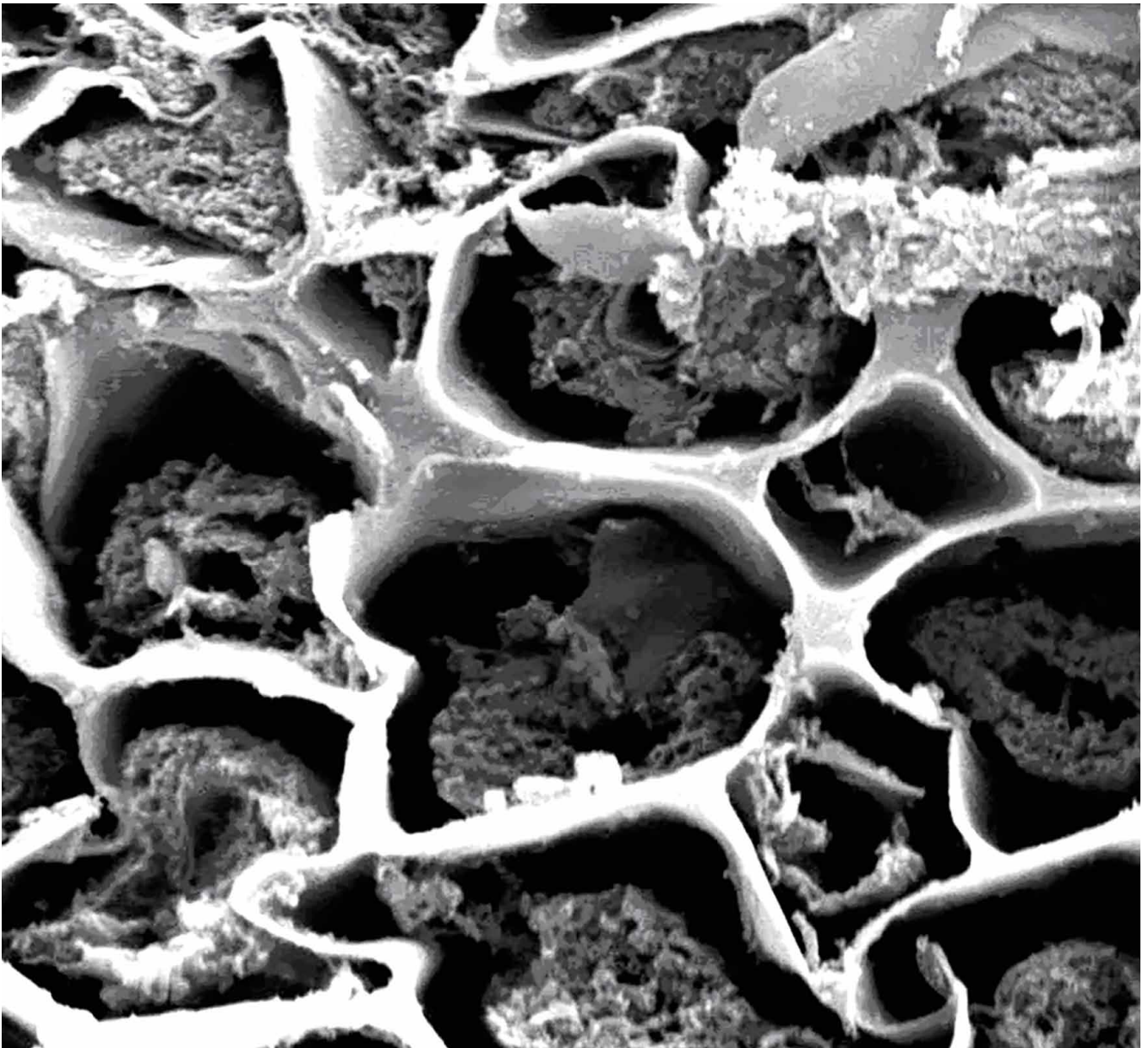




Historic England

# Preserving Archaeological Remains

Appendix 2 - Preservation Assessment Techniques



# Summary

This document is part of a suite of documents about the preservation of archaeological remains. It is a technical appendix to the main text (Preserving archaeological remains: Decision-taking for sites under development) and should be read in conjunction with that document, and where appropriate, the range of planning policy guidance detailed therein.

An introduction to soil chemistry is provided at the start of the document to explain the terms and concepts used in this and the other appendices (in particular Appendix 4).

Sections on specific preservation assessment techniques cover a range of archaeological materials including bone, wood, metal, fabric and leather, palaeoenvironmental remains and lastly, the sediments from which these materials are recovered. For each material, a brief description of principal decay mechanisms is provided, followed by a summary of current methods of preservation assessment.

A pro-forma form for recording peat and other organic deposits is provided in Annex 1

Additional methodological detail and technical advice is provided in the following appendices:

Appendix 1 – Case studies

Appendix 3 – Water environment assessment techniques

Appendix 4 – Water monitoring for archaeological sites

Appendix 5 – Materials for use in the reburial of sites

This guidance note has been prepared by Jim Williams

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**Front cover:**

SEM image of heavily degraded oak from Harter's Hill.

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# Introduction

This appendix is not a detailed ‘how-to’ manual for preservation assessment techniques. The approaches explained below should be carried out by experienced specialists, using published methodologies and criteria. As much of this information is only available in academic journals, conference proceedings and monographs, it is summarised here for ready and easy reference and to show how these studies can be used to inform discussions about long-term preservation.

It provides a guide for project managers to know what information to collect on site and what specialist involvement may be needed.

For some types of material, preservation assessment is an integral part of the post-excavation process, for example finds assessed during archaeological conservation. In other instances, the techniques for assessing the current state of preservation would not normally be applied to archaeological material if long-term preservation and reburial were not being considered. For example, whilst a waterlogged plant macrofossil assessment report should contain some comments on the preservation of the assemblage being studied, specialists would not normally record damage to the degree recommended below.

As was emphasised in the main document, detailed preservation assessment does not need to be carried out for every class of material recovered during excavation, but only on those which contribute to the significance of the site, or are likely to provide evidence of current and past environmental conditions which can be used to understand the potential for successful continued burial.

The sections below cover the main types of archaeological material recovered from sites (bone, wood, metal, fabric and leather, palaeoenvironmental remains and the sediments themselves). For the most part these are materials for which existing published assessment criteria exist. It is not an exhaustive list, and where material forms a major component of an assemblage and contributes to the site’s significance, specialist assessment, even at a qualitative level, will enhance decision-making.

The document begins with an introduction to soil chemistry to provide the context to many of the terms used within the rest of the document. Each of the subsequent sections contains a short summary of current knowledge about preservation and decay mechanisms for that class of material. These are followed by summaries of preservation assessment methods and a discussion for each material of when it might be considered good practice to assess their state of preservation.

# 1 Soil Chemistry

To understand fully the processes affecting site and artefact preservation, it is useful to look in more detail at soil chemistry. Whilst it is not essential for readers of this guidance to have a detailed knowledge of soil chemistry, there are certain aspects that do have a bearing on how sites are investigated and managed. The two key chemical parameters used in this document are pH and redox potential.

## 1.1 pH

The pH of a deposit has a bearing on the types of materials likely to be preserved (see Figure 2 in the main document). Any change in pH may have an impact on the survival of artefacts or organic matter. The extent of this impact is mediated by the 'acid buffering capacity' of the soil - the presence of alkaline materials that neutralise or buffer any new acid (Smit *et al* 2006).



**Figure 1**  
'Jelly bone' from Star Carr that has lost its mineral component.

A dramatic example of the problems caused by changes in pH comes from Star Carr, where exceptionally low pH (ie acidic groundwater), of between pH 2–4 has caused the almost complete dissolution of the mineral hydroxyapatite in bones, leaving only the collagen behind (see Figure 1); these soft bones have been described as 'jelly bones' (Milner *et al* 2011).

