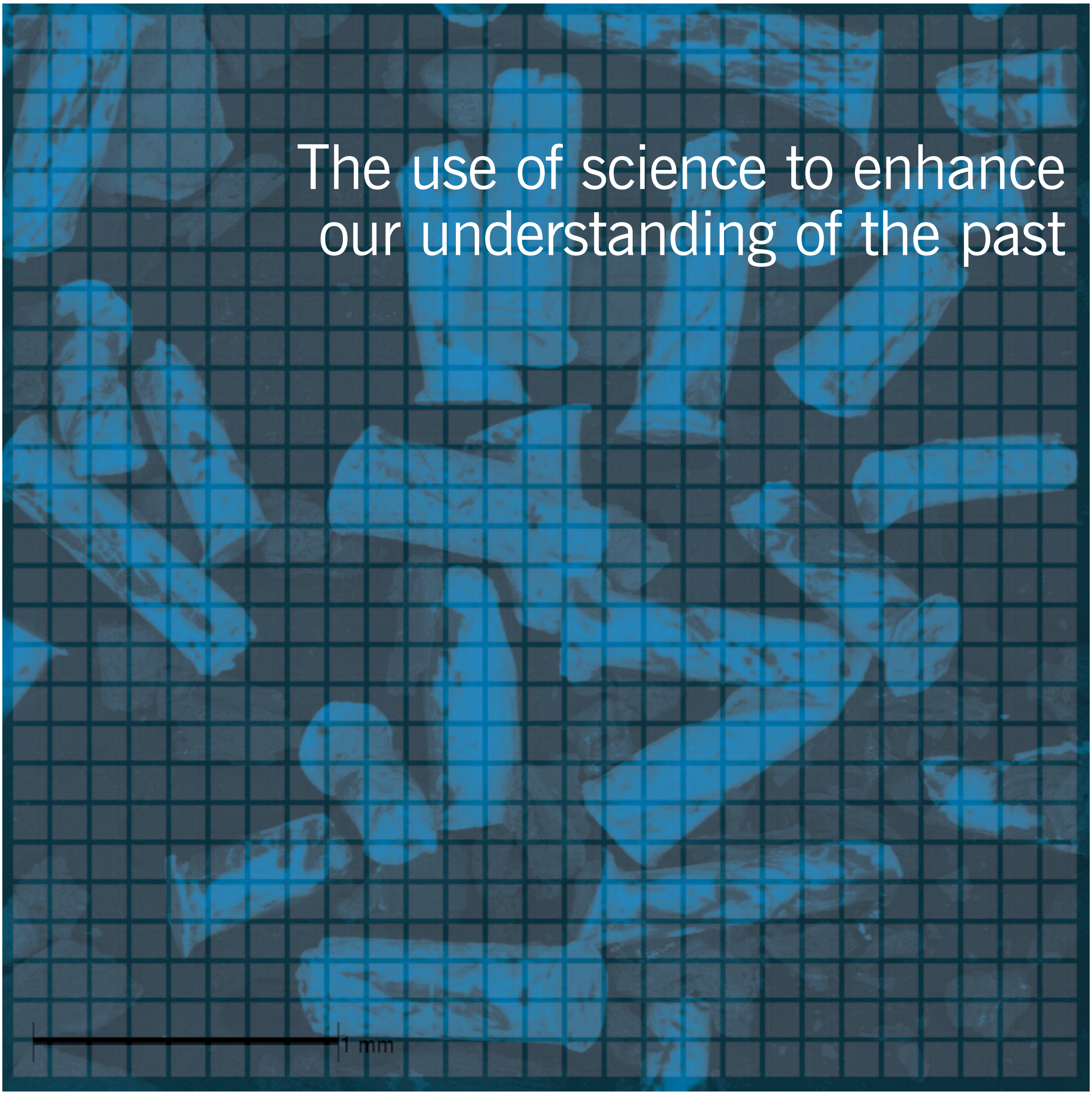
The use of science to enhance our understanding of the past



National Heritage Science Strategy

NHSS REPORT 2	DATE **JULY 2009**
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2009

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Cover image
SEM image of Bronze Age gold studs used to decorate the handles of daggers from Bush Barrow. This is a small selection of a total of about 140,000 gold pins which were recorded at the time of discovery. Material held at the Wiltshire Heritage Museum, Devizes, where other finds from the site are on display. SEM image provided courtesy of Mary Davis / National Museum Wales.

Executive summary

This is the second of three reports which provide the 'evidence-base' for a UK wide strategy for heritage science, covering both movable and immovable heritage. The formulation of a strategy is one of the recommendations to come from the House of Lords Science and Technology Committee inquiry into science and heritage held in 2006.

The report covers the use of science to enhance our understanding of the past. It reviews the principal drivers for scientific investigation in four subject areas *(chronology, people and the environment, understanding materials and detecting and imaging heritage assets)*, highlights the kinds of enquiries that heritage practitioners make about the past in these areas and indicates the range of scientific techniques that are available to address these questions. For each subject area and heritage sub-sector (archaeology, historic built environment and movable heritage i.e. museums, galleries, libraries and archives), a summary of the use of particular techniques is given, along with recommended areas for improvement. Three general themes are identified: *development of tools and access to equipment, raising awareness of existing techniques and their application, and data use and management*

The first theme (development of tools and access to equipment) describes the need for improvements to be made to existing equipment and methods, to enhance precision, accuracy, speed and area of coverage. It suggests that although large scale equipment and destructive testing of small samples is still necessary, improved access to and further development of portable, non-destructive techniques is a current priority. Along with the need for new tools, this report also suggests that more could be done to improve access to existing equipment (throughout the heritage sector and beyond) for use in heritage science applications.

The second theme (raising awareness of existing techniques and their application) suggests that significant improvements in the quality and quantity of heritage science could be made by providing the sector with improved guidance, advice and training for a range of issues that can already be addressed. It is clear that there is as much need for improvements in and further application of existing techniques as there is for the development of new ones.

The final theme (data use and management) contains recommendations to increase the availability of information produced by heritage science investigations, highlighting problems with both academic publications and unpublished internal or client reports. Additionally there is a need for improved storage and long-term curation of digital data resulting from heritage science work (especially data that have no analogue version). Increased digital access to and sharing of heritage science data would bring benefits to fellow practitioners and enhance public understanding and engagement.

The report identifies significant differences in the quantity of heritage science carried out between the four heritage sub-sectors covered in this report, with far greater amounts undertaken in archaeology compared with the other heritage sub-sectors.

The report does not identify how best to ensure that the issues outlined above are addressed. That is the purpose of the strategy, which will be drawn up utilising the information presented here and in NHSS reports 1 & 3.

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1 Introduction

This report is about how people use and develop science to answer questions that enhance our understanding of the past. The information these investigations generate helps us to learn more about heritage assets and assess their significance. This in turn engages the public; we are all fascinated by the past, about how people lived, their cultural influences and their environment. Science and new technologies allow us all to delve more deeply and look in ever increasing detail at works of art and museum objects, buildings, archaeological sites and landscapes. As well as providing immense enjoyment to millions of people, gaining a greater knowledge of heritage items is also important for sustainably managing these assets for the future. This report highlights the main areas where science is used to study the past and identifies where there are particular opportunities to improve our methodological tools and to increase the amount and/or quality of heritage science carried out in the UK.

What is heritage science?

The term heritage science is used in this report (and throughout the development of the strategy) to encompass all technological and scientific work that can benefit the heritage sector, whether through improved management decisions, enhanced understanding of significance and cultural value or increased public engagement.

1.1 Background

In 2006, the House of Lords Science and Technology Committee held an inquiry into science and heritage. Their report concludes that the previous high regard in which the UK heritage science sector had once been held is now under threat: the sector is fragmented and under-valued; conservation and sustainability of cultural heritage is not given enough importance in Government policy; there is insufficient transfer of new scientific research to heritage practitioners, and there is no strategic overview of research priorities for heritage science. One of the main recommendations of their report is the need for an all-embracing UK-wide strategy for heritage science.

This is the second report produced to underpin the development of this strategy and addresses *the use of science in enhancing our understanding of the past*. The first report explored *the role of science in the management of the UK's heritage* and identified areas where increases in understanding could improve current practice. Specific issues included the need for further investigation of the rate of decay and thresholds at which decay processes are initiated for a range of materials; the need for improved management of environments for display and storage and long term survival of heritage assets; and recommendations for additional development of assessment and monitoring tools, and improvements in access to information and equipment. A third report will look at practitioner and institutional capacity in relation to the needs, threats, opportunities and priorities for heritage science identified in reports 1 and 2. It will consider issues such as sector size (people and equipment), funding and training, both now and in the future.

1.2 How is heritage science information used

It is important to emphasis that heritage science should not take place on its own. It is not carried out just because it is possible, but as part of wider investigations into the past that utilise a range of other skills and tools. These include documentary research, scholarly and visual assessment and stylistic comparisons. In any well executed inquiry, scientific techniques are just part of a holistic programme of research and analysis, the means to an end, not the end in themselves. Heritage science stands at the interface of humanities/arts research and science.

The reasons why these investigations are carried out vary both within and between the different heritage sub-sectors. The extent of this variation and its causes are explored in more detail in the introductory sections of chapters 4-8.

The principal drivers for the investigation of the past, and therefore the use of science to enhance that work are:

- To increase our understanding about the past
  - As a society we have a deep rooted interest in the past and in understanding more about past societies and cultures, how they lived and died, their technology and their tools, costume and ornamentation, the resources they exploited, the environment they lived in, and how they changed it to their benefit.
  - A greater understanding of these issues also helps to inform us about the context and significance of things we have and the places we live in.
- To further public enjoyment and engagement
  - Scientific information and enhanced understanding of the past can engage the public through TV shows, books, web-based communication tools and displays in museums and historic places.
  - People enjoy the thrill of discovery and are interested in the science that informs it.
  - Heritage can provide an excellent platform to provide people with access to scientific practice, and improve the public understanding of science.
- To improve the management of our heritage
  - Understanding what things are made from and how significant they are is crucial for making appropriate recommendations about their long term management (as discussed in NHSS report 1).
  - It informs decisions about how cultural assets are studied, preserved and presented to the public.
- To support other industries
  - Investigating materials that have been decaying for thousands of years offers real time insight into understanding the long-term performance and decay of materials in support of applications within industry.
  - The application of new scientific techniques to heritage problems provides practical demonstrations of emerging science that can be easily understood by the wider public.

1.3 Structure of report

This report is split into six main sections. In Chapter 2, the main areas in which heritage science is used to increase understanding are summarised, and the types of questions we ask and the range of techniques employed are highlighted.

The following four chapters (3-6) describe the work that is actually taking place in each of the heritage sub-sectors, as identified in NHSS report 1:

- Archaeology
- The built historic environment
- Museums and galleries
- Libraries and archives

Each chapter begins by looking at the situations in which scientific techniques are used in heritage investigation within that particular sub-sector and identifies some of the reasons why usage levels vary. This is followed with a subject by subject assessment of the frequency of use of any given technique and recommendations for improvements. Links between statements within the 'areas for improvement' sections of each subject and the themes in the final chapter are made through the inclusion of topic numbers i.e. [4b] within the text. These three themes are numbered 4, 5 and 6 as themes 1, 2 and 3 are covered in Report 1.

These four chapters are unequal in length because of differences between the sub-sectors in the amount of heritage science used to increase our understanding of the past. Thus, the archaeology chapter is much larger than the libraries and archives chapter. This differs from the balance in the field of conservation science (it should be noted that the term 'conservation science' is often used as shorthand for heritage science applied to museum collections) which is reflected in NHSS report 1. Within this report there is quite a lot of overlap between sub-sectors so much of what is covered in archaeology is also true of the museum sub-sector for example. Chapter 3 is thus longer as it contains information that partly applies to later sections to avoid repetition and particularly to collections of excavated archaeological objects.

A final chapter highlights areas of commonality between these sub-sectors and suggests areas where cross-sector research, collaboration and cooperation would be beneficial.

1.4 Sources and methods

This report has been compiled by the Strategy Coordinator, drawing on previous strategies and studies as well as discussions with individuals from across the heritage and heritage science sectors and the Strategy Steering Group (see appendix 1). The majority of the information presented in this report is drawn from discussions with sector representatives and is not an academic literature review; in fact there are few sources of information that provide sufficient overview of the subjects covered here.

There are some issues which are not dealt with fully in this report. Conservation science is addressed in report 1 while sector capacity, funding and training will be addressed in more detail in report 3. More general information about the heritage sub-sectors used in this report and the types of material they contain is covered in chapter two of the NHSS report 1 which can be found on the strategy website (www.heritagesciencestrategy.org.uk).

