaturen och minskar därmed i vikt. Avgång av eventuellt kristallvatten i saltet ger också en viktminskning. Som framgår av tabellen gav ren alun endast en askhalt på 31 % (uppdrag 2005-0384).

Tabell 1: Glödrestbestämning (askhalt), totalt organiskt kol (TOC) samt totalt oorganiskt kol (TIC).

Prov	**Nr 18**	**Nr 22**	**Alun-ref.**
Glödrest (%)	24	34	31
TOC (mg/g)	37	78	
TIC (mg/g)	0	0	

De två proverna uppvisade låg halt TOC (37 respektive 78 mg/g). Inget oorganiskt kol (TIC = karbonat) kan heller påvisas. Sammantaget visar TOC och glödresten att de två proverna domineras av oorganiskt material.

Appendix 7

X-ray documentation before re-conservation

	Artefact ID No.	**1**	**2**	**3**	**4**	**5**	**6**
ARCHAEOLOGICAL FINDS DATA	**Fid No.**	262855	262856	118012	262857	262858	262859
	SHM no.	-99	-99	22028	-99	-99	23159
	Landskape	Go	Go	Sk	Go	Go	Ha
	Parish	Tingstäde	Tingstäde	Vallby	Tingstäde	Tingstäde	Övraby
	Site	Bulverket	Bulverket	Glimmingehus	Bulverket	Bulverket	Käringsjön
	Object	Dowel	Board	Trough	Stick	Log	Handle
X-RADIOGRAPHY BEFORE RECONSERVATION	**x-radiograph yes/no**	Yes	Yes	Yes	Yes	Yes	Yes
	Plane of artefact on x-raydiogr. transverse (TS)/ longitudinal (LG)	LG	LG	LG	LG	LG	LG
	Maximum thickness of artefact (mm)	34	66	42	75	82	44
	Hidden internal cracks / voids (number)	no	no	19 (of which 4 also show on the surface)	Several diffuse /4(?)	No	1
	Additional information from x-radiography	Lighter towards the ends, uneven alum-impregnation	Lighter towards the ends, uneven alum-impregnation, external cracks clearly visible	Lighter in the cross-cut end, i. e. higher conc. of alum, uneven alum-impregnation, two wooden plugs and adhesive joint and large hidden internal cracks long the grain clearly visible	Lighter in parts, uneven alum-impregnation	Lighter in parts, uneven alum-impregnation	Lighter in the cross-cut end, i. e. higher conc. of alum, uneven alum-impregnation, hidden internal cracks along the grain of the wood

	Artefact ID No.	**7**	**8**	**9**	**10**	**11**	**12**
ARCHAEOLOGICAL FINDS DATA	**Fid No.**	262861	263053	263054	263055	263056	263057
	SHM no.	21107	22028	22028	22028	-99	-99
	Landskape	La	Sk	Sk	Sk	Go	Go
	Parish	Jukkasjärvi	Vallby	Vallby	Vallby	Tingstäde	Tingstäde
	Site	Valkijärvi	Glimmingehus	Glimmingehus	Glimmingehus	Bulverket	Bulverket
	Object	Oar handle	Dowel	Plank	Corf	Dowel	Stick
X-RADIOGRAPHY BEFORE RECONSERVATION	**x-radiograph yes/no**	Yes	Yes	Yes	Yes	Yes	Yes
	Plane of artefact on x-raydiogr. transverse (TS)/ longitudinal (LG)	LG	LG	LG	LG	LG	LG and TS
	Maximum thickness of artefact (mm)	51	16	45	28	35	31
	Hidden internal cracks / voids (number)	6 (which also show on the surface)	No	No	No	No	Several diffuse /3(?)
	Additional information from x-radiography		Lighter in parts, uneven alum-impregnation	Lighter along the edges and around the hole, i. e. higher conc. of alum, uneven alum-impregnation	Lighter along the edges, uneven alum-impregnation	Clearly lighter along the edges, uneven alum-impregnation	Clearly lighter along the edges, uneven alum-impregnation

Appendix 7

X-ray documentation before re-conservation

	Artefact ID No.	**13**	**14**	**15**	**16**	**17**	**18**
ARCHAEOLOGICAL FINDS DATA	**Fid No.**	263058	263059	263060	263061	263062	263063
	SHM no.	-99	-99	-99	-99	-99	-99
	Landskape	Go	Go	Go	Go	Go	Go
	Parish	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde	Tingstäde
	Site	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket	Bulverket
	Object	Plank	Part of stick	part of stick	part of stick	part of stick	part of stick
X-RADIOGRAPHY BEFORE RECONSERVATION	**x-radiograph yes/no**	Yes	Yes	Yes	Yes	Yes	Yes
	Plane of artefact on x-raydiogr. transverse (TS)/ longitudinal (LG)	LG	LG and TS	LG and TS	LG and TS	LG and TS	LG and TS
	Maximum thickness of artefact (mm)	26	59	69	57	57	48
	Hidden internal cracks / voids (number)	No	2	No	No	No	No
	Additional information from x-radiography	Lighter in the center, uneven alum-impregnation	Lighter in parts, uneven alum-impregnation	Darker in the center, uneven alum-impregnation	Darker in the center, uneven alum-impregnation	In TS x-ray diffuse lighter areas towards the surface and darker in the center, uneven alum-impregnation	Darker in the center, uneven alum-impregnation

