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GRESHAM SHIP, PRINCES CHANNEL, THAMES ESTUARY CONSERVATION OF AN ELIZABETHAN SHIPWRECK ASSEMBLAGE

ARCHAEOLOGICAL CONSERVATION REPORT

Kelly Domoney

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

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GRESHAM SHIP, PRINCES CHANNEL, THAMES ESTUARY: CONSERVATION OF AN ELIZABETHAN SHIPWRECK ASSEMBLAGE

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SUMMARY

This report covers the investigation, conservation and analysis of concretions, tin-alloys, ceramics, glass and small wood finds from a 16th-century armed Tudor merchantman, the Gresham Ship, Thames Estuary.

ACKNOWLEDGEMENTS

This project would not have been possible without the support of the Port of London Authority who kindly sponsored the project. I am much indebted to the Gresham Ship Steering Committee and colleagues at University College London and English Heritage for their direction in devising research aims and conservation procedures employed in this study. In particular I would like to thank Dean Sully, Jacqui Watson and Angela Karsten for their support and advice on conservation treatments. I am grateful to Jacqui for identifying the small wood finds and her assistance in formulating the waterlogged wood treatment regime. I would also like to thank Karla Graham and Roger Wilkes for their assistance in using the X-radiography and analytical facilities at English Heritage.

KEYWORDS

Ceramic
Conservation
Glass
Iron
Maritime
Post medieval
Tin
Wood

ARCHIVE LOCATION

The site records have been deposited at the London Archaeological Archive, Mortimer Wheeler House, 46 Eagle Wharf Road, London N1 7ED (Site Code: PCO03). The small finds assemblage is currently housed at the Institute of Archaeology, University College London, 31-34 Gordon Square, London, WC1H 0PY and at Fort Cumberland and the large finds are temporarily stored at English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD

DATE OF CONSERVATION WORK

5th October 2008 - 1st April 2009

CONTACT DETAILS

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INTRODUCTION

This report covers the first phase of conservation of the finds assemblage recovered from a 16th-century armed Tudor merchant vessel, the Gresham Ship. Conservation was conducted at Fort Cumberland, Portsmouth between October 2008 and April 2009 as part of a six-month University College London MSc conservation internship hosted by English Heritage.

The Gresham Ship was discovered in April 2003 in the Princes Channel, Thames Estuary (National Grid Reference TR16128149) by the Port of London Authority (PLA) and subsequently excavated by Wessex Archaeology in 2003 and 2004. Since discovery, the ship has been relocated to Horsea Lake, Portsmouth, and the finds assemblage temporarily stored by English Heritage at Fort Cumberland. The ship and its finds are the focus of a five-year post-excavation research project co-ordinated by University College London (Gresham Ship Project [GSP]) and funded by the PLA. Details of the investigation, excavation and the interim archaeological report are published by Firth (2006) and Auer and Firth (2008).

The finds assemblage consists of four iron cannon, 42 iron bars, lead and tin ingots, 22 ferrous concretions, leather items of dress, six small wood finds including a pike and a barrel stave, copper and tin alloy small finds, three ceramic fragments and a glass bottle fragment. This report focuses on investigative conservation of the concretion assemblage, identification and examination of the small wood finds, and the conservation of tin-alloys, ceramics and glass.

CONCRETIONS

The concretion assemblage consisted of 22 ferrous concretions containing objects in various states of preservation. Upon recovery no information was available concerning the nature of potential finds within the concretions, therefore an investigation was conducted into appropriate conservation materials and methods for processing the assemblage. X-radiography was performed on all concretions to determine initial condition after which a selection was processed in order to produce a conservation plan for the remainder of the assemblage.

Condition assessment

Documentation and investigation comprised of photography, X-radiography and illustration (*see* Appendix A). X-radiography was conducted using an AGO HS 225kV Hi-Stability X-ray system with Kodak MX125 and Kodak AK film. X-radiography of the assemblage indicated the concretions contain a variety of artefacts in differing states of preservation. Imaging highlighted metallic materials to be in one of three states of

preservation: well preserved, completely corroded or partially corroded with core intact (*see* Table 1; Figures 1-4). The shape and surface details of completely corroded metals were preserved in the surrounding concretion and characterised by dark voids in the radiographs. In general, bulbous voluminous areas of dense concretion surrounded the voids. Radiography indicated tin-alloy artefacts to be well-preserved within the concretions. Wood was also common and found to be preserved in a part-mineralised state.

Table 1: State of preservation of metal artefacts within concretions

Type 1	Well-preserved metal
Type 2	Void of completely corroded iron objects
Type 3	Partially corroded iron object with intact solid core

Figure 1: Type 1: Find no. 90 - concretion containing well-preserved iron chain link

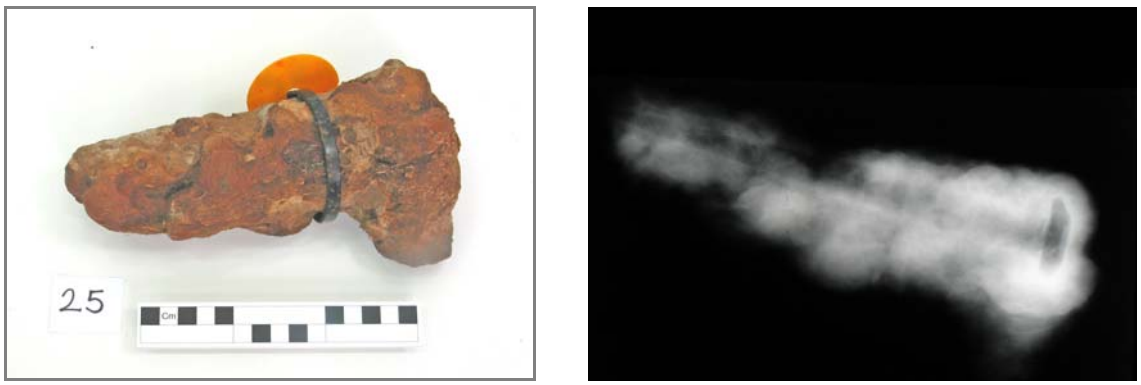


Figure 2: Type 2: Find no. 25 - concretion containing void of completely corroded nail

Figure 3: Type 3. Find no. 99 - concretion containing a hook with solid core and corroded outer edge

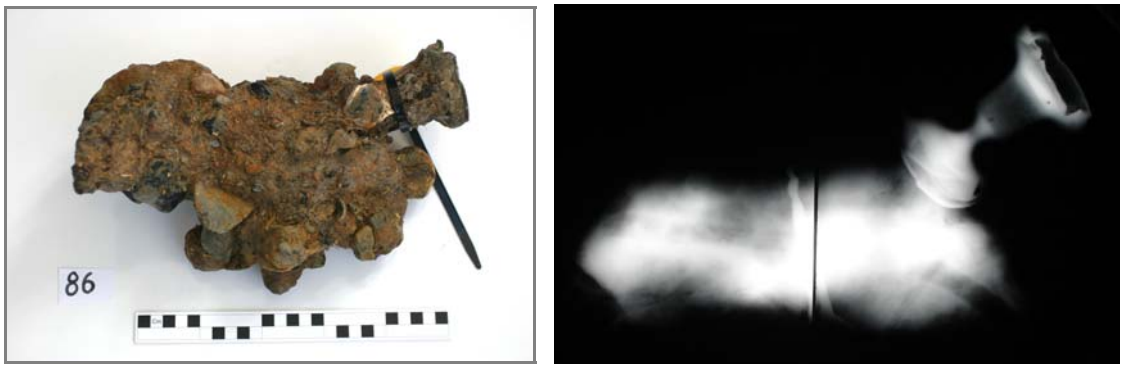


Figure 4: Find no. 86 - concretion containing well-preserved tin-alloy objects (Type 1) and voids of corroded wrought iron bar and nails (Type 3). Nb. Black line in centre of X-ray image represents the division between two plates.