These low pH conditions have arisen due to the oxidation of sulphides by oxygen, as previously waterlogged deposits became exposed to the air due to falling and fluctuating water levels caused by land drainage. This process of oxidation produced acid sulphates (Boreham *et al* 2011). Fluctuating water tables which cause previously waterlogged deposits to dry out and then be rewet are thus potentially very damaging to archaeological materials, certainly bone and other pH sensitive remains.

## 1.2 Redox potential

The redox potential (or reduction–oxidation potential) of a deposit is a measure of how oxidising or reducing a deposit is. To maintain favourable environmental conditions for the preservation of organic remains, reducing, rather than oxidising conditions are required.

Redox reactions involve the transfer of electrons from one substance to another. These reactions occur simultaneously in soil water systems, and involve a pair of coupled half reactions – a half reaction of oxidation (where an electron is lost) and a half reaction of reduction (where an electron is gained). In soils, the main source of electrons is carbon atoms which are produced from the decomposition (ie oxidation) of organic matter (present in most waterlogged soils) through bacterial activity (Bohn *et al* 2001).

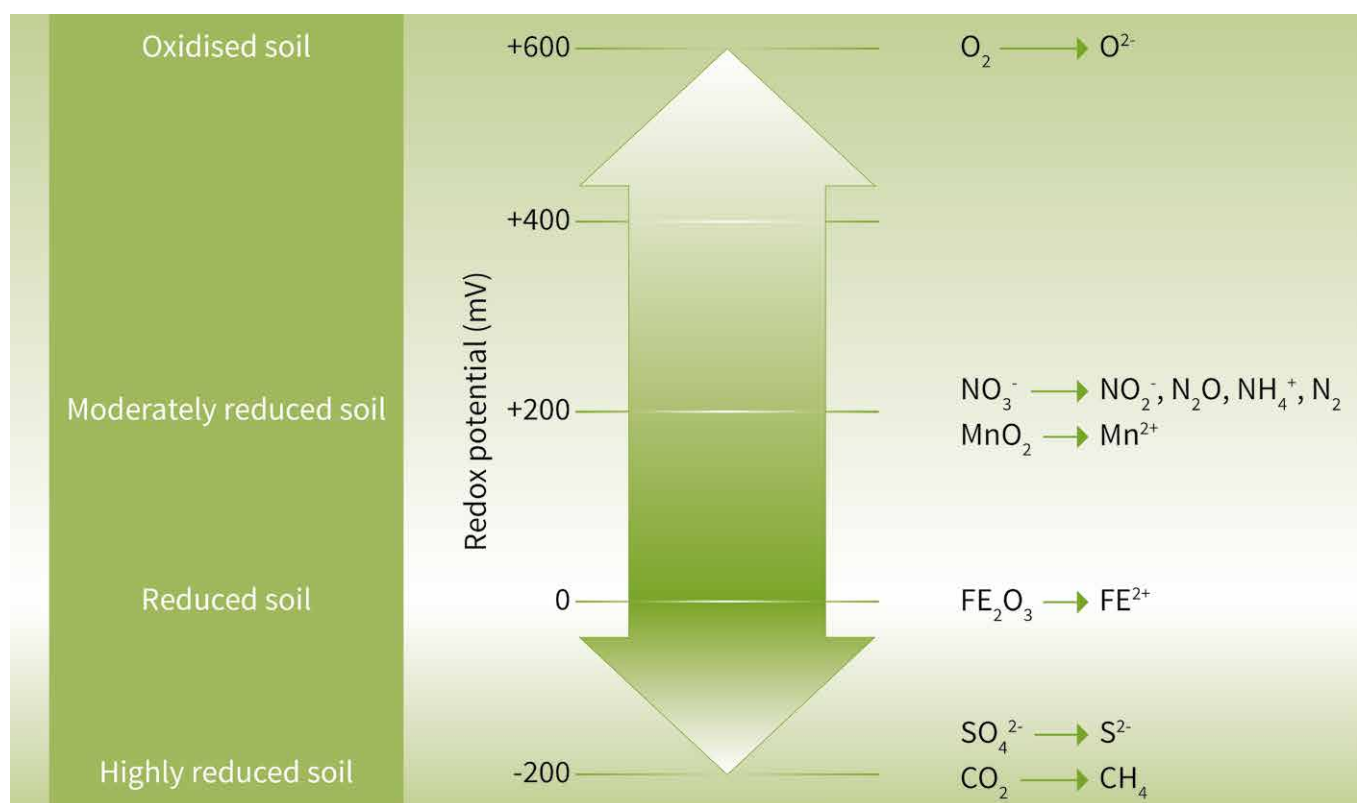
The redox potential of a deposit can therefore be seen as a measure of the presence of oxidising substances (Smit *et al* 2006: 70). The oxidant most commonly recognised in the degradation of archaeological remains is oxygen (Matthiesen *et al* 2015), the presence of which can cause oxidation of organic remains and metals (the latter seen as corrosion). When oxygen is absent, for example in waterlogged anoxic deposits, other electron acceptors become involved in oxidation reactions (nitrate  $\text{NO}_3^-$ , manganese  $\text{MnO}_2$ , ferric iron  $\text{Fe}_2\text{O}_3$ , sulphate  $\text{SO}_4^{2-}$ , and carbon dioxide  $\text{CO}_2$ ). These reactions only occur under certain conditions, mediated by temperature, pH, the presence of micro-organisms and the absence of oxygen. The rate at which these other oxidation reactions take place is far slower than is the case with oxygen.

When deposits become waterlogged, redox values will usually fall and the deposit becomes more reducing. Often, although not universally, lower redox values will be recorded at lower depths on site, where they are less affected by fluctuating water levels and where oxygen cannot penetrate or is used up in reactions higher up the soil profile. In part this occurs because the concentration of oxygen in water is much lower than in air, and oxygen diffusion through water is very slow (Bohn *et al* 2001).

The type of redox reactions which occur in soils can be determined with reference to the pH and redox potential of the deposit; redox potential is written as Eh, and measured in millivolts – mV. So that redox data are comparable between different measurement systems, they need to be calibrated against the Standard Hydrogen Electrode (SHE): see Appendix 4 for detailed discussion about redox measurement and data calibration. Where redox values are given in this guidance they are all calibrated in this way.

Table 1 and Figure 2 show the oxidation-reduction reactions which occur at different redox potentials. For example, organic matter is oxidised by sulphate substances ( $\text{SO}_4^{2-}$ ) in the soil, resulting in the production of sulphide ( $\text{S}^{2-}$ ). This reaction occurs when redox values are below about -100mV (at pH 7). Therefore the presence of more sulphides than sulphates in a sample would suggest that the redox potential is below -100mV and that the sample, and deposit from which it came was reducing. Conversely, the presence of more sulphates than sulphides in a sample could indicate that redox values were likely to be above -100mV, and the deposit therefore less reducing.

	Oxidized form	Reduced form	Approximate Eh at transformations
			mV SHE
Oxygen	O <sub>2</sub>	H <sub>2</sub> O	+600 to +400
Nitrogen	NO <sub>3</sub> <sup>-</sup>	N <sub>2</sub> O, N <sub>2</sub> , NH <sub>4</sub> <sup>+</sup>	250
Manganese	Mn <sup>4+</sup>	Mn <sup>2+</sup>	225
Iron	Fe <sup>3+</sup>	Fe <sup>2+</sup>	+100 to -100
Sulphur	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	-100 to -200
Carbon	CO <sub>2</sub>	CH <sub>4</sub>	less than -200



**Table 1**  
The most important redox pairs and the approximate redox values at the occurrence of transitions at the reference pH of 7.0 (After Vorenhout et al 2004).

**Figure 2**  
Example of the range in redox potential in waterlogged soils and the location in the redox range where the various oxidation-reduction reactions take place.

# 2 Bone

Bone is a complex structure composed of both organic and inorganic elements, predominantly collagen and hydroxyapatite respectively (Collins *et al* 2002; Jans 2005), which together give bones their strength and flexibility. With the exception of most human remains and a small number of complete animal burials, most archaeological bones will have undergone some form of transformation before burial – butchering; defleshing; cooking; boiling; drying out and / or surface weathering – all of which will influence their long-term survival.