The sub-sector divisions used in this report are to some extent arbitrary, but are useful in dividing it into manageable sections. There is clear and regular cross over between each of the sub-sectors:

- Most archaeological finds once excavated end up in museums, where they continue to be studied; some museums are actively involved in archaeological excavations.
- Museums and galleries research is also relevant to libraries and archives.
- Historic house museums cross many sub-sectors, being situated in historic buildings, and containing collections which might include material found in museums, galleries, libraries or archives.

The main benefits of dividing UK heritage science into these sub-sectors are to help to show what is different about each of the sub-sectors, and to highlight how those differences contribute to variations in the use of science to enhance our understanding of the past.

2 How heritage science can enhance understanding and public engagement with the past

Whilst scientific techniques are used in the main to enhance an 'academic' understanding of the past, it is essential that this knowledge does not remain solely within academic circles but is used more widely. This chapter explores the kinds of questions where scientific techniques can be used to enhance both academic and wider public knowledge, enjoyment and engagement with the past.

There are huge opportunities for heritage science to reach a broader public, through for example television and radio programmes, popular books and magazines, volunteering activities, clubs (such as Young Archaeologist Clubs), wide varieties of museum activities from glass-case exhibitions to open labs, hands-on activities and schools programmes, behind-the-scenes tours and talks at historic properties, and participation in national initiatives such as Heritage Open Days.

In this report the ways in which heritage science can enhance understanding and engagement is broken down into four main areas.

These are:

- *Chronology*
- *People and the environment*
- *Understanding materials*
- *Detecting and imaging heritage assets*

The topics covered and the range of investigative techniques discussed below are intended to be illustrative rather than exhaustive.

2.1 Chronology

Knowing how old something is, both in and of itself and also relative to other heritage assets is of central importance to almost all of the questions addressed in this report. Scientific dating can, for example allow us to investigate

- when an object or document was made, modified, reused or discarded,
- when and for how long a site or settlement was in use,
- different phases of construction or modification of buildings.

This in turn provides opportunities, for example, to study

- the introduction of new ideas, foods or technologies,
- the timing of human impacts on landscapes,
- authenticity and modification in works of art and other objects.

Figure 1
Coring in the roof at West Challacombe Manor (NT), Coombe Martin, Devon. This is a small 15th century manor house consisting of a central hall and two cross-wings. The hall has an oak false hammer beam roof. The felling date range produced by the dendro-chronological analysis of oak timbers from the false hammer beam roof is AD 1449-1475. Photo courtesy of Cathy Tyers

Scientific dating techniques include

- radiocarbon (C14) dating which can be used to date any carbon-based organic materials, such as wood, bone, plant remains,
- dendrochronology, tree ring dating which can provide precise and accurate dates (to nearest year in some cases) of the felling of a tree and is used for wood from archaeological sites and buildings in particular, and occasionally to date works of art with a wood support or components,
- luminescence dating of water-lain or wind-blown sediments containing quartz grains which provides a date when they were last exposed to light, i.e. when a ditch was filled in or when flood sediments were deposited, or when they were last heated, i.e. when brick or pottery was fired,
- archaeomagnetic dating of highly fired structures such as kilns or ovens and burnt soil,
- a range of other absolute techniques such as amino acid racemization (currently being used to date marine molluscs), tephrachronology (dating volcanic ash from deposits) and uranium series dating (to date calcite deposits in caves),
- relative dating techniques include the study of the introduction and use of particular pigments, media and other decorative materials, the identification of building stone sources from known dated quarries and the use of radar and infrared thermography to identify concealed structures and alterations, e.g. sealed openings, which inform a building's chronology and history of adaptation.

2.2 People and the environment

The scientific investigation of the remains of people themselves and the environment in which they lived tell us more about their lives and how people were influenced by and changed their environment. It is largely focused on the analysis of plant and animal (including human) remains and the sediments in which they are found, which provides information about past diets and environments.

Analysis of human skeletal remains (also called physical anthropology) can provide information about the life, health and death of individuals and through demographic studies contribute to wider understanding of societies and societal change. Such information can give insight into

- age at death, sex and stature (height) of an individual,
- what individuals might have looked like (through facial reconstruction),
- diseases and trauma, such as tuberculosis (TB), dental caries, rickets or occupational trauma, any of which could lead to loss of life,
- epidemiology of contagious diseases such as plague.

The analysis of what people ate, both individually and as a community can address questions about

- the exploitation of wild resources,
- domestication and management of animals and plant resources,
- shifts in the organisation of food acquisition and provision from
  - hunter gatherers to farmers
  - subsistence to market economy
- changing individual wealth and status through differences in diet,
- the role of plants and animals in ceremonial activities.

Analysis of the wider environment can show

- what environmental conditions were at any given time, and the effect of human activity in shaping and changing that environment,
- past changes in climate and environments which can help us to understand and adapt to current and future changes,
- the impact of environmental change on human activity, i.e. inundation of coastal or wetland areas during periods of sea level rise.

Figure 2
Fragments of moss from part of a turf making up the primary organic mound of Silbury Hill, Wiltshire. The biological remains from these turves show that chalk grassland pasture existed at the site over 4,400 years ago and that the livestock grazing this pasture were present in similar numbers to those found today.
Photo: Gill Campbell

Specific methods of analysis include

- visual and low powered microscopic examination of animal and plant remains from archaeological sites and identification and quantification of species to understand human diet, resource exploitation and past environments,
- analysis of residues in vessels or on objects -
  - microscopic analysis to identify burnt residues; chemical analysis of lipids and other biomolecules to show what was cooked or stored in pots,
- physical assessment and osteological analysis of human remains, i.e. measurement of bones, comparison of certain features with known standards,
- analysis of stable isotopes in bone –
  - carbon and nitrogen – which can provide information about the proportion of meat, fish and vegetables in a person's diet,
  - oxygen, strontium and sulphur – the variation between isotope values recorded from bones and teeth can be compared with geological measurements of these isotopes to map population movement.
- analysis of DNA which can be used to
  - identify sex,
  - show familial relationships,
  - investigate diffusion of the human race and subsequent population migrations,
  - identify some pathogens such as TB.

2.3 Understanding materials

This is about the things people make and use – from buildings and other structures to artefacts, and is concerned largely but not exclusively with materials. The questions are generic, concerning the manufacture, use and modification of all heritage assets. They apply equally to museum objects, works of art, books and manuscripts, built structures and archaeological material.

Studying what things are made from and how they were made provides information about

- what materials were available at any given point in the past and how they were exploited,
- where materials came from – trade and exchange of objects, goods and raw materials, sources of building fabric etc.,
- technological and artistic innovations,
- movement or diffusion of manufacturing expertise (i.e. people) and ideas,
- the knowledge that people had of the physical and aesthetic qualities of raw materials,
- the stylistic and technological influence that artists / craftspeople had on each other,
- the authenticity of an object or work of art (e.g. the use of particular pigments at a given date),
- changes that materials undergo according to age, use and function,
- the composition of objects which can aid conservation (mainly dealt with in NHSS report 1).

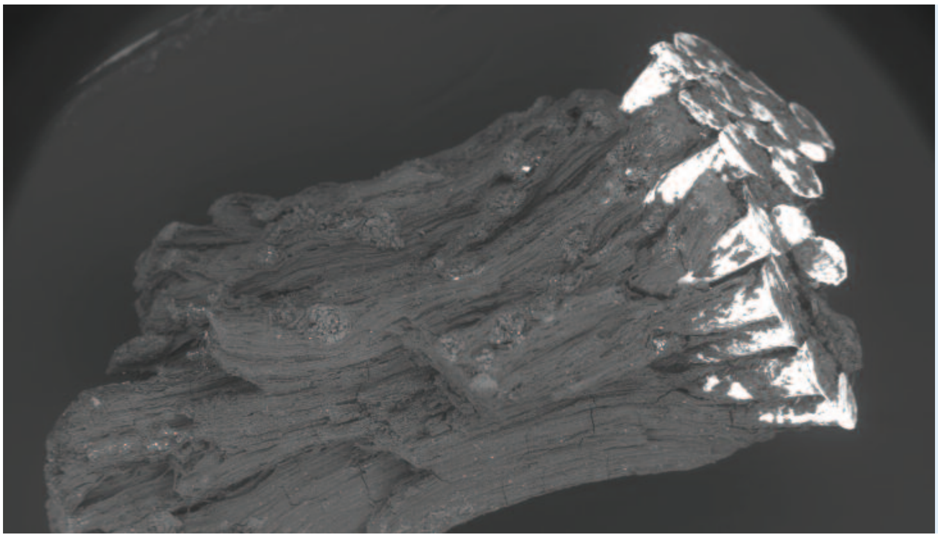


Figure 3
SEM image of a fragment of a Bronze Age dagger from the Bush Barrow with gold studs used to decorate the wooden handles. The cover image to this report shows some of the total of about 140,000 individual gold pins which were recorded at the time of discovery. SEM image provided courtesy of Mary Davis / National Museum Wales.

Aside from investigating how things were made and the materials they were made from, scientific analysis provides information on the history of objects, allowing us to understand

- how they were used in the past, i.e.
  - how a building or industrial site functioned,
  - how a particular tool was used.
- evidence of repair or adaptation, and thus original artistic / architectural intentions that may have been obscured by later alterations,
- how or why an item was discarded (though studying its burial / life history),
- how things deteriorate and how this helps us to understand their life history (or biography),
- previous conservation treatments (mainly dealt with in NHSS report 1).

Scientific methods used include

- microscopy, (optical, scanning electron microscopy, under UV light, polarised light etc.), for thin and cross-section analysis which can provide information on
  - species of wood,
  - type of stone,
  - specific pigments and layers used in painting or interior decoration,
  - raw materials used in pottery which can be used to identify provenance and trading patterns,
  - wear patterns on metal and stone tools (use-wear),
  - identification of botanical/biological species of objects or parchments,
  - identification of paper fibres.
- metallography (optical microscopy of polished sections, SEM-EDX) which can show manufacturing information, such as whether an object was cast or wrought – [a list of abbreviations is given in appendix 2],
- petrography, which can be used to determine the quarry and quarry bed from which stones have originated,
- x-radiography for identifying and analysing
  - degraded archaeological material,
  - identifying and investigating images under paintings,
  - studying textiles,
  - studying human remains,
  - investigating the structure of objects to visualise any additions or alterations.
- increasing use being made of new imaging techniques such as CT scanning, high energy radiography and digital methods,
- scanning electron microscopy (SEM) providing detailed images of material surfaces, and can additionally be used for a wide range of compositional studies when used with an appropriate analyser (i.e. EDX). Environmental SEMs are able to image waterlogged materials and biological activity in organic materials,
- analysis of compounds, elements and isotopes (techniques including XRF, XRD, FTIR, ICP-MS, Raman) which provide precise measurements of the materials present and their composition. This can be used
  - to understand what material is made from and its state of degradation,
  - for provenance studies,
  - to study composite objects to look for later additions.
- chromatographic and mass spectrometric analysis of residues or amorphous organic materials such as
  - food-based fats, oils, waxes on pots used for cooking and storage,
  - other dyes, gums, resins, pitches, bitumens, polymers, used for example in clothing, cosmetics or burial ritual i.e. incense.
- DNA and protein studies to identify species from skin/leather remains or the use of egg or glues as binders,
- experimental replication of ancient and historical technologies, also known as historically accurate reconstructions in some sub-sectors, which can be used to develop and test interpretations.

2.4 Detecting and imaging heritage assets

This is about how we locate, record and display heritage assets. Scientific techniques are used to

- identify and locate archaeological sites onshore and offshore
  - on which to conduct further research or to develop or test spatial or chronological hypotheses,
  - to inform future conservation strategies (e.g. in advance of development).
- identify different activity areas within sites, for example where metal working took place or where animals were stalled,
- reveal features not clearly visible to the naked eye, such as the use of different wavelengths of light to view palimpsests on parchment or to reveal hidden elements in paintings,
- produce an accurate digital record of an object, building, site or landscape to
  - use for analysis and interpretation, i.e. a measured survey of a building to understand different phases of construction,
  - digitally bring together documents or objects in separate collections to enhance study and access (i.e. virtual re-unification),
  - assist with visualisation, for example of buried land surfaces identified by geophysical survey,
  - digitally recreate (and physically from digital data) accurate replicas of objects that are too fragile to display or that may be damaged by taking moulds to make physical replicas.

Techniques include

- onshore and offshore geophysical survey, i.e. magnetometry, resistivity, ground penetrating radar (GPR), sonar,
- laser survey –
  - lidar survey (airborne laser altimetry) which provides surface topographical data,
  - ground based laser survey used to record objects and buildings, such as sculptures or details of carvings.
- ultra violet (UV), infrared (IR), near infrared (NIR), multispectral and hyperspectral imaging techniques that use different wavelengths of light to identify surface and subsurface differences in objects such as manuscripts and paintings and which also are another method of aerial reconnaissance of archaeological sites,
- intrusive methods such as borehole / geotechnical survey of sediments.