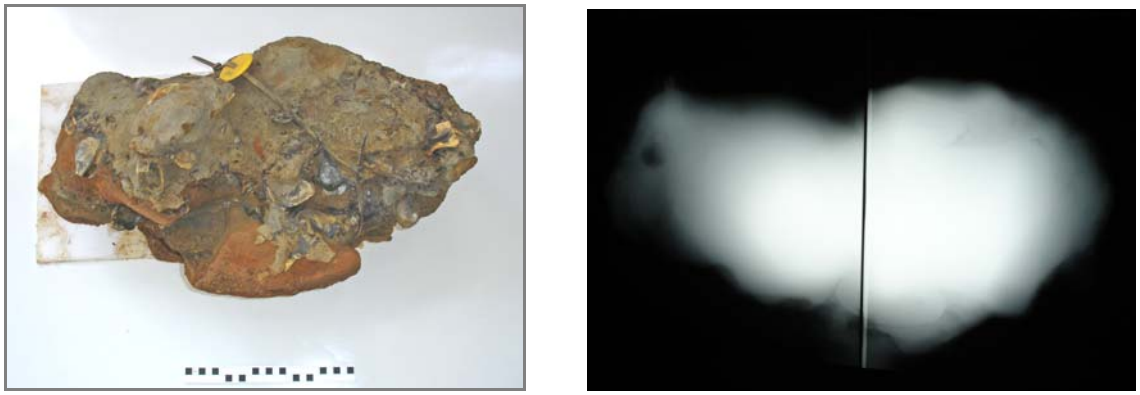


Figure 5: Type 4: Finds no. 202 - concretion containing object of indistinguishable form and preservation. Nb. Black line in centre of X-ray image represents the division between two plates

Due to the density of the larger concretions, features within the X-ray image were often difficult to ascertain (Figure 5). Digital photography of the X-radiograph proved to be a

useful tool in elucidating slight differences in density, precluding the need for further radiographs (Figure 6). Tracings of X-radiographs on Melinex (polyester sheeting) were found to be useful in recording associated positions of artefacts and voids within concretions. Tracings could then be used to inform the excavation procedure (Figure 7).

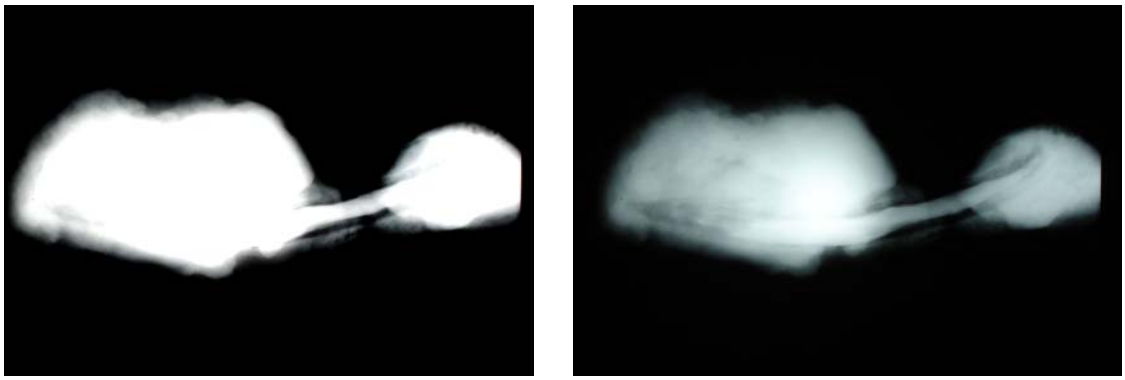


Figure 6: Two digital photographic exposures of an X-radiograph of concretion containing partially corroded hook (Find No. 99). Short exposure in the left image indicates the overall shape of the concretion. The longer time exposure in the right image helps to reveal the shape and corroded edge the hook tang (left hand side of image).

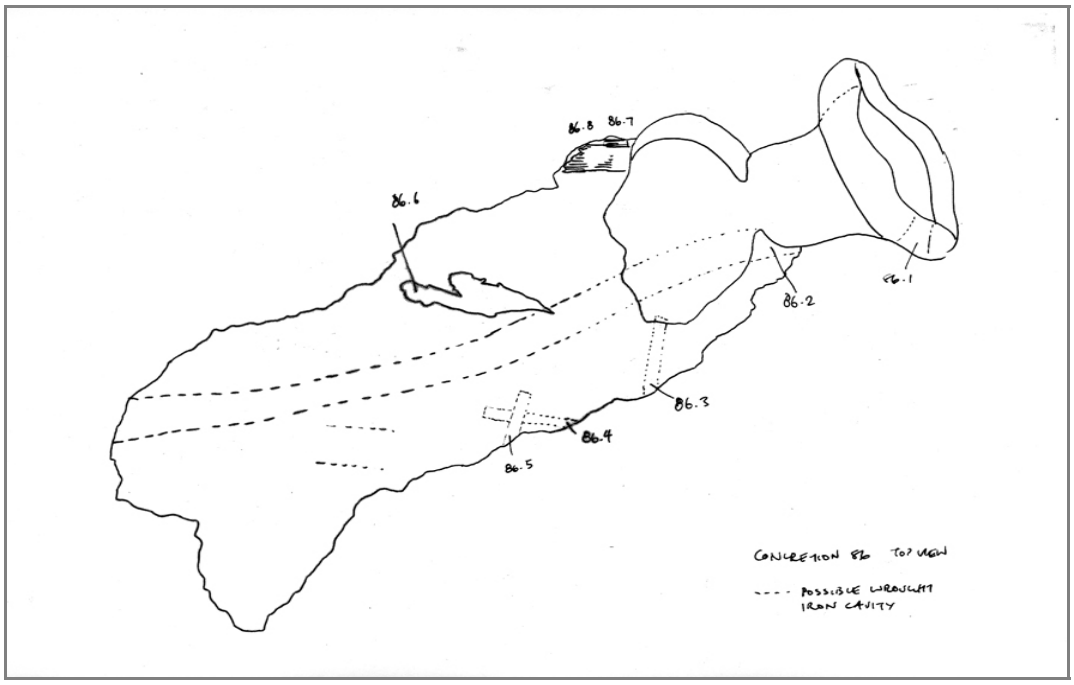


Figure 7: Find no. 86. Tracing of X-radiograph used to determine associated positions of artefacts and voids within the concretion prior to excavation

Treatment

Several methods were assessed by which to process the concretions; the use of each depended on the state of preservation and location of contained objects. Potential processing methods included stratigraphic excavation, breaking open into large un-fragmented sections and casting. Once sand and sediment had been cleaned away from the outer surface, and using x-radiographs as a guide, the 3-dimensional form of the contained objects and depth of concretion could be determined. The following processing methodologies were applied to concretions containing objects in different states of preservation.

Find nos. 86, 90: Concretions containing well-preserved metal objects (Figures 1 and 5)

The main aim of initial processing was to remove the bulk of the concretion in order to identify objects and materials for subsequent treatment and storage. Well-preserved metal objects were characterised by strong metal with limited corrosion and weak bonds between the object and the concretion (North 1987, 210). The most effective method employed on concretions which did not appear to contain ceramics or fragile organic objects, was to strike the concretion with a flat hammer. Strikes were made perpendicular to the surface of the concretion. A series of strikes loosened small sections of concretion which were then removed by hand.

The size of the tools used depended on the thickness of the concretion. For small concretions, or those with a thickness of 5cm or less, small hammers or geopicks were found to be adequate for processing. For larger concretions, or those with a thickness of 5cm or more, large flat hammers and small chisels proved most effective.

Concretions were struck in areas of weakness, such as cracks, or at the intersection of different materials, for example stones or shells in the concretion. Concretions were kept wet with a water spray during processing to avoid rapid air deterioration.

Once the bulk of the concretion was removed smaller tools such as vibrotools, dentist picks and small chisels were employed to reduce the mass enough to separate objects. Final traces of concretion were removed chemically or mechanically in the laboratory depending on material type and condition.

Find nos. 86, 200: Concretions containing voids of completely corroded iron objects (Figure 4)

The aim of processing concretions with completely corroded iron objects was to cast the remaining voids in order to preserve the form and surface details of the original object.

The corroded iron within the void was usually present as a slushy black iron-sulphide residue as identified via X-ray fluorescence analysis. Voids needed to be cleaned of residue before a casting material could be applied. To do this concretions were cracked into two or three large segments by striking with a hammer and chisel at a perpendicular angle along a pre-determined inscribed line. The aim of this method was to crack directly through the void and create segments with clean break edges in order to allow for tight reassembly. The iron sulphide residue was then removed by washing with small brushes and pipe-cleaners in running water.

The surface of the natural concretion moulds were partially dried by rinsing in acetone to enable the casting agent to cure effectively. Moisture remaining in the concretion acted as a natural release agent once the casts were fully cured.