After burial, bones continue to be affected by a range of biological, chemical and hydrological factors. Bacterial decay associated with the decomposition of soft tissues also affects bones; in some cases, enhanced levels of bone degradation are found in the immediate vicinity of the intestines where bacterial decay is greatest (Huisman *et al* 2009c). Roots, fungi and insects can also damage bones following burial.

The long-term survival of archaeological bone, and its bioarchaeological and biomolecular potential depends on the preservation of both collagen and hydroxyapatite components. As shown in the main document Figure 2, bone preservation is usually better in neutral to calcareous soil types. Acidic soils increase the chemical dissolution of the bone mineral (exposing the collagen to microbial attack).

Equally, over time, slow, long-term degradation of the collagen removes the ‘protection’ that it confers to the bone mineral, making it more brittle. It then becomes more susceptible to further chemical change and weathering (Collins *et al* 2002; Jans 2005). The rate of dissolution of the organic component of bones will depend on the flow of groundwater and hydraulic gradient between the bone and the soil (the difference in the ease with which water can pass through each). The dissolution of the organic component is greatly accelerated in sandy or gravelly soils (through which water can pass easily) or in bones buried close to the surface.

As bone degradation increases, bone pore sizes also increase, allowing greater volumes of water to pass through the bone, further increasing the quantities of dissolved mineral ions removed (Hedges and Millard 1995).

## 2.1 Bone preservation assessment - macroscopic

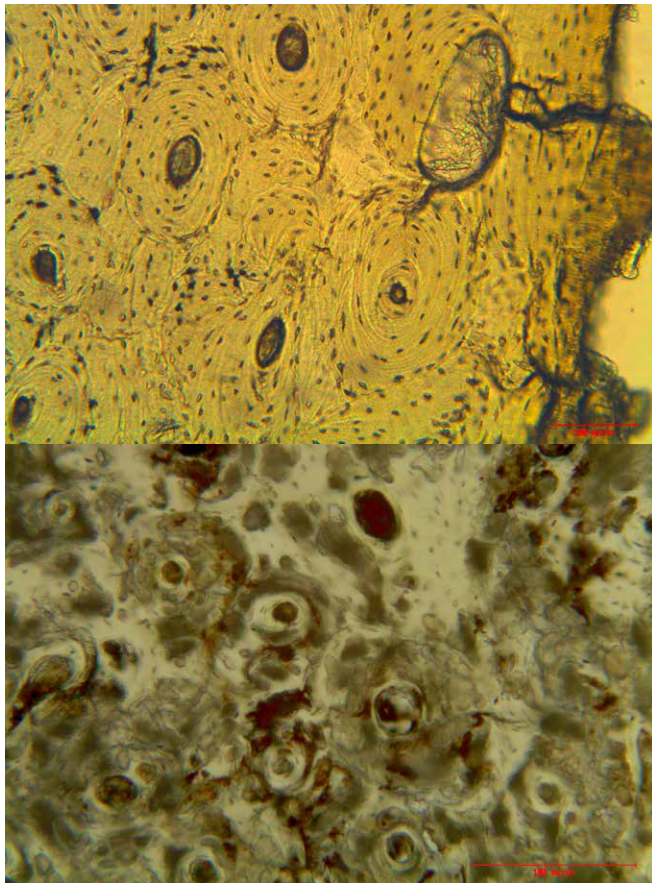
It is good practice for the state of preservation of bones to form an integral part of any assessment and analysis of human and animal bones (English Heritage 2004; 2014). For most sites, a simple macroscopic assessment, based on preservation categories, such as those in Table 2 is sufficient.

The analysis of human and animal remains can yield exceptional quantities of information from the morphological and morphometric assessment of excavated bones (English Heritage 2004; 2014; APABE 2013). This information will be substantially reduced where bone degradation occurs.



Category	Description
1	Strong, complete bone, skeletal elements are whole and undamaged
2	Fragile bone, fragmented bone, but completely reconstructable
3	Fragmented bone, bones are cracked and fragmented
4	Extremely fragmented bone, bones may not be recognisable
5	Bone meal or silhouette; fragmentary tooth crowns may still be present

**Table 2**  
Macroscopic preservation categories as developed by Gordon and Buikstra (1981) from Jans (2005).



**Figure 3**  
Bone thin sections illustrating different levels of preservation. Top image well preserved bone; bottom image extensive damage to bone structure.

## 2.2 Bone preservation assessment - microscopic

More detailed examination of bone preservation can be carried out by taking thin section slices (30µm) through the bone and studying them by transmitted and polarised light microscopy or Scanning Electron Microscopy. This approach, called histology provides further information, particularly on the impact of microbial degradation of the bone, which can alter the internal structure of the bone, leading to increases in porosity and loss of biomolecules such as collagen and ancient DNA - aDNA (Jans 2005). Categories of damage are given in the Oxford Histological Index – OHI – see Figure 3 and Table 3 (Hedges *et al* 1995; Millard 2001).

As microbial attack largely takes place in the first 500 years of burial, examination of material <500 years old will provide an assessment of the current state of preservation, rather than indicate potential future decay (Millard 2001). The one exception to this is with waterlogged bone. If histological analysis shows a high level of preservation, it is possible that microbial degradation could occur in the ground subsequently if the deposits dry out.

Index	Approximate % intact bone	Description
0	<5	No original features identifiable, except that Haversian canal may be present
1	<15	Haversian canals present, small areas of well-preserved bone present, or lamellate structure is preserved by the pattern of destructive foci
2	<50	Some lamellate structure is preserved between the destructive foci
3	>50	Some osteocyte lacunae preserved
4	>85	Bone is fairly well preserved with minor amounts of destructive foci
5	>95	Very well preserved, virtually indistinguishable from modern bone

**Table 3**

Histological index, from Millard 2001.

## 2.3 Bone preservation assessment - biomolecules

In addition to morphological studies, bone is also used for radiocarbon dating, stable isotope analysis and aDNA research. Collagen is the main biomolecule used for <sup>14</sup>C dating and stable isotope analysis. Methods have been tested to try to identify a quick and easy test for collagen preservation (to save dating / analysing bones which don't contain collagen). Some of this information may be gained from histological analysis, but currently the most effective method is elemental analysis for %N (nitrogen) (Brook *et al* 2010).

Assessing the preservation of aDNA is more complex and studies to find a single proxy measure for assessing the level of survival have to date been largely unsuccessful (Sosa *et al* 2013). A good starting point for choosing bones suitable for aDNA analysis is those yielding sufficient collagen for <sup>14</sup>C dating, but the only certain way to know is DNA screening (Götherstöm *et al* 2002).

## 2.4 What to assess?

For sites with large or significant assemblages of bones, it is good practice to consider whether reburial for a further period of time will impact long-term survival. This is particularly the case for sites where development or land-use change will or has resulted in changes to site loading, hydrology or groundwater chemistry. Additionally, when considering reburial or the continued burial of large or significant assemblages of human or animal bones, it may be appropriate to carry out an assessment of the preservation of collagen and potential for <sup>14</sup>C dating / stable isotope analysis, and by inference possibly aDNA, so that the future research potential of the buried material is understood better.

# 3 Wood

Wood is primarily composed of lignin, cellulose and hemicellulose, which together form the main components of cell walls. In life this combination provides the strength and rigidity that trees need. When trees die or are cut down and used, wood becomes susceptible to degradation by bacteria, fungi, algae and insects, see Table 4.

Seasoning, surface treatment, use and storage in a dry environment will allow wood to survive for long periods of time. On the other hand if wood becomes and stays damp it is at risk of fungal deterioration from brown, white or soft rot. When wood is buried in moist, but aerobic soils (most burial environments within north-west Europe), fungal degradation will lead to complete decay within only a few years (Huisman and Klaassen 2009). Similar loss will occur in waterlogged soils subject to seasonal / occasional drying out and oxygen ingress.