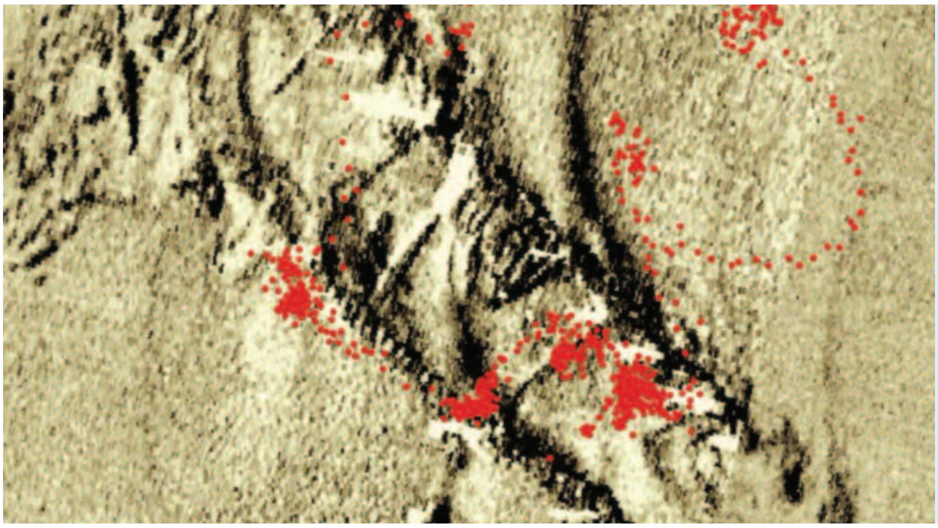


Figure 4
The combination of high resolution marine geophysical survey, underwater acoustic tracking (red dots) and real-time GIS is enabling fast, accurate and transparent evaluation of shipwrecks in difficult environments, as here on the wreck of the London, lost in 1665 in the Thames Estuary. © Wessex Archaeology

3 Archaeology

3.1 Situations in which scientific techniques are used

More so than in any other heritage sub-sector scientific techniques have become integrated into everyday archaeological practice. This is perhaps not surprising since archaeology is at its heart a subject based around the study of objects, sites and landscapes to learn more about the past. Thus an ever-increasing range of scientific techniques are developed to look in more detail, with more accuracy and precision, to learn about the people that made the artefacts, consumed the food and lived in the places where archaeologists find the material remains of their activity.

There are two distinct areas of activity in UK archaeology, that undertaken by archaeological contractors in response to development proposals (developer-funded archaeology), and the remaining work, carried out by university staff and students, archaeological units, archaeologists based in museums and state heritage services and local archaeological societies, undertaken more often than not as specific research projects.

3.2 Chronology – usage of techniques

- Radiocarbon (C14) dating is the most widely used scientific dating technique in the UK.
- Dendrochronology is routinely undertaken where waterlogged wood samples are found, particularly on prehistoric sites, shipwrecks and from waterlogged urban sites such as those found in London, York and Carlisle, although these situations are relatively rare.
- The application of luminescence dating of sediments is becoming more commonplace particularly on sites without material datable by radiocarbon or on older Palaeolithic sites beyond the range of radiocarbon.
- The use of luminescence dating, archaeomagnetic dating and a range of other less commonly applied techniques is limited due to
  - need for specific deposits / samples which do not regularly occur,
  - costs of analysis which are usually higher than radiocarbon, which if appropriate is used in preference,
  - perceived imprecision of particular techniques.

3.2.1 Chronology – areas for improvement

Radiocarbon

Radiocarbon is normally the technique of choice when appropriate samples are available because of its precision. However, in some circumstances, i.e. where calibration is difficult, other techniques may be chosen in preference.

Developments in the last ten years using Bayesian statistical modelling have completely altered C14 dating and improved the precision of our estimates of the dates of archaeological events to tens rather than hundreds of years. To achieve these improvements

- sample selection needs to be based on a coherent, question-based approach rather than the sometimes almost random dating of the few interesting or unknown features on a site [5a].
  - Currently, too many decisions about which dating laboratory to use and the number of dates to acquire are cost- and time-led rather than research-led; users of dating services should shop around for the best service for a particular site, not just go for the cheapest and quickest date [5a].

Methodological advancements which will lead to improvements in C14 dating include

- the development of a new radiocarbon calibration curve (e.g. using annually deposited layered lake deposits (varves) from Lake Suigetsu, Japan) will assist further in calibrating dates, particularly those older than 10000 years old [4a],
- pre-treatment of samples to reduce contamination (from burial) can also significantly enhance accuracy. More assessment of different techniques of pre-treatment is needed and the reporting of the treatment method used should be standardised since this has a bearing on the precision of date [4a],
- dating of single amino acids which is currently being developed as a method to avoid issues of contamination, thus improving the accuracy of dating human bone [4a].

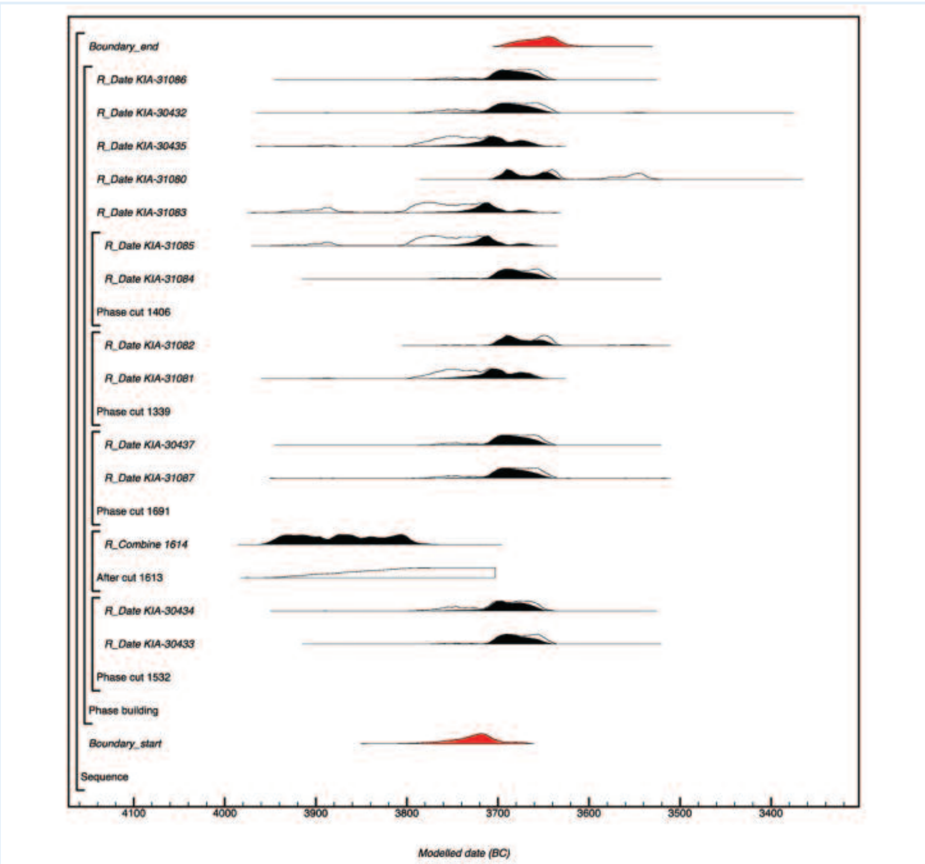


Figure 5
Probability distributions from a Neolithic building (Parc Bryn Cegin, Wales). Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one which is in outline, which is the result of simple radiocarbon calibration, and a solid one, based on the chronological model. The distributions in red are the estimated dates for the construction and end of use of the building. Modelling provides an estimate for the use of the building of between 20-95 years; by simply eyeballing the results we would have concluded that the building was in use for about 250-300 years! Image courtesy of Peter Marshall

Other techniques

- Increased precision of OSL (optically stimulated luminescence) dates can be achieved by using single grain (rather than bulk) methods [4a].
- More independent verification of OSL dates of older (Palaeolithic material) material by other dating techniques is needed to ensure reliability [4a].
- There is an increasing move towards the use of OSL rather than TL (thermoluminescence) for the dating of ceramic materials as it shows greater sensitivity.
- The archaeomagnetic dating calibration curve used to match results from sites with the direction of the magnetic north pole at any given time in the past relies on the verification of dates by other means. Dating of the same structures by alternative methods is still needed to refine the calibration curve and improve interpretation of past and future archaeomagnetic dates [4a].
- The use of archaeointensity dating (which measures the strength of the earth's magnetic field rather than the direction of magnetic north) needs to be extended to more sites to test its potential for more widespread application [4a].
  - One benefit of this technique is that it can be used on material that is no longer *in situ*, such as ceramics.
- Recent research on rehydroxylation dating of ceramics needs further validation but could potentially provide another source of dating of ceramics and bricks, particularly from the last 2000 years [4a].

3.3 People and the environment – usage of techniques

- The physical examination of plant and vertebrate remains is fairly routine for most UK archaeological projects.
- Palaeoenvironmental assessments of sites (i.e. palaeochannels in floodplains) are now becoming more commonplace.
- In general, environmental archaeological assessment has become a recognised 'core task' undertaken in almost all projects involving excavation.
- Detailed physical examination and recording of human skeletal remains is also carried out on most occasions when they are encountered.
  - In recent years there has been an increasing recognition and acceptance of the benefits of studying post-medieval human skeletal material.
- Analytical investigation (i.e. stable isotopes, DNA) is less common, although human remains and biological material are regularly used for C14 dating.
- The potential to carry out further research and synthetic studies of human remains in the future is being compromised by re-burial of remains after analysis as opposed to deposition in a museum or other suitable location with the rest of the site archive.

3.3.1 People and the environment – areas for improvement

Physical examination of plants and animal remains

There is a range of materials commonly studied by those undertaking environmental analysis such as pollen, plant macrofossils and animal bones. Other remains and techniques which could be applied in specific circumstances to yield information not provided by these common tools are sometimes neglected, limiting the potential of analysis. These include

- Invertebrates [4a] -
  - beetles,
  - chironomids (midge larvae – which are sensitive pollution indicators),
  - testate amoebae (indicators of sediment wetness).
- plant phytoliths [4a],
- charcoal (indicates woodland management and fuel use) [4a],
- climatic data from tree rings [4a].

Additionally, fish and marine resources appear to feature infrequently even in coastal areas (partially this is an issue of survival, recovery and sampling strategies).

Other methodological developments which would improve the physical examination of human remains and environmental material include

- more research to demonstrate the additional knowledge gain from increased sample size or more sieving of environmental samples, which should be undertaken as a cost / benefit exercise [4a],
- awareness of the need for larger sample sizes for animal bone assemblages – as the size of sites being excavated in the UK has tended to fall in the past few decades, samples of sufficient size for animal bone analysis that yield detailed results (e.g. that can provide useful ageing data) are becoming less common [4a],
- for human remains, more research is needed to improve methods to estimate age of death in adult skeletons [4a],
- for pollen studies, more analysis of small basins (rather than larger pollen traps) to provide information about local agricultural activity, and more generally, a need for analysis of deposits representing the last 1000 years [4a].

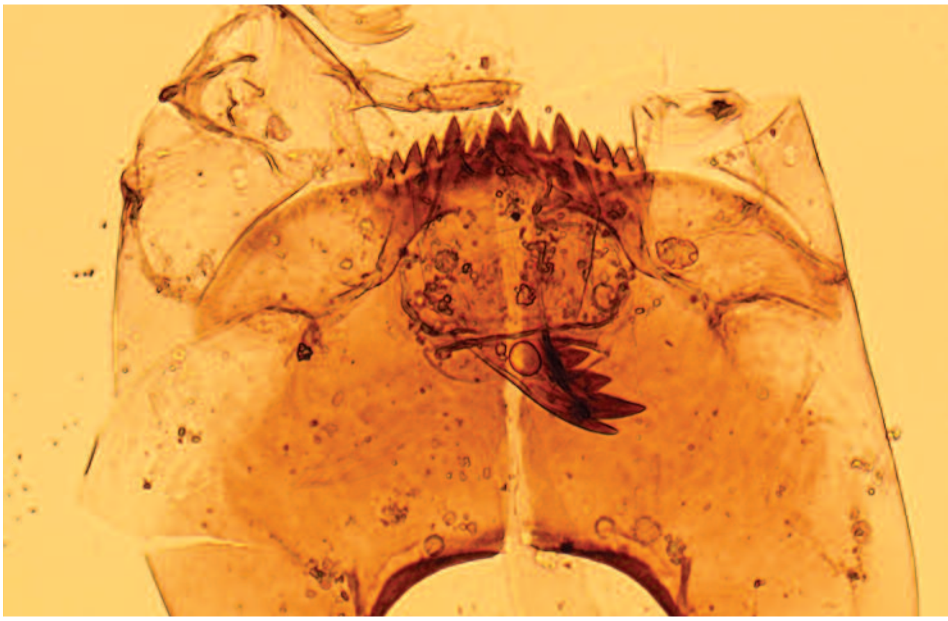


Figure 6
Midges are good "bio-indicators"; the head capsules of their larvae survive well in lake sediments and peat. Polypedilum nubeculosum-type head capsules (figured) are indicators of temperate climatic conditions and can occur in the littoral of eutrophic lakes. Image from Brooks et al, courtesy of Pete Langdon.

