



*Staffordshire Hoard  
Research Report 25*

**Analysis and Characterisation  
of the  
Staffordshire Hoard Organic  
Material**

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This report forms part of  
*The Staffordshire Hoard: an Anglo-Saxon Treasure*  
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## Information about this report

This report was produced in 2015 as part of Stage 2 of the project. At that time the final catalogue numbers had not been established and the joining of the fragments was ongoing. For this reason all fragments in this report are identified by their K numbers. The concordance of the K numbers given in the report to the catalogue numbers as they appear in the final publication is as given below. The list also includes the names of the objects as used in the final publication.

As is stated in the report a total of 144 items were selected after a preliminary inspection for further investigation. Of these seventy-nine were found to have organic material. The list below only provides a concordance for those seventy-nine. Fourteen of these were not directly associated with any hoard objects as they were material that had been collected from the soil during conservation. In the museums' accession system they retain the original K number assigned to the bag they were found in. The detailed reports on these items are appended here as Appendix IV. The detailed reports on the organics that were directly associated with objects form part of the documentation given for the objects within the database, and have been updated with their correct names.

This is the main report on the organic material in the hoard. For earlier work see Research Reports 3, 5 and 11.

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The owners, Historic England and Barbican Research Associates are grateful to the Esmée Fairbairn Collections Fund for the resources which enabled the work to be carried out.

K number	Catalogue number	Name in publication
1	544	Strip-mount in gold with garnet cloisonné decoration and ends angled at 45 degrees.
104	162	Hilt-collar in gold, of high form, with garnet cloisonné decoration.
127	546	Strip-mount in gold with garnet cloisonné decoration and ends angled at less than 45 degrees (part).
189	77	Pommel in cast silver, of cocked-hat form with double sword-rings, gilded low relief decoration, and mounts with filigree and a gem-setting (part).
270	542	Eye-shaped mount in gold with garnet cloisonné decoration.
273	550	Strip-mount in gold with garnet cloisonné decoration.
274	684	Silver 'arm' with one expanded semi-circular terminal
283	243	Pair of hilt-plates in gold of oval form with garnet bosses.
285	258	Hilt-plate in gold of oval form with gemmed bosses.
291	76	Pommel in cast silver, of cocked-hat form with double sword-rings, with cast interlace and niello inlay, and mounts with cloisonné and filigree decoration (part).
305	451	Mount in gold of strip form with filigree decoration.
306	63	Pommel in silver, of cocked-hat form, with filigree decoration (part).

continued

<b>K number</b>	<b>Catalogue number</b>	<b>Name in publication</b>
307	24	Pommel in gold, of cocked-hat form, with filigree decoration.
311	616	Gold boss with filigree collar.
324	162	Hilt-collar in gold, of high form, with garnet cloisonné decoration (part).
326	173	Hilt collar in gold, of narrow form, with garnet cloisonné decoration.
352	36	Pommel in gold, of cocked-hat form, with filigree and garnet cloisonné decoration.
356	562	Edge-mount in gold of L-shaped form with garnet cloisonné decoration.
357	563	Edge-mount in gold with garnet cloisonné decoration.
358	57	Pommel in gold, of cocked-hat form, cast with animal-heads, with incised Style II decoration, and panels with niello lines, all framed by imitation wire.
359	10	Pommel in gold, of cocked-hat form, with filigree decoration.
362	552	Strip-mount in gold with garnet cloisonné decoration and one pointed end.
400	551	Strip-mount in gold with garnet cloisonné decoration (part).
435	N/A	Unassociated organic
436b	N/A	Unassociated organic
451	578	Pyramid-fitting in gold with garnet and glass cloisonné decoration.
452	51	Pommel in gold, of cocked-hat form, with garnet cloisonné decoration.
455	4	Pommel in gold, of cocked-hat form, with filigree decoration.
458	32	Pommel in gold, of cocked-hat form, with filigree decoration.
476	508	Mount in gold from the tip of a hilt-guard with garnet cloisonné decoration.
545	541	Roundel with disc in gold, with garnet cloisonné, animal-ornamented panels and a glass gem-setting (part).
546	589	Helmet-crest channel, cast in silver and gilded, with animal ornament and animal-head terminal
565	577	Pyramid-fitting in gold with garnet and glass cloisonné decoration.
568	164	Hilt-collar in gold, of high form, with garnet cloisonné decoration.
570	158	Hilt-collar in gold, of narrow form, combining a band of filigree and a band of garnet cloisonné.
606	N/A	Unassociated organic
645	551	Strip-mount in gold with garnet cloisonné decoration (part).
653	565	Wing-shaped mount in gold with garnet cloisonné decoration.
673	553	Strip-mount in gold with garnet cloisonné decoration and one pointed end.
679	157	Hilt-collar in gold, of narrow form, combining a band of filigree and a band of garnet cloisonné.
701	29	Pommel in gold, of cocked-hat form, with filigree decoration.
710	19	Pommel in gold, of cocked-hat form, with filigree decoration.
712	545	Strip-mount in gold with garnet cloisonné decoration and ends angled at 45 degrees (part).
763	N/A	Unassociated organic
787	685	Socketed bracket in silver with wood remains (part).

Continued

<b>K number</b>	<b>Catalogue number</b>	<b>Name in publication</b>
843	543	Eye-shaped mount in gold with garnet cloisonné decoration.
850	160	Hilt-collar in gold, of high form, with garnet cloisonné decoration.
972	412	Mount in gold from the tip of a hilt-guard, with serpent ornament in niello.
1003	174	Hilt-collar in gold, of narrow form, with garnet cloisonné decoration.
1004	30	Pommel in gold, of cocked-hat form, with filigree decoration.
1012	590	Helmet-crest section, cast in silver and gilded with animal ornament and animal-head.
1056	362	Hilt-plate in gold with garnet cloisonné trim.
1058	181	Hilt-collar in gold, of narrow form, with garnet cloisonné decoration.
1062	556	Strip-mount in gold with garnet cloisonné decoration and serpent filigree mounts (part).
1079	413	Mount in gold from the tip of a hilt-guard.
1087	76	Pommel in cast silver, of cocked-hat form with double sword-rings, with cast interlace and niello inlay, and mounts with cloisonné and filigree decoration.
1097	17	Pommel in gold, of cocked-hat form, with filigree decoration.
1126	175	Hilt-collar in gold, of narrow form, with garnet cloisonné decoration.
1145	564	Edge-mount in gold of L-shaped form with garnet cloisonné decoration (part).
1155	159	Hilt-collar in gold, of high relief form, with garnet cloisonné decoration.
1179	N/A	Unassociated organic
1195	47	Pommel in gold, of cocked-hat form, with garnet cloisonné decoration.
1278	21	Pommel in gold, of cocked-hat form, with filigree decoration.
1341	N/A	Unassociated organic
1366	510	Mount in gold from the tip of a hilt-guard with garnet cloisonné decoration.
1395	N/A	Unassociated organic
1448	77	Pommel in cast silver, of cocked-hat form with double sword-rings, gilded low relief decoration, and mounts with filigree and a gem-setting.
1490	N/A	Unassociated organic
1536	621	Gold boss with filigree collar.
1551	N/A	Unassociated organic
1615	N/A	Unassociated organic
1620	636	Gold boss with filigree collar
1621	N/A	Unassociated organic
1637	N/A	Unassociated organic
1667	N/A	Unassociated organic
1680	N/A	Unassociated organic

## **Abstract**

This study forms part of an Esmeé Fairbairn Foundation-funded Staffordshire Hoard materials research project, completed between January and September 2015. This report focuses on the analysis of organic materials identified during initial conservation of the hoard objects at the Birmingham Museum and Art Gallery, during selective preliminary analytical research carried out by the Department of Conservation and Scientific research at the British Museum in London, and in a survey of the Staffordshire Hoard objects completed in January 2015. The research characterises organic materials through micro-Fourier Transform Infrared Spectroscopy (micro-FTIR), Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Spectroscopy (EDS) and Optical Microscopy (OM). Organic material was identified and characterised across seventy-nine 'K' numbered Staffordshire Hoard objects and samples. Amongst the materials characterised were beeswax, amorphous proteinaceous material thought to be animal glue, wood, bone, horn, amber, and leather. In addition, a number of inorganic materials were identified in close association with some organic materials including calcium carbonate, silicates, and copper derived corrosion products.

## Introduction

This survey of the Staffordshire Hoard organic materials forms part of an Esmeé Fairbairn-funded research project designed to characterise the materials and production techniques employed in the production of the Staffordshire Hoard objects. The research into the Staffordshire Hoard objects materials complements research into the metallic components of the Hoard objects completed by Dr. Eleanor Blakelock and Dr. Giovanna Fregni, and was carried out within the Conservation and Collection Care Department at the Birmingham Museum and Art Gallery, and at the Centre for Electron Microscopy within the Department of Metallurgy and Materials Science at the University of Birmingham between January and September 2015.

This work builds on a preliminary selective analysis of organic materials carried out by the Department of Conservation and Scientific Research at the British Museum, London<sup>1</sup> during which a range of organic materials including wood, horn, and various pastes composed of beeswax, animal glue, and sugars characteristic of plant gums were identified. These materials were characterized through a combination of FTIR and Raman spectroscopy, gas chromatography-mass spectrometry (GC-MS), optical microscopy (OM), and variable pressure scanning electron microscopy (VP-SEM).

This research aims to systematically characterize the organic materials used in the construction and decoration of the hoard objects, to identify patterns of additives to and mixtures of materials, and to identify patterns of material use within, and across the range of hoard objects.

## Methods

### *Sample Survey and Collection*

A survey of the numerous samples collected during the initial conservation cleaning process was undertaken to identify potential organic materials. Sample boxes were individually processed to separate viable organic samples from those considered to be of no analytical value, and where appropriate, to condense multiple small clay samples into as few vials as necessary. The individual vials were initially examined under stereo magnification, either in situ, or by emptying the contents onto a clean white ceramic tile. Smaller samples were examined under magnification using a Keyence VHX 1000 Digital Microscope as necessary. A small number of potential organic samples were identified from this survey. The majority of these samples had been stored in small glass vials labelled with the object number and a sample number corresponding to the conservation written documentation.

A survey of 4100 'K' numbered hoard objects was completed to identify potential organic materials. The survey combined analysis of written and photographic documentation, and primary examination of hoard objects using magnification as necessary. A total of 144 objects and fragments (see appendix II) were identified as potentially being constructed from or decorated with material of organic origin. These objects were taken to the conservation laboratory and a scaled and annotated photomicrograph was taken of each area of interest using a Keyence VHX 1000 Digital Microscope. Samples collected

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<sup>1</sup> Steele and Hacke 2013, Cartwright 2013, Stacey 2014.

from objects remote to the Birmingham Museum and Art Gallery were photographed using a handheld digital camera.

A small amount of material for FTIR analysis was removed by scraping with a fine needle under stereoscopic magnification. For some objects, potential organics were collected from multiple locations. Working under magnification ensured that the samples removed were as small and as localized as possible. In the majority of cases the amount of sample removed was invisible to the naked eye. A scaled and annotated photomicrograph was taken for each sample (where the facility was available) and the sample transferred to a small glass vial labelled with the object number, and a sub number identifying each discreet sample e.g. K290-1, K290-2 etc.

### ***Micro-FTIR***

Fourier Transform infrared microspectroscopy (micro-FTIR) was performed on a Bruker Lumos FTIR microscope with liquid nitrogen cooled MCT detector. The infrared spectra were recorded using attenuated total reflectance (ATR) mode in the range of 4000-600 $\text{cm}^{-1}$ . The scans averaged 64 scans at a resolution of 4 $\text{cm}^{-1}$ . A 64 scan background reading was completed at a resolution of 4 $\text{cm}^{-1}$  between each sample.

Samples were placed directly onto the microscope stage, and the motorized germanium ATR crystal with internal pressure control brought into contact with the sample. The microscope stage and ATR crystal were cleaned with acetone on a cotton swab, and allowed sufficient time to dry between each scan. Spectra were characterized through comparison with the Bruker Complete FTIR library, and the IRUG spectral database.

### ***SEM EDS***

Scanning Electron Microscopy was carried out using a Philips XL30 FEG environmental scanning electron microscope at the Centre for Electron Microscopy, at the University of Birmingham. In order to reduce oversampling of the limited organic material in the Hoard, in almost all cases the same subsamples of organic material collected for micro-FTIR analysis were used for SEM analysis. Sub-samples were fixed to the SEM stub with adhesive carbon tape, and were platinum coated. Images were taken using both the secondary electron and backscatter electron detectors, with the SEM operated at 10.0kV, at a spot size of 3.0, and working distances between 9.5 and 10.5 mm. Energy Dispersive X-ray Spectroscopy (EDS) was completed using Oxford Instruments X-SIGHT detector and Oxford Instruments INCA EDX Microanalysis System.

## **Results**

Of the 144 'K' numbered objects and fragments originally selected for FTIR analysis, seventy-nine contain or are formed from one or more materials of organic origin. A table of the 144 objects examined for potential organic material, including sixty-five with no organic material present or available for sample can be found in Appendix II. Of the seventy-nine objects found to have organic materials, thirty-two contain unspecified proteinaceous material, thirty contain beeswax, nineteen contain carbohydrate-based material, thirteen contain horn, three objects contain bone, and two contain amber. In addition, a number of non-metallic inorganic materials, and corrosion products were identified across the same seventy-nine objects including calcium carbonate in ten objects, clay minerals in twenty-three objects, and malachite in eight objects. Sixteen of the seventy-nine 'K' numbered objects identified as of organic origin are discrete samples collected during the initial hoard

excavation, but not associated with a specific metallic component, e.g. K1637 is consists four small balls of beeswax, K1490 is consists of small fragments of horn.

## ***FTIR analysis results***

### ***Organic Materials***

Proteinaceous material occurs in thirty-two hoard objects in total, and in most cases, as what appears to be animal glue in close association, or mixed with beeswax (see Appendix I, table 2). Animal glue is found in association with beeswax in twenty-five of thirty-one protein containing hoard objects (K1, K189, K270, K273, K291, K352, K362, K400, K455, K458, K546, K570, K645, K673, K712, K843, K850, K1003, K1012, K1056, K1058, K1062, K1448, K1536, K1620). The exact nature of the protein component in these pastes- collagenous, keratinous, or otherwise, is as yet open to interpretation.

Protein glue is found unmixed with other materials within the cells of two objects- (K104, K1145), as a crusty glue-like material inside a sword pyramid (K451), and in combination with beeswax within the cloisonné cells of a further fourteen objects (K1, K270, K273, K362, K400, K570, K645, K673, K712, K843, K850, K1003, K1056, K1155). Proteinaceous material is found mixed or in close association with beeswax inside seven pommels or bosses (in pommels K189, K291, K352, K455, K458, K1448, and in boss K1536).

The other occurrences of proteinaceous material not assigned to horn or bone materials are a small piece of leather not associated with a particular hoard object (K435), a fibrous yeast growth collected during conservation (K324), and as an unspecified protein on a hilt plate which may relate to degraded horn (K283).

Beeswax is identified in thirty hoard objects, and in twenty-five cases is found in close association with protein glue as described above (see Appendix I, table 1). Beeswax is found in association with proteinaceous glue within the cells of fourteen objects (K1, K270, K273, K362, K400, K570, K645, K673, K712, K843, K850, K1003, K1056, K1155). It is also found inside nine pommels or bosses (pommels K189, K291, K352, K455, K458, K701, K1195, and bosses K311, K1536), and is mixed with calcium carbonate material in three of these (K311, K701, K1195), and with proteinaceous glue in six others (K189, K291, K352, K455, K458, K1536).

Beeswax is found in several other locations in addition to within cloisonné cells and pommels. It is found in three conservation samples mixed with protein glue (K545, K1003, K1058), mixed with calcium carbonate (K546) and with protein glue (K1012) within the channel of a helmet crest, mixed with calcium carbonate and protein glue in the central panel of a cloisonné strip (K1062), mixed with protein glue inside a pommel ring (K1448), and as pure beeswax in four small ball-shaped fragments not associated with a specific hoard object (K1637). The archaeological significance of the beeswax balls falls outside of the scope of this report, but as the only example of a 'raw' material found amongst the hoard, their presence raises questions about the context under which the hoard was originally collected and deposited.

Horn is found in twelve objects in total, eight of which are fragments not associated with a particular hoard object (K436b, K606, K1341, K1395, K1490, K1551, K1615, K1667). Horn has been used in the construction of two hilt plates (K283, K285), attached to a fixing pin from a decorative element (K305), and as discreet fragments inside a boss (K1620).

Carbohydrate-based material is found in nineteen hoard objects. Sixteen of these occurrences appear to be cellulosic material (K274, K326, K356, K357, K452, K546, K701, K710, K763, K787, K1087, K1097, K1145, K1563, K1615, K1621). The remaining three occurrences appear to be plant extracts (K606, K1179) or plant gum (K1155).

There are no clear patterns as to the use of cellulosic materials across hoard objects. A small piece of wood is used as a joining piece between a decorative pommel cap fitting (K298) and its host pommel, and a larger piece of wood (K787) fits inside a flanged metal fixture. Four pommel caps have a woody interior component that appears to serve as a lining material (K452, K701, K710, K1097), and woody cellulosic material is identified within three cloisonné decorated edge strips (K356, K357, K1145). Woody material is found inside an unidentified metal object (K274), and within the central ridge of a helmet crest (K546), but many other cellulosic materials are small fragments collected during conservation, or fragments not associated with a particular hoard object (K326, K763, K1087, K1536, K1615, K1621).

Bone was identified in three hoard objects using FTIR and appears to have a structural role as interior fill in two objects (K972, K1079), and a decorative function in an ear-shaped piece (K653).

Amber is found at two locations within the hoard material. Small pieces of amber were identified by FTIR amongst a grouping of fragments not associated with a particular hoard object (K1395), and as what appears to be a repair material on a cabochon hilt ring (K679).

#### ***Organic Related Materials***

Calcium carbonate-based material is found in ten objects (K307, K311, K352, K359, K452, K546, K565, K701, K1602, K1195), seven of which are pommels or bosses (pommels K307, K352, K359, K452, K701, K1195, and boss K311). The calcium carbonate is mixed with silicates in four of these (K307, K352, K359, K452) in what appears to be a lime plaster-like material, and with beeswax and silicates in three (K311, K701, K1195). The other objects in which calcium carbonate is identified are a helmet crest ridge (K546) where it is mixed with beeswax and a protein component, as a crusty residue with silicate material inside a sword pyramid (K565), and mixed with beeswax and protein glue in the central panel paste for a cloisonné strip (K1062) (Appendix I, Table 3).

Silicate materials, most of which likely relate to clay from the burial environment, were detected on twenty-two objects (K1, K127, K131, K189, K270, K306, K307, K326, K352, K357, K358, K476, K546, K565, K568, K570, K679, K701, K1004, K1126, K1195, K1278). Silicates were detected in isolation in thirteen objects (K127, K131, K189, K270, K306, K326, K357, K358, K476, K568, K1004, K1126, K1278), mixed with beeswax in five (K1, K352, K546, K570, K1195), with protein glue in three (K1, K352, K570), and with calcium carbonate in four objects (K307, K565, K701, K1195).