Biological agent	Required environment	Impacts caused by biological agents
Bacteria	Wet / damp conditions  Aerobic bacteria require oxygen to be present. Facultative anaerobic bacteria can operate in oxic and anoxic environments. Obligate anaerobes only occur in anoxic conditions	Bacteria can cause loss of cell wall material  Anaerobic bacterial activity can lead to the deposition of iron sulphides in wood cells (the oxidation of these sulphides may result in acidification and further wood degradation)
Fungi	Require oxygen and a wood water content in excess of 18% (but less than 85%)	Loss of cell wall material and discolouration, leading to a loss of strength and slow disintegration
Insects	Require oxygen and can survive in wood of only 8% moisture content	Holes and cavities, followed by rapid disintegration

**Table 4**

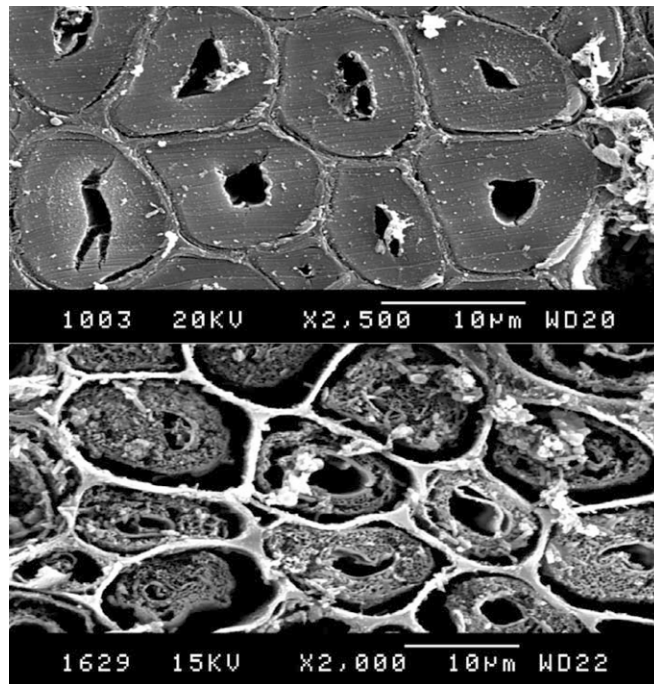
Biological agents that contribute to the decay of waterlogged wood and the effects they cause.

Table adapted from English Heritage (2010).

Even when wood is buried in entirely waterlogged conditions, degradation by bacteria and chemical changes to cell wall structure (Jones, M. 2013) mean damage still occurs. This degradation mainly affects the inner layer of the cell wall (Huisman and Klaassen 2009), leaving intact the outer wall (see Figure 4). As the cell wall is degraded, the material lost is replaced by water.

The maximum moisture content of a given sample of wood can be used to determine preservation (see Table 5). Values for maximum moisture content - defined as  $U_{max}$  - increase as a result of increasing porosity of the wood cell wall, caused by microbial decay.  $U_{max}$  values can range between 185% to greater than 400% depending upon the extent of decay. Maximum water content values are calculated by placing submerged samples under a vacuum to ensure that all the trapped air is removed.

$U_{max}$  values should not be confused with standard moisture content which is defined as the weight of water expressed as a percentage of the oven dry weight of the samples. Moisture contents typically range between 5% and 25% depending on species and ambient humidity. The rate of bacterial degradation is lowest in waterlogged soils with no through-flow of water.



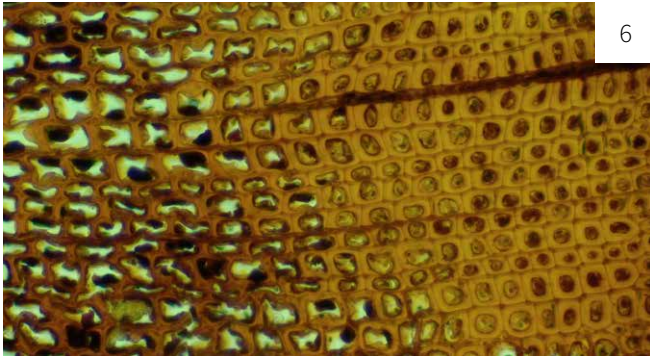
**Figure 4**  
Scanning Electron micrographs of oak in various conditions: well preserved (above) and degraded (bottom image). The degradation of the inner cell wall leaving behind the outer wall can be seen in this bottom image.

Level of degradation	Description
Heavily degraded	Wood containing over 400% water. This wood has lost all of its hard core
Medium degraded	Wood containing between 185 and 400% water. A hard core is present but is comparatively small
Slightly degraded	Wood containing less than 185% water. A hard core is still present beneath a thin deteriorated surface layer

**Table 5**  
Degradation categories for waterlogged wood (classification developed for oak; soft woods exhibit a more homogenous decay pattern than hard woods), from Jones, M. 2013.



5



6

**Figure 5**

Timber pile with poor preservation at the top (right) where it has been exposed to oxygen and degraded by soil organisms and well preserved at the base (left) where it has been permanently waterlogged.

**Figure 6**

Thin section of wood with signs of brown rot on the left of the image. Some cells are beginning to lose their shape at the bottom of the affected area.

The absence of these elements does not necessarily suggest poor preservation – they may not have been present on the object before burial. It is therefore important to consider the burial history of any object. Items such as timber piles may have different levels of preservation where the basal sections were buried beneath the water table but the upper sections have been exposed, see Figure 5.

The maximum moisture content of wood can be measured by various techniques, including weighing wet and dried wood and calculating the difference, or using a Sibert decay drill (Panter and Spriggs 1996). More detailed examination of wood by a wood specialist / archaeological conservator / conservation scientist would include visual assessment of the presence of fungi and bacteria, as well as the presence of iron sulphides and other metal salt deposits. The structure of wood can also be looked at by preparation of thin sections and examination using light microscopy (see Figure 6), or Scanning Electron Microscopy (*as in* Figure 4). FT-IR, FT-Raman (Fourier transform infra-red and Fourier transform Raman spectroscopy) and Py/GC/MS (Pyrolysis Gas Chromatography Mass Spectrometry) can also be used to investigate the proportion of the different elements of wood (lignin, cellulose, hemicellulose) present, providing an understanding of the extent of degradation.

### 3.1 Wood preservation assessment

**Waterlogged Wood** (2010) outlines the recommended techniques to assess the state of preservation of waterlogged wood. A summary of these are covered in this section.

Visual assessment can provide an indication of the preservation of wood, although additional examination is usually necessary as water in the wood cells can make wood appear to be well preserved. Other visual indicators of preservation include the presence of sapwood, bark or well defined tool marks that are lost when the wood surface degrades; the sapwood being the first element to decay (Brunning 2013: 150).

### 3.2 What to assess?

Where wood forms a major component of the finds assemblage and contributes to the site's significance, specialist assessment of the state of preservation of the wood, alongside information about moisture levels and groundwater regimes will assist with the decision-making process about future site preservation.

# 4 Metal

Most metals found in nature occur within ores and are largely stable (Edwards 1998: 87). When these ores are processed and metals are produced, the resulting 'metal' is chemically unstable and will favour reactions which will return these metals to their natural, more stable states. Archaeological metals, such as iron and copper, occur as compounds which, due to their instability, react readily with other chemicals in their environments, the main ones being oxygen and water. In burial environments where oxygen is absent, sulphate can play a key role in reactions.

Whilst in use, archaeological metals will undergo a certain degree of change as they react with the air. Non-ferrous (non-iron) metals, such as copper and bronze acquire a patina, a uniform protective oxidation layer on their surface, which largely prevents further corrosion (Huisman & Joosten 2009: 121). Iron objects (swords, knives, armour etc.) will corrode in temperate climates, so protection against water and oxygen by wrapping in another material (leather tool kits, sword scabbards) or applying a protective coating (such as lanolin from sheep's wool, or oil) to reduce oxygen and water penetration would probably have been necessary.

After burial, the rate and type of corrosion of metals is determined by local environmental conditions, in particular the presence of water, the availability of oxygen and sulphate and the pH of the deposits. Three types of burial environment, and the implications for metal corrosion are considered here (after Huisman 2009b: 93).