The interpretation of results from these analyses can be further enhanced through

- regional/local syntheses of environmental data which highlight current understanding and existing research themes,
- better access to national and regional reference collections and/or digital resources [4b],
- forging better links with Quaternary science communities.

Understanding soils and deposits

Despite the fact that almost all excavated archaeological sites are contained in a soil matrix and understanding soil formation and modification can aid on-site interpretation, the integration of geoarchaeology into excavation projects is not routine, and as a subject, it is certainly not taught in all UK archaeological departments. To improve this situation there needs to be

- better planning of geoarchaeology in archaeological projects [5a], as currently it is
  - undertaken on a fairly ad hoc and opportunistic basis,
  - integrated too late in the process of excavation to be of greatest value.
- more effective use of geochemical analysis (e.g. multi-element geochemical survey and the study of amorphous organic materials/residues) in soils [5a]. These can
  - enhance understanding of activity areas on sites and in structures,
  - have further applications for site prospection in some circumstances.

Stable isotopes

The analysis of carbon and nitrogen stable isotopes from human bones has been undertaken within many university-based research projects and there is further potential for its application within developer funded archaeological work [5a].

Improvements to understanding and interpretation of these data could be made by

- collating existing carbon and nitrogen stable isotope data (both from direct analysis and also as a 'by-product' from radiocarbon dating) which could highlight spatial and temporal variations and in turn could provide better understanding of the variability of isotope data [4a],
- combining isotopic data with information from the analysis of plants and animal remains to gain a better understanding of the different plant and animal components of past diets [4a],
- analysis of stable isotopes at the level of single amino acids to look in more detail at variability in current bulk collagen-based data [4a].

The analysis of strontium and oxygen stable isotopes (to study population movement) is less common, due to

- the complexity of local variation of geological isotopes,
- higher analytical costs (about ten times more expensive than for carbon or nitrogen).

Areas for potential development include

- mining of existing data sources such as the those held by the British Geological Survey (BGS) to enhance understanding of local isotopic variation [4a],
- further work to explore the potential of hydrogen and sulphur isotopes [4a],
- additional isotopic analysis of plants and animals (e.g. enhanced nitrogen levels in plants indicating manuring practices, use of stable isotopes to look at the movements of animals over different seasons) [4a],
- assessment of the effects of diet, as determined by isotope data, on radiocarbon dating of human bone [4a].

Lipids

Residues (i.e. lipids) in pottery from animal fatty acids and plant leaf waxes can demonstrate what has been cooked in a pot, not just for immediate consumption, but, for example, the use of pots for processing foodstuffs such as milk-based products.

Further application of this technique would be enhanced by

- redressing the current bias towards the analysis of domestic pottery; there is a need to look also at pots from funerary contexts which might, for example, indicate whether cremation vessels were previously used in other contexts [5a],
- identification by ceramic specialists of the types of questions about vessel use that need to be addressed [5a],
- improvement of predictive capacity to identify which pots might contain residues (roughly a third do), which would reduce the number of destructive samples taken that do not yield results [4a].

Methodological developments include

- analysis of triacylglycerols (rather than fatty acids) to identify animal species consumed [4a],
- further work on lipids in bone as indicators of past diet – cholesterol and fatty acids in bone are indicative of the whole diet rather than just the proteins (which are studied in the analysis of carbon and nitrogen stable isotopes from collagen) [4a],
- more experimental work to look at what influences lipid deposition and survival in pottery and other vessel types [4a].

DNA and protein

Modern DNA and protein research is rapidly evolving, driven by analytical developments notably in high throughput sequencing and bioinformatics. Major accomplishments (such as sequencing the human genome) can now be completed for a fraction of the time and cost and consequently research on humans, domesticates and pathogens is now focusing beyond the organism to the level of populations and individuals.

The application of these techniques to archaeological questions is still very much an emerging field.

- Currently, one of the most significant issues affecting ancient DNA research of human remains is the presence of contamination; how is it possible to discriminate between DNA of the remains and anyone who has subsequently handled this individual?
  - More research is needed to find ways to minimise contamination (see overleaf), selectively remove it and/or to discriminate between contaminating and ancient DNA [4a].

- On sites where it is known in advance that human remains are likely to be found, methods to minimise DNA contamination on-site and provision for optimal long-term storage, would both increase the value of the remains for future research [5a].
  - Although genomic developments are increasing our knowledge of a wide range of genetic markers (associated with population history, health or appearance), their application to archaeological material has yet to become widespread.
  - There is potential for this to happen fairly rapidly, due to the increasingly fine-grained genetic data from humans, domesticates and pathogens, coupled with advances in DNA capture and the falling cost of sequencing. Nevertheless until this is demonstrably successful, it will be hard to make the case for pre-emptive DNA sampling of skeletal material on most UK sites.
- A small number of research projects have also begun to look at the application of high-throughput proteomics technologies to archaeological research, in particular to the identification of samples and detection of metabolic disease. As with high-throughput sequencing, the potential of such approaches cannot be properly judged in the absence of large-scale demonstration projects [4a].

3.4 Understanding materials – usage of techniques

There is quite a lot of similarity of issues between materials analysis in archaeology and in museums and galleries. Other points which may also be relevant to this archaeological sub-sector are made later in section 4.5.

The UK has a rich research history into production methods and use of archaeological artefacts. This includes analysis of metal artefacts and metal processing waste, as well as petrographic and chemical techniques to characterise archaeological ceramics and glass. However, it is the case that

- there is a marked contrast between the regular use of scientific analysis in environmental archaeology and the much lower levels of analysis of other archaeological materials,
- the study of artefacts is often stylistic and typological (and by association chronological), rather than focused on elemental characterisation and manufacturing processes,
- although some chemical analysis may take place during conservation (investigative conservation) this is the exception rather than typical practice.

Figure 7
SEM examination and EDS analysis of copper alloy slag from a 17th-century context in Colchester. The analysis showed that the alloy used was of the sort used in the manufacture of cauldrons (not bells). © English Heritage.

3.4.1 Understanding materials – areas for improvement

Increasing analysis

Within the context described immediately above, there is less benefit in identifying in detail areas where specific improvements are needed (as in the last sections). Instead we have highlighted those areas where further growth is needed to improve take-up of materials analysis. In particular

- more emphasis needs to be placed on scientific analysis of archaeological objects, pottery, metals and glass in relation to composition, style, date, distribution etc. [5a],
- materials analysis should be seen as being as integral to site interpretation as environmental archaeology has become. For example this compositional analysis can contribute to the social and economic interpretations of the site and help to identify and explain
  - stylistic changes,
  - patterns in alloy use that are not accidental,
  - trade and distribution networks, such as Roman glass, which is all made in the Mediterranean and shipped for local manufacture of objects in individual provinces.
- there needs to be better integration of the study of production technology from excavations (i.e. metal working) with analytical investigation of metal objects from these sites [5a],
- an increase is needed in the scientific study of organic materials in general – whether at macro, micro or molecular level [5a].

The interpretation of materials analysis could be improved by

- additional compositional studies of existing material to provide more baseline information for comparison, including organic materials [4a],
- further analysis of previously well characterised collections using new techniques as new questions based on new knowledge have developed since previous studies were undertaken [4a],
- more collaboration with holders of geological data (such as the BGS) to provide comparative data for geochemical and elemental analysis of ceramic and lithic materials [4a].

Techniques / equipment

- There is an increasing trend towards non- or minimally-intrusive sampling (particularly of material in museum collections) which has implications for the type of analysis that can be carried out, although an increasing range of tools are becoming portable and non-destructive [4a].
  - So far, much of that work has focused on inorganic material. Further development is needed of non-destructive testing methods for the study of organic materials, and portable methods to produce molecular level information that is currently only possible in laboratories [4a].
  - Currently though, non destructive methods cannot provide all of the facilities and detail that are provided by conventional laboratory equipment. The need for this equipment and for limited and well justified destructive samples is still present and should not be sidelined.
- The development of digital x-rays removes the need for chemical processing, which will potentially speed up processing time and ultimately reduce costs. Additional benefits include easier and more effective digital image manipulation and, for some models, portability [4a].
  - However, any change should be accompanied by appropriate consideration of long-term archiving of digital x-rays [6b].

- Although most equipment developments are towards miniaturisation, portability and multi-interface, large scale resources like synchrotron and reactor facilities are powerful analytical tools which can be used to look at materials at an increasingly detailed level without sampling. Neutron diffraction for example can look through objects, measuring corrosion products and original metals to provide information on mineral and metal phase compositions, and to understand crystal structures or deformations which help with interpreting original production methods [4b].

3.5 Detecting and imaging – usage of techniques

As site location is a critical element of archaeological practice relevant survey techniques are often routinely applied.

- Throughout the UK geophysical survey is well recognised and frequently used in advance of development and research programmes.
- Geophysical survey offshore provides one of the main techniques of site prospection and so is commonly employed.
- By contrast, the use of airborne lidar and multispectral imaging is still in its infancy in terms of widespread application, although people are gradually becoming aware of the available techniques.
- The archaeological use of geotechnical data (collected for engineering purposes) is also becoming more common although more cooperation could take place between geotechnical and archaeological staff to improve quality of collected data.
- Due to much higher mobilisation costs for offshore geotechnical samples increased communication and shared resources between different marine data users are already in place.

Ground based laser scanning has been used recently to record rock art in north east England, but its potential for other on site archaeological applications has been largely untested.

- It could be more widely used as a tool during excavation for accurately recording and imaging fragile material before it is removed from site (i.e. textiles, wood with tool marks) [5a].

Figure 8
Towed magnetometer array consisting of two SQUID gradiometers with integral GPS system. Photo courtesy of Neil Linford. © English Heritage.

3.5.1 Detecting and imaging – areas for improvement

Onshore / terrestrial geophysics

There are certain parts of the country where underlying geology can make interpretation of geophysical data more difficult. This has led to the abandonment of the use of geophysics for site prospection in these areas due to misconceptions.

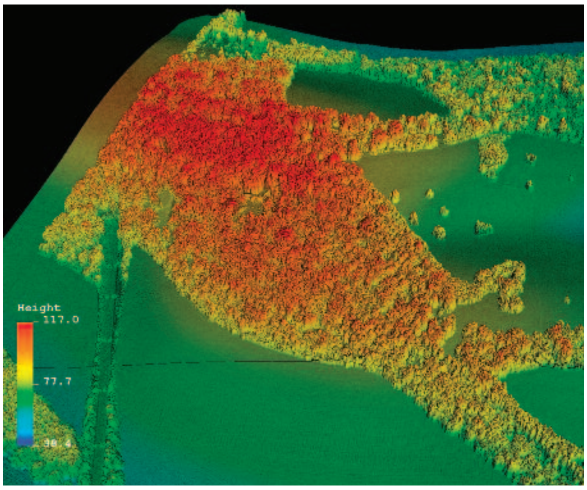
- Further research is needed to understand how these geological variables affect the results and to improve the consistency of survey techniques [4a].
- Guidance and advice to help combat these misconceptions and identify ways to improve reliability would also be beneficial [5a].

Recent developments and improvements to instruments and acquisition techniques have significantly enhanced the speed and resolution of surveys [5a]. These include

- the use of caesium magnetometers which can improve detection rates of deeply buried and/or weakly magnetised features,
- the introduction of cart / sledge systems for magnetic and electromagnetic surveys enables
  - larger areas to be covered more quickly and at higher resolution – landscape-wide geophysical surveys can be carried out on a much shorter timescale,
  - more than one geophysical technique to be used at the same time with the use of multi-sensor arrays,
  - GPS can provide precise real-time location of geophysical data, as well as topographic data.
- similar developments to speed up data collection for electrical techniques such as earth resistance are also being realised but need further development [4a],
- more widespread application of integrated methodologies.