Silicates were found inside cloisonné cells in six objects, mixed with beeswax and protein in two objects (K1, K570), and in isolation in four objects (K127, K131, K270, K568). Silicates were found inside six pommel caps in total, mixed with calcium carbonate in four (K307, K352, K359, K452), mixed with calcium carbonate and beeswax in one (K1195), with beeswax in one (K352), and in isolation in two objects (K189, K1278) (Appendix I, Table 3).

Malachite is found on eight objects of variable type, all of which have a gold component. Malachite is found in close association with beeswax and protein glue in six objects (K273, K570, K843, K1012, K1062, K1536), with beeswax in one (K270), and in isolation in one (K1366).

## ***SEM Analysis Results***

### *SEM paste analysis*

Paste samples from three pommel caps (K291, K352, K455) were analysed using scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS). In addition to studying the texture of the pastes, it was hoped that sandy particulate identified in some pastes in a preliminary study by the British Museum<sup>2</sup> and during sample preparation for FTIR could be elementally characterised. In order to avoid oversampling of limited organic material, samples previously collected for FTIR were used in this study.

All of the pastes analysed were collected from material inside pommel caps - K291-1 was collected from a large block of paste thought to have served as fill material for composite pommel K291, and K352-2 and K455-1 collected from material deep within their respective pommel caps. Each of the pastes were identified by FTIR as being composed from beeswax and an amorphous protein component thought to be animal glue. FTIR chemical mapping indicates that in sample K291-1 the beeswax and protein components are not homogeneously mixed together (see analysis report K291-1). This may account for the variation in the surface texture across K291-1 which ranges from amorphous in some areas to somewhat flakey and layered in others. Samples K352-2 and K455-1 exhibit what appears to be an amorphous surface, and in common with K291-1 have fine particulate distributed across their respective surfaces. In each of the three samples analysed using EDS, aluminium, silicon and oxygen are present across some areas of the sample (see analysis reports K291-1, K352-2, K455-1). The distribution of these elements across some parts of the sample likely relates to aluminosilicate or quartz-based earth minerals.

While it is possible that aluminosilicates were a deliberate addition to the paste at the time of original manufacture, these minerals are a major component of clay, and their presence here may simply relate to sample contamination from the burial environment. Further processing and analysis of these samples may help to determine if the aluminosilicates are distributed throughout the paste, or are only found on the surface. Distribution throughout the sample would support the idea of deliberate addition of sandy particulate to the paste during manufacture whereas surface distribution supports burial contamination as a more likely source. In addition to aluminosilicates, silver and chlorine were identified across some areas of sample K291-1 and K455-1. The silver and chlorine components map closely together in elemental distribution maps and are more localised than the wider distribution of aluminosilicates observed across the paste samples. This more localised particulate is likely silver chloride corrosion formed from a reaction between the silver components of the pommel caps, and chlorides from within the burial environment.

### *White Paste SEM analysis*

Two samples (K352-1 and K359-1) of material identified by FTIR as containing calcium carbonate were analysed using SEM with EDS. The FTIR spectra for these samples indicated that the white pastes were composed primarily of calcium carbonate with trace silicates, and were a close spectral match for a lime plaster reference sample. In both cases the samples were collected from white paste inside the pommel caps.

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<sup>2</sup> Steele and Hacke 2013.

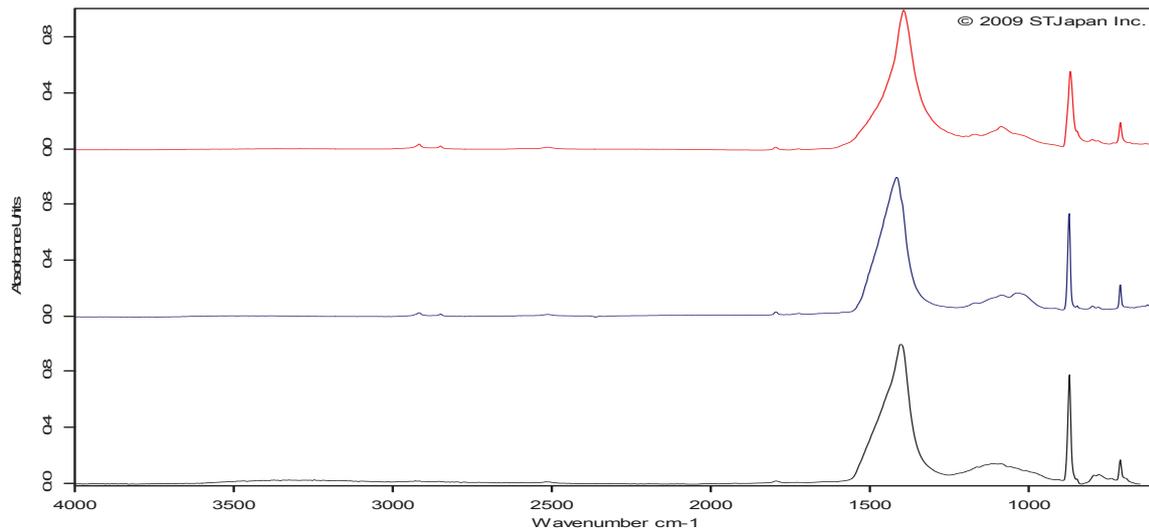


Fig. 1. Top (red) white paste from K359-1. Middle (blue) white paste from K352-1. Bottom, reference sample for lime plaster MJV1 extra, ST Japan 2009.

In the first instance secondary electron imaging was employed to examine the microstructure of the white paste samples. Figure 2 below illustrates that the individual particles for both pastes appear regular in size, and are irregularly shaped and have jagged edges. The sample texture is consistent with scanning electron images of quick lime published in Oates.<sup>3</sup> The samples were examined for evidence of microfossils typically present in unprocessed geological limestone, but none were visible in the white paste samples K352-1 or K359-1. The texture described and absence of microfossils in these pastes indicates that the material has likely been lime processed.

<sup>3</sup> Oates 1998, 148: 15.7b.

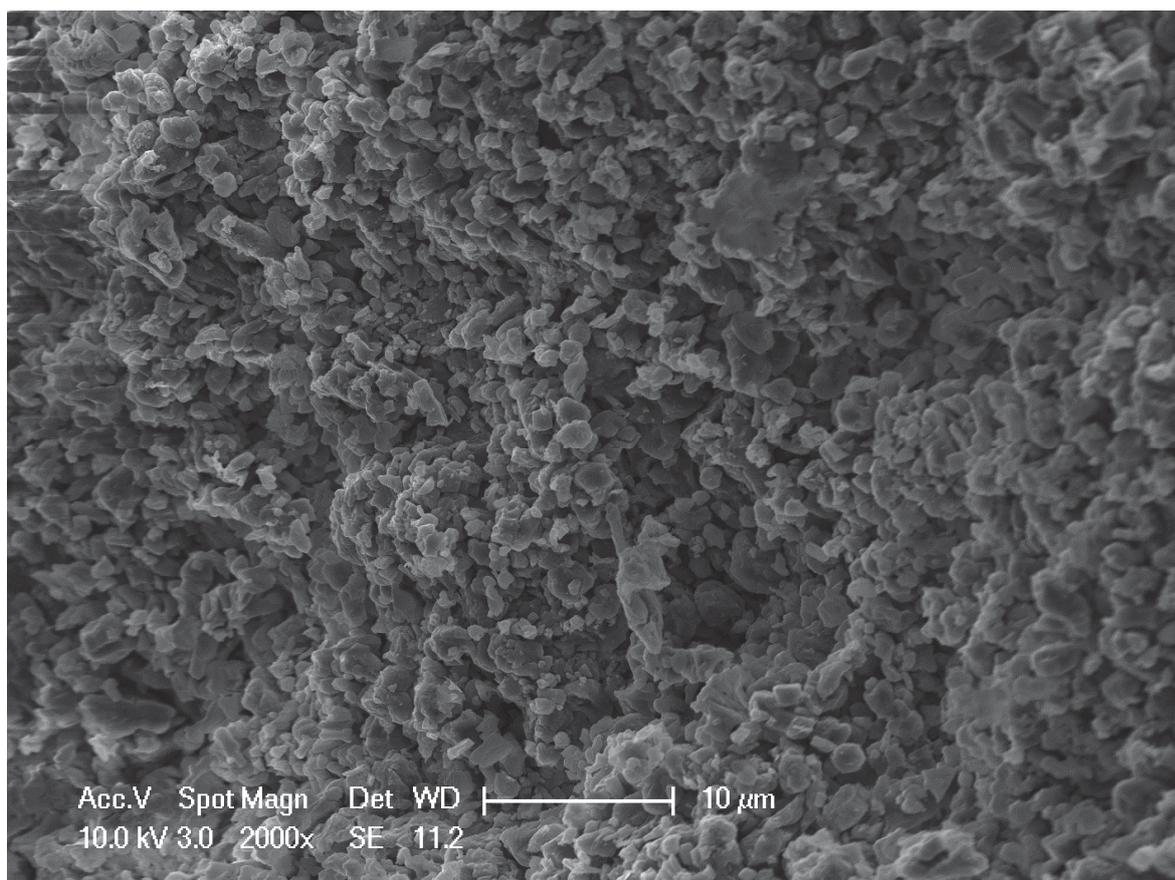


Fig. 2. Secondary electron image for paste K359-1 showing texture consistent with calcined material.

The samples were imaged using SEM in back scatter electron mode, and in both samples, the regularity of the grey tone across the samples indicates that the pastes are elementally somewhat homogeneous, with localised areas of elementally different material randomly distributed across the surface. Energy dispersive x-ray spectroscopy was employed to characterise the elements present in the samples. In both K352-1 and K359-1, the only elements detected were calcium, oxygen, and silicon. Carbon may be present in the pastes, but due to its low atomic mass, cannot be reliably detected using this technique. The calcium was distributed regularly across both samples, with oxygen and silicon locally and irregularly distributed in some areas. The distribution of oxygen and silicon maps closely in both samples suggesting a distribution of silicate-based material such as quartz within the calcium carbonate. The silicate could arise from impurities in the limestone source, as contamination from the burial environment, or as a deliberate addition to produce the lime plaster indicated by FTIR analysis.

## Discussion – Organic Materials

### *Beeswax and Protein Glue Mixture*

The protein glue and beeswax mixture found in twenty-five hoard objects was primarily identified by comparison of FTIR spectra with reference samples. Figure 3 below shows a representative beeswax and animal glue spectra collected from paste within silver sword ring K189. This spectrum is similar to those for the paste analysed from cloisonné cells K1, K270, K273, K362, K400, K570, K645, K673, K712, K843, K850, K1003, K1056, and K1155, and collected from inside pommel caps K291,

K352, K455, K458, and boss K1536. Figure 3 shows a reference spectrum for beeswax and for animal protein for comparison.

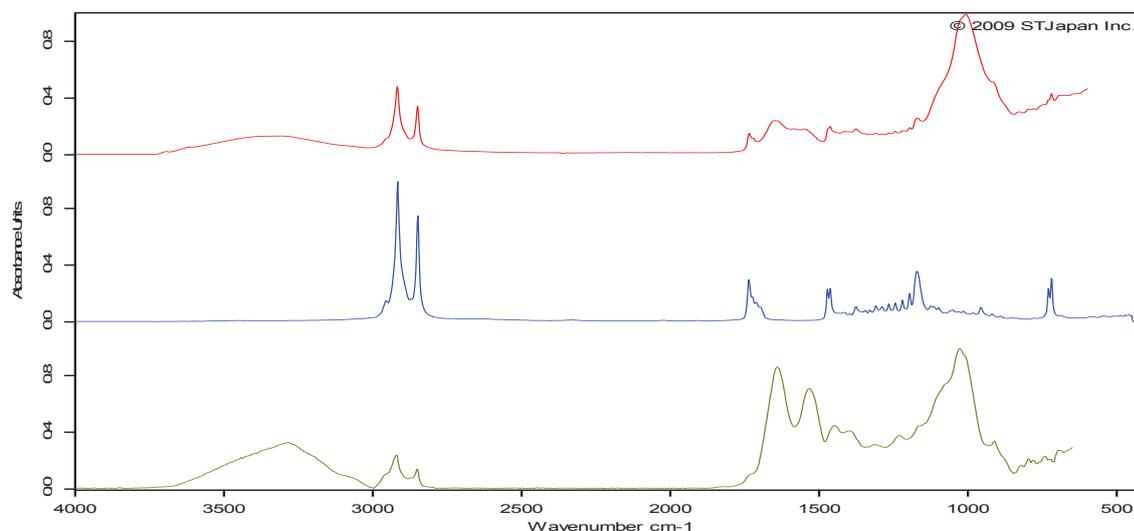


Fig. 3. Top (red) typical FTIR spectra for beeswax and animal glue paste (K189-1), middle (blue) beeswax reference sample, bottom (green) oxidised horse hair reference sample.

Beeswax is a natural wax produced by honeybees of the genus *Apis*. The honeybees most widely used for contemporary beekeeping are European races of *Apis mellifera*, a species of honeybee indigenous to Europe, Africa and the Middle East. The beeswax of *Apis mellifera* is chemically complex, but consists primarily of five main groups of components, namely free fatty acids, free primary fatty alcohols, linear wax monoesters and hydroxymonoesters, complex wax esters, and odd-numbered, straight chain hydrocarbons.<sup>4</sup> The composition of wax shows slight variation between subspecies, and occasionally as a result of the environmental conditions under which the wax was formed. However, variations between the waxes of *Apis mellifera* subspecies tend to occur in the relative amounts, rather than the types of chemical components present.<sup>5</sup> Natural products derived from plants and animals are rarely pure materials; and are more commonly a mixture of multiple components and impurities. In addition to the complex chemical structure described above, and depending on the extent of purification of the raw wax, beeswax may include chemical components from pollen, residual honey, propolis, and debris and waste products from pupae.

The FTIR spectrum for beeswax is characterized by dominant absorption bands around  $2950\text{cm}^{-1}$  and  $2850\text{cm}^{-1}$  that relate to C-H stretching of the methylene ( $\text{CH}_2$ ) groups, a band at  $1740\text{cm}^{-1}$  that relates to C=O bonding characteristic of the ester groups, a band around  $1460\text{cm}^{-1}$  relates to C-H bending, and a doublet between  $730$  and  $720\text{cm}^{-1}$  relating to non planar skeletal deformation vibrations of long chain hydrocarbons.<sup>6</sup>

The bands in the region  $1350 - 1180\text{ cm}^{-1}$  may be assigned to a phenomenon known as a ‘band progression’ present in fatty acids and fatty acid esters which result in a series of evenly spaced bands

<sup>4</sup> Kuznesof 2005.

<sup>5</sup> Kuznesof 2005.

<sup>6</sup> Derrick *et al.* 1999; Birshstein and Tul’chinskii 1977.

in this region. These are due to wagging and twisting vibrations of successive carboxyl coupled methylene groups.<sup>7</sup>

Whilst visual comparison of pure unknown materials like beeswax with their reference spectra is a relatively simple process, the complexity of spectra for mixtures of one or more materials can often obscure confirmative peaks for individual components. Figure 4 below shows a detail of the 1400-1150 $\text{cm}^{-1}$  region for the representative beeswax and animal glue sample K189-1 described in figure 3 above. The detail highlights subtle confirmative peaks for beeswax attributed to non-planar skeletal deformation vibrations of long chain hydrocarbons in this region described previously, but partially obscured within the mixture of beeswax and proteinaceous material in paste K189-1-1. The confirmative peaks for beeswax shown for paste sample K189-1-1 are visible across all of the pastes identified as containing beeswax.

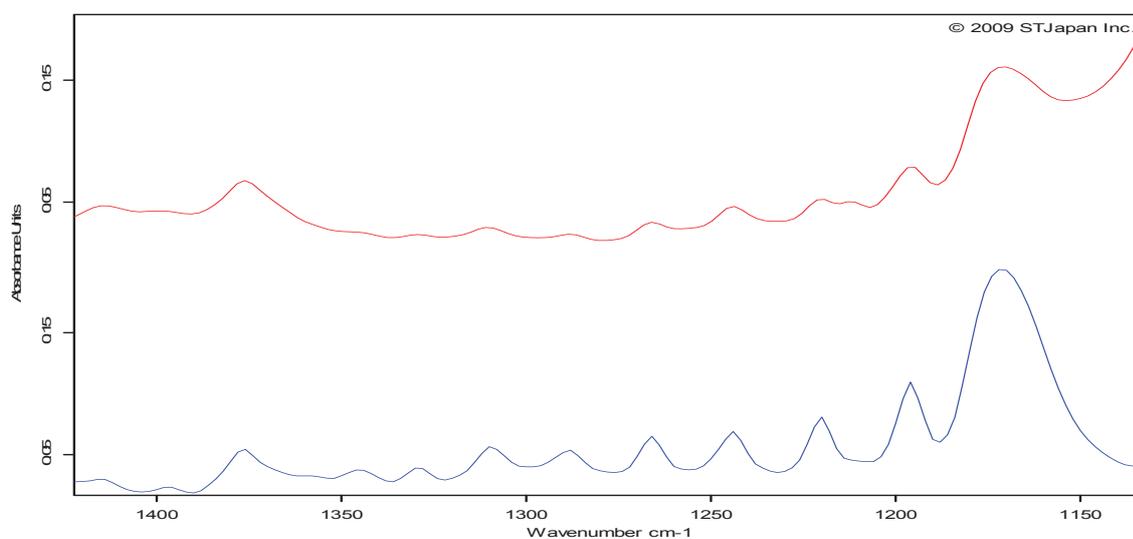


Fig.4. Detail of 1400-1150 $\text{cm}^{-1}$  region showing subtle comparative peaks between top (red) typical FTIR spectra for beeswax and animal glue paste (K189-1), and bottom (blue) beeswax reference sample, ST Japan 2009.

The proteinaceous component mixed with beeswax in pastes identified in twenty-five objects is considered, due to the protein consistent bands detected in the FTIR spectra, and lack of any discernible structure amongst the paste samples, to be animal glue. Egg white was considered as a possible protein component, but as egg white would begin to coagulate at the melting point for beeswax (65 °C),<sup>8</sup> it seems unlikely that this would have made a suitable paste mixture. Some question remains over the exact nature of the protein, but the melting points for beeswax and animal glue are more compatible. Animal glue is produced by processing animal parts from the hide, connective tissue, or hooves and horns, of mammals. Glues produced from hide and connective tissues are composed primarily of collagen whilst those formed from hoof and horn, are composed primarily from keratin.

Figure 5 below shows the spectra for the predominantly collagenous deerskin, and for a collagen-based ‘pearl glue’, and demonstrates that the spectrum for glue remains largely unchanged from the raw material from which it is produced.