- Oxygen rich (oxic) – Unsaturated for at least part of the year, which allows oxygen to penetrate. This includes most terrestrial sites.
- Anoxic (reduced), sulphate rich – permanently waterlogged with no oxygen, but rich in sulphate (common in marine and former marine sediments).
- Anoxic (reduced), sulphate poor – permanently waterlogged containing no oxygen or sulphate.

It should be noted that sulphate rich and sulphate poor conditions can exist in the same soil profile, where sulphates in waterlogged deposits lower in the sediment sequence have been reduced to sulphides, by sulphate-reducing bacteria. When water levels fall, these sulphides are themselves oxidised, leading to the production of acid sulphates which can cause an increase in acidity – see above section on soil chemistry for an example.



7

At Fiskerton, fresh iron coupons were inserted into the archaeological deposits at the site as a method of burial environment assessment and to understand more about the corrosion processes active on site. These are shown in Figure 7. They were removed at 6, 12 and 30 month intervals for inspection. Figure 8 shows the coupons after 30 months burial. On the right hand side, coupons from the top of the rod. The predominant corrosion products (identified using XRF) are iron oxides which formed in an oxic (oxygen rich) environment. In the middle, the fluctuating water table which led to intermittent saturation has caused rapid corrosion as stable passivating layers didn't form, due to rapid changes in pH and redox. On the left, corrosion had taken place in anoxic conditions, with the presence of siderite (which can be seen in the bottom image on the outside of the coupon) indicating low-sulphate, and thus anoxic conditions are present. Length of original coupons c50mm.



8

**Figure 7**  
Burial of 50mm length iron coupons from Fiskerton. They are tied to the rods between the white spacers and are partly hidden in these images by soil that is in the recesses.

**Figure 8**  
The corroded coupons after 30 months of burial.

## 4.1 Metal preservation assessment

It is essential that ferrous and a sample of non-ferrous finds (excluding lead alloys) should be X-rayed (see [Guidelines on the X-Radiography of archaeological metalwork](#) 2006) during the fieldwork phase of any project. It is particularly important that ferrous material, which is likely to be encrusted in corrosion products, is subject to X-radiography, as this is the quickest and most appropriate way to reveal the corroded object, show the extent to which corrosion has penetrated the object and assess its significance.

Corrosion on objects will usually be visible to the naked eye and will be described by an archaeological conservator as part of a condition assessment. This should state their nature, volume, stability and implications for preservation. In a limited number of cases where a conservator cannot identify a corrosion product visually, X-ray diffraction (XRD) analysis can be used to identify the chemical form of the corrosion (see English Heritage 2008).

Within the context of decision-making about long-term preservation on a given site, the analysis of the corrosion products on a metal artefact can provide information about the nature of the burial environment, as well as the object itself. For example, iron oxides are formed in oxic environments but would be absent from anoxic, reducing environments.

To ensure long-term preservation of metal artefacts, it is important that pre-existing burial environments are maintained. If a metal object was deposited in a waterlogged environment, the site needs to be kept wet with limited or no fluctuations in water level (see *for example* Figure 8). This is certainly the case for anoxic environments containing sulphides, which when exposed to oxygen, could lead to the production of sulphuric acid during the conversion of corrosion products.

Likewise, where metal has survived, albeit in a corroded state in an oxic environment, changing it to a reducing, waterlogged one may well lead to the loss of secondary information in corrosion products (such as impressions of organic material) as different reactions take place in this ‘chemically’ new environment.

When the examination of corrosion products is a planned part of preservation assessments, metals need to be placed in oxygen-free environments between recovery and analysis. This particularly applies to metals recovered from waterlogged anoxic environments.

## 4.2 What to assess?

Where a major component of the finds assemblage is comprised of metal objects which contribute to the site’s significance, specialist assessment of the current state of preservation of this material, carried out by an appropriately trained conservator as part of the conservation assessment will aid discussion about future preservation. This is particularly the case where any new development or change in site management is likely to alter the groundwater regime or significantly increase sediment loading.



Environment			Impact on metals		
		Ferrous	Copper alloy		
Oxygen rich	With archaeological iron, the extent and rate of corrosion is dependent on the supply of oxygen, as well as the pH, salinity and moisture content of deposits. Iron is usually better preserved in basic (pH above 7) sites than on acidic (and in particular acidic saline) sites. When corrosion occurs in oxygen rich deposits a dense layer of corrosion products form adjacent to the metal and in the soil around the object; other corrosion features include blisters which form on the original surface, and the hollowing out of iron from inside the object, eventually causing the loss of all metallic iron	When copper and copper alloys come into contact with oxygen, the copper dissolves to form a compact layer of copper oxide. Further corrosion and reactions of the copper and chemical elements in the environment forms other layers, of copper carbonates and in saline environments, copper chlorides. When corrosion is slow, a compact patina is formed; if it is more rapid, a crust forms. Occasionally, during rapid corrosion blistering can occur.			
Anoxic, sulphate rich	Although oxygen is absent, corrosion reactions still occur in sulphate rich environments (sulphate becomes an electron acceptor in the oxidation of iron). As with oxygen, iron on the inside of an object is oxidised (by reaction with the sulphate) and then dissolves and is transported out of the objects, and sulphide forms on the outside of the object. The precise corrosion product will depend on the presence of iron minerals in the soils. Corrosion in sulphate rich anoxic deposits can also lead to the total loss of the original object, leaving only a cavity surrounded by a grey-black concretion. As with oxygen, the rate of corrosion depends on the supply of sulphate, pH and salinity.	In sulphate rich anoxic environments copper and copper alloys (such as bronze) react to form copper sulphides, with corrosion pitting of the surface common. In saline acidic conditions, copper chlorides can also form.			
Anoxic, sulphate poor	In the absence of oxygen and sulphate, iron can still oxidise as a result of reactions with water or acid. In high pH soils (particularly with reduced, iron rich, lime rich groundwater) a crust of iron carbonate (siderite) can form on the iron. This crust is composed of iron from the burial environment and groundwater (rather than the object) and forms on the object (compared with corrosion in oxygen and sulphate rich environments, where iron is lost in the corrosion process). In acidic, sulphate poor soils (such as acidic peaty soils) the iron objects themselves are converted to siderite (see Williams et al 2008b).	There is little evidence of degradation of copper alloy materials in sulphate poor anoxic environments.			

**Table 6**

Summary of burial environments and their impacts on iron and copper alloy metals, from Huisman 2009b, Huisman and Joosten 2009, and English Heritage 2008.

# 5 Fabric and Leather

Fabric and leather, and other waterlogged organic artefacts are rarely found on most English archaeological sites, so our understanding of their use in the past is limited (English Heritage 2012). This material usually only survives in waterlogged, anoxic deposits, on urban sites, often in wells or cess pits, where leather can sometimes be found in large quantities. Fabric and leather may also be found preserved in association with metal objects, where corrosion products from the metal object have precipitated onto and protected the material through mineralization of the organic matter.

Waterlogged leather and textiles are very susceptible to decay in the presence of oxygen, mainly from microbial decay. Deposits containing these remains therefore need to be kept saturated and anoxic at all times. Both are also affected by changes in pH – plant-based fibres will decay in acidic conditions (even anoxic ones), whilst animal-based fabric and materials (such as leather) do not preserve well in an alkaline environment (Huisman *et al* 2009b).

Microscopic (including Scanning Electron Microscopy) assessment of fabric fibres and the leather's surface by a qualified conservator will enable a detailed understanding of the preservation of these materials to be drawn up as part of the conservation assessment. At the highest levels of magnification, details of individual fibres will be clearly visible, allowing the level of degradation to be assessed.

## 5.1 What to assess?

Textiles and leather are rare finds in the national context. Where these form even a minor component of the finds assemblage and contribute to the site's significance, specialist assessment of the state of preservation, alongside information about moisture levels and hydrological regimes will usually be necessary to understand fully the implications of any proposed development on the long-term preservation of this material.