Concretion segments were reassembled using 3M self-adherent flexible veterinary wrap. Visible cracks or gaps were plugged with Cling Film (low density polyethylene) and Plastazote (closed-cell cross linked polyethylene foam; Figure 8).

Two access points were drilled into the void; one for pouring in the casting agent, the other for allowing air to escape. One hole was drilled in concretions with voids that extended through to the surface (Figure 8).

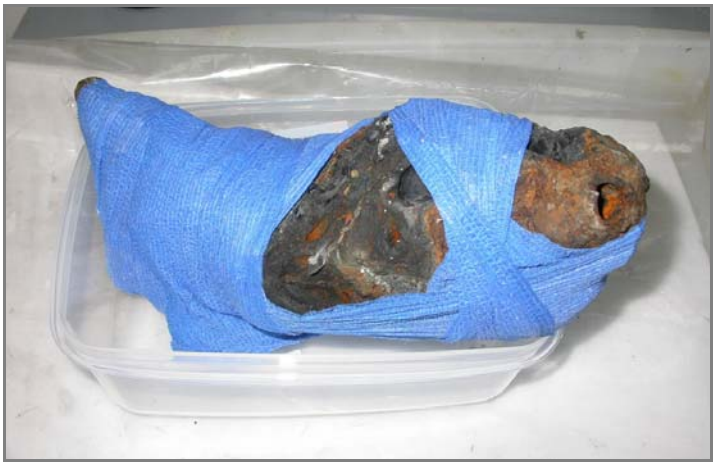


Figure 8: Three sections of concretion 86 held together using 3M flexible self-adherent veterinary wrap. Void entrances exposed.

Three types of casting materials were found to be useful for casting voids of different sizes and complexity. Silicone rubber was useful to replicate complicated forms due to its flexibility on removal. Epoxy resin effectively cast small intricate voids in a one-piece mould due to it low viscosity and low shrinkage. Polyester resin with iron weighting filler

proved useful for large several-part casts due to short curing time and low cost (*see* Table 2 for casting agent properties). Iron filler provided additional strength to the cast, preventing damage during excavation and providing an authentic iron colour.

Fully cured casts were removed using gentle hammering followed by vibrotools in the same manner described for concretions containing well-preserved metal objects (*see* Finds 86 and 90).

Table 2: Casting properties of epoxy, polyester resin and silicone rubber casting materials.

Casting material	Curing time	Viscosity	Working time	Tensile strength	Colour	Curing method
Silastic 3483 silicon rubber base and Silastic 83 curing agent	24 hours	17000 mPa.s	90-120 minutes	3.5 MPa after 7 days	White	Condensation reaction
Tiranti Multi-Purpose Polyester Resin (with 4% Butanox M-50 Liquid Hardener) was mixed with Tiranti Iron Weighting Filler in 60%/40% v/v ratio	20 minutes	180-600 cps	10 minutes	-	Brown	Exothermic reaction
Araldite 2020 epoxy resin with pigments	40-50 minutes	150mPa.s	30 minutes	-	Brown	-

Find no. 99: Concretion containing void of partially corroded iron object with intact solid core (Figures 3, 6 and 9)

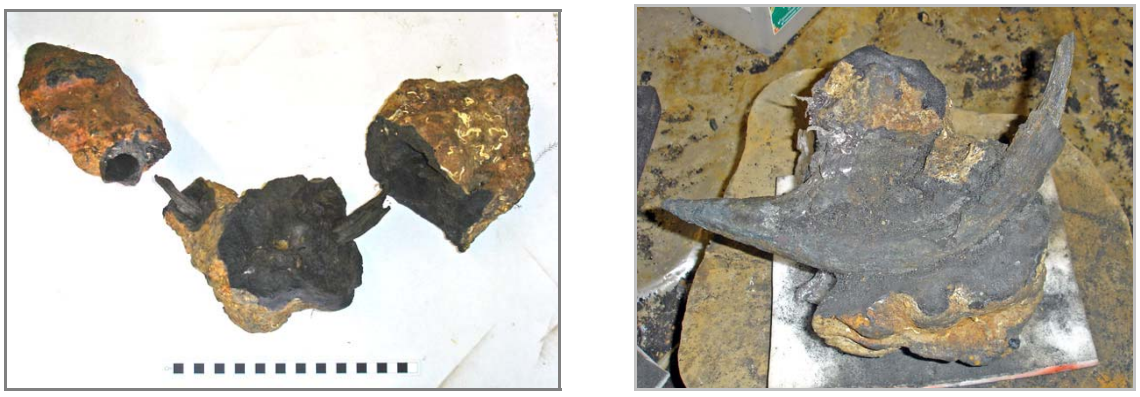


Figure 9: Find no. 99: concretion broken into segments (left); excavation of polyester cast (right)

X-radiography of find no. 99 indicated the concretion to contain a hook-shaped cavity with a potentially solid core. In order to ascertain whether the core was solid or consisted of fragmentary or slushy iron corrosion products the concretion was broken into four sections in the same manner as described for objects with complete voids. The concretion was found to contain a solid wrought iron core surrounded by slushy iron corrosion. The void was cleaned, sections reassembled, and cast in three stages with Tiranti General Purpose polyester resin with iron weighting powder (see Table 3 for mixing ratio). The three-part cast was necessary as the central core was liable to block the flow of the casting resin. The same casting methodology was used as described for concretions with complete voids.

Find no. 202: Concretion containing unidentified objects (Figures 5 and 10)

X-radiographs of the majority of the Gresham Ship concretions did not highlight readily identifiable features or objects. Concretion 202 was chosen as a test case to assess processing options which could then be applied to similar concretions. The concretion was gently cracked open by employing the flat hammer and chisel method. Hammering was conducted along fault lines and with care so not to fragment the outer concretion (and destroy potential moulds) or damage underlying objects. Once the solid underlying form of an iron cannon powder chamber was established the remainder of the concretion was excavated stratigraphically using light hammering in order to fragment the hard iron sulphide and calcium carbonate concretion matrix.

During excavation a hammer-head with partially mineralised wooden shaft and a fragment of rope were discovered and positions recorded on the Melinex plan.

Figure 10: Hammer (Find no. 202.2) and iron cannon powder chamber (Find no. 202.1)

After excavation, recovered artefacts were conserved by material type. The remainder of the removed concretion was processed into gravel-sized pieces, of approximately 10mm in diameter, using a flat hammer in case small objects such as coins were present.

Preliminary research indicated the powder chamber to be similar in style to iron examples excavated from two Spanish Armada shipwrecks: *El Gran Grifón* and *La Trinidad Valencera* off Fair Isle, Scotland and Kinnagoe Bay, Northern Ireland dating to 1588 (Martin and Parker 1988, 222 nos. 16 and 21). Further investigation into the form and style of find no. 202.1 has the potential to identify technical specifications of the original cannon, such as weight and shot weight, possible manufacturing centres and may provide further dating evidence for the ship.

IRON

Upon excavation the iron powder chamber (find no. 202.1) and chain links (find no. 90.1) were immediately immersed in a sealed tap water environment to retard further deterioration whilst an appropriate storage solution was sought. During immersion corrosion continued to occur along slag lines filling the bath water with red iron corrosion products. The objects were transferred to a 5% w/w solution of sodium sesquicarbonate in tap water which had an immediate stabilising effect on the iron by neutralising the acidity (to pH 9.9), preventing oxygen infiltration and forming a passivating film on the surface of the iron. Both objects are currently stabilised and undergoing pH monitoring whilst awaiting active desalination conservation treatment.

TIN-ALLOYS

Three tin-alloy objects underwent active conservation in this phase; two salt holders (find nos. 14 and 86.1; originally identified by Wessex Archaeology as candlesticks) and a spoon (find no. 86.7). The aim of the conservation was to identify appropriate and effective conservation procedures to remove iron sulphide and calcium carbonate concretion from tin-alloys. As few examples of tin objects survive from marine burial environments these objects were deemed significant for interpretation of the site (Cronyn 1990, 211; MacLeod and Wozniak 1997, 118). All three objects had been selected for an exhibition on the Gresham Ship at University College London to be held in May 2009 and were required to be conserved to display standard.

Analysis

Qualitative X-ray fluorescence analysis of exposed metal areas indicated each object to be manufactured from tin with varying amounts of alloying metals.