<sup>7</sup> Baeten *et al.* 2010

<sup>8</sup> Kuznesof 2005; National Food Service Management Institute 2009

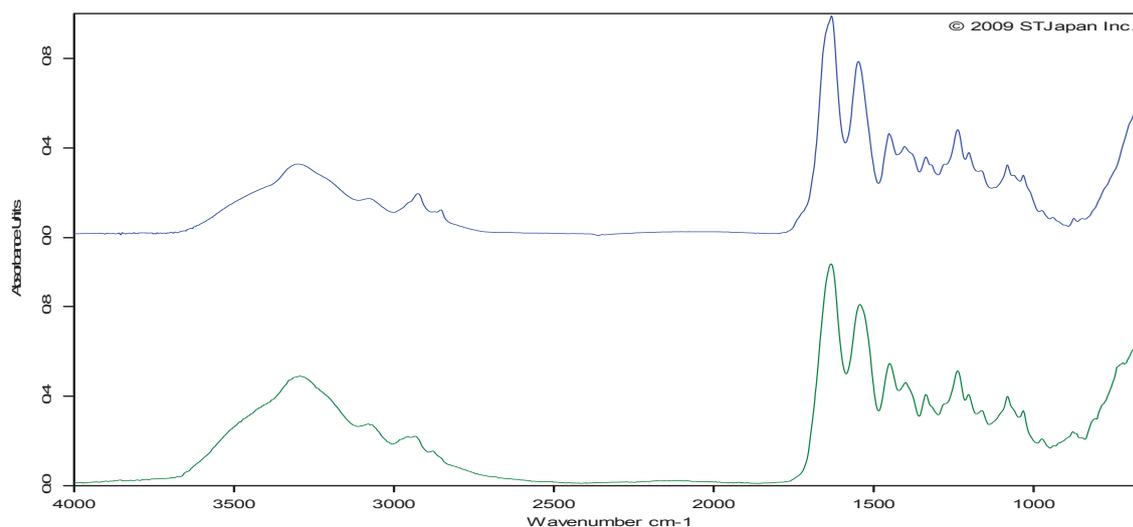


Fig. 5. Top (blue), Deer skin reference sample, ST Japan 2009. Bottom (green), collagen-based 'pearl glue' reference sample, ST Japan 2009. There is little spectral variation between collagen in the deerskin and in the material processed into glue.

Keratinous tissues such as those found in horn and hoof are formed from fibrous, helically arranged keratin molecules aligned to form intermediate filaments, and embedded in a non-filamentous protein matrix. In mammalian keratinous tissue, the orientation of the keratin fibres, and the extent of disulphide crosslinking between the keratin filaments influence the mechanical properties of the tissue. The mechanically hard and chemically unreactive nature of horn and other hard keratinous tissues is largely due to disulphide crosslinking between cysteine amino acid residues in the protein matrix, with cysteine residues making up between 7% and 20% of the total amino acid residues in keratinous tissue.<sup>9</sup>

In order to process hard keratinous tissues into animal glue, it is necessary, therefore, to disrupt the crosslinking cysteine molecules. Studies of oxidised hair from humans by chemical bleaching and by weathering,<sup>10</sup> and hair from horses by chemical bleaching,<sup>11</sup> demonstrate that oxidised keratin has a lower cystine content and a higher cysteic acid content, supporting the conclusion that oxidation of keratin protein, such as occurs during processing into animal glue, occurs primarily at the cystine disulphide bonds.

In common with collagenous materials, the FTIR spectra for keratinous materials exhibit characteristic bands for amide I (C=O stretching) between 1700 and 1600  $\text{cm}^{-1}$ , and amide II (CN stretching and NH bending) between 1560 and 1500  $\text{cm}^{-1}$ , a sharp, broad band centred at around 3300  $\text{cm}^{-1}$  related to N-H stretching, and a doublet between 3000 and 2800  $\text{cm}^{-1}$  relating to C-H stretching of methylene groups are characteristic of both collagenous and keratinous proteinaceous materials.<sup>12</sup> In oxidised keratinous materials, however, an intense peak at about 1030  $\text{cm}^{-1}$  is attributable to S=O bonding in cysteic acid described previously.<sup>13</sup> Figure 6 below shows the characteristic protein peaks for three keratinous materials. The top spectrum in this figure relates to

<sup>9</sup> Faterpekar *et al.* 2008; McKittrick *et al.* 2012; Kakkar *et al.* 2014, O'Connor *et al.* 2015.

<sup>10</sup> Robbins 2002.

<sup>11</sup> Kennedy *et al.* 2013.

<sup>12</sup> Welsch *et al.* 2012; Kennedy *et al.* 2013; Mansilla *et al.* 2011; Derrick *et al.* 1999.

<sup>13</sup> Welsch *et al.* 2012, Kennedy *et al.* 2013, Mansilla *et al.* 2011.

deteriorated horn collected from hilt plate K285 (confirmed as horn by SEM structural analysis in report K285-1-7) and shows the peak for S=O bonding characteristic of cysteic acid in oxidised keratinous material. As no reliable spectrum for hoof glue was available, a reference sample for horse hair (middle) and oxidised horse hair (bottom) are shown for comparison to similar keratinous hard tissue, and to further demonstrate the S=O peak at  $1030\text{cm}^{-1}$  characteristic of oxidised cysteine.

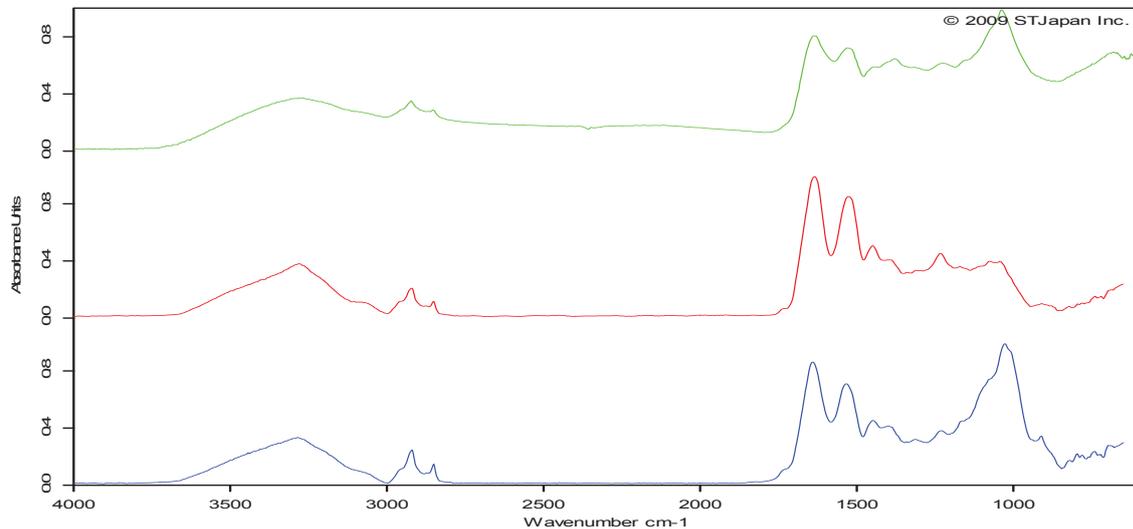


Fig. 6. Top (green), Deteriorated horn sample K285-1. Middle (red), Horse hair reference sample, ST Japan 2009. Bottom (blue), Oxidised horse hair reference sample, ST Japan 2009.

The proteinaceous component in the beeswax and animal glue pastes identified in twenty-five hoard objects (K1, K189, K270, K273, K291, K352, K362, K400, K455, K458, K546, K570, K645, K673, K712, K843, K850, K1003, K1012, K1056, K1058, K1062, K1448, K1536, K1620) exhibits protein peaks which may be characteristic of either collagenous or keratinous glue, but in all samples, a peak which may arise from S=O bonding in cysteic acid is present.

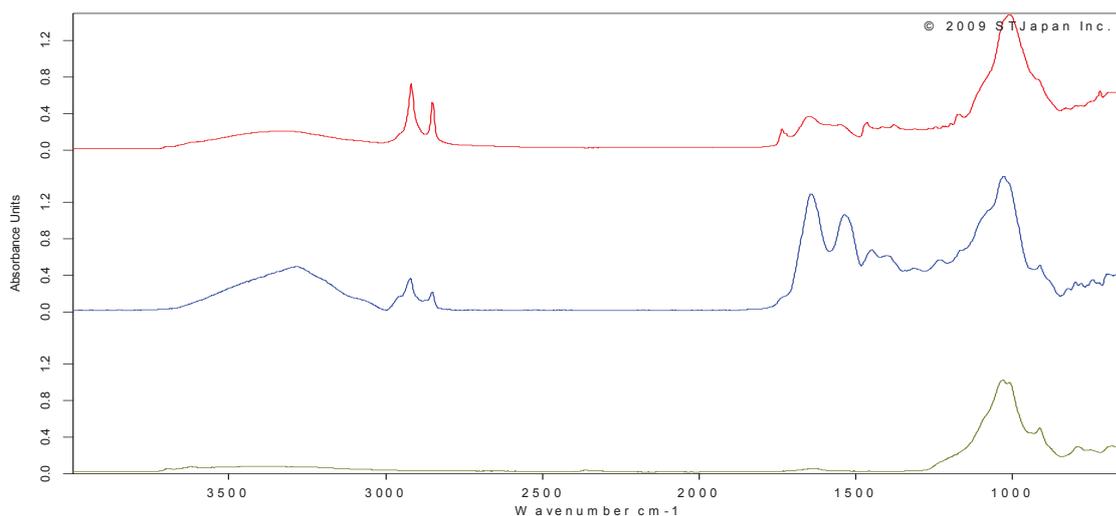


Fig. 7. Top (red), Paste sample K189-1. Middle (blue), Oxidised horse hair reference sample, ST Japan 2009. Bottom (brown), Diatomaceous earth reference sample, ST Japan 2009.

Initial interpretation of the peak at approximately  $1030\text{cm}^{-1}$  attributed it to Si-O bonding characteristic of silicate-based material. Generally speaking, silicates are characterized by a region of strong absorption near  $1000\text{cm}^{-1}$  due to Si-O stretching, and a second region of absorption near  $500\text{cm}^{-1}$  arising from Si-O bending, often in combination with other cation-oxygen vibrations.<sup>14</sup> The Si-O band near  $1000\text{cm}^{-1}$  shown in the reference spectrum for diatomaceous earth in figure 7 above, could be interpreted as contributing to the dominant peak in the spectrum for sample K189-1 also shown in figure 7, and to similar peaks in the other 24 beeswax and protein paste samples analysed in this study. Clay minerals show 'Reststrahlen bands' in the region below  $1200\text{cm}^{-1}$ , where Si-O vibrations absorb most of the radiation and contribute to an intense signal,<sup>15</sup> so that even a small amount of silicate material distributed through the paste would produce an intense band in this region. The band at  $1030\text{cm}^{-1}$  in the Staffordshire Hoard pastes could therefore be attributed to silicate material, cysteic acid from oxidised keratinous material such as hoof glue, or a combination of both.

SEM EDS elemental analysis of three beeswax and protein paste samples collected from inside pommel caps (K291, K352, K455) and described previously, identified silicon and oxygen distributed across the surface of these samples, but it is unclear if the silicates identified are solely responsible for the peak at  $1030\text{cm}^{-1}$ , or if the peak arises from a combination of silicate material and the protein component of the paste. It is also unclear if the silicates relate to contamination from the burial environment, or to the deliberate addition of finely ground particulate such as quartz to the paste mixture. Steele and Hacke report an inorganic component in the pastes analysed in the preliminary British Museum paste study described previously, as aluminosilicates such as are found in iron oxide containing earth pigments.<sup>16</sup> The regularity with which the intense band at approximately  $1030\text{cm}^{-1}$  appears in beeswax and protein paste samples suggests that the idea of clay mineral contamination from the burial environment is unlikely. Further analysis of the elemental composition and distribution of inorganic material across a larger sample group of Staffordshire Hoard pastes is required to clarify this position.

Giostra *et al.* completed analysis of backing pastes from a fifth or sixth century Ostrogothic belt buckle with cloisonné decoration from Tortona, Italy.<sup>17</sup> Fourier transform infrared microspectroscopy (micro-FTIR) identified a high proportion of silicates and a minor amount of calcite, together with beeswax and a proteinaceous component within the paste. The silicates were identified by an intense band at  $1030\text{cm}^{-1}$  as is found in many of the Staffordshire Hoard pastes, although it is possible that this report has incorrectly interpreted the intensity of the peak as relative to the amount of silicate in the paste. Additional X-ray diffraction (XRD) analysis completed on the inorganic component of the paste identified quartz as the major component, consistent with the SEM EDS analysis of the pastes from K291, K352, K455 described previously.

Gas chromatography-mass spectrometry (GC-MS) analysis of amino acids derived from the protein component of the Tortona buckle paste ruled out the presence of a collagenous protein due to the absence of hydroxyproline, and determined egg white as a more likely protein component. As described previously, egg white would begin to coagulate at the melting point for beeswax, raising questions about the compatibility of this mixture.

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<sup>14</sup> Djomgoue and Njopwouo 2013.

<sup>15</sup> Madejova and Komadel 2001.

<sup>16</sup> Steele and Hacke 2013.

<sup>17</sup> Giostra *et al.* 2008.

The mixture of protein glue and beeswax identified in the cells of fourteen gold and garnet cloisonné objects, and inside some pommel caps in this study broadly agrees with the findings of a preliminary FTIR and GC-MS investigation of Staffordshire Hoard pastes carried out by the Department of Conservation and Scientific Analysis at the British Museum.<sup>18</sup> The study does not identify a specific source for the protein component of these pastes but suggests animal glue, egg, or milk proteins as possibilities.

Organic materials identified by FTIR analysis in the same British Museum report as containing organic pastes were not detected for two objects (K131 and K1388) in this study. The lack of organic material for K131 in this study may be due to variation in sampling locations for scant organic remains, while K1388 was not analysed in this report for lack of evidence of organic material on initial microscopic examination. The additional GC-MS analysis employed in the British Museum study identified sugars characteristic of plant gums in pastes collected from two objects (K270 and K673), in association with a beeswax and proteinaceous component identified by FTIR. The report does not speculate on why plant gum would be added to an already complex paste mixture, but it is possible that the plant sugars detected in these pastes were not deliberate additions, and relate to contamination of the beeswax component with honey or propolis described previously.

A thorough analysis of pastes used in the construction of garnet cloisonné objects is reported in Arrhenius.<sup>19</sup> She describes pastes for a range of cloisonné techniques that are not represented in the Staffordshire Hoard including those for cement cloisonné, sand putty, and fused paste techniques. These pastes are formed from a range of organic and inorganic materials including calcite, silica, quartz, sulphur, and wax. All of the cloisonné pastes identified in this study fall into Arrhenius' category of clasped cloisonné style. These pastes are identified as being composed primarily of organic substances 'like resin', with particles of charcoal-like crystalline material present in some samples. McFadyen notes that the clasped cloisonné construction described in Arrhenius is the technique more commonly observed in the Anglo Saxon cloisonné jewellery analysed in his work.<sup>20</sup> The variation in paste composition across Anglo Saxon cloisonné jewellery observed by McFadyen calls into question Arrhenius' over simplification of paste composition for clasped cloisonné objects, and notes that a lack of clarity on the exact purpose of clasped cloisonné backing pastes has confused this subject.

Arrhenius writes that the pastes were placed in the bottom off the cells to provide a yielding foundation into which the garnets could be set, and does not consider the adhesive function of the paste. Coatsworth and Pinder suggest that it was not necessary for the paste in clasped cloisonné objects to have an adhesive function due to the combined friction fit of the foil and garnet combination setting, and the burnishing of the top of the cell wall used to clasp the garnet in place.<sup>21</sup> They also point out that in addition to the bedding function described in Arrhenius, the pastes would have allowed the maker to achieve a flush surface finish across the numerous individual garnets of varying thicknesses. The authors summarise recipes from the ancient literature which demonstrate a range of possible materials from which pastes might have been formed in the Anglo Saxon period including ox glue and gagatis stone, powdered marble and fish glue, and glue made from hide and stag horn, and speculate that wax found in association with calcite in four Anglo Saxon pieces

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<sup>18</sup> Steele and Hacke 2013.

<sup>19</sup> Arrhenius 1985.

<sup>20</sup> McFadyen 1998.

<sup>21</sup> Coatsworth and Pinder 2002.

analysed by Arrhenius may have had an adhesive function, but as the sampling locations within these objects was unclear, they could not be certain.

The lack of paste in comparable material from Sutton Hoo has further confused the question of paste function. Coatsworth and Pinder note the lack of pastes in garnet cloisonné objects from Sutton Hoo as puzzling, but suggest that empty spaces in the cloisonné cells behind the garnets and foils indicate that pastes may have been present at one time, but were lost in the acidic burial environment at Sutton Hoo. The authors do not agree with the theory that the cells were deliberately produced without paste, simply because the goldsmith had nothing to gain by adding further complexity to the already complicated cloisonné production process. McFadyen agrees with Coatsworth and Pinder on this assertion and questions the requirement for spaces behind the inlays in the Sutton Hoo objects if not for backing pastes.

In response to confusion surrounding paste function, Mc Fadyen carried out a series of experiments to determine the suitability of pastes of different composition for clasped cloisonné production. Attempts to neatly ‘ladle’ pastes formed from heated beeswax and ground chalk, and heated animal glue and ground chalk, into a framework of replica cloisonné cells proved unsuccessful due to the high viscosity of the pastes, the rapid cooling of the pastes when in contact with the metal framework, and even when the metal framework was heated prior to application, the formation of undesirable menisci within the cells. The issues relating to the undesirable cooling, viscosity, and high surface tension of the pastes identified in Mc Fadyen’s experiment may suggest that the combination of beeswax and protein components employed in the Staffordshire hoard pastes was designed to overcome these issues. Additional experimental analysis of different paste mixtures, outside the scope of this study, would be required to determine the characteristics of different paste mixtures. McFadyen concludes that the reason that no standard paste formula has been identified may be due to a combination of maker preference for one paste composition over another, variable material supply, or makers attempting to replicate an observed paste of desirable quality without sufficient understanding of the composition or the chemistry of the material. The similarity in composition of the cloisonné pastes used in the Staffordshire Hoard cloisonné objects as evidenced by FTIR analysis in this project suggests that the goldsmiths or makers had some shared understanding of materials desirable for paste production that included beeswax, animal glue, and possibly a finely ground mineral component. While FTIR analysis has identified the major components of the cloisonné pastes, this technique cannot determine sufficient variation in the paste to indicate individual workshop practices. More sensitive analysis across a range of paste samples using gas chromatography with mass spectrometry (GC-MS) may provide additional evidence to this end.