# 6 Other Archaeological Materials

Pottery is a fairly robust material, but can be damaged by extended periods of surface exposure (weathering) and other physical processes. Where the firing process has been incomplete or where firing temperatures were low, pottery is more porous, facilitating water ingress and potential damage by freeze-thaw cycles, crystallisation of mineral salts or mechanical damage.

Glass is one of the most fragile archaeological finds, and is prone to physical damage and breakage during use, discard and deposition. It is also susceptible to weathering, leading to the development of a thin iridescent surface layer; softening and becoming crumbly; loss of transparency and development of an opaque surface crust and crizzling - the development of fine cracks (English Heritage 2011).

Although glass composition and production processes affect how and whether glass degrades, the greatest impact (aside from mechanical damage) comes from moisture, and in particular fluctuating wet and dry conditions (Huisman et al 2009a). Medieval glasses are damaged by continual waterlogging, where the glass can break down through the process of hydrolysis. However, a lot of Roman glass is soda glass and like modern milk bottles, is more robust. The appearance of glass may not therefore be a good indicator of the burial environment in all instances and specialist input is likely to be required.

## 6.1 What to assess?

Where low-fired pottery, pottery with fragile slips or glass form a major component of the finds assemblage for a site and contribute to the site's significance, if the retention of the site within a development is being considered, a detailed preservation assessment should form part of the post-excavation assessment, and contribute to decision-making about future mitigation strategies.

# 7 Waterlogged Plant and Invertebrate Remains

The main types of material covered in this section include waterlogged plant remains (plant macrofossils), pollen and insects (invertebrates), which are all excellent indicators of activities taking place at a site, living conditions, diet, health, past environments and climatic change. This palaeoenvironmental material is most regularly preserved in anoxic waterlogged environments, and as such is susceptible to decay if below-ground conditions change. The loss of all or part of these assemblages will impact on potential palaeoenvironmental reconstruction; if less robust taxa are unidentifiable or absent through loss, this will significantly affect the analysis, not just because missing species will mean an incomplete understanding of past environments, but because decay may mask evidence of the deposit's formation history. This information is crucial because palaeoenvironmental remains in a given deposit are likely to have a complex and varied pre-depositional history, and may have entered the burial environment through a range of different mechanisms.

The principal causes of deterioration of these materials are fragmentation (ie mechanical damage) and erosion / corrosion (chemical degradation). These impacts can occur before, during and after burial. Fragmentation can happen through transportation (by air, water, etc), consumption, or post-depositional compaction

(for example by trampling). Erosion results from biochemical oxidation, for example by fungi and bacteria within the soil or from microorganisms and acid attack within predator digestive tracts, or chemical oxidation within the soil in aerial or sub-aerial environments. Material may also have been altered before burial by human activity, by cooking, or through craft or industrial processes (Kenward *et al* 2008; Tinsley 2013).

Kenward and Hall (2004) noted that the potential for survival of any palaeoenvironmental material, and degree of erosion (decay) will depend largely on the range of degradation mechanisms to which the material is subjected during the process of burial, and the speed with which the material enters anoxic deposits. They have suggested that plant macrofossil and insect assemblages exhibiting a range of differential decay, typically affecting the more 'fragile' components to a greater degree than robust ones, are indicative of deposits which have remained waterlogged since burial (when the initial decay took place). Conversely, assemblages containing material which is more uniformly decayed are likely to represent deposits impacted by recent changes to water levels and anoxia, where chemical erosion of all remains and the 'surrounding amorphous organic material in the matrix' has occurred, suggesting burial conditions are no longer optimum.

## 7.1 Waterlogged plants and invertebrates assessment

Detailed preservation assessment of palaeoenvironmental materials is not usually carried out to the level outlined below as part of post-excavation assessment and analysis, so would need to be specifically planned. Preservation assessment of this material has two purposes. Firstly, it provides direct evidence of how well each class of material survives, and whether further burial within a development is possible without putting this evidence at risk. However, assessing plant and insect remains can also be a useful proxy measure of environmental conditions for the site as a whole. It is particularly useful for studying the state of preservation of a sediment sequence, as palaeoenvironmental material is often more ubiquitous than other archaeological material described above. It can therefore be used to show preservation potential of deposits from which no other finds have been recovered. This is also

useful for sites where construction or drainage has led to a drop in water levels. Assessing palaeoenvironmental material can demonstrate how deep the impact has penetrated the site.

A range of assessment criteria have been developed over the last 40 years. Those described below have recently been used and refined within a large scale preservation analysis of sites in the Somerset Levels, called MARISP - Monuments at Risk in Somerset's Peatlands (Bunning 2013); see case study in Appendix 1. Past methods of assessment are given in Bunning (2013) and Jones *et al* (2007).

For waterlogged plant macrofossils two main categories can be recorded: fragmentation (showing mechanical damage to seeds and fruit) and erosion / corrosion (recording chemical change, such as pitting, loss of surface sculpturing or damage to epidermal cells) (Jones, J. 2013), see Table 7 and Figure 9.

Deterioration type	Description	Score
Fragmentation	Seed/fruit entire	0
	25% fragmented	1
	25-50% fragmented	2
	50% fragmented	3
Erosion/corrosion	25% erosion of seed coat	1
	25-50% erosion	2
	50% erosion	3

**Table 7**

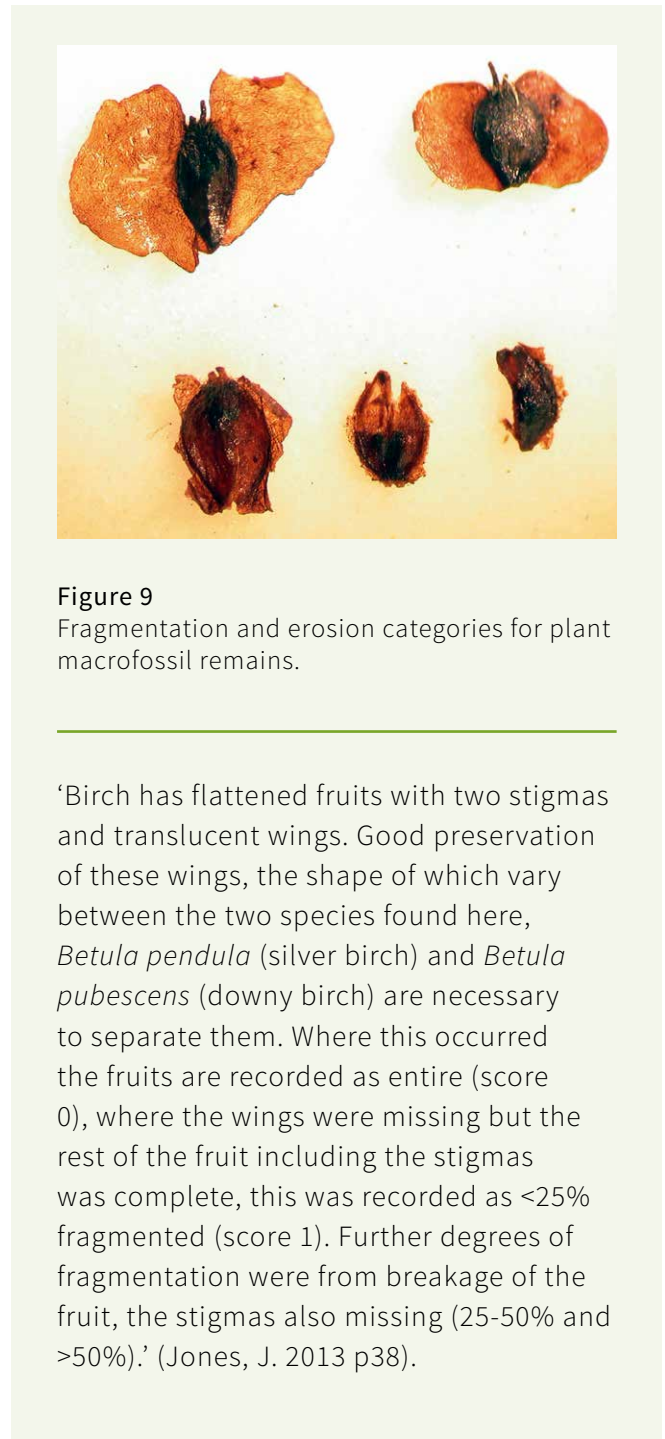
Fragmentation and erosion categories for plant macrofossil remains. From Jones, J. (2013).