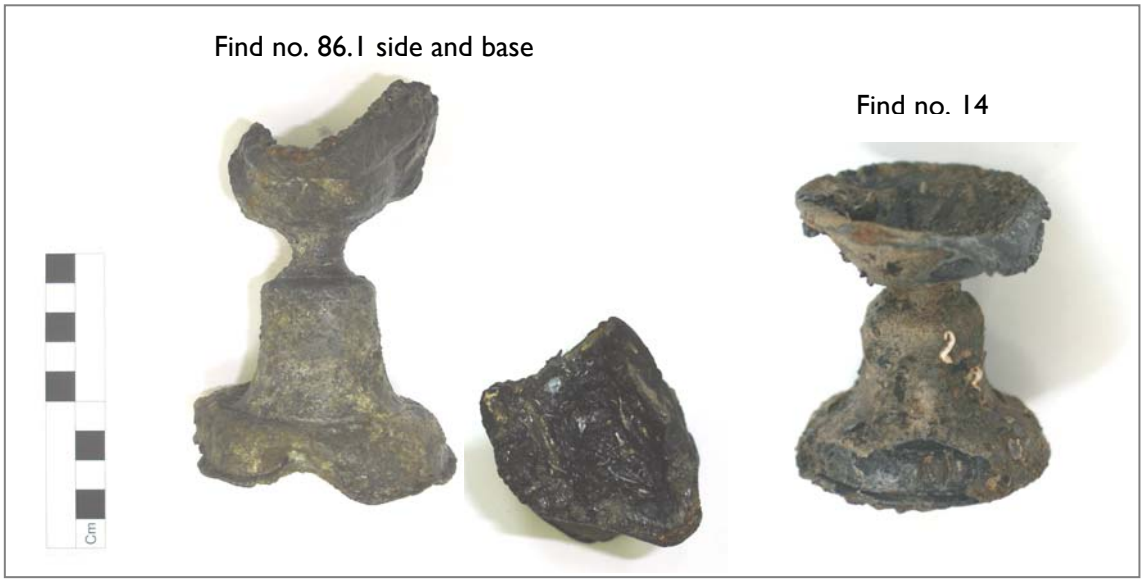


Figure 11: Salt holders 86.1 and 14 before conservation

Condition assessment

Visual examination and initial investigative cleaning of a salt holder (find no. 86.1) and spoon (find no. 86.7; both excavated from concretion find no. 86) indicated the presence of strongly adhered iron sulphide concretion as well as calcium carbonate marine encrustation. As concretion covered approximately 80% of each surface the condition of the metal was difficult to ascertain, however, exposed sections the outer surfaces consisted of a fine grey protective patina typical of tin oxide corrosion (Cronyn 1990, 211). Iron sulphide concretion adhered to one of the salt holders (find no. 86.1) disguised the form of the metal base (Figure 11).

Calcium carbonate marine encrustation on the surface of the second salt holder (find no. 14) measured between 2mm and 7mm in thickness. Investigative cleaning revealed a paste-like black and grey corrosion layer directly below the encrustation in which original surface features including the moulded design were present. The paste-like nature of the tin corrosion layer therefore impacted on removal methodology of the harder concretion crust.

Objects made from low lead-pewter are recommended to be treated as tin rather than lead; tin being the more chemically sensitive metal (Hamilton 2000). Treatments needed to take into account the pH of conservation materials as tin is documented to corrode in storage solutions below pH 8 (Hamilton 2000).

Treatment

Due to the research nature of the Gresham Ship Project the tin-alloy group was identified as a test case to document different approaches to tin-alloy conservation.

Spoon

Mechanical cleaning was chosen to remove iron sulphide concretion from the surface of the spoon (find no. 86.7). Scalpel cleaning was effective in removing thin layers of concretion (1mm in thickness) but was liable to result in scratch marks. Vibrotools were tested in dense areas of concretion, however the vibrations were considered to be too damaging to the underlying object. Air abrasion without aluminium abrasive powder proved useful in removing dense areas of concretion, however rapid removal resulted in a matted effect on the metal surface, possibly due to residual aluminium powder in the pressure chamber.

Figure 12: Spoon (find no. 86.7) after conservation

Removal of the concreted layer revealed a stem with a square cross-section and a moulded decorative design along two sides ending in a volute scroll at the base of the bowl (Figure 12). In a comparison with thirty-five Tudor and Stuart period pewter spoons excavated at riverside sites in Southwark, only one similar example is recorded and identified as a continental import (Egan 2005, 112 Fig. 102 no. 540). A maker's mark may have been present at the base of the spoon's bowl, however, due to heavy corrosion in this area the remains of a mark are not visible or detectable by X-radiography.

Salt holders

Mechanical removal was attempted on both salt holders, however, due to the strong adherence and density of the concretion compared to the underlying metal this method was abandoned in favour of chemical means so not to risk physical damage to the objects.

An experiment using different concentrations of dilute hydrochloric acid in tap water was conducted on salt holder no. 86.1 in the following order:

1. 1% HCl localised application in cotton wool over 48 hours

2. 2% HCl localised application in cotton wool over 48 hours

3. 5% HCl localised application in cotton wool over 48 hours

4. 2% HCl total immersion bath over 24 hours

5. 5% HCl total immersion bath over 24 hours

The final bath (5% HCl in tap water) proved to be the most efficient method for removing the iron sulphide as the acid gradually dissolved calcium carbonate inclusions, which in turn loosened the sulphide matrix. Following the effectiveness of HCl in this test, a 5% HCL in tap water solution was chosen to remove encrustation adhered to salt holder no. 14.

Figure 13: Salt holders (find nos. 86.1 and 14) after conservation

Following concretion removal both salt holders were desalinated to remove residual HCl. Desalination consisted of immersion in a running tap water bath for 5 hours followed by five static tap water baths over a 2 week period. Conductivity and pH of the baths were regularly monitored. During desalination both objects exhibited active, localised corrosion in the form of white spots occurring on deteriorated sections of metal. White products formed after 2 days on find no. 14, and after 7 days on find no. 86.1. The corrosion product from object 14 was sampled and identified as tin oxide by X-ray fluorescence analysis (*see* Appendix C). The formation of white products are likely due to the pH of the water bath as tin is recorded as having a propensity to corrode in pH of less than 8 (Hamilton 2000). Corrosion products may have formed faster on find no. 14 compared to find no. 86.1 due to the advanced corrosion of the alloy prior to immersion.

Chemical treatment proved extremely effective at producing clean objects with fine surface detail and at leaving all corrosion layers intact (Figures 13 and 14). The test emphasised the importance of maintaining high pH of immersion solutions for tin-alloy objects, even in areas with hard tap water.

Post-treatment analysis

After treatment, examination of one of the salt holders (find no. 14) under optical microscopy indicated the presence of a green wax-like substance inside the cavity and in areas around the rim (Figure 15). The substance was sampled and its composition analysed using Fourier transform infra-red spectroscopy (FTIR; *see* Appendix D). The resulting spectrum was compared to samples of beeswax and beef tallow (kindly donated by the Mary Rose Trust); common materials used in candle manufacture in the 16th century. No comparative bond-peaks were present. Further comparative FTIR analysis with lead and tin carbonate samples from the Infrared and Raman Users Group online spectral library (www.IRUG.org) resulted in similar peaks in the 700, 1100, 1450 and 1750 wavenumbers (cm^{-1}) regions. Results suggest that the substance consists of a tin or lead corrosion product or residual marine encrustation.

Figure 14: Detail of moulding on salt holder (find no.14) after HCl treatment

Figure 15: Wax-like substance in central cavity of salt holder (find no. 14) sampled for FTIR analysis

CERAMICS AND GLASS

Two ceramic fragments (find nos. 31, 34) and one glass fragment (find no. 58) underwent active conservation during this phase (Figure 16). The aim of the conservation was to

desalinate and stabilise for display in the Gresham Ship exhibition at the Institute of Archaeology, London and Docklands Museum in May 2009. Conservation also provided an opportunity to assess appropriate desalination and drying methods for low-fired, high-fired, glazed and non-glazed ceramics and glass finds recovered from a marine environment.