	Artefact ID No.	**19**	**20**	**21**	**22**	**23**	**24**
ARCHAEOLOGICAL FINDS DATA	**Fid No.**	263064	263065	263066	263067	263068	362395
	SHM no.	-99	-99	22289	22289	22028	23159
	Landskape	Go	Go	Up	Up	Sk	Ha
	Parish	Tingstäde	Tingstäde	Lagga	Lagga	Vallby	Övraby
	Site	Bulverket	Bulverket	Mora Ang	Mora Ang	Glimmingehus	Käringsjön
	Object	Part of stick	Log	Stick	Unidentified	Cask head	Handle
X-RADIOGRAPHY BEFORE RECONSERVATION	**x-radiograph yes/no**	Yes	Yes	Yes	Yes	Yes	Yes
	Plane of artefact on x-raydiogr. transverse (TS)/ longitudinal (LG)	LG and TS	LG	LG	LG	LG	LG
	Maximum thickness of artefact (mm)	48	80	10	10	15	24
	Hidden internal cracks / voids (number)	No	2	5 (which also show on the surface)	No	No	part 1: 2 part 2: 3 part 3: 7
	Additional information from x-radiography	Lighter in parts, uneven alum-impregnation	Lighter in parts, uneven alum-impregnation	Clear cracks across the grain of the wood	Lighter in parts, uneven alum-impregnation, external cracks across the grain of the wood clearly visible	Indication of cracking across the grain of the wood on smaller piece	Lighter in parts, uneven alum-impregnation

Appendix 7

X-ray documentation before re-conservation

	Artefact ID No.	**25**	**26**	**27**	**28**	**29**
ARCHAEOLOGICAL FINDS DATA	**Fid No.**	272166	263071	263072	271780	272172
	SHM no.	23159	23159	23159	23159	23159
	Landskape	Ha	Ha	Ha	Ha	Ha
	Parish	Övraby	Övraby	Övraby	Övraby	Övraby
	Site	Käringsjön	Käringsjön	Käringsjön	Käringsjön	Käringsjön
	Object	Unidentified	Stick	Log	Distaff	Unidentified
X-RADIOGRAPHY BEFORE RECONSERVATION	**x-radiograph yes/no**	Yes	Yes	Yes	Yes	Yes
	Plane of artefact on x-raydiogr. transverse (TS)/ longitudinal (LG)	LG	LG	LG	LG	LG
	Maximum thickness of artefact (mm)	19	60	67	15	23
	Hidden internal cracks / voids (number)	no	2	4	1 (which also shows on the surface)	no
	Additional information from x-radiography	Lighter in parts, uneven alum-impregnation, several cracks and an adhesive joint across the grain of the wood clearly visible	Lighter in parts, uneven alum-impregnation	Clearly lighter in the cross-cut end of the wood, uneven alum-impregnation	Lighter in the cross-cut end, i. e. higher conc. of alum, uneven alum-impregnation, cracks across the grain of the wood and one hidden crack along the grain of the wood clearly visible	Lighter towards the ends, uneven alum-impregnation

Appendix 8

Pictures before and after re-conservation

Photos: Swedish National Heritage Board

Object 1 Before re-conservation

Object 1 After re-conservation

Object 2 Before re-conservation

Object 2 After re-conservation

Object 3 Before re-conservation

Object 3 After re-conservation

Object 4 Before re-conservation

Object 4 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 5 Before re-conservation

Object 5 After re-conservation

Object 6 Before re-conservation

Object 6 After re-conservation

Object 7 Before re-conservation

Object 7 After re-conservation

Object 8 Before re-conservation

Object 8 After re-conservation

Pictures before and after re-conservation

Object 9 Before re-conservation

Object 9 After re-conservation

Object 10 Before re-conservation

Object 10 After re-conservation

Object 11 Before re-conservation

Object 11 After re-conservation

Object 12 Before re-conservation

Object 12 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 13 Before re-conservation

Object 13 After re-conservation

Object 14 Before re-conservation

Object 14 After re-conservation

Object 15 Before re-conservation

Object 15 After re-conservation

Object 16 Before re-conservation

Object 16 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 17 Before re-conservation

Object 17 After re-conservation

Object 18 Before re-conservation

Object 18 After re-conservation

Objekt 19 Reference, no re-conservation

Object 20 Before re-conservation

Object 20 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 21 Before re-conservation

Object 21 After re-conservation

Object 22 Before re-conservation

Object 22 After re-conservation

Object 23 Before re-conservation

Object 23 After re-conservation

Object 24 Before re-conservation

Object 24 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 25 Before re-conservation

Object 25 After re-conservation

Object 26 Before re-conservation

Object 26 After re-conservation

Object 27 Before re-conservation

Object 27 After re-conservation

Object 28 Before re-conservation

Object 28 After re-conservation

Appendix 8

Pictures before and after re-conservation

Object 29 Before re-conservation

Object 29 After re-conservation

SWEDISH NATIONAL HERITAGE BOARD
RIKSANTIKVARIEÄMBETET

Swedish National Heritage Board | Phone: +46 (0)8-5191 8000 | E-mail: registrator@raa.se | www.raa.se

The affect of different salts that have entered from the natural surroundings, or been added in the form of various treatments, has presented one of the biggest challenges to the preservation of many of our most important archaeological wooden finds. The development and use of alum salt as a conservation treatment, between 1860 and 1950, represents one of the first attempts to preserve archaeological wood. Initial results showed that treatment could quite remarkably retain the shape and form of old deteriorated wood, but the destructive effects of the salt soon proved to be disastrous. This investigation probes the problems and effects associated with alum, and offers possible solutions.