Each (individual) plant macrofossil studied as part of the preservation assessment is given a score, and at the end of the analysis of each sample, the scores are added, and the total divided by the number of individuals in the sample, to provide a 'preservation index'. The lower the score, the better the preservation. Such indices can then be used to compare samples within and between sites.

Additionally, as part of the MARISP project, a brief description of the characteristics of each taxon was produced to improve the standardisation of recording, and images taken, see Figure 9. By recording each preservation assessment to taxa, a qualitative assessment is produced of the impact of the seed / fruit's intrinsic resistance to damage and decay. An example is given below for birch.

The success of this recording method depends to some extent on sufficient numbers of a single species (MNI) being found within the sample. Where diversity is high and taxa are only represented by one or two individuals the method can be less useful and the specialist will need to use their knowledge of the preservation properties of the different taxa present. For example, the presence of preserved legumes would probably suggest excellent preservation conditions whereas if only bramble and elder seeds are present, decay is likely to have occurred.

Pollen preservation assessment records two categories of damage: biochemical deterioration and mechanical deterioration (Tinsley 2013). Biochemical deterioration is caused by biochemical oxidation which results in pitting and etching of the exine (the outer coat of the pollen grain) or by chemical oxidation within aerial / sub-aerial environments. Mechanical deterioration records broken grains, which have been damaged during transport, and crumpled grains, which have been compacted within sediment, in particular resulting from the progressive extrusion of water. As part of the MARISP project photographs were taken to improve consistency.



**Figure 9**

Fragmentation and erosion categories for plant macrofossil remains.

'Birch has flattened fruits with two stigmas and translucent wings. Good preservation of these wings, the shape of which vary between the two species found here, *Betula pendula* (silver birch) and *Betula pubescens* (downy birch) are necessary to separate them. Where this occurred the fruits are recorded as entire (score 0), where the wings were missing but the rest of the fruit including the stigmas was complete, this was recorded as <25% fragmented (score 1). Further degrees of fragmentation were from breakage of the fruit, the stigmas also missing (25-50% and >50%).' (Jones, J. 2013 p38).

Within a preservation assessment the number of indeterminate grains should also be recorded (as is common practice in pollen analysis). The higher the number of indeterminate grains in the sample, the greater the loss of information, which in turn affects the reliability of any reconstruction based on that sample. This measure can also be used as a basic proxy for preservation, but does not allow more quantitative inter and intra-site comparisons to be made.

As with the plant macrofossils, quantitative assessment of deterioration data can be carried out to provide a preservation index for pollen. For each sample, 100 identifiable pollen grains should be assessed and scored using the criteria described above, see *also* Table 8. The scores are then totalled (the mechanical deterioration score being weighted because it had fewer individual categories) then divided by 100 (the number of pollen grains analysed) to give the preservation index (Tinsley 2013). Again, the lower the score, the better the preservation.

A summary of preservation categories for pollen and plant macrofossils, their scores / indices and what that means for potential for long-term survival is given in Table 9 (from Jones *et al* 2007).

Criteria for preservation assessment for insects had been drawn up prior to the MARISP project (Kenward and Large 1998), again using the categories of chemical erosion and fragmentation. As this assessment system pre-dated the MARISP project, no preservation indices were created. For each sample analysed, erosion and fragmentation are recorded against an eleven point scale, with the lowest and highest scores for the assemblage noted, and also the extent to which the rest of the assemblage reflects that ‘modal’ score (see Table 10 for an example of the recording criteria used). Colour change (in terms of change away from dry museum material) and a range of additional properties (abrasion, compression, crushing, local holing, charred, pitting, cracking etc), are also recorded.

Deterioration type		Description	Processes responsible	Category	Score	Weighting for calculation of preservation indices
Well preserved		No observable deterioration		1. well preserved	0	0
Biochemical deterioration	Corroded	Exine pitted, etched or perforated	Biochemical oxidation related to fungal/bacterial activity	2. <¼ corroded	1	0
				3. ¼-½ corroded	2	
				4. >½ corroded	3	
	Degraded	Exine thinned and/or structural features fused and indeterminate	Chemical oxidation within aerial and sub-aerial environments	5. partly degraded	1	
				6. extensively degraded	2	
				7. outline of grain only	3	
	Mechanical deterioration	Broken	Grain split or fragmented	Physical transport of pollen grains	8. partly broken	
9. extensively broken					2	
Crumpled		Grain squashed	Compaction of grains within the sediment, particularly resulting from the progressive extrusion of water	10. partly crumpled	1	
				11. extensively crumpled	2	

**Table 8**  
Preservation categories used for identified pollen grains in the MARISP samples (Tinsley 2013).

Preservation category	Pollen Preservation index range		Plant macrofossil Preservation index range		Risk of loss of palaeoenvironmental information under existing environmental conditions
	biochemical	mechanical	fragmentation	erosion	
Excellent	<0.5	<0.5	<0.75	<0.5	Currently little
Good	0.5–0.8	<0.5	0.75–1.0	<0.5	Low risk
Moderate	0.8–1.5	<0.8	1.0–1.5	0.5–1.0	Risk of some limited loss of susceptible taxa
Poor	1.5–2.0	<0.8	1.5–2.0	1.0–1.5	Differential decay likely to have started, susceptible taxa present at low frequencies may be lost
Very poor	>2.0	<0.8	>2.0	<1.5	Assemblages may become increasingly biased towards resistant taxa

Date:	Recorded by:	Site code:	Context:	Sample:						
Approximate adult beetle and bug MNI:	0	<5	5-10	10-20	20-30	30-50	50-100	100-200	200-500	>500
Approximate number of other insects/invertebrates:	0	<5	5-10	10-20	20-30	30-50	50-100	100-200	200-500	>500
Enough fossils for realistic estimation of preservational characters?	Yes						Borderline		No	
Based on:	Beetles only			All insects			All invertebrates			
Some probably rotted completely away?	Yes	Perhaps	No	If yes, guess what proportion:			Some	Many	Most	
Are individuals apparently represented by few or many of their sclerites?										
Recorded:	In flot		Sorted		In meths		On filter paper		Mounted	
Property	Degree		Modes				Distribution type		Comments on E and F characteristics, including distribution across ecological groups. Are any taxa notably damaged or well preserved?  (codes as below)	
	From	To	Mode 1	Strength	Mode 2	Strength				
Erosion				W D		W D	Normal	Skewed +		
				S V		S V	Skewed -	Flat		
Fragmen- tation				W D		W D	Normal	Skewed +		
				S V		S V	Skewed -	Flat		

### Top: Table 9

Preservation indices for pollen and plant macrofossils for the MARISP data set (Jones *et al* 2007).

### Bottom: Table 10

One section of a larger preservation recording sheet for insect remains (Kenward and Large 1998).

## 7.2 What to assess?

All classes of palaeoenvironmental material are useful for understanding the preservation of a given deposit or site, provided sufficient care is taken to differentiate between pre- and post-depositional degradation. Given the ubiquity of palaeoenvironmental remains in waterlogged deposits, they provide a useful material for condition assessment in these situations, particularly as the published criteria are available

for specialists to use and provide a standardised way of recording damage and decay.

Additionally, when deposits containing waterlogged palaeoenvironmental remains contribute to the site's significance, specialist assessment of the state of preservation, alongside information about moisture levels and hydrological regimes is needed when decisions are made about future preservation of these deposits.