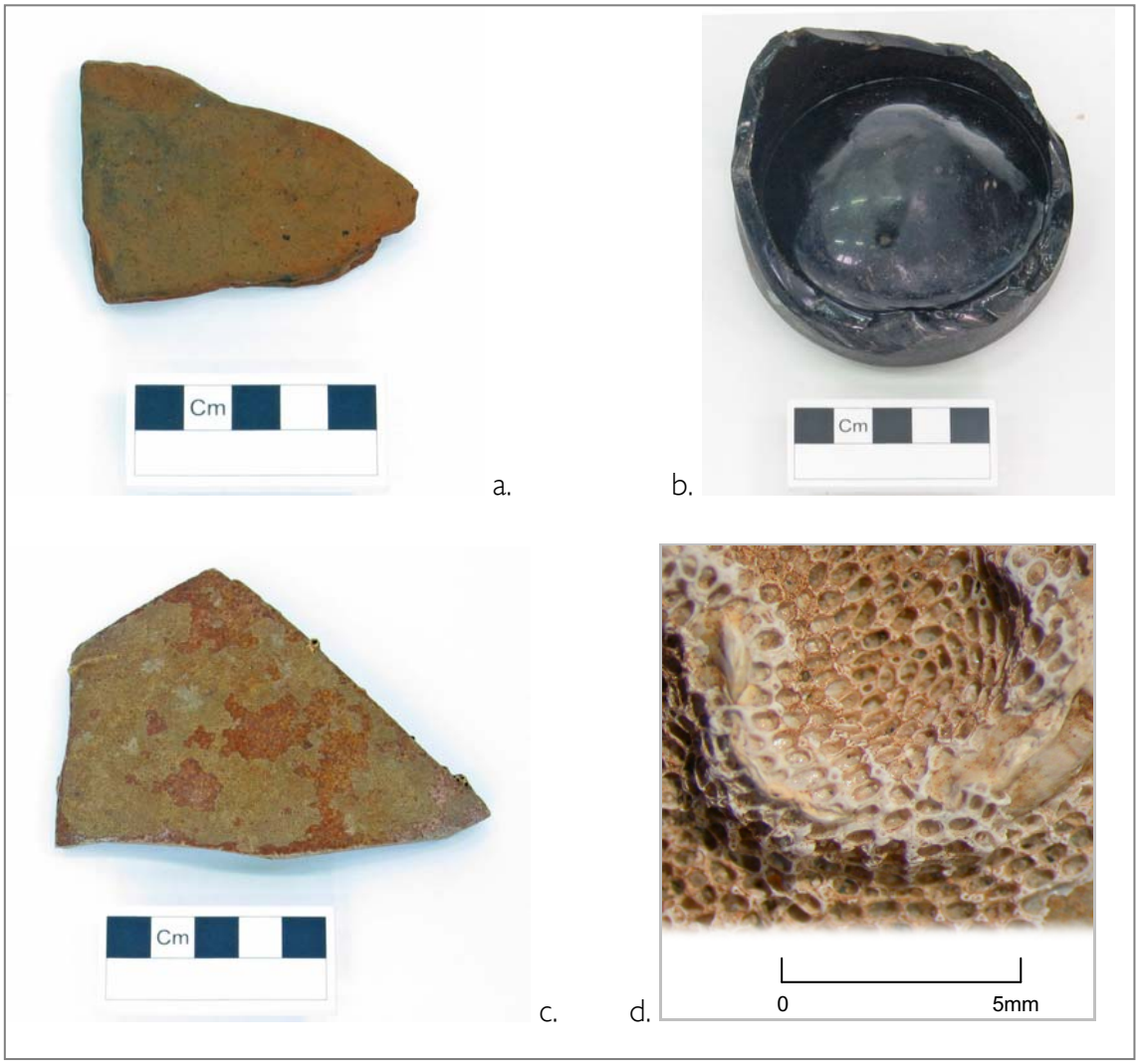


Figure 16: Ceramic and glass objects before treatment. a) Find no. 31, b) Find no. 58, c) Find no. 34, d) detail of an exoskeleton within the marine encrustation adhered to ceramic no. 34.

Condition assessment

Find no. 31 is a fragment of a red, low-fired ceramic. Visual examination of the cross-section indicated the fragment to have been fired in a reducing atmosphere followed by

an oxidising atmosphere as shown by the colour variation in cross-section (grey central section and red outer edge). The fragment had been stored in tap water in a polythene bag prior to treatment. The surface was soft and easily scratched with a scalpel, particularly the cross-section. Softening may indicate the ceramic returning to its clay state in the presence of water.

Find no. 34 is a fragment of a high-fired white ceramic with grey inclusions and a red-coloured glaze. Examination under optical microscopy indicated that the body was in a stable condition with glaze intact. The entire inner surface and cross sections were covered with strongly-adhered marine encrustation ranging between 1mm and 4mm in depth. Exoskeletons within the encrustation were visible under optical microscopy (Figure 16 d). The glaze exhibited star-shaped fractures throughout. Red spots of iron corrosion occurred throughout the glaze. The fragment had been stored in tap water in a polythene bag prior to treatment.

Find no. 58 consists of a base fragment of a straight-sided brown/blue glass bottle with dome-shaped indented base. Examination under optical microscopy indicated the glass to be solid and not liable to fracture. The outer surface exhibited scratches, chips and thin iridescence throughout. Break edges and the inner surface were weathered to a lesser extent than the outer surface. No residues were visible within the bottle interior.

Treatment

Desalination followed by controlled air-drying were considered to be appropriate treatment options for ceramic no. 31 and glass no. 58 due to potential salt problems resulting from the marine burial environment. Ceramic no. 34 was chosen to test the efficacy of different $CaCO_3$ softening agents in removing strongly adhered marine encrustation prior to desalination.

Two softening agents were chosen for testing: 10% w/w solution of Calgon (sodium hexametaphosphate) in tap water and a 5% w/w solution of tetra-sodium ethylene di-amine tetra-acetic acid (EDTA) in tap water. The high alkalinity of both solutions, pH 11 and pH 10.7–12.0 respectively, is noted to slowly dissolve calcite within marine concretions (Pearson 1987, 254). Although both softening agents were liable to soften potential calcium carbonate inclusions in the ceramic body, Calgon was chosen as a test case due to its slow reaction with $CaCO_3$ compared with EDTA tetra-sodium salt.

Ceramic no. 34 was immersed in 10% w/w solution of Calgon in 3 litres of tap water and monitored on a daily basis for softening. After 14 days Calgon appeared to have no obvious softening effect on the marine encrustation. Rather than test the effectiveness of EDTA, it was decided to abandon the softening test as a decision had been made by the Gresham Ship exhibition planners to display the fragment as an object exhibiting a typical marine conservation problem.

All objects were desalinated in separate containers in the following stages:

1. Immersion in 100% tap water

2. Immersion in 50% tap water and 50% deionised water

3. Immersion 100% deionised water

The conductivity of each bath was monitored using an InoLab pH/Cond 750 meter. Bath water was changed once conductivity levels had stabilised. Objects were moved to the next stage once conductivity reached the same levels as the original bath solutions.

Each object was air-dried in atmospheric conditions in the English Heritage conservation laboratory and regularly monitored for salt crystallisation.

After 30 days, objects showed no signs of salt crystallisation or fracture indicating that desalination had been completed successfully. The first stage of desalination in 100% tap water was the most time consuming as each object took between 1 and 2 months to reach the same conductivity levels as tap water. The subsequent stages were completed in 1 month. The process may have been speeded up if the bath water was changed more regularly.

Analysis

The third ceramic fragment in the Gresham Ship assemblage, find no. 215, was targeted for FTIR analysis after a weathering layer of resin on the inside surface was identified during investigative cleaning (Figure 17). The fragment had previously been dried and identified as a piece of Spanish Olive ware by Wessex Archaeology finds specialists in 2003. The fragment showed no signs of salt crystallisation and was in a stable state for display in the exhibition.

Research into Spanish Olive ware indicated that resin was often used as a buffering agent to prevent jar contents from seeping into the porous ceramic fabric (Smith *et al* 1994, 129). Pine resins (*Pistacia* sp.) have been recorded as being commonly utilised for this purpose and jars with resin probably carried liquid such as vinegar, wine or olive oil (Mills and White 1989, 37; Beck and Borromeo 1990, 51; Marekn 1994, 106).

The resin layer was sampled and analysed using FTIR and the resulting bond peaks were compared with several species of pine-resin from the Infrared and Raman Users Group online spectral library (www.IRUG.org; *see* Appendix E). Comparative peaks were observed in all pine resin samples of different sub-species in the 1457, 1384, 1246 and 1181 wavenumber (cm^{-1}) regions. The results from this analysis strongly indicate the

sample to consist of pine resin. Investigation ceased at this point due to time restrictions, however, the ceramic has been identified for future research study in the Gresham Ship Project. For example gas-chromatography may help identify the sub-species, potential manufacturing centres for the ceramic or trade routes for ship and its cargo.