### *Horn*

Horn is a tough, flexible, mouldable, and fusible natural plastic that has been exploited as a raw material for functional or decorative applications in the production of cultural objects. True horns are found only on the skulls of ruminant artiodactyls such as cattle, sheep, goat, and antelope. The bone horn cores grow out from the frontal bone of the skull and the horn develops from its epithelial covering, forming a sheath with a finely layered ‘cone-within-cone structure’. Horn has a longitudinal, fibrous grain and the surface may have thin, uneven, circumferential ridges marking the edges of sequential cones, particularly toward the junction with the skull.<sup>22</sup>

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<sup>22</sup> O’Connor *et al.* 2015.

The FTIR spectrum for horn exhibits peaks characteristic of all proteinaceous materials as described for collagenous and keratinous materials. The spectra for horn samples identified in the hoard objects shown in figure 8 below- hilt plates K283, K285, attached to a fixing pin from a decorative element K305, and as discreet fragments inside a boss K1620, are all similar in appearance, with the cysteic acid related peak indicative of oxidised keratinous material visible at approximately  $1030\text{cm}^{-1}$ .

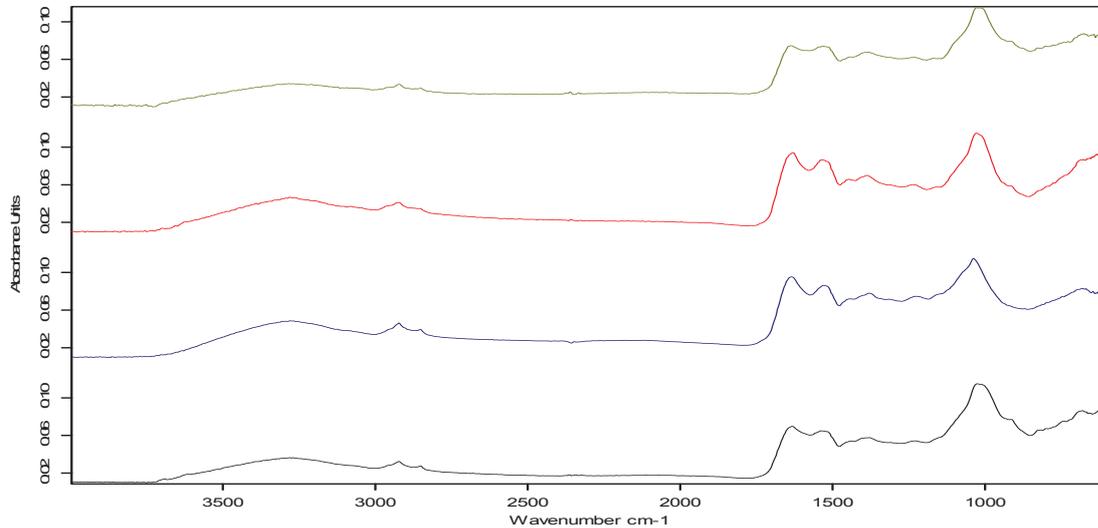


Fig. 8. Top (green) K1620-1-3. Upper middle (red) K283-1-1. Lower middle (blue) K285-1-7. Bottom (black) K305-2-1.

The spectra for K238-1-1, and reference samples for cow and buffalo horn are shown in figure 9 below. The peak at approximately  $1030\text{cm}^{-1}$  visible in K283-1-1 is not present in either of the reference samples. The references are an otherwise excellent spectral match for that of sample K238-1-1.

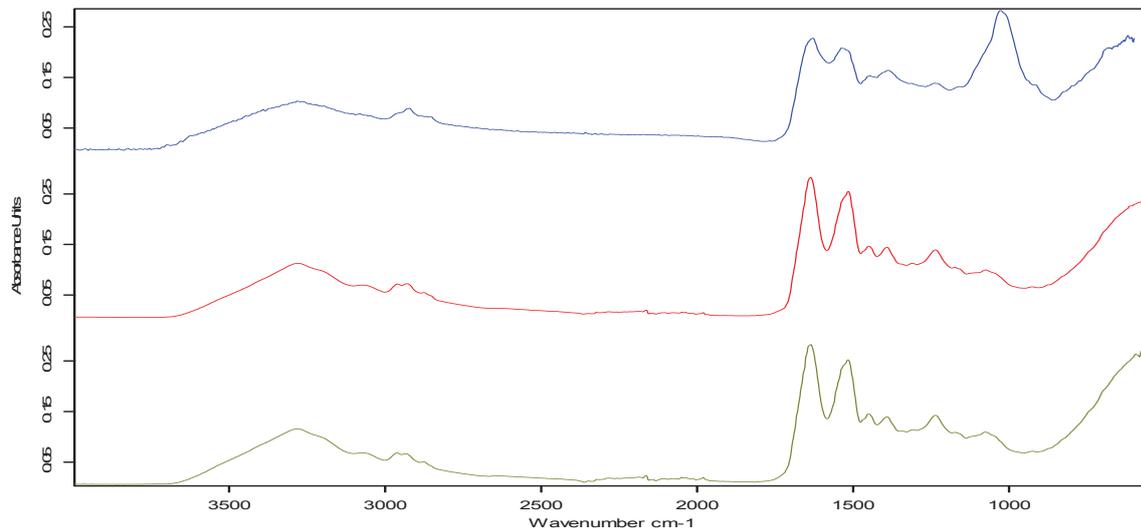


Fig. 9. Top (blue), horn sample from K283-1-1. Middle (red) cow horn reference spectrum, Birmingham Museums 2015, bottom (green) buffalo horn reference spectrum, Birmingham Museums 2015.

VP-SEM analysis carried out on horn samples from hilt plate K283 by Cartwright<sup>23</sup> who concluded that blackening of the material in addition to fracturing, delamination and deformation observed indicated that the horn had been affected by heat. The blackening of the horn is somewhat misleading, and while it is possible that this material was subjected a strong heat source, the blackening and oxidation may also relate to bio deterioration of the tissue, such as observed in equine hoof disease.<sup>24</sup> The peak at approximately  $1030\text{cm}^{-1}$  for K283-1-1 shown in figure 9 above indicates that the cysteine crosslinks that contribute to the mechanical strength of the horn have partially oxidised. The loss of mechanical function associated with the oxidation of cysteine crosslinks would almost certainly contribute to delamination, fracturing, and possibly deformation of this material.

Cartwright<sup>25</sup> assign proteinaceous material identified through VP-SEM analysis, in pommel cap K352, as heat affected horn. FTIR analysis of material collected from inside pommel cap K352 indicates a mixture of beeswax and a proteinaceous component in one sample (K352-2-5), considered by its close association with the beeswax component and lack of visible structure to be proteinaceous glue. Additional SEM analysis carried out on sample K352-2 did not identify structure within the sample as would be expected for horn material, but this may be due to the location from which the sample was collected in relation to a potentially localised distribution of horn material.

Cartwright also suggests that dark coloured material collected from inside boss K1620 is cellulosic in nature, and conclude through VP-SEM analysis that the material is charcoal formed from *Betula pendula*, or silver birch wood. Dark coloured material collected from inside boss K1620 was identified in this study by FTIR as proteinaceous in nature as shown in figure 10 below. The charcoal component identified by Cartwright was not identified in this study.

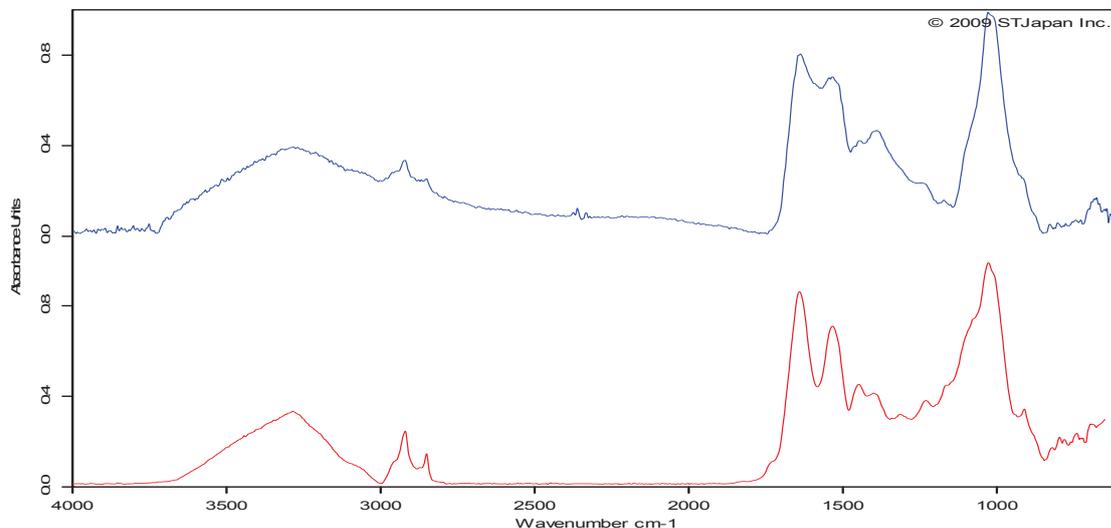


Fig. 10. Dark coloured material collected from inside boss K1620 (K1620-1-3, top), shown for comparison with oxidised horse hair reference sample, ST Japan, 2009.

<sup>23</sup> Cartwright 2013.

<sup>24</sup> Radostits *et al.* 2006.

<sup>25</sup> Cartwright 2013.

### *Cellulosic Material*

Carbohydrate-based material is found in nineteen hoard objects. Sixteen of these occurrences appear to be cellulosic material which in almost all cases relate to woody plant matter. Plant fibres are largely composed of cellulose, along with hemicelluloses, pectins, lignin, and extractives in greater or lesser quantities, which may include bound water, residual protein, sugars, flavonoids, tannins, terpenes, fats or waxes. The relative proportions of the compounds vary in accordance with the nature of the cell and its function.<sup>26</sup> As the predominant component of plant fibres is cellulose, and other major constituents (hemicelluloses and pectins) are also polysaccharides, the FTIR spectra of different cellulosic plant materials are superficially similar and cannot be readily distinguished by eye.<sup>27</sup> In addition, degradation of one or more components of the plant material e.g. through oxidation of the cellulose molecule, will influence the position and intensity of spectral peaks relative to non-deteriorated reference spectra.<sup>28</sup>

There are, however, a number of fairly consistent spectral peaks indicative of cellulosic carbohydrate within a sample. The majority of cellulosic carbohydrates will exhibit a broad band from 3600–3100cm<sup>-1</sup> arising from O-H stretching in bound or absorbed water.<sup>29</sup> A broad band relating to C-H stretching from aromatic hydrocarbons at 3100-3300 cm<sup>-1</sup> can be obscured or partially obscured by the broad O-H stretching band described previously.<sup>30</sup> Additional peaks relating to the cellulose component of plant material include peaks for C-H stretching of methylene groups between 3000 and 2800cm<sup>-1</sup>, C-H deformation in cellulose and hemicellulose at 1371cm<sup>-1</sup>, C-H vibrations at 1319 cm<sup>-1</sup>, an intense peak at about 1030cm<sup>-1</sup> relating to C-O bonding (this is typically a combined peak for cellulose and hemicellulose), and a shoulder at 897cm<sup>-1</sup> relating to C-H bending. Additional shoulders at 1155cm<sup>-1</sup> and 1105cm<sup>-1</sup> on the C-O band at about 1030cm<sup>-1</sup> relate to stretching and contraction (so called ‘breathing’) vibrations within the benzene rings, and glycosidic linkages between carbohydrate molecules respectively.<sup>31</sup>

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<sup>26</sup> Beck 2005; Evert 2006.

<sup>27</sup> Garside and Wyeth 2003.

<sup>28</sup> Stuart 2007; Ciolacu *et al.* 2011.

<sup>29</sup> Tipson 1968; Stuart 2007; Naumann *et al.* 2007, Bodirlau and Teaca 2009.

<sup>30</sup> Tipson 1968.

<sup>31</sup> Tipson 1968, Naumann *et al.* 2007, Bodirlau and Teaca 2009.

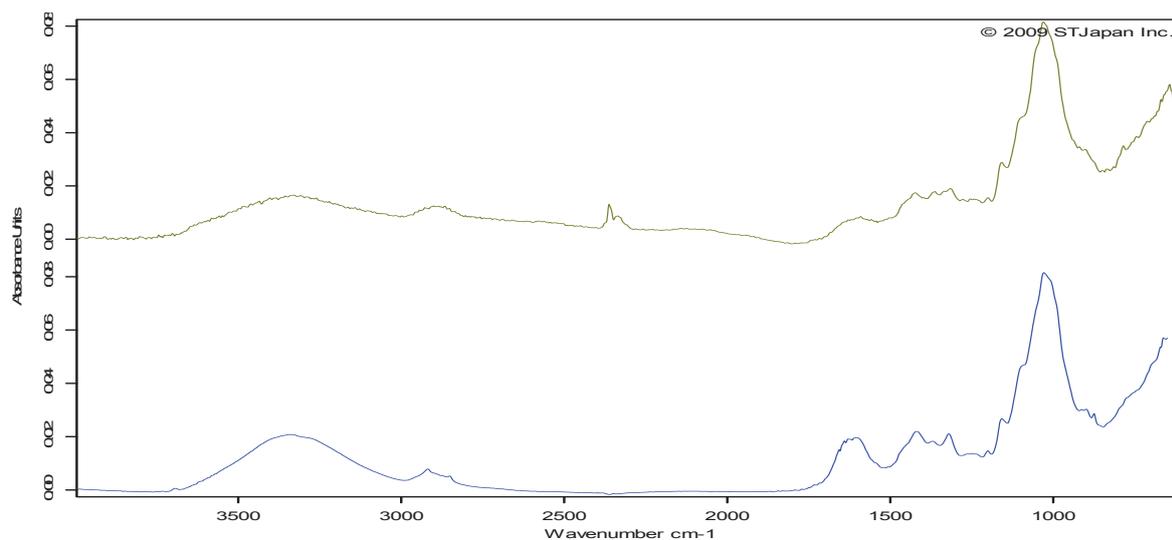


Fig. 11. Top (green) Cellulosic material from K452-2. Bottom (blue) Papyrus reference sample, shown here as a generic example of cellulosic material, ST Japan Inc. 2009

The spectral features described for cellulosic materials are visible in the spectra for sample K452-2 in figure 11, a woody cellulosic material that appears to line the interior of pommel cap K452. A reference sample for papyrus is shown for comparison with a generic cellulosic material.

Four pommel caps have a woody interior component that appears to serve as a lining or bedding material (K452, K701, K710, K1097). The FTIR spectra for K452 and K701 are a reasonably close spectral match for woody cellulosic material (see figure 12 below), while those for K710 (consolidant contamination), and K1097 (advanced state of deterioration), are less clear and require inventive interpretation. The characterisation of these samples is supported by analysis of their microstructures which in all cases indicate woody cellulosic material. The use of wood inside pommel caps K452, K701 and K1097 shows some variation. The wood from pommel K1097 is only found in the very bottom of the pommel filling the cap, whereas the wooden component from pommels K452 and K701 come to midway up the pommel and are ‘topped up’ with white paste. Each of these ‘linings’ are indented in the upper surface, which could indicate partial collapse due to deterioration, or could suggest the wooden linings served to bed the tang of the sword in place, preventing the harder metal of the tang from misshaping or penetrating the softer gold alloy from which these pommels are formed. Such wooden ‘packing pieces’ are identified in two swords at Buckland Anglo Saxon Cemetery, Dover- grave 375, sword b and grave 414, sword b.<sup>32</sup> In both cases mineral preserved ash wood (*Fraxinus excelsior*) is identified on the hilt of the swords including near the upper guard end of the tang, and is considered by the authors to be packing material placed between the tang and the other hilt components. The idea of organic packing material, in this case horn, is also expressed in regard to an iron sword (833/1) from the excavations at Mucking where wedges of horn are considered to have been used to hold the hilt components firmly in place.<sup>33</sup> Little remains of the contents of pommel K710 to speculate on the use of wood in this object, but the suspected cellulosic material was collected from the interior surface, deep within the pommel cap.

<sup>32</sup> Parfitt and Anderson 2012.

<sup>33</sup> Hirst and Clark 2009.

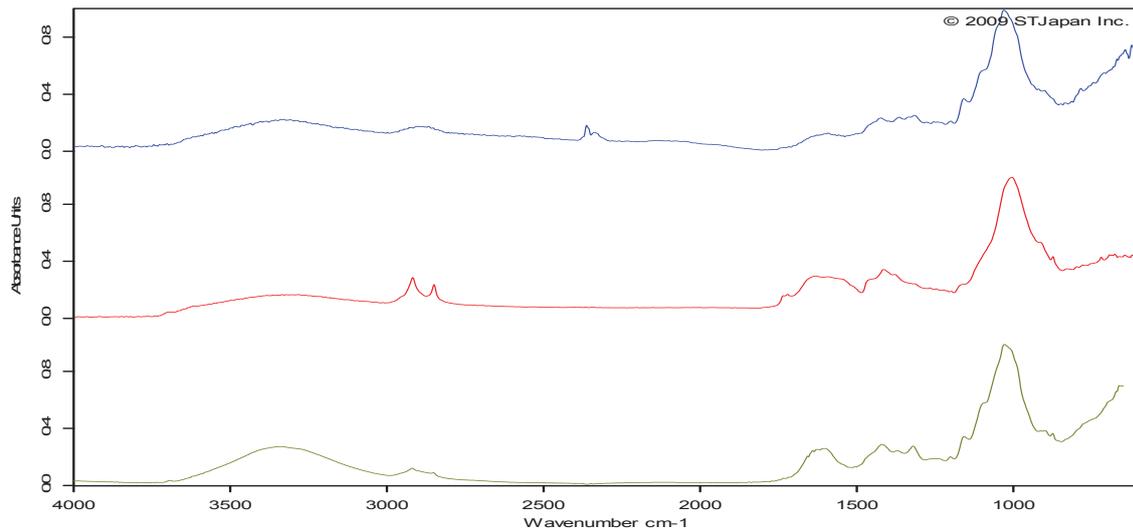


Fig. 12. Representative spectra for woody cellulosic material from inside pommel cap top (blue) K452-2-1, and middle (red), K701-3-1. Bottom (green), papyrus reference sample, ST Japan 2009, shown here as a generic example of woody cellulosic material.

The woody cellulosic material identified within three cloisonné decorated edge strips (K356, K357, K1145) supports the idea that these pieces were at one time attached to a wooden substrate. The woody samples are all collected from within narrow channels along the sides of the edge strips indicating that the substrate would have occupied the space within the strip edges. The FTIR spectra for K356-1-7 and K1146-2-4 shown in figure 13 below are a close spectral match for that of the papyrus shown as an example of a generic woody cellulosic material. Silicates distributed across the surface of sample K357 (not shown) are thought to relate to the burial environment, and dominate the spectrum, obscuring confirmative peaks for cellulose around the 1000cm-1 region. Optical microscopy and SEM analysis of samples collected from K357 indicates a woody cellulosic microstructure (see analysis report K357-2-2).