Offshore geophysics

- Geophysical survey (using acoustic and magnetic survey methods) is routinely applied and the greatest benefits come from the deployment of a range of techniques in combination (rather than the use of any single technique) and analysis in combination with coring and grab sample information.
- Marine geophysics is mainly carried out by non-archaeological contractors; the information is used by a wide range of other industries.
- As data collection is expensive, there is a lot of data sharing at an individual project level and there is a government backed drive to increase digital data archiving in 'data archive centres' [6b].
- Data archiving and sharing is more advanced than in terrestrial geophysics, mainly due to the collection cost – collect once, use often [6b].
- Although there is some archaeological development of specific tools (such as 3D Chirp – a surface-towed sub-bottom profiling system), most technical development involves testing new commercial products on the market in known situations to compare and contrast their usefulness for archaeological application.
  - One area for further development is the identification of acoustic signatures of archaeological materials [4a].



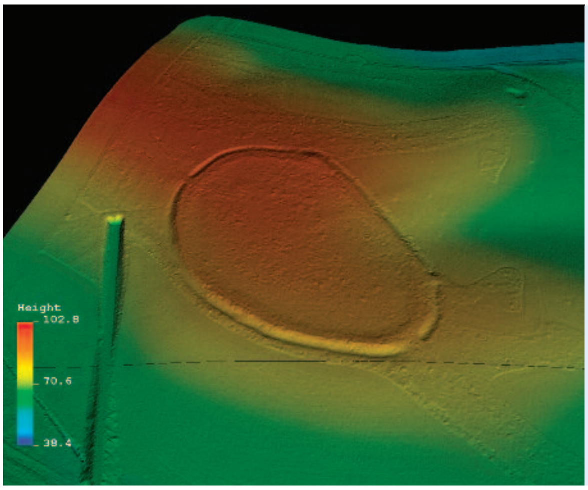


Figure 9a *Left*
Figure 9b *Right*
Lasers from the plane contact the leaves, branches, trunks and finally the ground and are reflected back to the receiver in the plane (Figure 9a). The 'last pulse' return has travelled the furthest distance, i.e. that reached the ground. These data are processed to produce images of landscapes and otherwise hidden earthworks (Figure 9b). Image shows an Iron Age Univallate Hillfort of Ring Hill within the grounds of Audley Park, Essex. Lidar flown by Infoterra on April 5th 2009. © English Heritage

Airborne remote sensing – lidar

Currently, lidar is used in the UK to create highly resolved digital terrain models (DTMs), including those from which the effects of the tree canopy can be removed to reveal earthworks. These data have also been applied to the identification of palaeochannels in river valleys. Although lidar is becoming more commonly applied it is nonetheless much underused.
For example

- more could be made of existing lidar data, to identify archaeological sites in pasture [5a].
  - These are sites that would rarely show up on aerial photographs except in very oblique light.
  - This would increase numbers of sites in local authority Historic Environment Records and provide a wider landscape context for these sites.
- lidar survey also provides accurate three dimensional models, essentially mapping the location of any features surveyed which can then be exported into any GIS package [5a],
- these 3D surface models could be used to monitor long-term change (for example earthwork erosion) through repeat flights.

Other areas where there is further scope for lidar include

- additional work to investigate the potential of the intensity data (signal amplitude) to look at crop mark changes outside of the range of the visible spectrum in similar ways to multi-/hyperspectral surveys [4a],
- exploration of the potential of full waveform lidar which produces data at a higher resolution – most lidar systems in the UK are discrete digital return lidar [4a].

Airborne remote sensing – multi-/hyperspectral survey

Multi- and hyperspectral remote sensing techniques have a large potential for use in archaeological prospection but are underutilised.

- Because these techniques operate across spectral bands from the visible to short wave infrared these tools can reveal changes to vegetation caused by buried archaeology that are not always picked up by conventional aerial photography, as changes in crop growth may be seen more clearly outside of the visible spectrum.
- Much of the development work has already been undertaken and the greatest area for improvement is thus its application to a wider range of landscapes and sites [5a].

4 Built historic environment

4.1 Situations in which scientific techniques are used

There is less scientific analysis of the built historic environment in terms of understanding the past as compared with archaeology. The investigation of building history has to a considerable extent remained a largely visual, scholarly activity based on cultural factors, documentary research and the analysis of comparative examples from publication.

Scientific analysis of buildings and structures is not commonplace.

- The relative cost of scientific analysis and the general lack of knowledge about what techniques are available and what benefits they would bring often reduces demand.
- Scientific techniques are more frequently used on larger projects, particularly those backed by or involving government agencies (such as Historic Scotland or English Heritage) or bodies such as the National Trust.
- Buildings / architectural history is mainly an 'art history' subject and very few buildings historians are regularly pursuing research using scientific techniques, or perhaps more specifically working on the development of scientific methods.
  - Scientific information derived from interventions that would inform understanding of the building, its builders and occupants is not often used this way.
  - More collaborative and interdisciplinary studies could help to break down these cultural divides.
  - There are for example tensions over who interprets scientific data; those from an arts/humanities background feel that analysts are not sufficiently familiar with historical and documentary sources to be able to draw reliable conclusions.
- Areas covered in this chapter include dating, survey techniques and materials analysis. Issues associated with climate change, energy efficiency and sustainability were covered in NHSS report 1 and will not be discussed further here.

Drivers for the use of scientific techniques include

- assessment of the cultural significance of buildings, and the relative cultural values of specific parts and components,
- conservation/preservation of buildings (see NHSS report 1),
- academic study, for books, articles etc, looking at how buildings developed over time, planning of the buildings, was it innovative, how was it used or modified,
- visitor engagement (e.g. display enhancements) in historic houses,
- for scientists, heritage buildings provide a high-profile and interesting series of subjects upon which to test new techniques, including non destructive techniques to locate voids and areas of damp.

Most analysis is prompted by conservation / redevelopment and although NHSS report 1 was concerned with building conservation, it is included here too because the conservation of a structure is the 'buildings' equivalent of developer-funded archaeology. More critically, where changes to building fabric are proposed, for example replacing roofing timbers or altering the internal configuration of rooms, information is needed about how significant particular elements are and whether they should be retained or can be replaced. Techniques such as dendrochronology or historic interiors research, can play a crucial role in making these decisions.

It is also clear that for much buildings research, scientific contributions often bridge the gap between understanding the history and aiding conservation.

4.2 Chronology – usage of techniques

The main scientific technique used to date buildings is dendrochronology which is well recognised with a fairly widespread application in the UK, particularly in England and Wales.

- It is used
  - to confirm the date of structural elements (often to corroborate documentary evidence, but also to provide a date where no documentary evidence exists),
  - to understand complex construction and modification histories,
  - to inform conservation and repair decisions,
  - occasionally when owners just want to know more about the date of their buildings.
- A small range of other scientific dating techniques that can be applied to buildings include luminescence dating of bricks (initially using TL dating but recently focused on OSL), C14 dating of mortars and potentially in the future, rehydroxylation dating.
- None of these techniques is used widely for building dating, and some need further assessment; most however do not provide the precision required by those studying buildings.
- Historic interiors research also provides information which helps establish chronology and is dealt with fully in section 4.4.1.

4.2.1 Chronology – areas for improvement

Dendrochronology

- Most dendrochronology in the UK is carried out on oak. This is the main structural timber used until the 18th Century when imported Baltic and North American softwoods begin to predominate.
- There is not so much dated UK reference material for softwoods, so dendrochronological dating of post 18th century buildings is often less successful.
  - An on-going opportunistic programme of sampling of softwoods has been taking place which has helped to improve assessment and understanding.
  - A more structured and targeted approach could further enhance softwood dating in the UK, integrating the assessment of building timbers with documentary evidence such as port records [4a].
- Dendrochronology sometimes cannot produce dates when samples cannot be cross-matched with a dated reference chronology or when there are insufficient rings (at least 50 are normally needed to provide a reliable date). Current research is looking at the application of Bayesian methods to identify whether there are ways to improve dating success with fewer rings whilst still maintaining reliability [4a].
- The success rate for dating varies across the UK. In Scotland, parts of south west England and in East Anglia fewer buildings are dated successfully, in part due to a lack of suitable local reference material. Additional targeted work in these areas is needed to develop a more comprehensive local picture that can be compared with national data sets [4a].
- There are also some areas of the country where non-oak hardwoods are used in vernacular building construction (such as elm and ash) and further work on the potential of dendrochronology for these species is still needed [4a].

Other techniques

- Research projects have demonstrated that OSL and rehydroxylation dating can provide dates on known age bricks and mortars and the next stage is to test them on a wider range of domestic buildings to demonstrate their benefits in action [4a].
- Dating bricks themselves only dates the manufacture, not the placement of the bricks. Work in progress on OSL dating of mortars may provide an additional method (to C14 dating) to date construction activity, particularly for those later periods when C14 dating is not applicable [4a].

Figure 10
Luminescence dating of known age buildings, such as Tattershall Castle, Lincolnshire (shown here), to assist in the development of this technique. The independent date range for the sampled part of the building was AD1445-1450, luminescence dates were 1455 ± 33 and 1455 ± 34. Image and data courtesy of Ian Bailiff.

4.3 People and the environment

Within this report this is predominantly a topic which relates to archaeological material and movable biological remains. Further information, beyond these physical remains (i.e. human skeletal and environmental material) can be gained from the scientific examination of buildings and structures.

- Modelling of indoor and external environments can be used as a tool for investigating the health of individuals within indoor environments.
  - For example the exposure of individuals to smoke indoors and the impact on health.
- Analysis of organic building materials such as timber and thatch can provide data about climate and the environment.
  - The analysis of late medieval smoke-blackened thatch provides a unique insight into local agricultural history and botany.

4.4 Understanding materials – usage of techniques

The main areas for material research in buildings are

- historic interiors research.
  - This includes establishing the chronology of rooms, understanding how they have been structurally altered (using documentary evidence and preliminary on-site investigation) and the removal of any paint samples for cross-section analysis.
  - Marker materials help date paint layers and identification of pigments which may have faded or darkened helps us to assess the original appearance of specific decorations.
- analysis of building stone to identify the source of material or of concrete to understand components,
- characterisation of historic mortars through particle size analysis of aggregate which reveals information about date, source and technology of these mortars (as well as informing repair decisions),
- metallurgical analysis for example to differentiate between wrought iron and steel in early steel framed buildings and also impart information on material strength/stability and identify the cause of past structural failures.

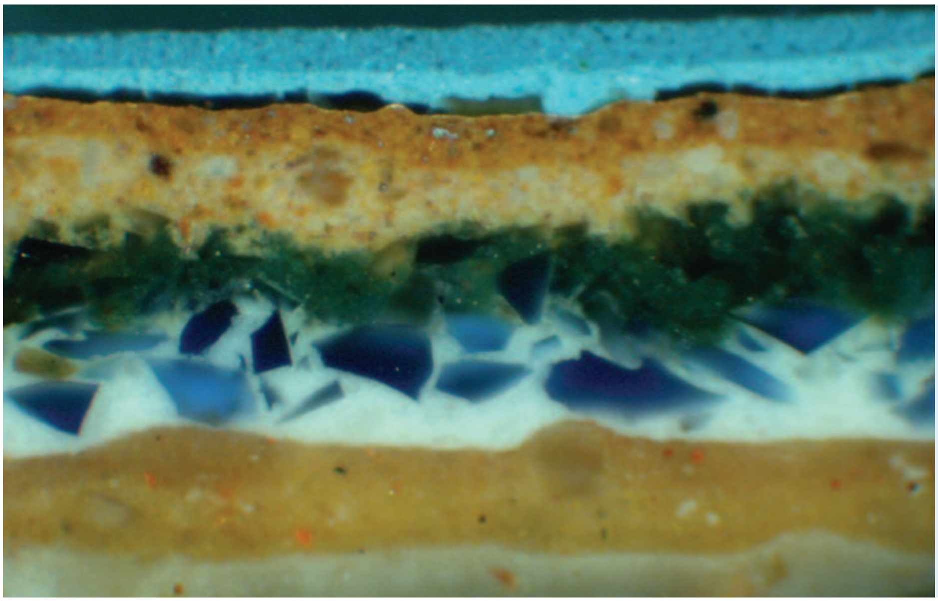


Figure 11
A cross-section of a paint sample taken from the frieze of the Star Chamber, Bolsover Castle. Image courtesy of Helen Hughes. © English Heritage.

4.4.1 Understanding materials – areas for improvement

Overall, the use of scientific techniques of materials analysis in the built historic environment is low.

- Mortar and stone analysis provide data to ensure appropriate materials are used where damaged fabric needs to be replaced.
  - Previous mis-matches between "breathable" lime mortars and water-tight cements have led to damage of building fabric. This has led to an understanding that new mortars should match as closely as possible the properties of previous mortars.
  - There is an increasing recognition of the need for more detailed analysis of mortars in particular, to ensure that new mortar matches both colour and physical properties of existing mortar [5a].
- Architectural paint research is a widely recognised technique within the study of historic interiors and is often applied on major conservation and historic house enhancement projects as part of a suite of other, mainly non-scientific investigative techniques to understand how the house developed and how its interior spaces were decorated and used.
  - Although the value of historic interiors research for determining the original colour scheme for interior walls is well understood, the greater benefits of historic interiors research as a comparative dating tool for different parts of any buildings is often overlooked [5a].
  - Most paint analysis is carried out using microscopic examination of transverse sections of paint samples mounted in resin. SEM and chemical analysis can also be undertaken.
  - There is limited application of advanced analytical techniques, particularly as existing microscopic techniques yield sufficient information for most studies.