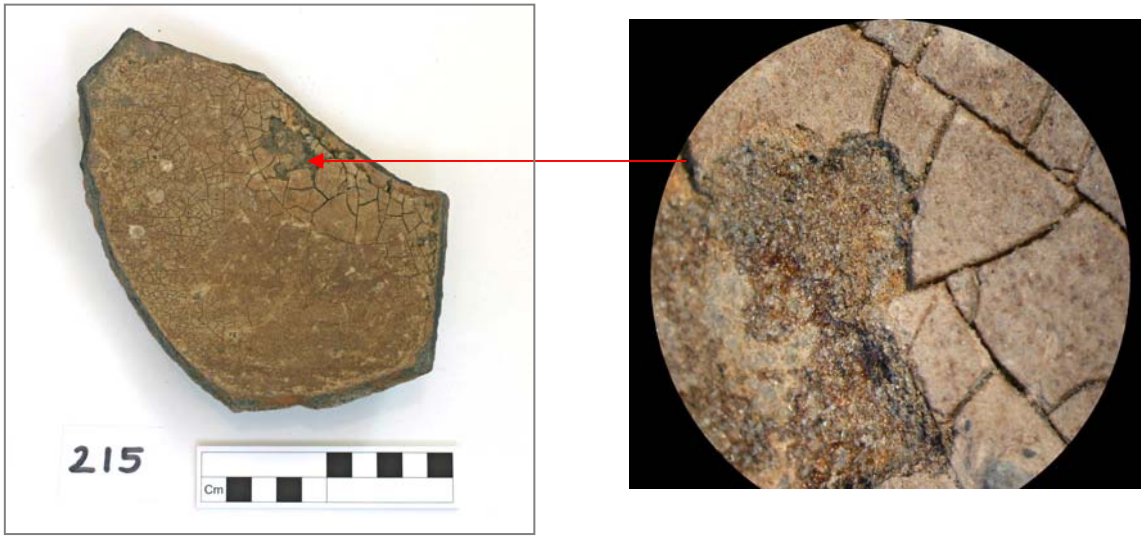


Figure 17: Find no. 215 - fragment of Spanish Olive ware with weathered resin on inside surface. Photomicrograph image scale: 10:1

SMALL WOOD FINDS

Six small wood finds were assessed as part of the first conservation phase. Finds consist of a pike tip (no. 204; Figure 18), barrel stave (no. 11; Figure 20), treenail (WA 54135) and three unidentifiable small objects (nos. 32, 82, 207; Figures 19 and 20). The condition of each object was documented and species of wood identified. The aim of the assessment was to produce a conservation treatment plan to stabilise the wood finds for archive deposition. The proposed treatment would be initiated and completed as a part of a later University College London MSc Conservation project in 2009/2010. The assessment also aimed to determine the research potential of the material for the Gresham Ship Project.

Condition assessment

Detailed documentation (photography, illustration, dimensions, X-radiography, and species identification) was conducted in order to fully assess the treatment regime needed for each wooden artefact. Drawings noted the transverse, tangential and radial planes in order to assess impregnation rates and potential shrinkage during treatment.

All six fragments were in a solid dense condition, although the pike (find no. 204) exhibited severe marine mollusc attack at one end (Figure 18). Dense calcium linings visible in X-radiography indicated borer tunnels had penetrated one-third of the pike's length. The pike tip also exhibited iron staining, most likely resulting from an iron or steel fitting.

A small wedge fragment (find no. 32) exhibited heavy iron corrosion staining and associated concretion from an iron pin which, when viewed as thin-sections under transmitted-light microscopy, appeared to have partially mineralised the wood (Figure 19).

A thin layer of bacterial slime was present on the outer surface of the treenail (WA 54135) obscuring the surface detail. Under optical microscopy, cell walls appeared intact with a black/red substance filling the cell lumen, possibly resulting from iron mineral inclusions.

Species identification

Species identification was conducted by Jacqui Watson using thin-sections under light transmitted microscopy in order to assess impregnation rates and molecular weights of polyethylene glycol needed for treatment. Five samples were identified as oak (*Quercus* sp.); known for problems associated with consolidation using polymers with large molecules, cross checking on radial surfaces and wide cracks in tangential surfaces post-treatment. One small fragment (find no. 207), possibly part of a barrel lid, was identified as pine (*Pinus* sp.); a species which responds well to impregnation and freeze-drying due to its simple cell structure.

Figure 18: Pike (204) before conservation. Wood borer activity visible in X-radiograph

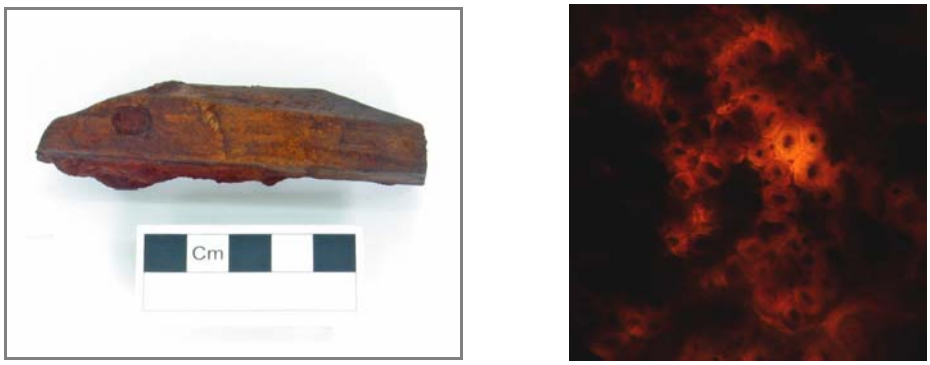


Figure 19: Find no. 32 before conservation. Photomicrograph of ring porous cell arrangement showing intact early wood cells (TS x40). Cell lumen filled with iron corrosion products.

Figure 20: Find nos. 11 and 207 before conservation. Oak barrel stave and pine barrel lid with marine growth

All fragments underwent desalination in tap water over a period of 4 months to remove the bulk of soluble marine salts. Objects were stored in a refrigeration unit at 4°C to prevent bacterial degradation. Conductivity levels of bath water were monitored using an InoLab pH/Cond 750 meter. Bath water was changed when levels stabilised and desalination was completed when conductivity levels reached the same as tap water.

Recommended treatment

Iron staining posed several problems for pre-treatment and post-treatment stability of the wood. Potential problems include: physically blocking the microstructure of wood making it impermeable to bulking agents; physical degradation caused by oxidation of iron sulphides into sulphuric acid and structural damage caused by crystallisation of iron pyrite crystals (Watson 1984, 213, 217; Jones 2003, 63). The use of a complexion agent such as DTPA (diethylenetriaminepentaacetic acid) was assessed as a method to reduce residual insoluble iron salts (Fe^{3+}) to soluble salts (Fe^{2+}) prior to bulking.

Based on the condition assessment the following treatment regime (*see* Table 4) was prepared in consultation with Jacqui Watson (EH) and Dean Sully (UCL).

Table 4: Proposed treatment regime for the small wood finds

Find no.	Object type	Wood species	Pre-treatment	Drying
82	-	oak	DTPA; 25% PEG 400	Vacuum freeze dry
32	-	oak	25% mannitol in tap water	Vacuum freeze dry
204	-	oak	10% PEG 400/10% PEG 4000 (1st stage conducted under cool conditions to minimise bacterial growth).	Vacuum freeze dry
207	Part of barrel lid	pine	DTPA; 10% PEG 400/15% PEG 4000	Vacuum freeze dry
WA 54135	Treenail	oak	UV light to remove bacterial slime; DTPA; 15% PEG 400, 20% PEG 4000 (1st stage conducted under cool conditions to minimise bacterial growth).	Vacuum freeze dry
11	Barrel stave	oak	DTPA; 25% PEG 400	Vacuum freeze dry

CONCLUSION

The first phase of conservation has been successful not only in stabilising several groups of finds for archive deposition but also in extracting information for further archaeological research. An investigative approach to conserving the concretions has been largely effective in discerning object form and condition prior to excavation. This approach has been essential to inform a protocol for conserving the remainder of the assemblage with minimum damage to contained finds. Conservation of the metal, ceramic and glass finds has taken an investigative and remedial approach in order for the objects to be handled and displayed in the University College London Gresham Ship exhibition in May 2009. The investigative approach taken to conserving the small wood finds has enabled an appropriate treatment regime to be formulated in order to stabilise the finds for deposition in the site archive and handling by future researchers.