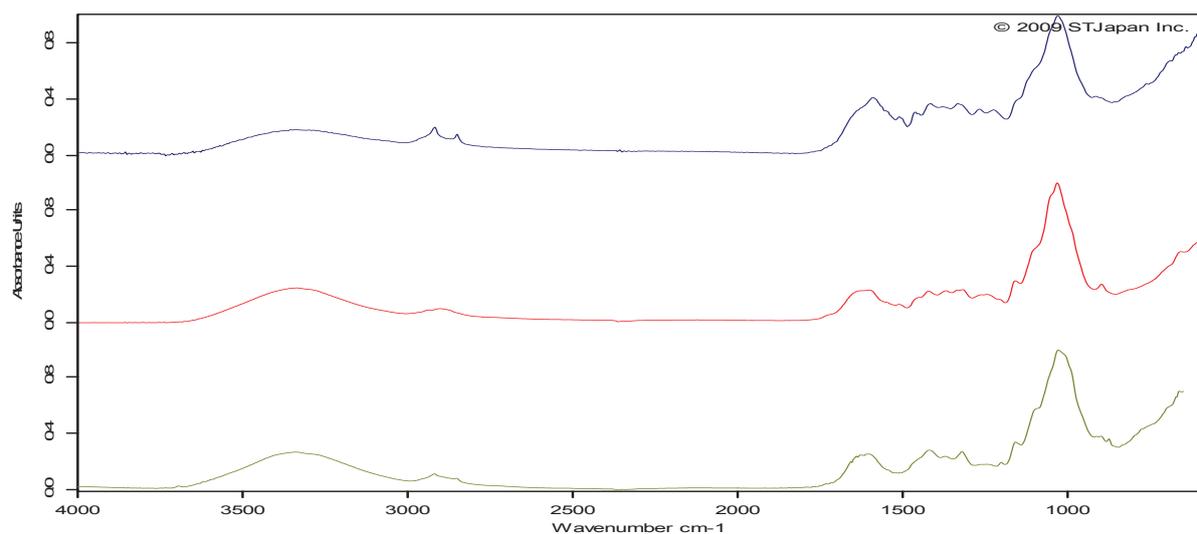


Fig. 13. Comparison of woody material collected from cloisonné edge strip top (blue) K356-1-7, and middle (red) K1145-2-4, with bottom (green), reference spectra for papyrus, ST Japan 2009, shown here for comparison with generic woody cellulosic material.

Sample K290 is a piece of wood that appears to have been employed as a joining material between an ornate pommel cap and a pommel ring K298. The piece has a grey coloured paste-like material loosely attached to the surface on one side, which may relate to its function as a joining piece between the two pommel components, or may be attributed to contamination from the burial environment. VP-SEM analysis by members of the British Museum Department of Conservation and Scientific Research identified the wood as *Fraxinus excelsior*, or European ash, a good, all-purpose timber, much used for hafts, and many weapon/tool components. The British Museum team describe ash wood as strong, durable and flexible.<sup>34</sup>

K787 is a large piece of wood that appears to form the centre piece to a silver part of a flanged bracket fitting, and deemed consistent with the burial period for the hoard object group. The wood is identified as *Carpinus betulus* or hornbeam wood, a strong, heavy and extremely durable wood, suitable for the production of many types of objects such as tool handles, bowls, dishes, mallets and blocks.<sup>35</sup> The wood is in remarkably good condition, and does not appear to have undergone any significant deterioration during burial. FTIR analysis was completed on white fibrous material embedded within the wooden component of K787, with highly cellulosic material indicated (see analysis report K787-1-1). It is unclear how this material became closely embedded in the surface of K787, but contamination of the burial environment with a highly cellulosic material such as paper or tissue would account for the cellulosic material identified.

A cellulosic component was identified within a curved silver ‘U’ shaped channel K546, considered to be the ridge component of a helmet crest. The cellulosic material characterised by FTIR and SEM analysis, was discovered in close association with a calcium carbonate-based paste (see analysis report K546-5-1). This assemblage is discussed in more detail in the section on calcium carbonate-based pastes at page 33-4.

Wood was identified in close association with horn material during preliminary analysis of K274- two joining silver/copper fragments- by the department of conservation and scientific research at the British Museum.<sup>36</sup> The wood was identified as *Fraxinus excelsior*, European ash. FTIR analysis of a sample of woody material collected from inside the break edge of K274 was inconclusive.

### *Bone*

Bone was identified in three hoard objects using FTIR and optical microscopy, and appears to have a structural role as interior fill in two objects (K972, K1079), and a decorative function in an wing-shaped piece (K653). Bone is a dynamic, highly vascularized tissue that is formed from a complicated composite containing both inorganic and bio-organic compounds. The inorganic to bio-organic ratio is approximately 75% to 25% by dry weight and about 65% to 35% by volume. This ratio not only differs among animals, among bones in the same animal and over time in the same animal, but also exerts a major control over the material properties of bone, such as its toughness, ultimate strength and stiffness.<sup>37</sup>

The mineral element of bone is mainly hydroxyapatite, which may be loosely described by the formula  $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ . Chemically, this is a fairly stable compound but the apatite lattice is very tolerant of substitutions, for example, OH can be replaced by  $\frac{1}{2}\text{CO}_3$  or  $\frac{1}{2}\text{O}$ ; Ca by Sr, Ba, Pb, Na or

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<sup>34</sup> Cartwright 2013.

<sup>35</sup> Shearman *et al.* 2014.

<sup>36</sup> Cartwright 2013.

<sup>37</sup> Dorozhkin 2009.

vacancies; and PO<sub>4</sub> by HPO<sub>4</sub>, AsO<sub>4</sub>, VO<sub>4</sub>, SiO<sub>4</sub> or CO<sub>3</sub>. In addition, a variety of ions, particularly of metals, can be attached to the surface of hydroxyapatite crystals by adsorption rather than substitution during burial.<sup>38</sup>

The organic matrix of bone consists of collagen and a series of non-collagenous proteins and lipids. About 85–90 wt. % of the total bone protein corresponds to collagen fibres. FTIR spectroscopy constitutes an excellent tool to characterize the bone matrix because its main components (carbonated hydroxyapatite and collagen) absorb infrared radiation at distinct, almost complementary, regions within the 4000-500 cm<sup>-1</sup> range.<sup>39</sup>

The most intense bands arise from the mineral component of the bone, in accordance to its larger proportion in the composite. Bands at 600 and 557 cm<sup>-1</sup> correspond mainly to PO<sub>4</sub><sup>3-</sup> bending vibrations, despite some minor contribution from collagen (amide bands) in that region. Absorptions at 1012 and 961 cm<sup>-1</sup> correspond to the symmetric and asymmetric stretching of phosphate, respectively. It should also be mentioned that acidic phosphate (HPO<sub>4</sub><sup>2-</sup>), a frequent anionic substitution in the crystal lattice of hydroxyapatite, usually originates a band at ca. 1110 cm<sup>-1</sup>, which is normally overlapped with that from the PO<sub>4</sub><sup>3-</sup> asymmetric stretching vibration.<sup>40</sup>

Biological apatites present in bone, dentin and enamel contain different amounts of carbonate, principally from CO<sub>3</sub> replacement of PO<sub>4</sub> ions.<sup>41</sup> Bands at around 870 cm<sup>-1</sup> (bending) and 1450-1400 cm<sup>-1</sup> (stretching) arise from carbonate substitutions in the crystal lattice of hydroxyapatite.<sup>42</sup> The predominantly collagen protein component of the bone, where it is present at all in archeological material, is indicated by carbonyl stretching at about 1650cm<sup>-1</sup> (amide I), C-N and N-H vibrations at around 1550cm<sup>-1</sup> (amide II), and to a broad N-H stretching band centred around 3350cm<sup>-1</sup>, with the latter often partially obscured by a broad H<sub>2</sub>O band between 3700-2500 cm<sup>-1</sup>.<sup>43</sup> The higher ratio of mineral to protein in bone means that the protein peaks described above are often quite subtle in relation to the intense mineral related bands.

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<sup>38</sup> O'Conner 1987; Barralet *et al.* 1998; Elliot *et al.* 2002.

<sup>39</sup> Stuart 2007; Price and Burton 2011; Figueiredo *et al.* 2012.

<sup>40</sup> Figueiredo *et al.* 2012; Querido *et al.* 2013; Fleet *et al.* 2004.

<sup>41</sup> S'lo'sarczyka *et al.* 2005.

<sup>42</sup> Figueiredo *et al.* 2012.

<sup>43</sup> Figueiredo *et al.* 2012, Querido *et al.* 2013.

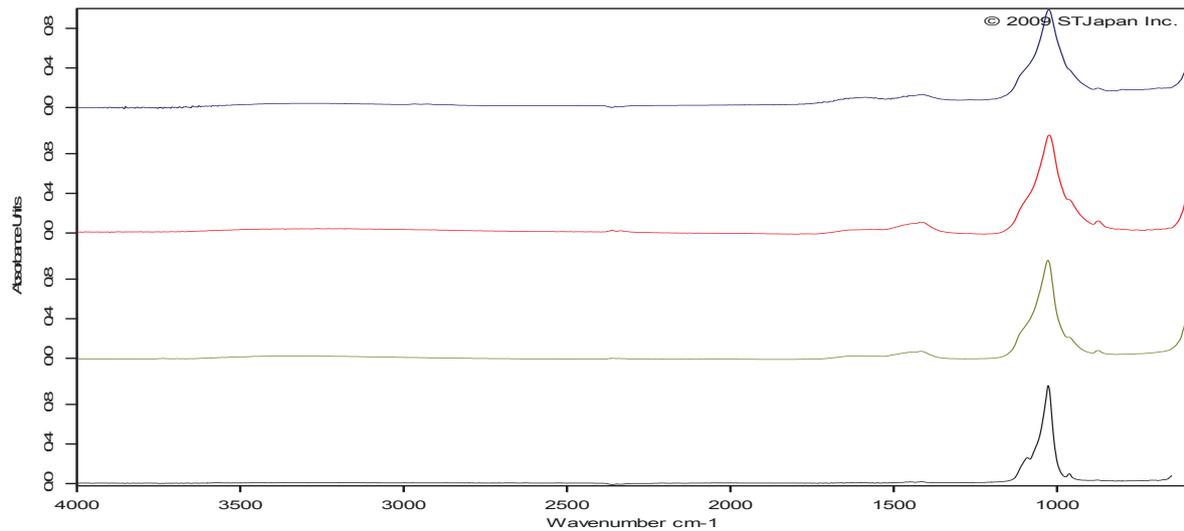


Fig. 14. Top (blue) K653-1-2. Upper middle (red), K972-1-7. Lower middle (green), K1079-1-1. Bottom (black) hydroxyapatite reference spectrum, ST Japan 2009.

Whilst there is no protein component discernible in the three bone sample spectra shown in figure 14 above, the intense peaks for phosphate symmetric stretching at approximately  $1012\text{cm}^{-1}$ , and the shoulder on these peaks at about  $960\text{cm}^{-1}$  relating to asymmetric stretching of the phosphate are clearly visible. The subtle bands observed at approximately  $1450$  and  $870\text{cm}^{-1}$  in K653-1-2, K972-1-7, and K1079-1-1, but not present in the hydroxyapatite reference spectrum likely relate to carbonate substitutions in the crystal lattice of hydroxyapatite. The inlay in object K653 has been independently characterised by optical microscopy as mammalian bone.<sup>44</sup> Photomicrographs of the fill material inside K972 and 1079 (see example in figure 15 below) were examined by Sonia O'Connor (*pers. comm.* 2015) and were determined to show features of both compact and cancellous tissues. O'Connor cautions that due to the heavily distorted nature of the structures, it has not been possible to rule out antler as a possible source.

<sup>44</sup> O'Connor 2011



Fig. 15. Photomicrograph showing irregular microstructure in fill material for K972.

The green colouration for the bone inlay in K653, considered by O'Connor as possibly due to an interaction between the bone and copper component of the gold backing plate for this object, is also present in samples K972-1, and K1079-1. LaNiece's findings<sup>45</sup> correlate with O'Connor's<sup>46</sup> assertion that the green staining is likely due to an interaction with copper salts. LaNiece notes that bone and ivory appear more prone to this type of staining than other white pastes in her study. As described previously, a variety of ions, particularly of metals, can be attached to the surface of hydroxyapatite crystals by adsorption rather than substitution during burial.<sup>47</sup>

#### *Amber*

Amber is fossilized tree resin that has undergone evaporation of resin volatiles, and geological maturation due to oxidative processes arising from extremes of temperature, pressure and water levels.<sup>48</sup> Amber in existence today may have been exuded as resin from trees and flowering plants from the Cretaceous Period (145-65 million years ago) through to the Miocene Period (23-5 million years ago). The trees in different geographical regions were distinct enough to have recognizable characteristics in the resin they exuded, and thus have chemical differences in their amber forms.<sup>49</sup>

Infrared spectroscopy is an established and widely used method for characterising ambers.<sup>50</sup> Amber spectra exhibit a broad band between 3600-3500  $\text{cm}^{-1}$  due to O-H stretching of alcohols, and aliphatic

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<sup>45</sup> La Niece 1988.

<sup>46</sup> O'Connor 2011.

<sup>47</sup> O'Connor 1987.

<sup>48</sup> Caldararo *et al.* 2013; Brody *et al.* 2000; Mills and White, 1977.

<sup>49</sup> Maish *et al.* 2012; Thicket *et al.* 1995; Caldararo *et al.* 2013

<sup>50</sup> Stuart 2000; Brody *et al.* 2001; Murillo-Barroso and Martinon-Torres 2012; Caldararo *et al.* 2013.

C-H stretching and corresponding C-H bending bands between 3200 and 2800  $\text{cm}^{-1}$ , and 1500-1300  $\text{cm}^{-1}$  respectively. The asymmetric C-H stretch of the methyl (shoulder at 2963  $\text{cm}^{-1}$ ) and methylene groups (peak at 2926  $\text{cm}^{-1}$ ) occurs at a slightly higher frequency than the symmetric vibrations of the methylene groups (2856  $\text{cm}^{-1}$ ).<sup>51</sup> An asymmetric band between 1800 and 1600  $\text{cm}^{-1}$  is formed from a series of overlapping C-O stretching peaks originating from esters at 1785  $\text{cm}^{-1}$ , ketones at 1746  $\text{cm}^{-1}$ , and two carboxylic acid groups at 1695  $\text{cm}^{-1}$  and 1649  $\text{cm}^{-1}$  (Trucia *et al.* 2014).

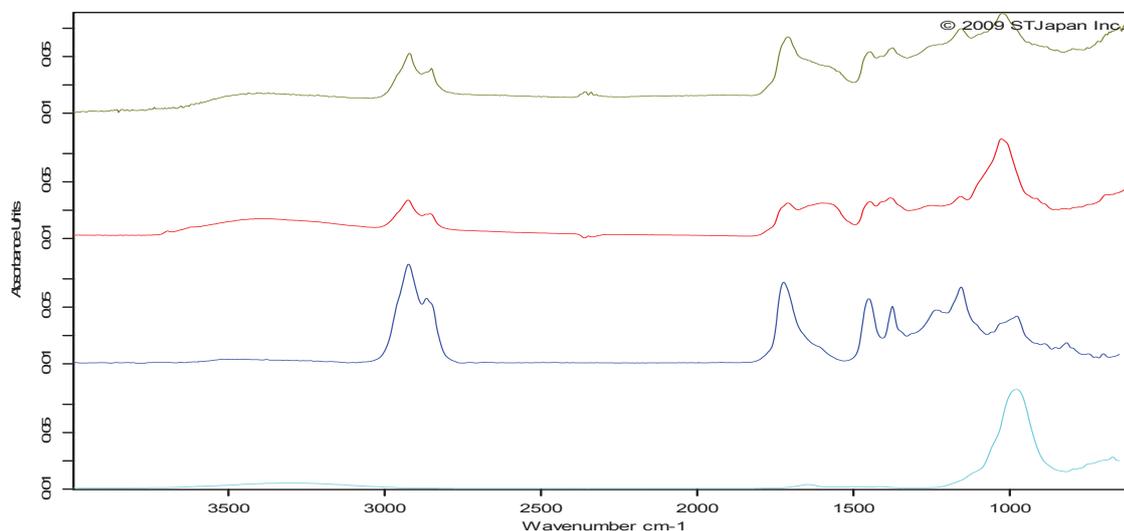


Fig. 16. Top (green), K679-1-5. Upper-middle (red), K1395-1-1. Lower-middle (blue), Amber reference spectrum, ST Japan 2009. Bottom (cyan) Aluminosilicate reference spectrum, ST Japan 2009.

The spectra for samples K679-1-5 and K1395-1-1 in figure 16 above share many peaks with those from the reference sample. An additional intense peak at approximately 1000  $\text{cm}^{-1}$  in both amber samples may relate to fine silicate particulate from the burial environment on the sample surfaces. The dominant band in the aluminosilicate reference sample in figure 16 is a close spectral match in both position and intensity, for the bands present in samples K679-1-5 and K1395-1-1.

Much emphasis has been placed on the so called ‘Baltic shoulder’ region in FTIR analysis of amber within the archaeological literature. A sharp peak between 1160 and 1150  $\text{cm}^{-1}$  relates to C-O bonding in diethyl succinate, the ester of succinic acid, the precise location of which is influenced by the C=O (double) bond in this compound.<sup>52</sup> The Baltic shoulder on this peak appears between 1250 and 1175  $\text{cm}^{-1}$ , and was at one time believed to be unique to amber from trees around the Baltic sea region. More recent research indicates that while the feature is almost always present in Baltic amber samples, it may also present in North American and Asian amber.<sup>53</sup> Figure 17 below shows the C-O peak at approximately 1155  $\text{cm}^{-1}$  in both K679-1-5 and K1395-1-1 with the shoulder present in both samples between 1250 and 1175  $\text{cm}^{-1}$  although more subtly in K1395-1-1 than in K 679-1-5. The degree of inclination of the Baltic shoulder has been related to the degree of preservation of the resin, with a zero degree of inclination denoting well preserved resins and the negative increase of the band

<sup>51</sup> Trucia *et al.* 2014; Murillo-Barroso and Martinon-Torres 2012.

<sup>52</sup> Murillo-Barroso and Martinon-Torres 2012.

<sup>53</sup> Brody *et al.* 2001; Murillo-Barroso and Martinon-Torres 2012; Caldoraro *et al.* 2013.

being directly correlated to the degree of oxidation of the succinate.<sup>54</sup> The shoulders are quite flat in both samples suggesting a good state of preservation for the amber.