In part, one of the greatest needs must be to increase awareness of material science elements in building analysis, through the provision of guidelines, case studies and training. Better collaboration between scientific analysts, surveyors and building historians is needed to maximise the benefit of the data that results from scientific investigation of materials in terms of interpreting the building's history and use.

4.5 Detecting and imaging – usage of techniques

An accurate measured survey is an essential tool for understanding historic buildings and structures, particularly in the context of any redevelopment or conservation planning and subsequent interventions.

- Measured surveys can be produced using photogrammetry, reflector-less EDM survey or from laser scans.
- Although most technical developments and most of the discussion below focus on laser scanning, it is certainly not the most common technique used to produce measured surveys.
- Reasons for this are higher costs of laser survey and that requirements for drawings and archives are for 2D not 3D data, so once collected, 3D point clouds still need to be turned into a two dimensional drawing, i.e. the measured survey.
- As well as providing data from which to produce a measured survey, laser scanning can be used to measure change over time (e.g. movement, erosion) and other long term monitoring.
- Data can be animated to produce 3D graphic models to enhance visualisation. These models can be used to display original surface treatments i.e. original paint or dye colours to increase interpretation and understanding, or to reconstruct historic buildings.

The other area of use of scientific techniques is in non-destructive imaging.

- Recent developments of radar and infrared / thermal imaging have provided methods for distinguishing contrasting building fabrics e.g.
  - Identifying voids in walls,
  - Blocked doorways,
  - Timber framing under later renders or plaster,
  - Building defects,
  - Identifying the effects of previous building alterations (i.e. blocked chimneys causing alternative water ingress inside buildings).
- These developments can reduce the need for intrusive damaging interventions into the building fabric.
- However, all need to be properly interpreted and the success of these applications in the past has been mixed.
- Use of such techniques is still limited, but as technologies improve and the cost of infrared cameras comes down, their use could increase.

Scientific technology adapted from other sectors such as the use of endoscopes and digital cameras allows for lower-tech investigation behind panelling, within cavities and voids, drains and cable routes to understand building construction without having to remove or damage original material.

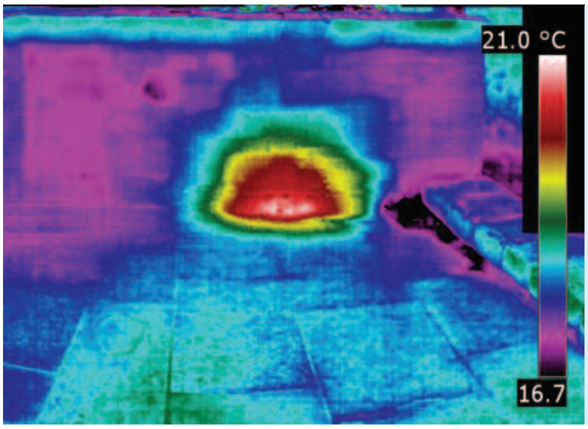


Figure 12a *Left*
Figure 12b *Right*
Heat from a concealed flue in a parapet wall. The flue from the chimney of the kitchens at Stirling Castle has been blocked up and covered, with the area above becoming used as a parapet. However, heat rising from the flue is still visible to thermal imaging. Images by Maureen Young, Historic Scotland.

4.5.1 Detecting and imaging – areas for improvement

GPR and thermal imaging

- The use of ground penetrating radar for building analysis is still fairly developmental.
  - Reductions in equipment size and weight are making it easier to use in a range of situations.
  - Potential has been demonstrated but more development and further testing to characterise better the situations in which positive results will be achieved is needed [4a].
- Similarly, although infrared imaging has seen fairly widespread use to look at heat loss and air movements, particularly in modern buildings, its application to heritage questions can be affected by inappropriate weather or climatic conditions.
  - Whilst low-cost equipment may be able to identify large and obvious hidden features (such as blocked doors or windows), repeat visits and experimentation may be needed to yield more detailed results that can avoid the need for destructive opening up of a wall [4a].

Laser survey

Measured survey can enhance our understanding of the physical structure of buildings and act as a basis for interpreting them to visitors and other users. Laser scanning is likely to become a popular method of data capture for measured survey as costs reduce and as the resolution and speed of scanning increases.

- However, skills are still needed in registration / digitisation of point cloud data into line drawings and in the interpretation of the buildings.
  - Tightly defined specifications and standards for measured surveys help to ensure that appropriate information is captured and included in surveys [5a].

There are a number of areas where further development should take place in the coming years. These include

- more work is needed to determine the value of intensity laser data [4a],
- potential to combine laser scanning with conventional photography and photogrammetry, to link images and measured data,
  - Developments in 3D cameras which capture images with distance measurements will expand further these issues in coming years [4a].
- potential to look at combining of laser scanning and other remote sensing techniques (such as multi- and hyperspectral imaging) to give information about different building materials to aid interpretation or to differentiate between building fabrics to aid automatic digitisation of wall elements [4a],
- most technical developments are driven by other users such as engineering, medical and automotive industries, but areas for development that would improve application to heritage assets include
  - improved scanner performance in daylight [4a],
  - improved accuracy of facade scanning to sub-mm level to enable the technique to fulfil its potential for monitoring fabric damage and loss rates [4a].

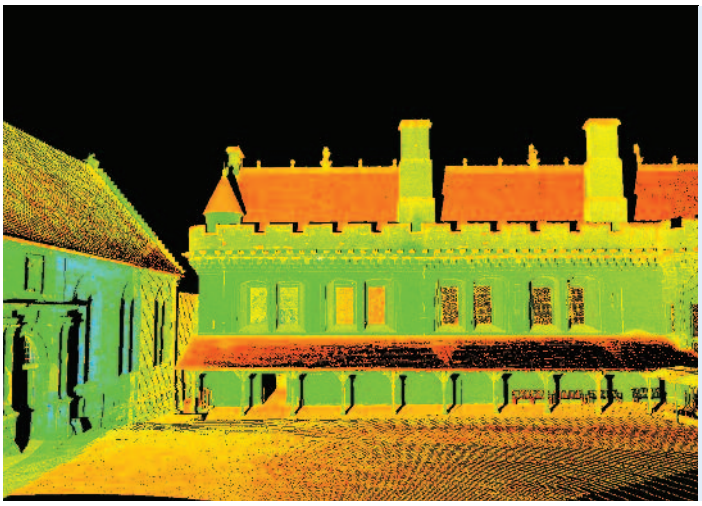


Figure 13
A point cloud representation of the courtyard at Stirling Castle, showing the Great Hall (ahead) and Chapel Royal (left), obtained using a Leica ScanStation 2. The point to point distance is 5 mm. Image: Alan Simpson, Historic Scotland.

5 Museums and galleries

5.1 Situations in which scientific techniques are used

Most scientific analysis takes place in the context of new exhibitions, gallery and store refurbishments, acquisitions, loans or cataloguing (including long-term programmes of technical and artistic study of the collections) and for the detection of fakes. Artworks or objects are removed from storage (or existing exhibitions) and undergo conservation assessment and sometimes treatment (to stabilise and improve condition and appearance).

Figure 14
An Egyptian glass scarab from the British Museum. Compositional analysis of the glass aided comparison with other similar items, dating the object to the Third Intermediate Period. However, the analysis also provided vital information about why the object was degrading, enabling recommendations to be produced for its future storage. © Trustees of the British Museum.

- Analysis at this stage (particularly materials science analysis) informs any conservation intervention and provides additional information and enhanced knowledge about the work of art or object which can be used for public engagement (i.e. display) and interpretation.
  - Although conservation was the focus of NHSS report 1, it is very difficult to separate it out from this report in the context of science in museums and galleries because much of the analytical work that takes place has a dual purpose.
- The detection of fakes and forgeries is an area where science is used to authenticate objects, and this work has proved fascinating to the public both through books written on the subject and through exhibitions such as 'The Art of the Fake, held at the British Museum in 1990.
- Institutions like the British Museum, Tate, the Victoria and Albert Museum, the National Museums in Scotland and Wales and the National Gallery have been at the forefront of the development and application of analytical techniques to investigate works of art and museum objects.
- Analytical techniques have also been developed in universities and university museums which have collections (Courtauld Institute of Art, Hamilton Kerr Institute, Cambridge University etc).
- However, outside these larger institutions scientific analysis by museum staff is virtually non-existent.
- There are a few freelance scientists who provide analytical services for smaller museums and the private sector.
- As well as initiating research, museums and galleries are also the recipients of requests for in-house sampling and analysis on objects within their collections from external researchers and requests for external researchers to carry out their own analysis on the collection.
  - There has been a shift in emphasis from museum-based research by curators, to museums encouraging the use of their collections for research by universities and others.
- This research feeds back to museums and galleries and this enhances knowledge of the collection.
- Increasing digitisation and web availability of museums' catalogues allows external researchers to gain better understanding of the capacity of the collections for research, although this is an area where further work is needed to get more collection details on line.

5.2 Chronology – usage of techniques

Dating of works of art and non-archaeological objects in museums and gallery collections is mainly based on documentary analysis and non-technical art history, such as stylistic influences. Scientific analysis is used to supplement this research.

- The main scientific dating technique is dendrochronology of wood panel paintings and a number of national collections have had many of their paintings examined or are engaged in rolling programmes of analysis.
- The other main method of dating for paintings is the identification of pigments and media in paintings, textile dyes, metal threads and gilding type and then dating by when a material first becomes available or goes out of use.
  - Results are quite broad because diffusion of innovation is not immediate or constant and current research is aiming to understand better these issues through the integration of Bayesian statistical analysis and studies of actual patterns of use within collections.
- Other techniques such as C14 or luminescence are not applicable or do not usually provide any greater precision than existing documentary sources (except where techniques are used to differentiate between originals or fakes where these is likely to be a considerable variation in age – e.g. older ceramics, textiles).
- As highlighted in the introduction section on museums and galleries, most dating (in common with other scientific analysis) is only carried out at larger museums and galleries and then only on very specific cases, usually stimulated by new acquisitions or displays.
- Dating of material in museums collections (particularly for archaeology) is often undertaken as part of wider, collaborative research projects (such as the recent re-dating of the 'red lady' of Paviland). The impetus for these projects does not normally come from the museum but they are the beneficiary of the improved chronological resolution for their objects.
- In this role, museums often provide the 'reference set' of materials with known context or materially-defined dates that can then be used to calibrate other methods.

A limited amount of dating is also carried out to confirm authenticity in the art market, for auction houses and dealers.

- Techniques include dendrochronology, pigment analysis and very rarely luminescence dating of ceramics, but this is fairly low frequency.
- More work on authentication is carried out in the USA where it is driven by due diligence legislation, particularly to ensure that items acquired by the government in lieu of taxation are what they purport to be.

5.2.1 Chronology – areas for improvement

Recommendations for technical advancements in dating techniques are given in section 3.2.1.

5.3 People and the environment – usage of techniques

Research into human remains or environmental materials is not currently, nor has been in the past the focus of much museums-initiated scientific study outside of the large national museums, with the possible exception of analysis of Egyptian mummies.

- As with dating above, museums are often the recipients of requests for sampling of human remains for work such as stable isotopes or DNA, or samples of pottery for residue analysis.
- As many of these techniques entail destructive analyses, museums need policies for sampling which balance the benefits of current and future sampling with the preservation of items in the collection.

Although the conservation of natural history collections was included in the NHSS report 1, their study and interpretation are essentially natural science and not heritage science and are not discussed further here.

5.3.1 People and the environment – areas for improvement

Recommendations for technical advancements in the analysis of human remains, diet and past environments are given in section 3.3.1.

5.4 Understanding materials – usage of techniques

Understanding materials lies at the heart of most heritage science work undertaken at museums and galleries and there are a number of different drivers for analysis, such as new exhibitions, acquisitions, and catalogues / publication.

- Analytical information is used in conservation, to enhance collection records and provide additional material for public display and web page features.
- In some cases the focus of the analytical work is conservation-led, in others learning more about the object or work or art for display or a catalogue is the driver.
- Commonly used techniques are microscopy (including optical, cross-sections, polarising light microscopy, ultraviolet fluorescence microscopy and SEM), X-radiography and instrumental analysis (such as EDX, XRF, FTIR, Raman, GC-MS, LC-MS).
- Most of the research is led by the museums / galleries themselves and there appear to be few external requests for sampling of materials (although this may be because of an awareness in the sector of the limited capacity of museum laboratories to undertake external work). In part this reflects a current lack of emphasis on large, object-focused characterisation projects.
- The British Museum and National Museums Wales also have a legal duty under the Treasure Act and Portable Antiquities Scheme to provide analysis of treasure items (silver / gold / prehistoric base metal hoards).