# 8 Additional Analysis - Sampled Deposits

In addition to characterising individual components of deposits (bone, metal, wood, palaeoenvironmental material), it is also beneficial to study the soil itself as a useful guide to the conditions of the burial environment. Soils can be analysed using standard geoarchaeological techniques, in particular:

- Detailed sediment description and lab analysis
- Chemical analysis
- Thin section analysis.

## 8.1 Detailed sediment description and lab examination

To fully understand a deposit or range of deposits and their current environmental conditions, a range of basic information is needed from field and laboratory studies. In the field, a simple texturing analysis (see Historic England 2015: 25, 49) should have been carried out as part of context recording. This provides a useful start in understanding how water and oxygen will move through deposits – movement will be easier in more coarse grained soils.

Two further assessments, particularly for soils containing organic remains, are water content and organic matter content. Water content can be assessed by weighing a sample of soil, then oven drying it and re-weighing it after drying. A loss on ignition test is carried out to calculate the organic matter content of a given deposit. A

dried sample is heated in a kiln, and the resulting weight compared with the starting weight (see Historic England 2015). These tests could be used to investigate and characterise different deposits within a sediment sequence, or for replicate tests in the future to assess the degree of change over time (ie loss of organic matter). Where soil moisture monitoring is going to be carried out, porosity measurements are also needed, in addition to water content and LOI.

As peat and similar organic deposits are not often found on archaeological excavations, a blank recording sheet has been produced to assist those less familiar with recording these types of deposit. It can be found at the end of this document. It is based on a system designed by Troels-Smith (1955; see Historic England 2015: 49 for more information). It contains categories such as elasticity and humification, and has options to record a range of deposit components, such as wood debris or moss. It can also be used to record peat and other organic-rich deposits recovered from borehole and auger surveys. Equally, it could be adapted to fit contractors' existing own recording systems. Other sediment classification systems may be preferred by some palaeoenvironmental or geoarchaeological specialists.

## 8.2 Chemical analysis

One way of measuring the current environmental conditions of a site is to take soil samples for chemical analysis. These samples need to be taken carefully to limit their exposure to atmospheric conditions; once taken, samples should be kept

sealed and cold and sent for analysis immediately. Sampling and handling methods are set out in the British Standard for Site Investigation (BSI 2015). Laboratory analysis should only be conducted at a UKAS (United Kingdom Accreditation Service) approved laboratory.

The presence of oxidised chemical species would indicate an oxidised environment, whereas reduced species (such as  $S^{2-}$ ) would suggest more reducing conditions were present. This information is relatively cheap to collect and analyse (in comparison to implementing a water monitoring programme to collect similar information), and can be used to define those areas on sites where environmental conditions suitable for long-term preservation exist.

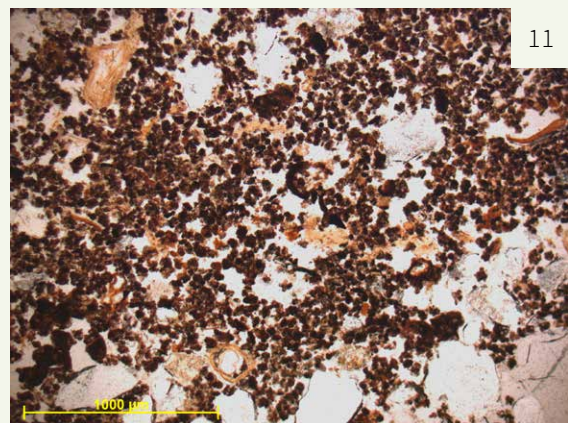
### 8.3 Thin section analysis

Just as changes to minerals through oxidation / reduction can be studied in metals and by chemical analysis, similar studies could be carried out by looking at the minerals within soils using thin section analysis or micromorphology (Historic England 2015). Using this technique, the presence of particular minerals provides an indication of the current and past state of preservation of deposits, and can also be used in a similar fashion to the chemical analysis described above. For example, the minerals vivianite ( $Fe_3(PO_4)_2$ ) and siderite ( $FeCO_3$ ) can only form and remain stable in deposits where oxygen and sulphate are absent (otherwise they oxidise to form iron oxides or iron sulphides). The presence of these minerals would therefore indicate reducing, low redox conditions (Huisman *et al* 2009d).

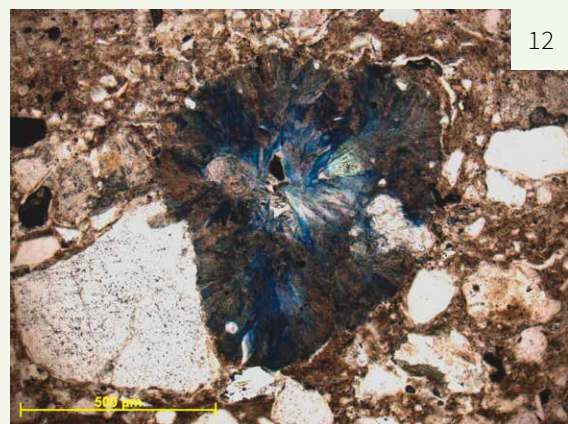
Thin section analysis can also be used to characterise and record a range of soil features such as soil structure, and the presence and preservation of organic matter. The additional benefit of thin section analysis is that it shows not just the current preservation of a deposit, but also formation processes that have taken place over time. It is not a quick technique so will not usually be suited for sites where rapid decisions need to be made about site preservation.



10



11



12

Example thin sections: Figure 10 shows well-preserved organic material (Sphagnum leaves); Figure 11 shows where organic material has been completely degraded and converted to faecal pellets by soil fauna; Figure 12 shows a mineral Vivianite, which is a large star shaped crystal that has formed under reducing conditions. It has turned blue in the presence of oxygen during sampling and analysis (it is usually white).

## 8.4 What to assess?

The techniques outlined in this section provide additional options for understanding the environmental condition of the deposits encountered on archaeological sites. The choice of any particular technique will depend on the

availability of funding, knowledge and experience of the project team. The methods outlined above will not all be needed in all situations. Additionally information on soil chemistry may come from other aspects of site investigation (ie geotechnical survey) which may provide useable information for preservation decision-making.

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# 10 Annex 1

## Recording sheet for peat and other organic rich deposits

Depth - cm		Physical features							
Upper	Lower	Score 1-4				Colour - describe + Munsell	Structure	Sharpness of boundary to layer above	Degree of humification
		Darkness	Stratification	Elasticity	Dryness				

Components (total = 4)															
Mosses	Woody plants	Herbs	Wood detritus	Herb detritus	Fine detritus	Charcoal	Gytija	Humus	Clay	Silt	Mud	Sand	Gravel	Man-made material	Comments, notes

Physical features	
Darkness	Varies from 0 in the lightest shades (pure quartz, lake marl); 1=pale; 2=medium; 3=dark to 4=black peats, charred deposits.
Stratification	Visual or structural horizontal banding or layering within a layer. 0=completely homogeneous or breaks in all directions to 4=clear thin layers or bands.
Elasticity	Sediment's ability to regain shape after being squeezed or bent. 0=plastic clay or sand; to 4=fresh peat.
Dryness	0=clear water, 1=very wet runny sediments, 2=saturated sediments (normal condition below the water table), 3=moist, unsaturated material, 4=air dry material.
Colour	Smear a little on a piece of white paper and compare with Munsell soil colour charts. Changes in colour with exposure to air should be noted in 'comments' field. Good idea to have a separate sheet of card, with site labels etc, and record all smears (with core number and depths) for semi-permanent record.
Structure	Dominant structural feature – fibrous, granular, homogeneous.
Sharpness of boundary to layer above	0=diffuse, spread >1cm; 1= very gradual 1cm-2mm; 2=gradual 1-2mm; 3=sharp 0.5-1mm; 4=very sharp <0.5mm.
Degree of humification	How humified or disintegrated are the organic components. Measured by squeezing between the fingers. 0=fresh peat, clear water; 1=dark coloured, 'muddy' water; 2=organics mostly decomposed about half being squeezed through; 3=a few fibrous remains, about three quarters squeezing through; 4=so decomposed nearly all squeezes through.

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# 11 Acknowledgements

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