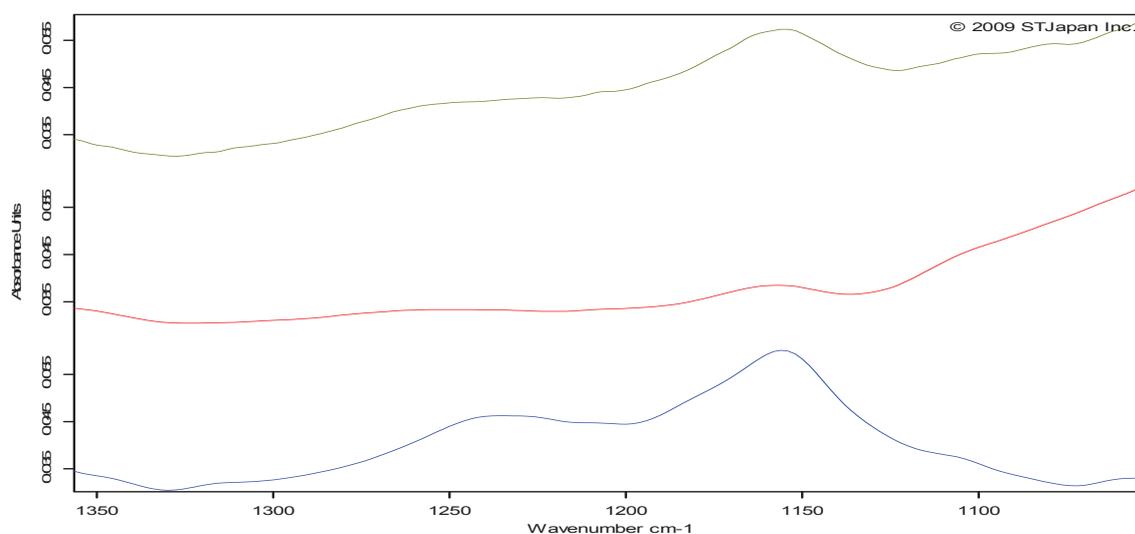


Fig. 17. Detail showing 'Baltic Shoulder' region for top (green), K679-1-5, middle (red), K1395-1-1, and bottom (blue), Amber reference spectrum, ST Japan 2009

## *Discussion - Inorganic Material*

### *Calcium Carbonate*

Calcium carbonate-based material is found in ten objects (K307, K311, K352, K359, K452, K546, K565, K701, K1062, K1195), seven of which are pommels or bosses (pommels K307, K352, K359, K452, K701, K1195, and boss K311). The calcium carbonate is mixed with silicates in four of these (K307, K352, K359, K452) in what appears to be a lime plaster-like material, and with beeswax and silicates in three (K311, K701, K1195). The other objects in which calcium carbonate is identified are a helmet crest ridge (K546) where it is mixed with beeswax and a protein component, as a crusty residue with silicate material inside a sword pyramid (K565), and mixed with beeswax and protein glue in the central panel paste for a cloisonné strip (K1062).

The white pastes used as fill materials in some Staffordshire Hoard objects were produced by processing calcium carbonate sources from nature. The chemical components of calcium carbonate—calcium, dissolved carbonate ions and carbon dioxide—are widely distributed in nature and are precipitated in two ways; either through direct crystallisation within a body of water, or by carbonate-secreting sea creatures.<sup>55</sup> Diagenesis of calcium and carbonate sediments (often with a minor magnesium carbonate component) on the sea bed over time produces the limestone deposits that form the basis of the white pastes identified in the hoard objects.<sup>56</sup>

Calcium carbonate is a complex inorganic compound that contains a calcium ( $\text{Ca}^{2+}$ ) cation, and a carbonate ( $\text{CO}_3^{2-}$ ) anion. Whereas most simple anionic compounds do not produce any vibrations in the mid-IR range, the carbonate ion is a covalently bonded functional group in itself, and undergoes

<sup>54</sup> Murillo-Barroso and Martinon-Torres 2012.

<sup>55</sup> Spiropoulos 1985.

<sup>56</sup> Oates 1998; Spiropoulos 1985.

internal molecular vibrations that occur within the mid-IR range. The attached cation has a slight impact on the position of the absorption bands for the complex anion, with heavier cations shifting the bands to a lower frequency, particularly at lower wavenumbers.<sup>57</sup> Peak shifts to slightly higher wavenumbers than those known for calcium carbonate may indicate therefore the presence of magnesium carbonate within a sample.

Calcium carbonate shows a smooth symmetrical and broad absorption band from C-O stretching at about  $1414\text{cm}^{-1}$ . Additional peaks at about  $872\text{cm}^{-1}$  and  $712\text{cm}^{-1}$  relate to C-O out of plane and in-plane bending within the carbonate ion respectively. Because few organic compounds have strong absorptions in this region, these sharp bands are very useful for confirmation and identification of carbonates in a spectrum.<sup>58</sup> Splitting of the two lower wavenumber peaks indicates the presence of the aragonite crystalline phase in the calcium carbonate sample, whereas non-splitting indicates the calcite phase.<sup>59</sup> As aragonite transitions to the calcite crystalline phase at elevated temperatures,<sup>60</sup> or over time in the presence of water,<sup>61</sup> the aragonite crystalline phase is not normally associated with heat processed calcium carbonate materials such as quick lime, lime putty or milk of lime.

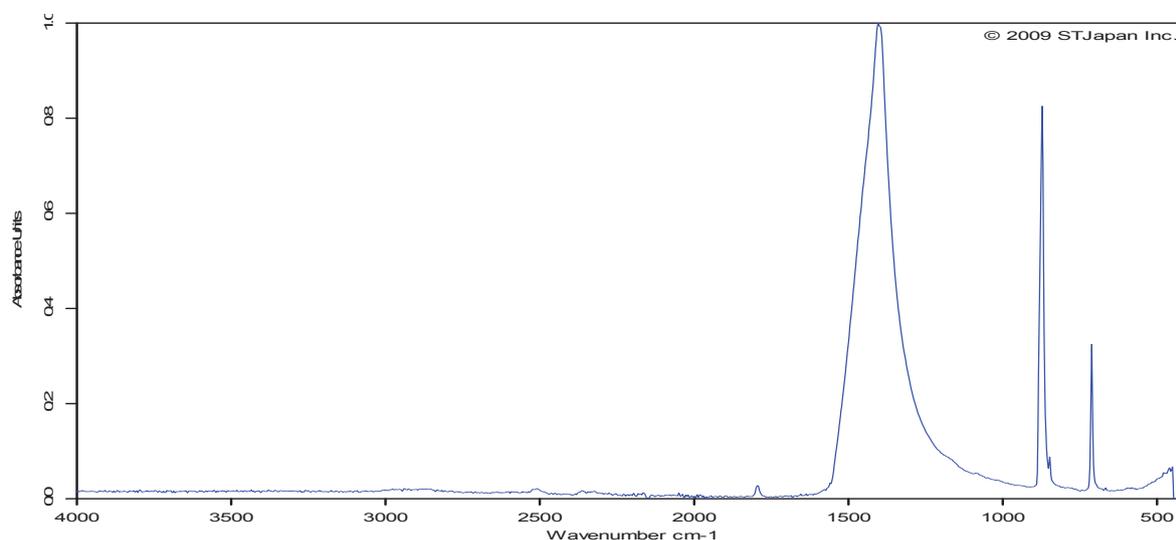


Fig. 18. Calcium Carbonate Heavy Spectrum ST Japan Inc. 2009

The use of white pastes in the construction of some Staffordshire Hoard objects is not without precedent for jewellery and small objects from this period. Arrhenius<sup>62</sup> includes a comprehensive analysis of the pastes used in the production of Merovingian garnet cloisonné objects which are stylistically and materially comparable with some objects from the Staffordshire Hoard. The work identifies a number of pastes employed in different garnet cloisonné production techniques that range in composition from predominantly organic in nature as found in clasped cloisonné backing pastes, through ‘fused pastes’ formed from calcite, quartz, wax, and occasionally sulphur compounds, to sand putty pastes with organic binders.

<sup>57</sup> Derrick *et al.* 1999.

<sup>58</sup> Derrick *et al.* 1999; Trinkūnaitė-Felsen *et al.* 2012; Adler and Kerr, 1963.

<sup>59</sup> Trinkūnaitė-Felsen *et al.* 2012.

<sup>60</sup> Balmain *et al.* 1999; Oates 1998.

<sup>61</sup> Oates 1998.

<sup>62</sup> Arrhenius 1985.

In an x-ray diffraction study of 183 pastes used in the construction of garnet cloisonné objects,<sup>63</sup> seventy-eight were identified as containing calcium carbonate. In fourteen objects, the calcium carbonate was mixed with wax. Where quartz is present in samples in Arrhenius' study, the rounded particle shape observed indicates that the texture of the quartz was naturally occurring, and was not achieved by crushing. The work discusses the possibility of quick lime, water, and aggregate being mixed to create a hard setting calcium carbonate paste for some cloisonné objects, and notes that pastes containing aragonite are unlikely to have been lime processed, as the crystalline structure calcite, not aragonite, is formed in the transition from calcium hydroxide to calcium carbonate. In addition to being used as a backing material behind cloisonné garnets, Arrhenius notes the use of a beeswax and lime mixture in a cloisonné piece from Egberts Shrine, Trier, and the use of 'pure' calcite pastes to add body to items such as disc brooches discovered at Miingersdorfi Köln, St. Denis, Marilles, and Rosmeer, buckles from Taplow and Wynaldurtz, a button and a mount from Tibbie and Spelvik respectively, and a sword pommel cap from Vallstenarum.

Coatsworth and Pinder report the use of pastes to add bulk to spaces between plates in Anglo-Saxon, Merovingian and Lombardic brooches, including in a plated disc brooch from Gilton, Kent formed from a mixture of calcite, aragonite, a small amount of quartz, and beeswax.<sup>64</sup> They note that while only a small number of Sutton Hoo objects contain pastes, the acidic burial conditions at this site were such that calcite pastes, unless mixed with wax or a similar acid resistant organic binder, were unlikely to have survived burial.

Biborski *et al.*<sup>65</sup> identify 'chalk mixed with beeswax' inside a possibly eighth century pommel cap from a Slavonic trade and handicraft settlement in Rostock-Dierkow, Germany. Hamerow *et al.* report the use of white paste in the construction of a brooch from a high status seventh century female burial from West Hanney, Oxfordshire.<sup>66</sup> The spaces between the plates of the brooch are filled with a paste composed from calcium carbonate. Shearman identifies white paste used to secure the garnet cloisonné in a brooch from Bosshall, Ipswich, as formed from calcite and beeswax,<sup>67</sup> and notes that the brooch appears to follow the typical construction of an Anglo-Saxon composite brooch as described by Avent 1975.<sup>68</sup> Stevenson identifies a mixture of chalk and beeswax used to join components of the Hunterston brooch.<sup>69</sup> La Niece studied the white inlays in a range of silver disc brooches, almost all of which are from Kent, and dated to the sixth and early seventh centuries AD.<sup>70</sup> Calcite was identified in the central cells of three brooches from Faversham, but it was unclear if the pastes served as white inlays, or were the backing pastes for lost garnets or other inlay materials. The author describes the pastes as lacking the structure which would be expected of shell.

Calcium carbonate-based materials are found inside six Staffordshire Hoard pommels and one boss (pommels K307, K352, K359, K452, K701, K1195, and boss K311). Analysis of the white pastes in pommel caps K352 and K359 by FTIR and SEM EDS indicates a pure calcium carbonate source that has been processed to produce a lime plaster-like material. The FTIR spectra for white pastes samples

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<sup>63</sup> Arrhenius, 1985.

<sup>64</sup> Coatsworth and Pinder 2002.

<sup>65</sup> Biborski *et al.* 2010.

<sup>66</sup> Hamerow *et al.* 2015.

<sup>67</sup> Shearman 1993.

<sup>68</sup> Avent 1975.

<sup>69</sup> Stevenson 1974.

<sup>70</sup> La Niece 1988.

from inside pommel caps K307 and K452 are comparable to those for K352 and K359 (see figure 19 below).

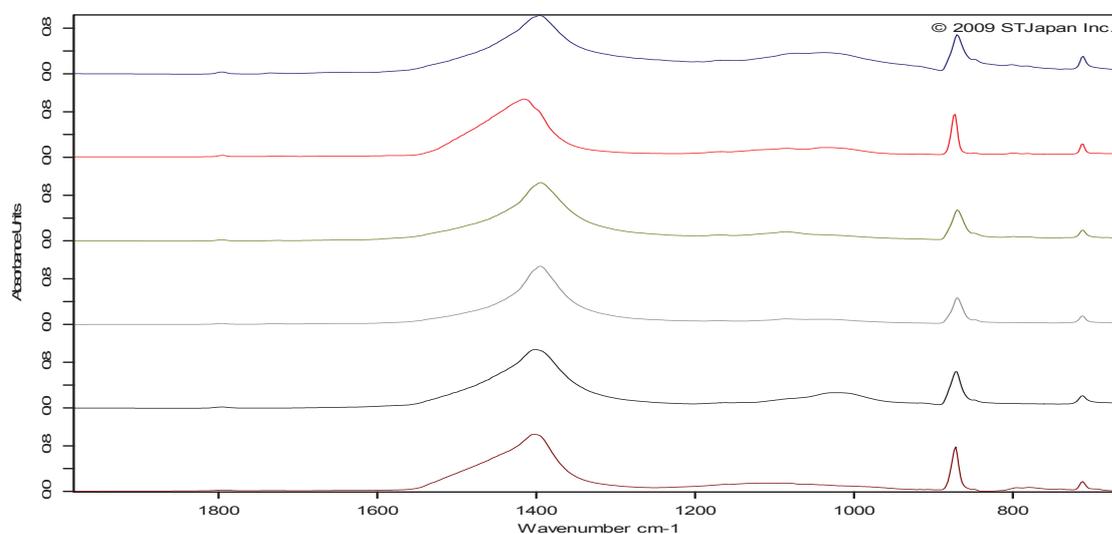


Figure 19. Spectral comparison of 1800-650  $\text{cm}^{-1}$  region for white pastes collected from pommel caps from top: K307-1-1 (blue), K352-1-3 (red), K359-1-1 (green), K452-1-2 (grey), and from residue inside sword pyramid K565-1-4 (black). A reference sample for lime plaster MVJ-1 extra (brown) is shown, bottom, for comparison.

Slight positional variations in the carbonate C-O stretching bands at about  $1414\text{cm}^{-1}$  are due to variations in the carbonate cation in these samples indicative of impurities, with cations of higher atomic number than calcium shifting the peak to lower wave numbers. Slight variations in the intensity and position of the bands between  $1100$  and  $900\text{cm}^{-1}$  likely relate to variations in the nature and quantity of silicates within the paste mixture or residue. The absence of splitting of the lower wavelength peaks at  $870$  and  $712\text{cm}^{-1}$  shown in detail in figure 20, indicates an absence of aragonite in these pastes, and is consistent with calcined calcium carbonate material. The position of the peaks in this detail region, particularly the peaks at  $712\text{cm}^{-1}$  suggests that the raw material used in the production of these pastes was more likely calcite than dolomite. The lighter magnesium cation associated with dolomite would be expected to shift the peak at  $712\text{cm}^{-1}$  toward approximately  $730\text{cm}^{-1}$ . Regardless of slight variations in the pastes shown in Figures 19 and 20, the FTIR spectra indicate similarities between the pastes for K352 and K359, and those identified in the other pommels described above.

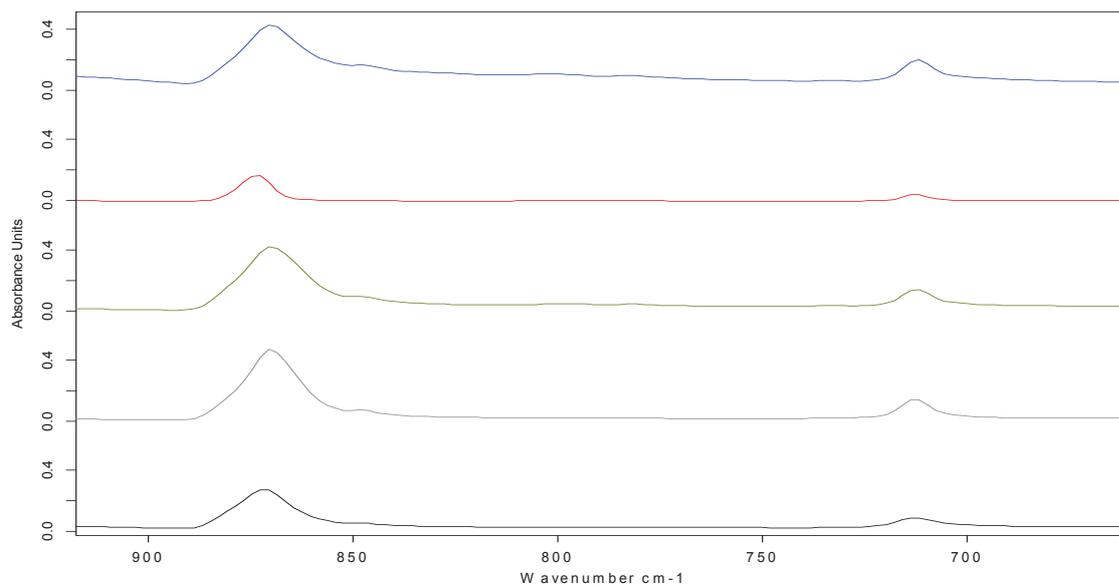


Fig. 20. Spectral comparison of 900-650  $\text{cm}^{-1}$  region for white pastes collected from pommel caps from top: K307-1-1 (blue), K352-1-3 (red), K359-1-1 (green), K452-1-2 (grey), and from residue inside sword pyramid K565-1-4 (black). A reference sample for lime plaster MVJ-1 extra (brown) is shown, bottom, for comparison.

It is interesting that the pastes identified inside the pommel caps K307, K352, K359, and K452 all show peaks at 2920 and 2850  $\text{cm}^{-1}$  that may indicate the presence of a trace organic component, possibly a binder (Figure 21). These peaks are not present in the calcium carbonate residue collected from inside sword pyramid K565.