Figure 15
X-Radiograph of the side image of the Guyer-Anderson cat. The image shows the location of core pins (used during the casting process), a crack in the body and also where a cylindrical object has been inserted in the head. © Trustees of the British Museum.

5.4.1 Understanding materials – areas for improvement

Developing and increasing use of new tools

- In developing new tools for analysis the emphasis is currently on non-destructive techniques and portability (for example FTIR, NIR, UV imaging, Raman, XRF), but other areas include combination multi-instrument systems (e.g. UV, NIR and IR; XRF, XRD, or Raman combined with SEM, NMR and NIR imaging) with simultaneous analysis of the same area and software tools which analyse and compare results to arrive at an answer [4a].
  - There is an increasing awareness that no one technique can offer answers to every situation.
  - There is a desire to reduce handling of objects / works of art for analysis so only using one machine with combined tools will speed up analysis and reduce handling.
- Despite this increasing emphasis on non-destructive / non-intrusive analysis and portability of equipment there are still instances where non destructive techniques are currently not detailed enough (some pigment analysis for example), and more development of these systems is still needed.
  - There are also opportunities to use non-destructive techniques to give a general characterisation of an object or work or art and to help select areas for additional sampling. More demonstration of these approaches is needed to look at ways in which destructive sampling can be reduced [4a].

Improving current activity

For those currently engaged in scientific analysis in or for museums and galleries key issues are

- improved sharing of resources which would allow existing practitioners to access a wider range of tools [4b],
- improved range of, or access to facilities for organic analysis, to identify materials such as resins, binders, gums and original and conservator-applied coatings [4a & b],
- an absence of reference data for materials analysis, particularly for the identification of organic materials (from ethnographic materials specifically).
  - As there are only limited numbers of scientists involved in heritage science research in materials in museums and galleries, greater collaboration and sharing of analytical research results would be beneficial. For example, sharing results from instrumental analysis and information about the objects that have been analysed [6b].
  - FTIR spectra have been shared internationally by heritage scientists for a decade or more, and chromatographic and mass spectrometric data sharing has begun in the last few years; for other techniques this has still to begin.
- the potential for greater use of the internet for archiving of analytical reports [6a]; currently
  - many routine analyses are not published,
  - only internal museum staff know what projects are being undertaken,
  - results are therefore not immediately available to heritage science colleagues,
  - there is therefore little opportunity to learn from the work of other heritage scientists,
  - this will be explored again in NHSS report 3.
- the main difficulty in sharing data lies in the mutually exclusive collecting policies of many UK museums and galleries. None can give time to set up a resource for the wider community, and no UK body exists to do this for the moveable heritage either,
- this issue is not UK-specific: UK/US/EU databases for similar collections would be more appropriate.

Improved interaction between the archaeological science community and the museum science community would help with some of these issues.

Figure 16
Visitors in the Reveal exhibition, at the National Conservation Centre, Liverpool. © National Museums Liverpool.

Enhancing collection research and public engagement

The public is fascinated by science and forensic science, by the detective work involved in analysis of objects to learn more about the materials and the people who made them, and which are fakes or forgeries. People like to see the 'back room' activities that contribute to the generation of knowledge.

- Increasingly, the result of materials analyses in museums and galleries are being made available to a wider audience. These are examples of best practice that could be adopted more widely [6c] –
  - The gallery display on heritage science and 'open lab' with the analytical equipment and staff visible to visitors at the National Conservation Centre, Liverpool, Science Week at the British Museum, and Conservation in Focus activities at some museums.
  - Hands-on activities such as object cleaning offered in conservation-related public programmes at the Manchester Museum.
  - Popular displays at the National Gallery showing the discoveries made by scientific analysis of paintings.
  - Publication of technical bulletins by the British Museum and National Gallery, both of which are, or soon will be, freely available on the internet.
  - Use of museum and gallery web pages to provide additional material relating to existing displays, such as the results of analytical investigation.

As well as providing more information about scientific analysis to the public, museums and galleries could do more to foster collection research by external researchers by identifying outstanding questions or significant collections held, such as highlighting opportunities for analysis for the characterisation of particular materials, such as Iron Age brooches.

- Results of this research would enhance the knowledge of the collection without the need for additional funding [6c].

Increasing access to scientific analysis

There is a big disjuncture in the use of analytical science to enhance collections knowledge between large, national institutions and all of the remaining museums and galleries [6c].

The conservation treatment of paintings and other fine art material in some significant collections is carried out within the private sector, which has little access to analytical science, and only minor access to imaging techniques.

- Other factors that contribute to this imbalance in the use of science are a
  - lack of knowledge or knowledge that is outdated by some years about what questions could be answered with what techniques,
  - lack of funding and staff time,
  - lack of access to facilities for research.

Research funding and staff time for research are not currently priorities in many museums, and this is reflected in the decreasing amount of scientific information going into public displays.

Furthermore, facilities (and, of equal importance, technicians and skilled scientists that can operate them and interpret the results respectively), are located in only a few institutions. Some facilities and expertise are unique to a single UK institution with access of reference materials.

- At present none of the institutions with scientific equipment provides a commercial heritage science 'service' to external clients, i.e. other museums, although there are a few private sector contractors, particularly material scientists, providing analytical investigations of museum objects [4b].

Issues about access to equipment and resource sharing will be addressed in more detail in NHSS report 3.

5.5 Detecting and imaging – usage of techniques

- The use of x-radiography, UV and infrared light is well developed in the analysis of paintings and drawings, etc (technical art history) and the increasing availability and reduced costs of infrared imaging equipment should increase the potential for its further use, along with multi-spectral imaging.
- The other main area of detecting / imaging in museums and galleries is close range 3D laser scanning which can be used to
  - record an object to produce an accurate (+/- 0.1mm) 3D digital model which can be can be rotated and viewed from multiple directions (unlike 2D images),
  - monitor condition of objects,
  - share digital models / data with researchers worldwide – this reduces travel for people and objects,
  - increases public access and awareness.

Figure 17
Close range laser scanning of a Classical marble statue (of Athena). Photo courtesy Conservation Technologies (National Museums Liverpool). © Martin Birchall Photography.

- All these imaging techniques are available through small private companies in the UK, in contrast to the majority of analytical techniques which are not.
- Scanning of material from dispersed collections can enable digital reunification of objects to enhance study.
- Computer models can be used to digitally recreate past appearance, i.e. colour and digital images can be used for virtual display if the original is not available.
- Data from scanning can be used to create physical models through computer controlled machining (say of a marble statue) or through 3D printing.
  - This can allow handling.
  - This helps to create replicas where the original is too fragile to take a physical mould from.
  - Scans and x-radiographs may be the only record of some archaeological objects if they are too fragile to be separated from the soil that surrounds them or they are totally corroded.

5.5.1 Detecting and imaging – areas for improvement

- There is significant potential in the coming years to explore further multispectral and hyperspectral imaging techniques for investigating paintings and other works of art, drawing on existing research experience in other countries and other fields of study in the UK [5a].
- There may be restrictions on moving some objects to analytical facilities because of security, high insurance values and environmental control needs for some fine art objects. There is less of a restriction for archaeological objects.
- The current level of use of close-range laser scanning is not high, because it is seen as an expensive tool and too specialised for most museums to start developing their own expertise.
  - However, the potential for increasing access to objects, providing replicas for handling and improving visualisation is high [5a].
- There are also data archiving issues; scan data and outputs do not have an analogue format and therefore preservation of these digital data is essential, especially if they are to be used in future monitoring studies.
  - Currently there is no centralised repository for museum and gallery digital data; no one currently has an overview of, or responsibility for curation and migration to avoid obsolescence of these data [6a].
  - Furthermore, there is no common format for data, which makes sharing of data between institutions more difficult [6a].

6 Libraries / archives

This section is short, reflecting the current state of use of scientific analysis for libraries and archives. However, where books and archives are used as museum objects, rather than sources of information, then they can be considered within the previous section on museums and galleries, and a similar set of scientific resources may be used for their study, as outlined below. For example, sources of paper, pigments in manuscripts, and types of parchment are analysed to answer questions about date and provenance.

6.1 Situations in which scientific techniques are used

The use of scientific analysis to aid understanding and interpretation of library and archive material is limited, as most research in this sub-sector has been based on the meaning of the text of the documents rather than on the books or manuscripts themselves. One of the few areas where materials are studied is the examination of paper and watermarks to illuminate sources of supplies and printing workshop practice and to authenticate documents.

- Factors that have intensified the lack of scientific analysis are
  - the scale of collections and of operation of many libraries and archives,
  - the primary emphasis on access and usage which means that many libraries and archives have no or very few staff engaged in conservation or preservation, let alone research. This situation is particularly acute in local authority organisations,
  - that most material, particularly the most significant collections, is not permitted to leave the library or archive,
  - that until recently, analytical equipment was not portable enough to take to the material and the taking of destructive samples was not generally permitted.
- However, portable non-destructive equipment developments have increased the potential for analysis to take place and the development of multi-instrument tools with the ability to take different measurements at the same time will allow rapid studies of large numbers of books / manuscripts to take place as a routine practice [4a].

Figure 18a ,18b & 18c *Left to right*
(a) Syriac manuscript overwritten on Greek; (b) Multi-spectral imaging enhances original text; (c) Image analysis to improve the legibility of the Greek text. Images of a British Library manuscript taken using the MuSIS multi-spectral imaging system. Image courtesy of FORTH Photonics, Athens.

Recent scientific investigations of paper, books and manuscripts have included

- infrared and multispectral imaging to study palimpsests – where parchments have been used, scraped clean then used again – to look at the previous text,
- near infrared spectroscopy for the non-destructive determination of the composition (and condition) of paper,
- forensic analysis of inks, watermarks and paper fibres to look at developments in writing and printing technology,
- Raman spectroscopy for the non-destructive identification of pigments on illuminated manuscripts,
- analytical studies of the animal species from which the parchments or leather binding has been produced.
  - There is potential to use newly emerging proteomics techniques for the identification of parchment and leather [4a].
  - As many documents are of a known date and location, these themselves provide a large genetic database for study by other disciplines.

These types of investigations are currently few and far between, only carried out on the most significant items in library and archive collections (such as Domesday Book, Gutenberg Bible) and usually only as part of a specific display / public engagement project. Examples include

- x-ray diffraction and amino acid analysis of Domesday Book to understand more of the making and meaning of this manuscript as well as to determine its current condition,
- particle-induced x-ray emission (PIXE) used to study the composition of Dürer's metal-point drawings on paper and to put manuscripts by Galileo in chronological order, based on the composition of the ink,
- Raman laser spectroscopy of the Lindisfarne Gospels which has enabled correct identification of the pigments and has illuminated trading routes that were otherwise unknown.

The other area where technological developments are used in the library and archives sub-sector is in the digitisation of books, documents and audio material and their dissemination on the internet and digital displays / listening posts inside libraries and archives [6b & c].

- This allows greater public access to otherwise fragile or inaccessible material (e.g. 'Turning the Page') and can significantly aid the international study of documents in particular through the digital reunification of dispersed collections. Significant examples are
  - the Codex Sinaiticus, the world's earliest New Testament (reunified virtually 6 July 2009) and the International Dunhuang Project,
  - the digitisation of 26,000 volumes of the 1911 census, now available on-line through the National Archives website.

The majority of recent scientific work in the libraries and archives sector though has been directed towards better understanding of degradation (i.e. subjects covered in NHSS report 1), including

- long-term studies to monitor changes in materials and collections in real-time,
- accelerated ageing tests are used to test materials used in conservation (such as adhesives) and those used in exhibition and building construction,
- characterisation and condition studies of paper.

7 Areas of commonality

The ways different scientific disciplines are currently used to help us understand more about the past has been summarised for each of the sub-sectors of heritage science in the last four chapters.

As these chapters clearly demonstrate, there is a real diversity in the amount of scientific work undertaken between each of the sub-sectors. This has to some extent been created by the split of heritage science activity into the two NHSS reports as much scientific input into issues of collection care, monitoring, condition assessment and treatment within the movable and built historic environment sub-sectors in particular is covered in NHSS report 1.

Other contributing factors to this imbalance include

- very different drivers for why investigative and thus analytical work is carried out,
- different sources of funding for work,
- differences in balance between where scientific services are provided – in house or brought in from external contractors,
- different levels of 'market' involvement in the provision of services,
- differences in the size of workforce and level of academic input (which is much greater in the archaeological sub-sector) – issues which are discussed more fully in report 3.