REFERENCES

Auer, J and Firth, A 2008 'The Gresham Ship: an interim report on a 16th century wreck from the Princes Channel, Thames Estuary'. *Post-Medieval Archaeology,* 41(2)

Beck, C and Borromeo, C 1990 'Ancient pine pitch: Technological perspectives from a Hellenistic shipwreck'. *MASCA Research Papers in Science and Archaeology* 7, 51-58

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

Egan, G 2005 *Material culture in London in an age of transition. Tudor and Stuart period finds c1450-c1700 from excavations at riverside sites in Southwark,* MoLAS Monograph 19. London: Museum of London Archaeology Service

Firth, A 2006 'Old Shipwrecks and New Dredging: An Elizabethan Ship in the Thames', *in* Grenier, R, Nutley, D and Cochran, I (eds) *Underwater Cultural Heritage at Risk*. ICOMOS, 35–38

Hamilton, D 2000 *Methods of Conserving Underwater Archaeological Material Culture*. Conservation Files: ANTH 605, Conservation of Cultural Resources I, Nautical Archaeology Program, Texas A&M University,[http://nautarch.tamu.edu/class/ANTH605 Accessed on 25th April 2009]

Jones, M (ed) 2003 *For Future Generations. Conservation of a Tudor Maritime Collection*, Archaeology of the Mary Rose, Volume 5. Portsmouth: Mary Rose Trust

MacLeod, I and Wozniak, R 1997 'Corrosion and Conservation of Tin and Pewter from Seawater', *in* MacLeod, ID, Pennec, SL and Robbiola, L (eds) *Metals 95*. London: James & James, 118–123

Marken, M 1994 *Pottery from Spanish Shipwrecks, 1500-1800.* Gainesville: University Press of Florida

Martin, C and Parker, G 1988 *The Spanish Armada.* London: Guild Publishing

Mills, J and White, R 1989 'The identity of the resins from the Late Bronze Age shipwreck at Ulu Burun (Kas)'. *Archaeometry* 31(1), 37–44

North, N 1987 'Conservation of metals', *in* C. Pearson (ed) *Conservation of Marine Archaeological Objects.* London: Butterworths, 207–252

Pearson, C 1987 'Conservation of ceramics, glass and stone', *in* C Pearson (ed) *Conservation of Marine Archaeological Objects*. London: Butterworths, 253–267

Smith, R, Bratten, J, Cozzi, J and Plashett, K 1998 *Emanuel Point Ship Archaeological Investigation 1997-8*. Archaeology Institute of West Florida University. [http://www.flheritage.com/archaeology/projects /shipwrecks/emanuelpoint/epsAI9798.pdf Accessed on 25th April 2009]

Watson, J 1985 'Research into aspects of freeze-drying hardwoods between 1982 and 1984', *in Waterlogged Wood: Study and Conservation. Proceedings of the 2nd ICOM Waterlogged Wood Working Group Conference, Grenoble, 28-31 August 1984.* Grenoble: Centre d'étude et de traitement des bois gorgés d'eau

APPENDIX A

X-radiography of concretion assemblage: identified forms and condition

Find No.	X-ray No.	Dimensions (cm)	Optimal X-radiography settings *			Material	Identified object/form
			Voltage (kV)	Current (mA)	Exposure (mins)		
12	GSP XR 12.1a-c; GSP XR 12.2 a-c	22x19x5	150	3	1.5	Metal (completely corroded)	Unidentified object
20**	-	70x39x 34				-	-
25	GSP XR 25.1a-d; GSP XR 25.2a-d	22x13x8	200	3	1.2	Metal (completely corroded)	Bolt
26	GSP XR 26.1a-c; GSP XR 26.2a-d	31x5x5	150	3	1.5	Metal (well-preserved)	Modern cable
27	GSP XR 27.1a-c; GSP XR 27.2a-c	41x15x 16	210	3	1.5	Metal (completely corroded)	Chain links
29**	-	103x46x34				-	-
66	GSP XR 66.1a-d; GSP XR 66.2a-d	29x8x10	190	3	1	Wood	2 joined fragments, unidentified object
68	GSP XR 68.1a, b; GSP XR 68.2a, b	24x23x 10	200,210	3	1.5,1.8	Metal (completely corroded)	Bar
70**	-	56x27x 17				-	-
83	GSP XR 83a-d	7x6x5	60, 70. 80, 100, 150	3	0.8, 1.0, 1.2, 1.3, 1.5	Unidentified	Impression of stamp with leaf design
86	GSP XR 86.1a-c; GSP XR 86.2a-d	31x20x 14	200	3	1.5	Metal (well preserved and completely corroded)	Salt holder; spoon bar; 4 nails
93	GSP XR 93.1a-c; GSP XR 93.2a-d	60x30x 30	210	6,12	1.5	Wood; metal	Unidentified objects
94***	-	21x21x 15				-	-
95	GSP XR 95a-d	22x18x 15	200	3	1.5	Wood; metal (well preserved and completely corroded)	Unidentified object; bolt; bar
96	GSP XR 96.1a-d; GSP XR 96.2a-d	19x15x 14	200	3	1.5	Metal	Bar (completely corroded)
97	GSP XR 97.1a-c; GSP XR 97.2a-d	27x12x 14	200	3	1.5	Unidentified	Unidentified object
99	GSP XR 99.1a-c; GSP XR 99.2a-c	39x16x 20	210	3	1.5	Metal (partially corroded with solid core)	Hook
200	GSP XR 200.1a-c; GSP XR 200.2a-c	48x19x 19	210	6	1.5	Metal (completely corroded)	Chain links

202	GSP XR 202a, b	56x34x 33	210	3	1.5	Metal	Unidentified object with handles
203	GSP XR 203.1a-d; GSP XR 203.2a-c	42x19x 18	210	6,7	1.5	Metal; wood	Unidentified object; bar
209	GSP XR 209.1a-f; GSP XR 209.2a-c	25x21x 12	200	3	1.5	Metal (completely corroded)	Bar
216	GSP XR 216a-d	13x11x9	160	3	1.5	Fibre	Rope fragment
217	GSP XR 217a-d	4 fragments: 18x12x4; 8x7x3; 9x4x2; 5x2x2	140, 160	3	1.5	Fibre	Rope fragment
218	GSP XR 218a-c	16x13x9	120	3	1.5	Fibre	Rope fragment

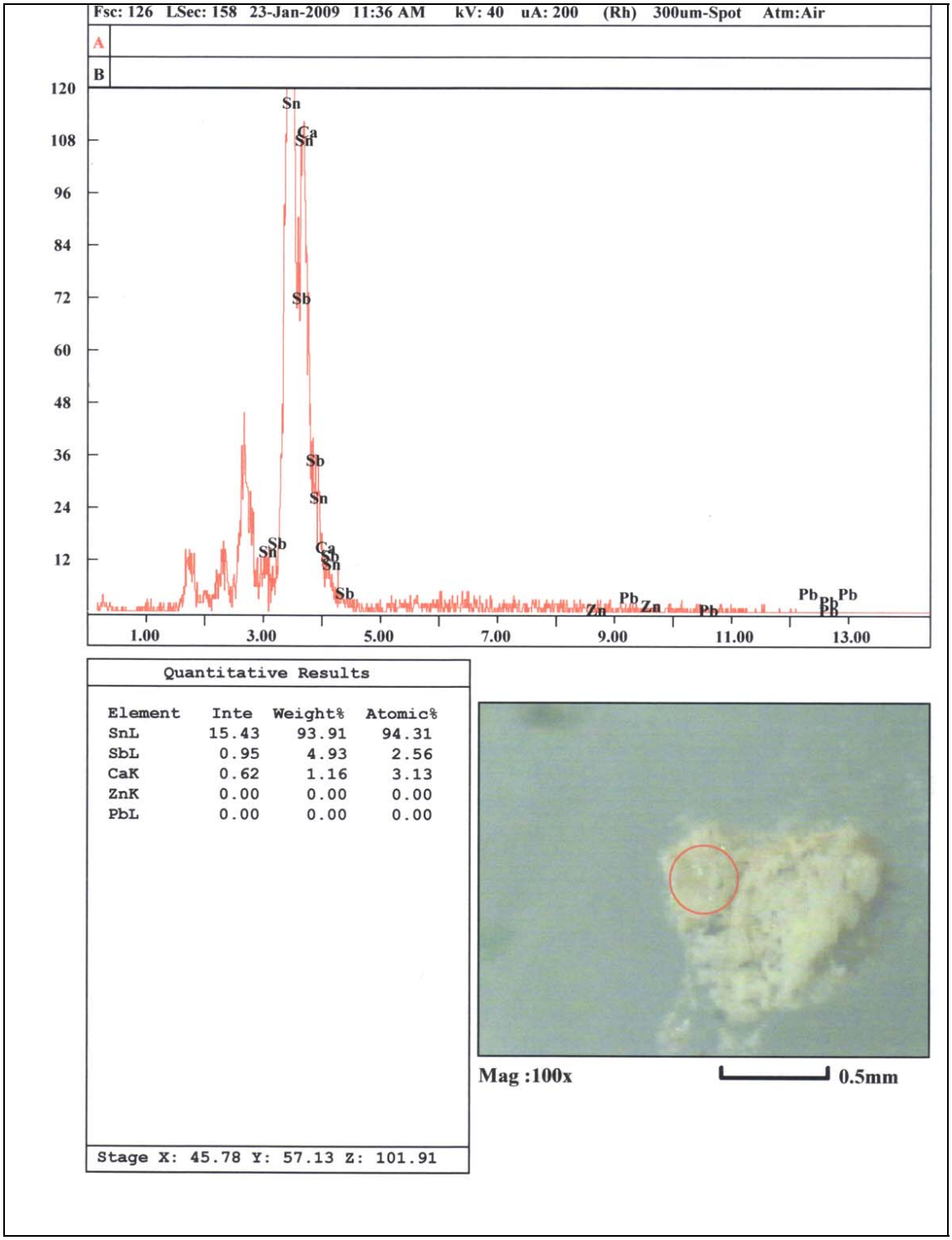
* Optimal settings are specific to size and density of individual concretions and will be dependent on machine type