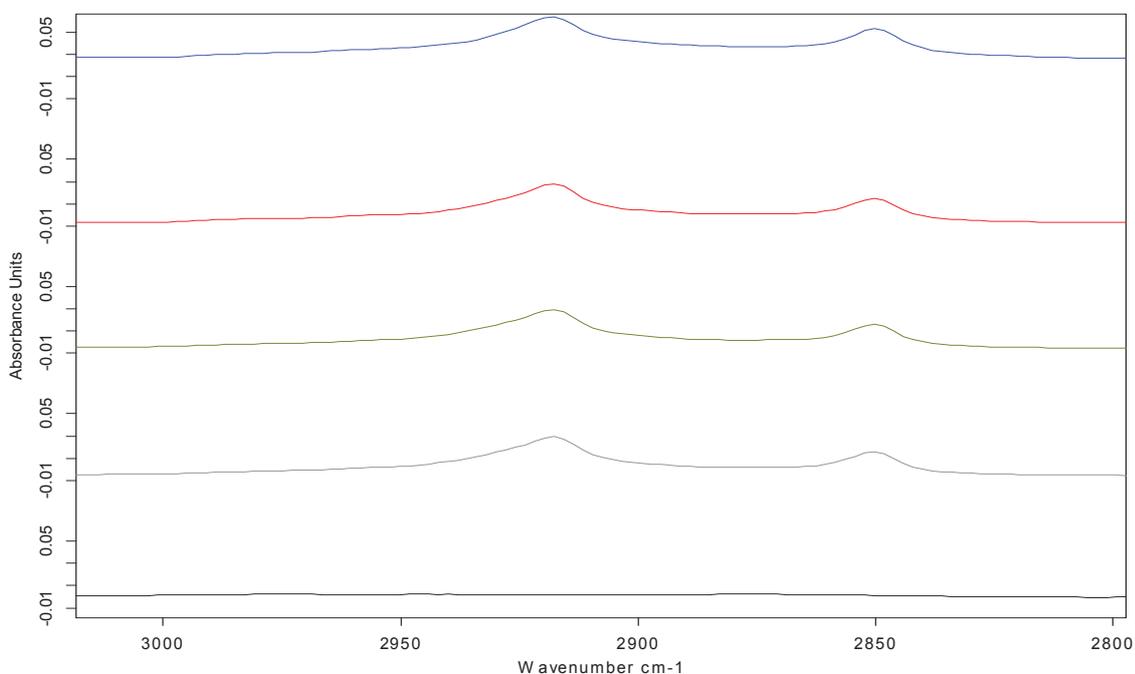


Fig. 21. Detail of 3000-2800 $\text{cm}^{-1}$  region showing C-H stretching of the methylene ( $\text{CH}_2$ ) groups present in pastes K307-1-1 (blue), K352-1-3 (red), K359-1-1 (green) and K452-1-3 (grey). These peaks are absent in the residue from K565-1-4 (black).

The white pastes from pommel caps K311, K701, and K1195 are formed from calcium carbonate-based material with a silicate component, and beeswax. The spectra shown for the white pastes from these three pommels are shown in figure 22 below.

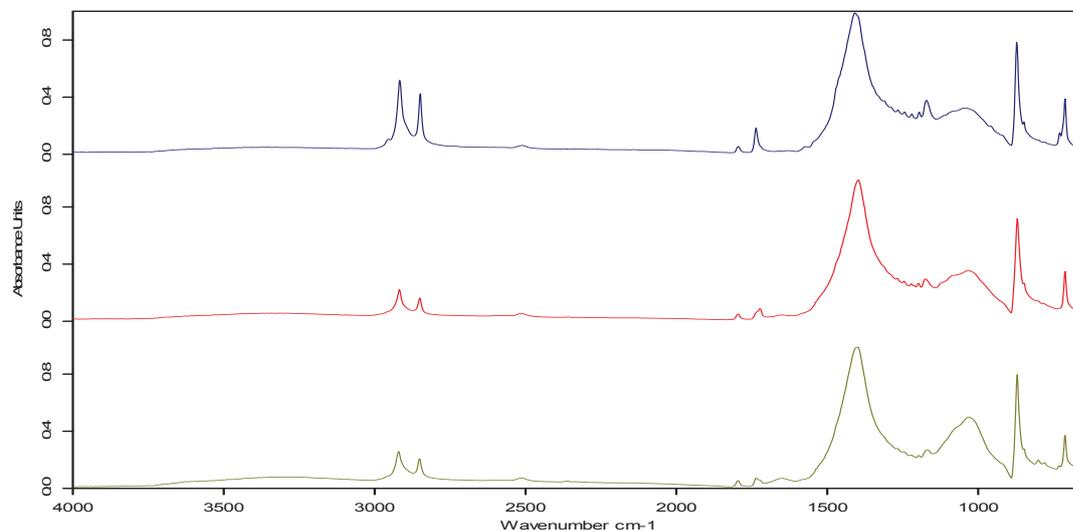


Figure 22. White paste samples from inside boss, top (blue) K311-1-1, and pommel caps, middle (red) K701-2-7, and bottom (green) K1195-1-2.

While much of the beeswax spectral component is somewhat obscured in the spectra above, the confirmative peaks at 2920, 2850, and 1740 $\text{cm}^{-1}$  are clearly visible. The detail of the spectral region between 1600 $\text{cm}^{-1}$  and 650 $\text{cm}^{-1}$  shown in figure 23 below more clearly demonstrates the band progression peaks between 1350 and 1180 $\text{cm}^{-1}$ , and the C-H bending doublet at 730 and 720  $\text{cm}^{-1}$  described previously as indicative of beeswax.

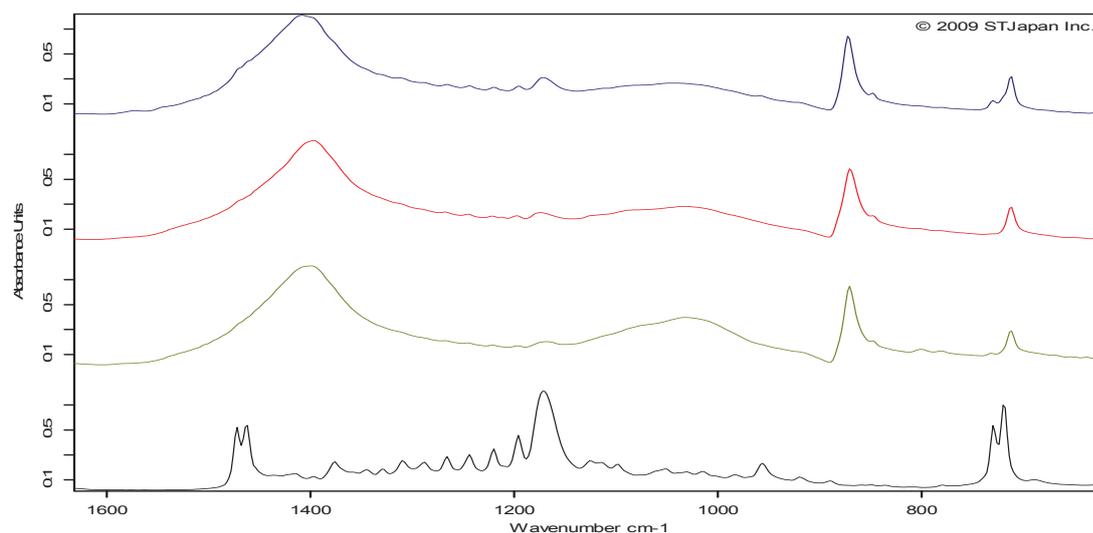


Fig. 23. Detail of 650-1600 $\text{cm}^{-1}$  spectral region showing confirmative peaks between 1180 and 1350 $\text{cm}^{-1}$  for K311-1-1 top (blue), K701-2-7 upper middle (red), and K1195-1-2 lower middle (green), compared against beeswax reference spectra, ST Japan 2009, bottom, black.

It is unclear from the FTIR spectra if the calcium carbonate component of these mixtures is lime processed material, or if the beeswax has been mixed with a geologically sourced, minimally processed material such as powdered chalk. The silicate peaks present in the spectra for white paste samples K311-1-1, K701-2-7, and K1195-1-1, could indicate a mixture of beeswax and lime plaster material such as that indicated for pommel caps K307, K352, K359, and K452, or a mixture of beeswax and chalk powder with a silicate component inherent either as impurity, or deliberately added to adjust the texture of the paste. A wax binder would be unnecessary to 'set' lime plaster, indeed, a wax binder would likely hinder the ingress of atmospheric carbon dioxide necessary to harden lime plaster from its putty-like calcium hydroxide to its solid calcium carbonate state. It is possible that the maker had observed the use of lime plaster in other objects, but did not fully understand the setting process into calcium carbonate, adding the molten beeswax binder as a result of previous paste production experience.

It is also possible that there was a stratification of lime plaster and beeswax within the pommel caps, with each added as a discrete layer. The particular area from which the FTIR samples were collected from each pommel interior may have been a discrete lime plaster layer, as with pommel caps K307, K352, K359, and K452, or at a point of transition from lime plaster to beeswax layer which would account for the mixture of components in K311-1-1, K701-2-7, and K1195-1-1. The subtle C-H stretching peaks identified in the white pastes from pommel caps K307, K352, K359, and K452 lend support to this idea. The photomicrograph of the interior of boss K311 in figure 24 below demonstrates a seemingly random mixture of white calcium carbonate and dark coloured beeswax, and at least one of the spectra collected for K701 (701-2-4) indicates lime plaster with no beeswax component present. A more detailed SEM-EDS study of the white pastes from these pommel caps, and their distribution within the pommel interior, would be helpful in clarifying this issue.

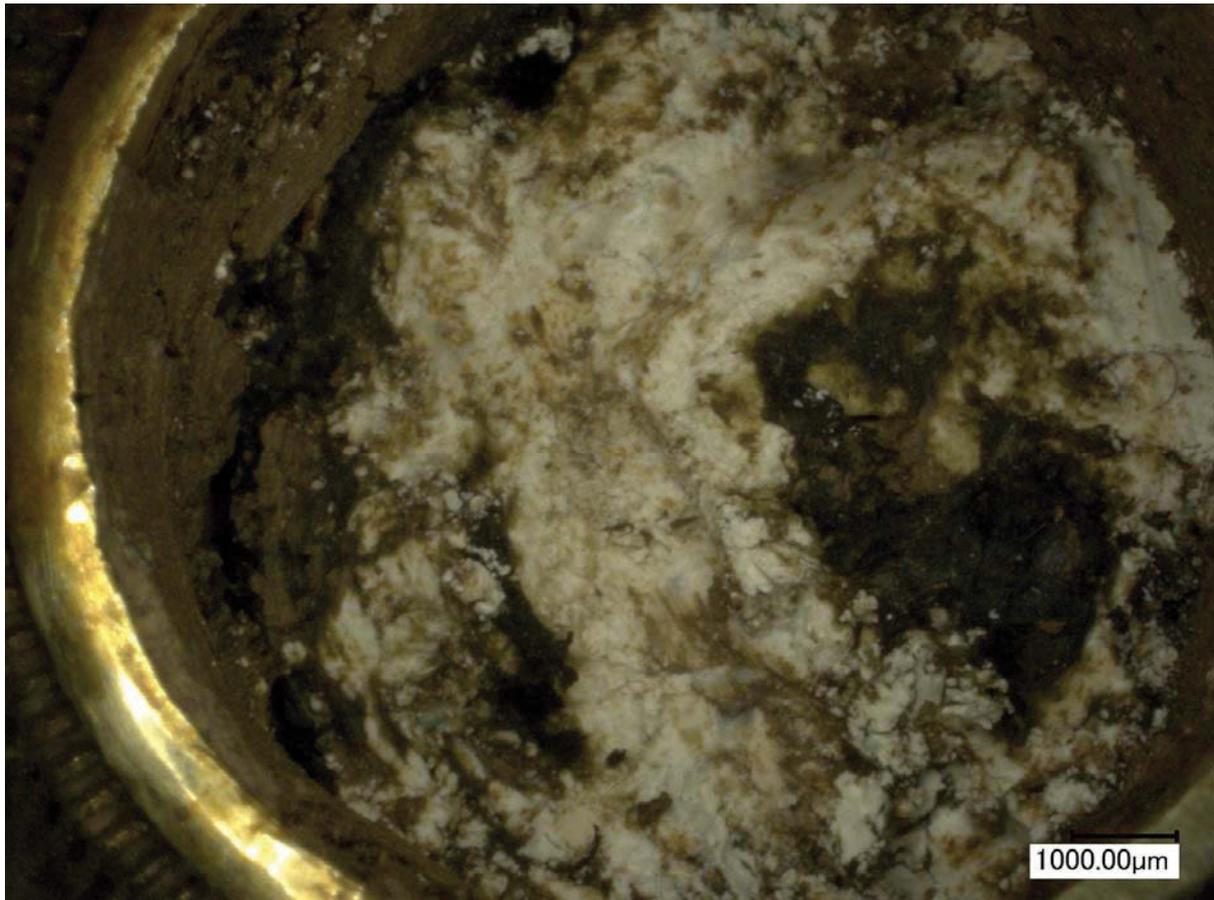


Fig. 24. Photomicrograph showing uneven distribution of beeswax (dark material) and calcium carbonate (white material) inside boss K311.

The variety of source material available for the production of limestone ranges from pure calcium carbonate sources such as cretaceous chalk as found in the UK and France through to dolomitic rock containing a significant proportion of magnesium carbonate. The conditions under which limestone sediment is laid down impacts the resulting purity, and deposition of sand or clay during this process introduces, to a greater or lesser extent, impurities such as silica, alumina and iron oxide.<sup>71</sup> High calcium limestone is composed primarily of the minerals calcite or aragonite ( $\text{CaCO}_3$ ),<sup>72</sup> with the colour of limestone often reflecting the levels and nature of the impurities present. White deposits are generally of high purity, various shades of grey and dark hues are usually caused by carbonaceous material and/or iron sulphide, and yellow, cream and red hues are indicative of iron and manganese.<sup>73</sup> The white colour of the pastes present in the Staffordshire hoard objects, in combination with the elemental purity indicated by EDS analysis of the white pastes from pommel caps K352 and K359 suggest a pure calcium carbonate source material such as chalk or marble, or possibly marine shells, was used to produce these fill materials. The exact location from which geological sources of pure calcium carbonate may have been mined is open to speculation, but the chalk deposits found throughout Kent in the English South coast is one possibility.

<sup>71</sup> Oates 1998; Spiropoulos 1985.

<sup>72</sup> Spiropoulos 1985.

<sup>73</sup> Oates 1998.

Processing limestone into lime putty, plaster, or mortar is a relatively complex process that involves heating the material to a high temperature such that carbon dioxide (CO<sub>2</sub>) begins to dissociate from the limestone. The temperature at which this occurs depends on the ratio of calcium carbonate (CaCO<sub>3</sub>) to magnesium carbonate (MgCO<sub>3</sub>), and on the crystallinity of the limestone. MgCO<sub>3</sub> begins to decompose at about 725°C and CaCO<sub>3</sub> at about 900°C.<sup>74</sup> After the resulting material, known as quicklime, has cooled it is slaked- partially hydrated with a controlled volume of water in an exothermic reaction- to produce either calcium hydroxide powder, lime putty, or milk of lime depending on end use.<sup>75</sup>

While the production and use of lime products is widely recorded in Roman literature and archaeological sites, including a battery of six lime kilns excavated at a legionary site at Iversheim, Germany,<sup>76</sup> the production and use of lime products during the period and place in which the Staffordshire Hoard objects were produced, is less well understood. Certainly there are other uses for lime products besides as mortar, plaster, or lime washes. The alkali nature of milk of lime is exploited in the processing of animal skins, in dyeing, and in adjusting the acidity of soil for agricultural purposes for example. The lack of evidence for large scale lime production in the early Anglo Saxon period may rule out lime production for agricultural purposes, but small scale production of lime products suitable for processing animal skins, dyeing, and producing the white pastes found in the Staffordshire Hoard could have been achieved in a carefully arranged lime rick as described in Spiropoulos, and demonstrated by experimental archaeology at Colonial Williamsburg, Virginia, in the United States. Writing about the feasibility of establishing lime burning facilities in contemporary developing communities, Spiropoulos states that “although it is difficult for a layman to design and determine the optimum operating conditions of a kiln, under the circumstances where a small batch or continuous mixed feed operation is appropriate and feasible, the layman could implement it with a general knowledge of the subject and a minimum of specialist assistance.”<sup>77</sup>

Some question remains as to the function of the white pastes identified within the pommel caps and boss described above. Certainly filling the interior volume with a material such as lime plaster or beeswax, would improve the strength under compression for the associated pommel or boss. It is also possible in the case of the pommel caps, that the fill material played a role, in addition to other fixtures such as rivets, in attaching the pommel to the sword. As the tang of the sword extended beyond the grip, to the inside of the pommel, the paste may have served to ‘bed’ the pommel in place around the tang, as would the wooden lining material identified inside pommel caps K452, K701, and K1097 described previously.

The white paste collected from inside a metal channel believed to be the crest ridge of a helmet, is somewhat different than the white pastes used in the pommel caps and boss described above. The helmet crest paste is compacted and burnished with fine surface striations visible such that preliminary examination of the paste considered it may have been a bone inlay. Sample K546-3-4 shown below appears to be a mixture of a protein component thought to be of keratinous origin as described previously, in addition to the beeswax, and calcium carbonate identified in other pastes. The

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<sup>74</sup> Spiropoulos 1985.

<sup>75</sup> Oates 1998; Spiropoulos 1985.

<sup>76</sup> Oates 1998.

<sup>77</sup> Spiropoulos 1985, 33.

protein component for sample K546-3-4 is not immediately apparent in figure 25 below, particularly as the broad amide a band normally centred at around  $3300\text{cm}^{-1}$ , is extremely vague. The amide I and II bands at about  $1650$  and  $1550\text{cm}^{-1}$  respectively are present however, as is the intense peak at approximately  $1030\text{cm}^{-1}$  considered in this study to be potentially indicative of keratinous protein glue. The C-O stretching peak at  $1414\text{cm}^{-1}$  from the calcium carbonate component, overlaps with the beeswax C-H bending band in this region at around  $1460\text{cm}^{-1}$  and although not immediately apparent, is present.

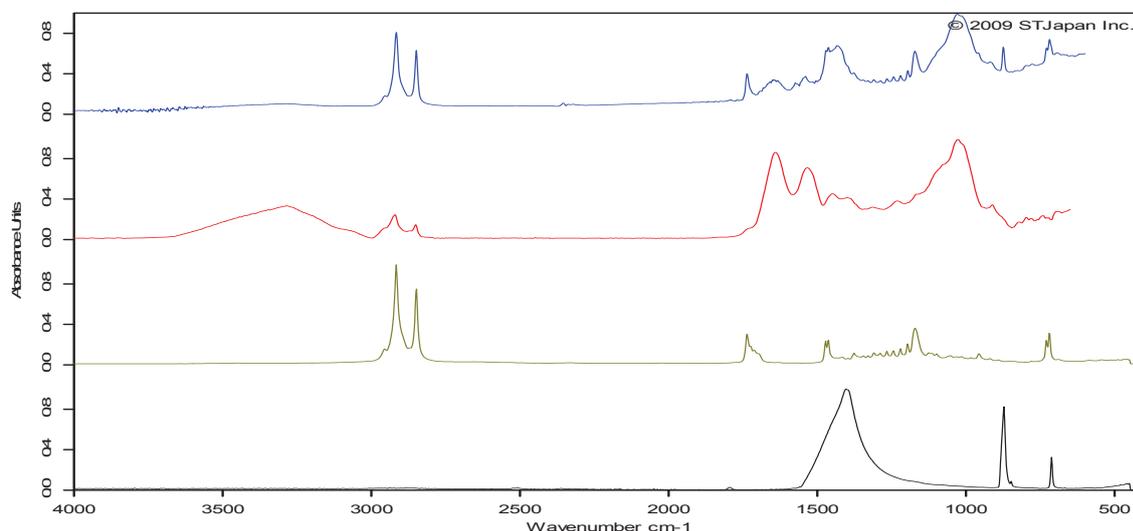


Fig. 25. Comparison of white paste sample K546-3-4 top (blue), with upper middle (red), oxidised horse hair reference, ST Japan 2009, lower middle (green), beeswax reference sample, ST Japan 2009, and bottom calcium carbonate reference, ST Japan 2009.