There are many detailed ideas contained within each chapter which relate solely to that topic. By highlighting these issues in this report we are signalling our views that these are issues that are being, and that need to be tackled at these sub-sector and topic specific levels. Identifying them here provides heritage managers, museums directors, professional institutes and funding bodies with a short overview of what we believe are the areas where improvements to methods, further applications of existing and new technologies and increased funding are needed.

There are however a number of generic themes that come out of these previous sections, as well as from individual discussions, which highlight areas of particular significance which are common to all heritage science sub-sectors, many of which will be followed up in more detailed in the NHSS report 3. These are listed below, continuing the theme numbering from NHSS report 1. The themes link to the previous chapters by the topic references i.e. [4b] included within the text. The themes are

Theme 4 – Development of tools and access to equipment

Theme 5 – Raising awareness of existing techniques and their application

Theme 6 – Data use and management

Figure 19
Portable XRF analysis of an Egyptian cartonnage for display at Brighton Museum. Image courtesy of Dana Goodburn-Brown.

7.1 Theme 4 – Development of tools and access to equipment

New and improved tools – Topic 4a

One of the recurring themes of both this and the first NHSS report was the need to develop new tools and to continue to improve existing tools.

- Improvements should bring improved precision, speed, resolution and increased area of coverage.
- For materials analysis in particular the need is for portable, non intrusive / non destructive equipment, increasingly recognising the benefits of multi-instrument capacity.
  - This allows machines to travel to materials, which is beneficial when studying collections where destructive sampling is not always possible and removal of material is either discouraged or complicated by issues of insurance, physical security and the need for environmental control.

Accessing fixed equipment – Topic 4b

Some techniques are not yet suitable for development of portable equipment, and some existing portable tools do not have the resolution or precision of larger, fixed equipment.

- These larger machines are expensive to purchase and operate and only exist in a small number of locations.
  - They are key for getting molecular-level information which portable and non-destructive techniques cannot yet provide.
- Improved arrangements for access by external users and perhaps new ways of sharing of resources, (including formal partnerships to split the costs of buying and running new equipment) may
  - aid existing researchers by increasing the range of techniques that are readily available to them,
  - help heritage science centres to make better use of existing facilities.

7.2 Theme 5 – Raising awareness of existing techniques and their application

Guidance and advice – Topic 5a

One of the most frequently encountered issues across all of the sectors and subject areas was that more analysis could be undertaken if people had a greater awareness of the potential of any given technique and the types of questions that it could answer through its use. Many practitioners consulted in the development of this report pointed to the need for guidance, advice and training to raise awareness of what is possible. This guidance needs to be targeted towards the decision makers as well as the practitioners.

There is a substantial need for additional guidance to enhance people's knowledge about specific techniques.

- This can take many forms from basic, non technical awareness raising and signposting to further information, to more specific guidelines, standards and specifications which help to define procedures and aim to improve practice.
- English Heritage has developed a good range of free guidance documents in archaeological science and the conservation and recording of historic buildings.
  - Other heritage bodies, professional institutes, and special interest groups have also produced guidance on these and other subjects.
- Similar free guidance and more simple awareness raising leaflets are needed for other sectors and across the whole of the UK.

Written guidance also needs to be backed up by readily available, impartial, authoritative advice.

- Although many heritage scientists give freely of their time, there are very few people employed specifically to advise on heritage science issues and suitable courses of action.
  - The English Heritage Regional Science Advisors and archaeological science staff are a notable exception.

Finally, to back up guidance and advice, training of potential users of heritage science is also a valuable way to raise awareness and increase standards.

Alongside guidance there is a need for the continued use and development of research agenda (such as existing regional or period-based archaeological research agenda). These provide an essential means of directing research activity, including heritage science work, to address relevant questions within a clear framework. Updating these agenda in the light of new evidence ensures research activity remains current and up to date.

Figure 20
Some of the grey literature reports held in the Lincolnshire Historic Environment Record. Photo courtesy of Lincolnshire County Council, Historic Environment Record.

7.3 Theme 6 – Data use and management

Reports – Topic 6a

The results of most academic heritage science research are published in peer-reviewed journal articles, conference reports or books, which are held by libraries and therefore available for others to access and use.

- Although this makes research accessible to other academics, it is less commonly accessed by those outside academia.
- Conversely, a significant proportion of heritage science research is not carried out in universities through research grants but takes place as part of the management and display of collections in museums and galleries or is the result of development work on archaeological sites or historic buildings.
  - Whilst the amount of this work that gets published varies by sub-sector, the majority of studies result only in internal or client reports, so called 'grey literature'.
- In developer-funded archaeology these reports are deposited with the local authority historic environment record where they are publicly accessible.
- Increasingly, through initiatives such as OASIS (Online AccesS to the Index of archaeological investigationS), information about these reports is being made available online.
  - Increasingly these records also contain digital versions of these reports.
- Similar initiatives for other areas of heritage science would certainly be of benefit, providing better awareness of what work is taking place as well as ready access to reports.
  - Already many institutions and national agencies are providing access to digital versions of their work through the web; what is lacking is more general application and central coordination of activity so that it is quick and easy to access.

Digital data storage and sharing – Topic 6b

Aside from the need for coordination of indexing and online availability of reports, another problem is that projects are producing increasingly large amounts of digital data, for which storage issues need to be addressed.

- Not all of these data may be used in the final project output or are suitable for inclusion in report appendices (3D point cloud data from digital scans for example).
- Some data have no analogue format and as more people work digitally, paper based records are becoming less common, so more heritage science information is being created and maintained solely in a digital format.

This raises concerns for the long term survival of these data (which is why it is raised here).

- However, the fact that so many of these data are available in digital format means that sharing of research data (as is currently the case with FTIR data) has never been easier.
  - Any developments of digital data storage for heritage science should consider ways to increase the use and share-ability of these data.

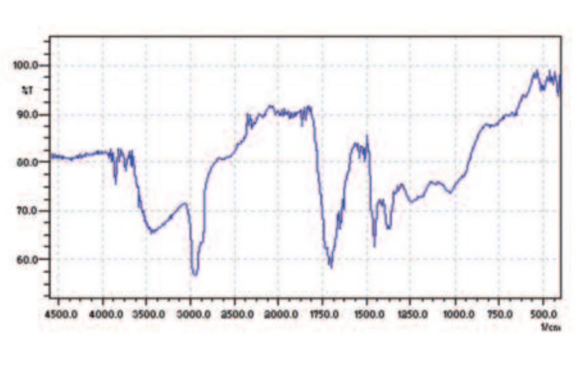


Figure 21
FTIR spectrum of a resinous coating from Egyptian coffin fragments. © National Museums Liverpool

Widening access – Topic 6c

The collation of heritage science data will also facilitate greater use of these data by external researchers and increase access and further public engagement and participation.

- This is also the case for information about museums collections.
  - Online resources will help external researchers identify material that they wish to analyses.
  - Proactive identification of those potential data sets by museums will increase the likelihood of study.

8 Summary conclusions

The focus of this report is on the ways in which we can increase the amount and quality of heritage science currently undertaken to enhance our understanding of the past. Our recommendations for new and improved tools, better access to existing facilities and more guidance to raise awareness of current techniques may all appear to be very methodologically focused. What needs to be emphasised through is that good quality scientific analysis of heritage assets does not happen just because we have the tools and technical know how. Such work needs to be undertaken as part of a properly framed research programme to address clearly defined questions and although we might wish to see more science undertaken, it needs to be focused on outputs and their use rather than on just the use of available techniques.

This report also highlights how results from heritage science investigations can and should be used to further public understanding and engagement with historic buildings, collections and sites. Much is being done already, for example the work of museums and galleries highlighted in section 5.4.1, but there are still many more opportunities that remain to be exploited. Heritage scientists need to be aware of opportunities not just for telling people about the past, but involving them in the process of discovery

Finally, it is clear that of the heritage science work discussed within this report, the quantity of output is not distributed evenly between the heritage sub-sectors, or for that matter within them, i.e. there is a big variation in heritage science work at the large and national museums compared with the remaining institutions. However, the greatest difference highlighted by the report is the high level of heritage science activity in the archaeology sub-sector compared with the other heritage science sub-sectors. One of the goals of the strategy must be to try to encourage individuals and organisation to place a greater emphasis on the scientific investigation of buildings and collections to enhance our understanding of the past. This report is just one step in that process.

9 Next steps – seeking your views

The purpose of this report is to provide a snapshot of the state of science used to gain a better understanding of the past. It also aims to highlight areas (both specific and general) where there are opportunities to increase the use of science in the future. More so than our first report, the different ways that each of the sub-sectors operates has meant that it has been hard to draw out generalities that apply equally to all sectors; many of the opportunities for increasing heritage science research are specific to particular sub-sectors and often to individual topics or methods within these sub-sectors.

We would like to know your views on our sector-specific thoughts. Are the opportunities that we highlighted to increase the use of scientific techniques the right issues? Have we missed anything out? Have we adequately identified the barriers that currently limit the use of science to study heritage assets in each sub-sector?

We have identified three overarching, strategic issues which we feel are common to all sub-sectors. These are

- Development of tools and access to equipment
- Raising awareness of existing techniques and their application
- Data use and management

We believe that these are topics where greater sector coordination is needed and that collaboration, improved communication and resource sharing will help to tackle many of the individual sub-sector issues that we have identified in this report. We would like to hear your views on these strategic issues and whether you think these three themes cover the main priorities for increasing the use of science in understanding the past.

A response form for you to send us your views on will be available through the NHSS website www.heritagesciencestrategy.org.uk along with this report. Please respond by the 4th September 2009.

10 References

Strategies, reports, articles and books

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Discussions and correspondence with heritage practitioners (in addition to steering group)

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Andy Hammon
Anna Bülow
Anne Finnie
Antony Firth
Ashok Roy
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Bernard Thomason
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Cathy Tyers
Christopher Ramsey
David Saunders
Diane Gwilt
Dominique de Moulins
Gill Campbell
Graham Martin
Helen Hughes
Ian Bailiff
Ian Brocklebank
Jane Henderson
Jen Heathcote
John Cattell
John Feather
Joyce Townsend
Justin Dix
Justine Bayley
Kate Lowry
Keith Challis
Ken Smith
Ken Uprichard
Kostas Ntanos
Lyn Wilson
Martin Cooper
Mary Davis
Matthew Collins
Maureen Young
Maurice Davies
May Cassar
Mike Corfield
Neil Linford
Neil Maylan
Nicholas Eastaugh
Noel Fojut
Oliver O'Grady
Paul Bryan
Paul Linford
Pete Ditchfield
Peter Marshall
Richard Evershed
Richard Jones
Robert Hedges
Sean O'Reilly
Simon Mays
Siobhan Stevenson
Siobhan Watts
Sue Stallibrass
Terry Brown
Tom Higham
Vanessa Straker

Web-based resources

http://news.bbc.co.uk/1/hi/scotland/edinburgh_and_east/8058185.stm
http://www.bl.uk/onlinegallery/virtualbooks/index.html
http://www.bl.uk/treasures/treasuresinfull.html
http://www.britishmuseum.org/about_this_site/audio_and_video/latest_news.aspx
http://www.helm.org.uk
http://www.museumsassociation.org
http://www.nationalgalleries.org
http://www.nationaltrust.org.uk

Appendix 1

List of steering group members

Sarah Staniforth – Chair (National Trust)
Professor Peter Brimblecombe (University of East Anglia)
Dr Craig Kennedy (Historic Scotland)
Katy Lithgow (National Trust)
Dr Nick Merriman (Manchester Museum)
Dr Sebastian Payne (English Heritage)
Professor Mark Pollard (Oxford University)
Helen Shenton (The British Library)
Dr Jim Tate (National Museums Scotland)
Professor Heather Viles (Oxford University)
David Watkinson (Cardiff University)

Appendix 2

Abbreviations from text

C14	Radiocarbon
CT	Computed tomography
DTM	Digital terrain models
EDM	Electronic Distance Measurement
EDX	Energy-dispersive X-ray spectroscopy
FTIR	Fourier transform infrared spectroscopy
GC-MS	Gas chromatography-mass spectrometry
GIS	Geographical information system
GPS	Global positioning system
ICP-MS	Inductively coupled plasma mass spectrometry
IR	Infrared (spectroscopy)
LC-MS	Liquid chromatography-mass spectrometry
Lidar	Light detection and ranging
NDT	Non destructive testing
NIR	Near-Infrared (spectroscopy)
OSL	Optically stimulated luminescence
PIXE	Particle-induced X-ray emission
Raman	Raman spectroscopy
SEM	Scanning Electron microscope
TL	Thermoluminescence
UV	Ultra violet
XRD	X-ray diffraction
XRF	X-ray fluorescence

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