** X-radiography not conducted due to density of concretion

*** X-radiography not conducted as concretion excavated as a part of a pilot study at University College London where appropriate X-radiography facilities were unavailable

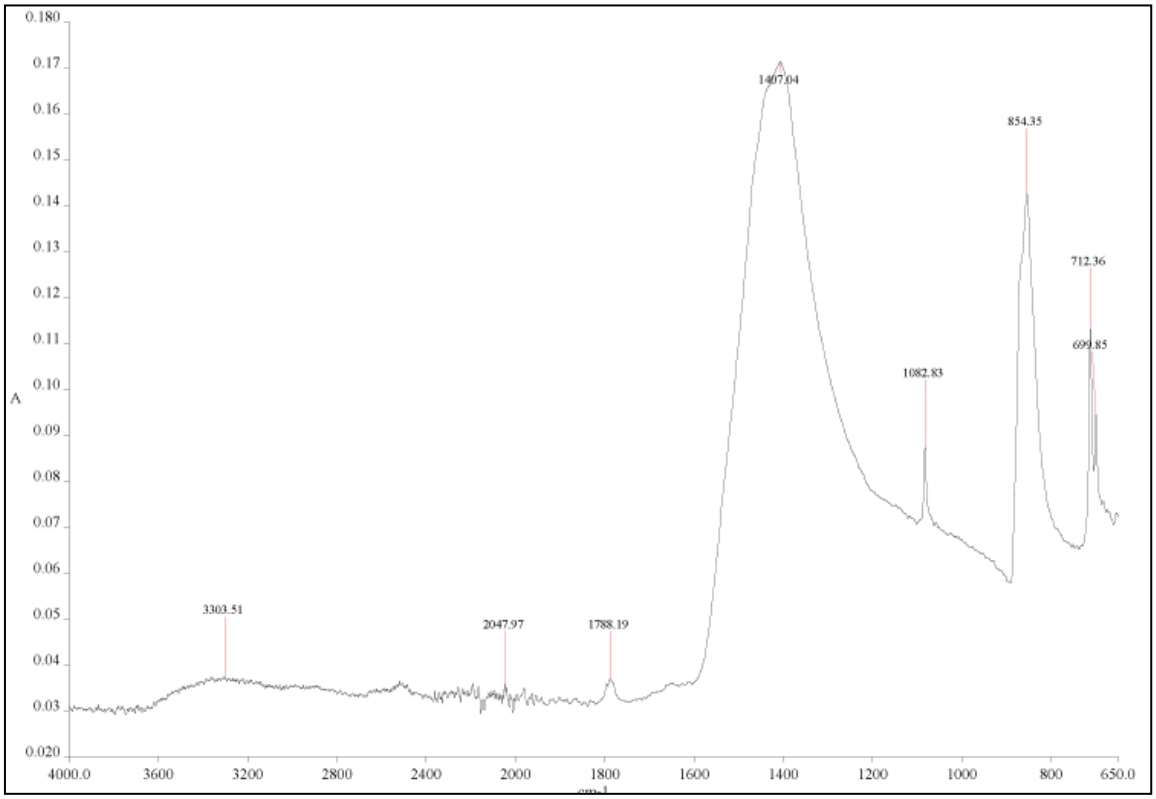
APPENDIX B

Results of X-ray fluorescence analysis on white corrosion product on salt holder (find no. 14)



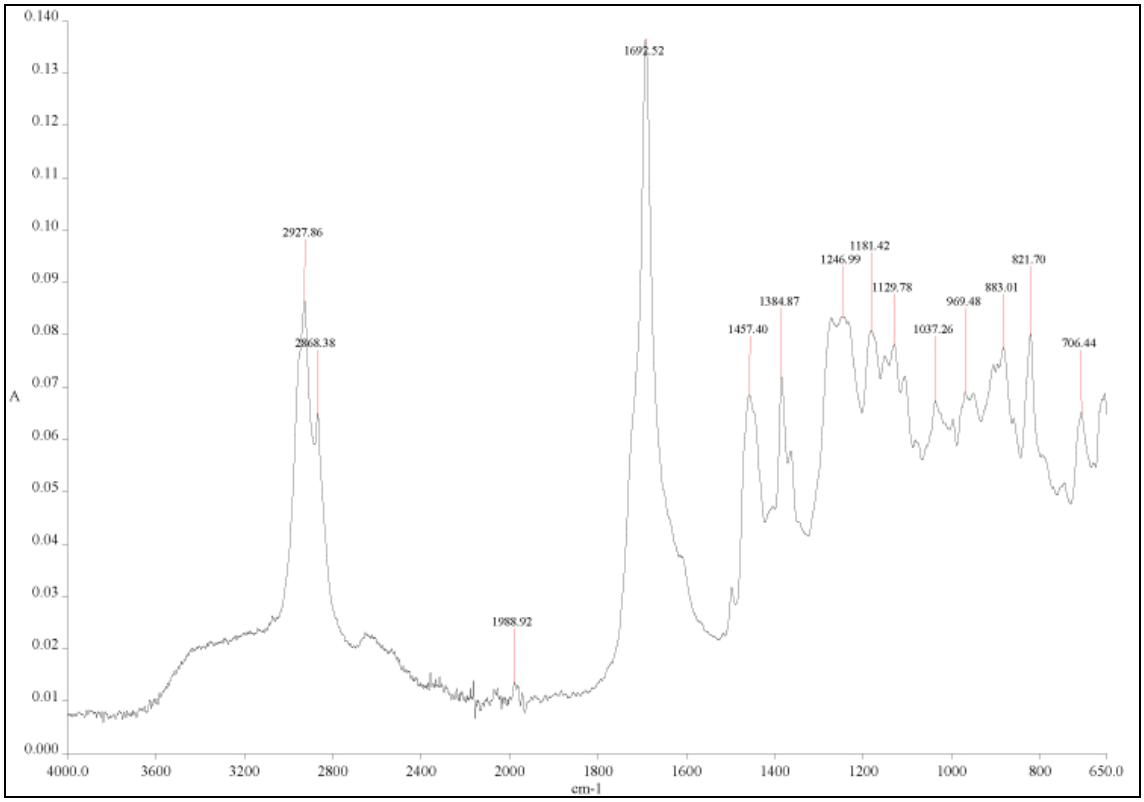
APPENDIX C

Results of Fourier transform infra-red analysis on green wax-like substance located inside salt holder (find no. 14).



APPENDIX D

Results of Fourier transform infra-red analysis on resin material located on inside surface of Spanish olive jar fragment (find no. 215).





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