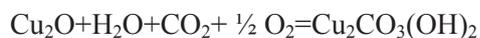
Helmets from the early Anglo Saxon period are extremely rare, and as such it has been difficult to ascertain the purpose of the white paste within the helmet ridge. It is tempting to speculate that the paste served as a bedding material for a crest of animal or vegetal fibres similar to those observed in Late Roman Ridge helmets (*pers. comm.* Dr. Christian Miks, Romisch-Germanisches Zentralmuseum). While there is no evidence of indentations in the surviving paste as one might expect from embedded fibre tufts, it is possible that the crest fibres were embedded in a separate component, perhaps made from wood, and bedded in place against the adhesive paste mixture. A reluctance to disturb the fragile remains within the channel means that the distribution of the paste and its relationship to the other materials identified with the channel including woody cellulosic material, and beeswax and silicate paste, is not fully understood.

### *Malachite*

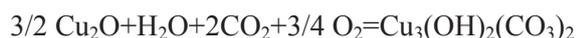
Malachite is found on eight objects of variable type, all of which have a gold component. Malachite is found in close association with beeswax and protein glue in six objects (K273, K570, K843, K1012, K1062, 1536), with beeswax in one (K270), and in isolation in one (K1366). The presence of copper derived crystalline substances that derive from the metal components of associated objects is noted by Arrhenius.<sup>78</sup> Verdigris, malachite, and brochantite were observed in some pastes in Arrhenius' study of Merovingian cloisonné material.

<sup>78</sup> Arrhenius 1985.

The mineral, pigment, and corrosion product malachite is basic carbonate of copper  $\text{Cu}_2\text{CO}_3(\text{OH})_2$ .<sup>79</sup> The pale green coloured corrosion product malachite, found in association with some organic samples, is likely formed from interactions between copper oxide from the gold components in some objects, and  $\text{CO}_2$  rich ground water from the burial environment in the following reaction (Scott 2002, Luo *et al.* 2010):



Azurite is a vitreous blue coloured copper carbonate, and is often formed in association with malachite in the following reaction:<sup>80</sup>



As this reaction requires more carbon dioxide and oxygen than that required to form malachite, malachite is the predominant form of copper carbonate corrosion product.<sup>81</sup> In addition, azurite is less stable than malachite and may be converted to it in the presence of moisture through loss of carbon dioxide, particularly in alkali conditions.<sup>82</sup>

Malachite is a hydrated carbonate, and as such has a broad absorption band due to O-H stretching between 3700 and 3100  $\text{cm}^{-1}$  that incorporates peaks at 3400 and 3320  $\text{cm}^{-1}$ .<sup>83</sup> Additional peaks relating to O-H bending are found between 1100 and 1000  $\text{cm}^{-1}$ . The split peak between 1530  $\text{cm}^{-1}$  and 1350  $\text{cm}^{-1}$  relates to C-O stretching, and a complex series of peaks between 900 and 650  $\text{cm}^{-1}$  arise from O-C-O bending vibrations from the hydrated carbonate ion.<sup>84</sup>

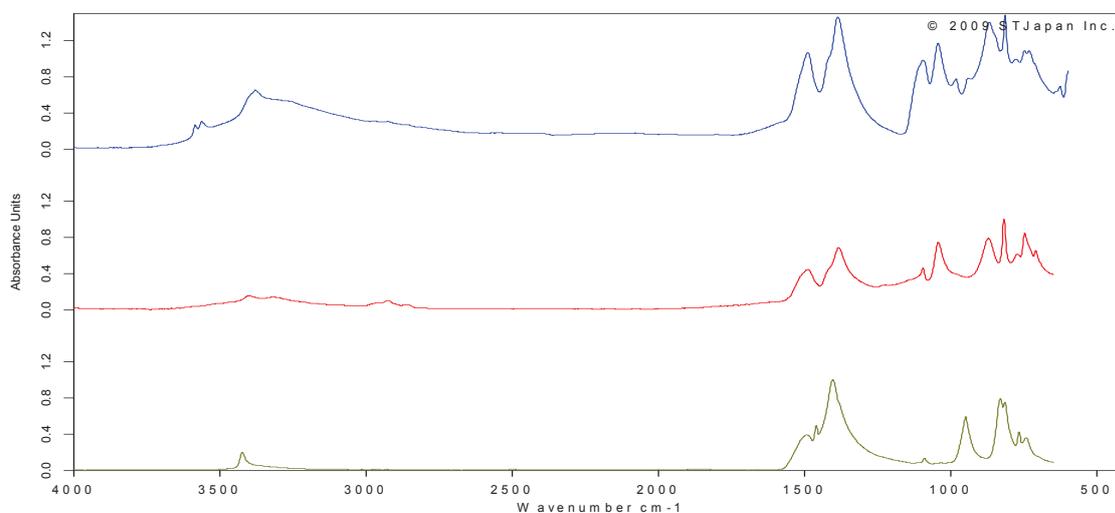


Fig. 26. Comparison of green-coloured material from K270-4-2 top (blue) with reference spectra for malachite, middle (red) and azurite, bottom (green), ST Japan 2009.

<sup>79</sup> Scott 2002; Gettens and Fitzhugh 1974; Luo *et al.* 2010.

<sup>80</sup> Scott 2002; Luo *et al.* 2010; Goffer 2007.

<sup>81</sup> Scott 2002; Luo *et al.* 2010.

<sup>82</sup> Scott 2002.

<sup>83</sup> Derrick *et al.* 1999.

<sup>84</sup> Derrick *et al.* 1999.

## Conclusion

This study characterises a range of organic materials across seventy-nine 'K' numbered objects from within the Staffordshire Hoard. In sixty-six cases the organic materials are directly related to a specific hoard object, and in thirteen cases the 'K' numbered objects were discreet organic samples collected during excavation, but not related to a specific hoard object.

The majority of the organic materials identified relate to pastes used as fill materials inside pommel caps and bosses, and as backing pastes within the cells of cloisonné objects. The composition of the pastes found within cloisonné cells commonly includes a mixture of beeswax, and an as yet unidentified amorphous proteinaceous component, considered likely in this study to be an animal derived glue. The presence of an intense peak centred around  $1030\text{cm}^{-1}$  in FTIR spectra for these pastes could relate to the presence of silicate materials, identified by SEM EDS analysis in some samples and in preliminary work by the British Museum,<sup>85</sup> to cysteic acid indicative of oxidised keratinous material such as would be expected from a glue formed from horn or hoof material, or a combination of both. Peptide Mass Fingerprinting has been suggested as an option to characterise the nature of the protein component present in some these pastes.

Given the location of the cloisonné pastes identified in this study, the cloisonné cell construction, and the available contextual information, the cloisonné pastes are more likely to have served as bedding and alignment material for the gold foil and garnet components of the cloisonné, than as an adhesive to hold these components in place. Experimental analysis of the viscosity, surface tension, and melting and cooling characteristics of different paste mixtures may clarify the reasoning behind the choice of beeswax, proteinaceous material, and inorganic particulate employed in the cloisonné pastes.

The white pastes associated with ten hoard objects (K307, K311, K352, K359, K452, K546, K565, K701, K1602, K1195) are formed from calcium carbonate material. In some cases the calcium carbonate appears to have been lime processed and mixed with silicates to form lime plaster. In other objects, the calcium carbonate is mixed with silicates, beeswax and/or an unspecified amorphous proteinaceous component, and the extent of the calcium carbonate processing is less clear. The exact function of the calcium carbonate fill pastes is not fully understood, but it seems likely that the fill would contribute to strength under compression, and possibly adhesion of individual components to their host objects. Further analysis of the distribution of organic binders within the pastes may refine understanding of white paste use across a range of objects.

In addition to pastes, a number of structural materials including wood, horn, and bone are identified across the hoard objects. The use of woody cellulosic material in the Staffordshire Hoard ranges from joining and structural pieces such as in K298 and K787, to pommel lining material in K452, K701, K710, and K1097, and as possible substrate material as identified in association with three cloisonné decorated edge strips K356, K357, and K1145. The species level identification of wood from Staffordshire Hoard objects,<sup>86</sup> and the location of wooden components within their host objects, indicates a functional as opposed to decorative function for these materials. Many of these smaller wooden components would have been hidden from view during the use life of the object indicating a somewhat different material status to that of the horn found on hilt plates K283 and K285, the amber

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<sup>85</sup> Cartwright 2013.

<sup>86</sup> Cartwright 2013, Shearman *et al.* 2014

used in what appears to be a lost or damaged garnet repair on hilt ring K679, and the decorative bone inlay on K653, although bone appears to have a more functional role as fill material in K972 and 1079.

The harvesting, processing, and manipulation required of the organic materials identified in this study asks questions of the materials and technical understanding, not just of the jewellers, but of the range of support workers who collected beeswax, produced animal glue, burnt and slaked lime, and worked materials such as horn, wood and amber for the production or repair of the Staffordshire Hoard objects. The jewellers position at the centre of a cross section of Anglo-Saxon society from elite end users of the hoard material, to suppliers of precious materials such as gold and garnets, to presumably low status organic material providers, paints a complex narrative of the social and physical environment in which the hoard objects were produced.

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## **Appendix I**

### **Material Distribution and Mixture Pattern Tables**

### Beeswax Distribution and Mixture Patterns

Object Number	Sample from Cell	Sample from Pommel	With Protein Glue	With CaCO <sub>3</sub>
K1	X		X	
K189		X	X	
K270	X		X	
K273	X		X	
K291		X	X	
K311		BOSS		X
K352		X	X	
K362	X		X	
K400	X		X	
K455		X	X	
K458		X	X	
K545			X	
K546				X
K570	X		X	
K645	X		X	
K673	X		X	
K701		X		X
K712	X		X	
K843	X		X	
K850	X		X	
K1003	X		X	
K1012			X	
K1056	X		X	
K1058			X	
K1062			X	X
K1155	X		X	
K1195		X		X
K1448			X	
K1536			X	
K1637				
<b>Total</b>	14	9	25	5

Table 1. Table showing beeswax sample location and mixture patterns across Staffordshire Hoard objects sampled.

## Protein Distribution and Mixture Patterns

Object Number	Sample from Cell	Sample from Pommel	With Beeswax	Other
K1	X		X	
K104	X			
K189		X	X	
K270	X		X	
K273	X		X	
K283				POSSIBLY HORN
K291		X	X	
K324				YEAST
K352		X	X	
K362	X		X	
K400	X		X	
K435				LEATHER
K451				GLUE
K455		X	X	
K458		X	X	
K545			X	
K570	X		X	
K645	X		X	
K673	X		X	
K712	X		X	
K843	X		X	
K850	X		X	
K1003	?		X	
K1012			X	
K1056	X		X	
K1058			X	
K1062			X	
K1145	X			
K1155	X		X	
K1448		?	X	
K1536		BOSS	X	
K1620				POSSIBLY HORN
Total	16	7	25	4

Table 2. Table showing protein sample location and mixture patterns across Staffordshire Hoard objects sampled.

### Calcium Carbonate Distribution and Mixture Patterns

Object Number	Sample from Pommel	Sample from Other Location	With Beeswax	With Silicate
K307	X			X
K311	BOSS		X	
K352	X			
K359	X			
K452	X			X
K546		CREST RIDGE	X	
K565		PYRAMID INTERIOR		X
K701	X		X	
K1062		PANEL BACKING	X	
K1195	X		X	X
Total	7	3	5	4

Table 3. Table showing calcium carbonate sample location and mixture patterns across Staffordshire Hoard objects sampled.

## Silicate Distribution and Mixture Patterns

Object Number	Sample from Cell	Sample from Pommel	Sample Other	Alone	With Beeswax	With Protein Glue	With Calcium Carbonate
K1	X				X	X	
K127	X			X			
K131	X			X			
K189		X		X			
K270	X			X			
K306			Conservation Sample	X			
K307		X					X
K326			Conservation Sample	X			
K352		X			X	X	
K357			Corner Strip	X			
K358			Conservation Sample	X			
K476			End of Object	X			
K546			With Cellulose		X		
K565							X
K568	X			X			
K570	X		With Malchite		X	X	
K679			With Amber				
K701		X					X
K1004			Conservation Sample	X			
K1126			Conservation Sample	X			
K1195		X	Conservation Sample		X		X
K1278		X		X			
Total	6	6	11	13	5	3	4

Table 4. Table showing silicate sample location and mixture patterns across Staffordshire Hoard objects sampled.

### Malachite Distribution and Mixture Patterns

Object Number	With Beeswax	With Protein Glue	Alone
K270	X		
K273	X	X	
K570	X	X	
K843	X	X	
K1012	X	X	
K1062	X	X	
K1366			X
K1536	X	X	
Total	7	6	1

Table 5. Table showing malachite sample location and mixture patterns across Staffordshire Hoard objects sampled.

## **Appendix II**

### **List of Objects Examined for Organic Material**

### Objects Examined for Organic Material

<u>K1</u>	K16	<u>K104</u>	K107	K118	<u>K127</u>	<u>K131</u>	<u>K189</u>	K237	<u>K270</u>	<u>K273</u>	<u>K274</u>
<u>K283</u>	K284	<u>K285</u>	K286	K287	K290	<u>K291</u>	K296	K299	<u>K305</u>	<u>K306</u>	<u>K307</u>
<u>K311</u>	<u>K324</u>	<u>K326</u>	K328	K347	K349	<u>K352</u>	<u>K356</u>	<u>K357</u>	<u>K358</u>	<u>K359</u>	<u>K362</u>
K369	K371	K373	K374	K380	K384	K388	<u>K400</u>	K420	<u>K435</u>	<u>K436b</u>	K447
<u>K451</u>	<u>K452</u>	<u>K455</u>	K457	<u>K458</u>	K463	K465	K468	K469	<u>K476</u>	K544	<u>K545</u>
<u>K546</u>	K554	<u>K565</u>	<u>K568</u>	<u>K570</u>	K575	<u>K606</u>	K643	K644	<u>K645</u>	<u>K653</u>	K654
K655	K660	K662	K663	K666	K668	<u>K673</u>	K674	K678	<u>K679</u>	K680	K681
K691	K697	<u>K701</u>	<u>K710</u>	<u>K712</u>	K716	K722	K737	<u>K763</u>	K767	K773	<u>K787</u>
K788	K820	<u>K843</u>	K844	<u>K850</u>	K959	K967	K969	<u>K972</u>	K1001	<u>K1003</u>	<u>K1004</u>
<u>K1012</u>	K1050	<u>K1056</u>	<u>K1058</u>	<u>K1062</u>	<u>K1079</u>	K1084	<u>K1087</u>	<u>K1097</u>	<u>K1126</u>	<u>K1145</u>	<u>K1155</u>
K1166	K1167	<u>K1179</u>	<u>K1195</u>	K1247	K1275	<u>K1278</u>	K1313	<u>K1341</u>	<u>K1366</u>	<u>K1395</u>	<u>K1448</u>
<u>K1490</u>	<u>K1536</u>	<u>K1551</u>	<u>K1615</u>	<u>K1620</u>	<u>K1621</u>	<u>K1637</u>	<u>K1667</u>	<u>K1680</u>	K1712	K5018	K5031

Table 1. Table showing 144 objects examined for potential organic material. Organic material identified in seventy-nine objects with numbers underlined.

144 objects were selected for further analysis-based on primary visual inspection. Microscopic analysis identified material of possible organic origin in seventy-nine objects within this group, but no organic material was identified in sixty-five objects from the group of 144.

**Appendix III**  
**Glossary of Analytical Techniques**

**Backscatter Electron Microscopy (BSE):** Backscattered electrons consist of high-energy electrons originating in the electron beam, that are reflected out of the sample by elastic scattering interactions with sample atoms. Since heavy atoms with a high atomic number are stronger scatterers than light ones, images recorded with back-scattered electrons contain compositional information. BSE microscopy produces a grey scale image of the sample with increasingly lighter shades of grey representative of elements with a higher atomic number. Heavier elements appear as bright specks within a BSE image in comparison to darker coloured lighter elements. In this study, BSE microscopy was employed to identify areas of interest for closer elemental analysis using EDS.

**Energy Dispersive X-Ray Spectroscopy (EDS/EDX):** In addition to secondary electrons and backscattered electrons, X-rays are generated by the bombardment of a sample with primary beam electrons. Analysis of characteristic X-rays emitted from the different elements within a sample provides quantitative elemental information that can be interpreted to characterise the type and distribution of elements present within a sample

**Micro Fourier Transform Infrared Spectroscopy (micro-FTIR):** In Fourier Transform Infra-red (FTIR) spectroscopy samples are subjected to a broad frequency spectrum of infrared light. The bonds between the atoms in a molecule absorb the infrared energy at frequencies specific to the particular arrangement and distribution of the elements present. Micro-FTIR analysis applies the same principal, but can direct the infrared light toward small discrete points within a sample. The pattern and intensity of frequencies absorbed by a sample can be plotted in a spectrum and used to characterize its chemical composition by analysing the range of absorption peaks for the unknown sample in relation to those for known chemical bonds, or by comparing the spectrum with reference libraries of spectra for known materials. In practice, identification of an unknown sample spectrum often involves a combination of both of these techniques.

**Secondary Electron Microscopy (SE):** In this technique secondary electrons that are ejected from sample atoms by inelastic scattering interactions with primary beam electrons are detected to form an image. Since more secondary electrons can leave the sample at surface edges than on flat areas, the variation in secondary electrons detected can be exploited to identify variations across a sample surface. Imaging with secondary electrons therefore provides useful information about morphology and surface topography of a sample.

**Variable Pressure Scanning Electron Microscopy (VP- SEM):** With non-conductive samples, an electron charge can accumulate within a sample, creating undesirable 'charging artefacts'- lines, streaks, and black spots that obscure detail in the resulting images. Variable Pressure SEM operates in much the same way as a conventional SEM, but with additional mechanisms to vary the pressure within the sample chamber. The chamber is pressurised with enough gas to ionize and neutralize the build up of electron charge in the sample chamber and thus reduce the charging artefacts. Variable Pressure SEM is also useful for delicate samples that would be unable to withstand the high pressure vacuum associated with conventional SEM techniques.



# *Staffordshire Hoard Research Reports*

Staffordshire Hoard Research Reports were produced by the project

## *Contextualising Metal-Detected Discoveries: Staffordshire Anglo-Saxon Hoard*

Historic England Project 5892

The Staffordshire Hoard is owned by the Birmingham City Council and the Stoke-on-Trent City Council and cared for on their behalf by Birmingham Museums Trust and The Potteries Museum & Art Gallery.

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