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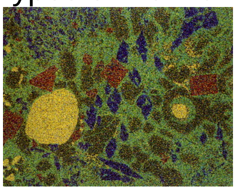
Our new electron microscope

Our new high resolution scanning electron microscope, installed in July this year, is already proving to be of great use in the analysis of archaeological materials

The Ancient Monuments Laboratory has recently upgraded its analysis facilities with the purchase of a new scanning electron microscope and X-ray analyser. The new system will not only replace the previous equipment, but will also allow laboratory staff to do new types of work and to increase efficiency.



Screen image of a lithage cake (a by-product of silver refining) made on the Scanning Electron Microscope

Applications

Electron microscopy has been used for a wide range of applications in English Heritage's work. In this technique, the sample is bombarded with a beam of electrons. Secondary electrons are emitted from the surface and these create an electron 'picture' of the sample, which is viewed on a monitor. Very high magnification and a good depth of field are possible, making the method ideal for the examination of biological samples found in archaeology, such as mineralised wood or animal hairs. Those electrons which are scattered back towards the line of the electron beam can also be detected, using a backscatter detector. The backscattered image gives information about the topography (surface relief) of the sample and about its composition by indicating the distribution of heavy and light elements.

The electron beam also causes X-rays to be emitted from the surface of the sample. The energies of these X-rays are characteristic of the elements present in the sample. An X-ray spectrum is collected using an X-ray detector, so that the chemical composition of the sample can also be investigated.

Specifications

The new scanning electron microscope (SEM) is a Leica-Cambridge Stereoscan 440i. The microscope is driven by a PC in the Windows environment and imaging is on a large, high-resolution colour monitor. The microscope settings can be changed using pull-down menus, a three-key mouse, and a variety of 'hotkeys' on the keyboard. The stage is automated and can be moved about using an onscreen joystick. A range of noise-reduction facilities and image enhancement 'look-up tables' are available, giving clear, photo-like pictures and a variety of information types about the structure of complex samples. Images can be annotated freely, for example, with comments about particular areas of the sample or about the microscope settings. Images are recorded in digital format, allowing them to be imported into word-processed reports and printed on a variety of hardcopy devices (eg video-printer, Polaroid camera, laser printer). Libraries of images can be built up on the computer and used as reference material in later work. A large sample chamber permits the examination of whole objects as well as small polished samples mounted in resin or Bakelite blocks.

The new energy-dispersive X-ray analysis (EDX) system includes a thin-window germanium X-ray detector, giving improved resolution and, for the first time at the laboratory, permitting the analysis of light elements. This will improve our ability to build up informative compositional pictures. For example, in a ferrous slag sample, X-ray dot maps can be plotted for oxygen and carbon as well as for iron, manganese, and silicon, thus giving more accurate indications about the nature of each phase. The detector is integrated with the SEM using the Oxford ISIS analysis package.

Work in progress

The new equipment was only installed and commissioned in July, but already the potential of the system is being explored in a variety of projects. Secondary electron imaging is being used to build up a reference library of animal fibres, some collected from rare breeds collections. Preliminary research suggests that the backscattered detector's topographic settings will be of invaluable assistance in recording and analysing images of toolmarks on artefacts. This technique may allow us to identify occasions when a single tool was used on two artefacts, indicating that both artefacts were made in the same workshop. This will be of great interest to specialists working on material from Anglo-Saxon cemeteries, where even relative dating is rare.

The author operating the Scanning Electron Microscope

The EDX facilities are currently being refined to permit accurate analysis of debris from a post-medieval glassworking furnace in Staffordshire. Chemical characterisation of the window glass made at this site will allow us to compare it with glass used in historic houses of the period and to investigate the changes in glass technology that took place at this time. Paint researchers are using EDX at high magnifications to investigate the compositions of individual paint layers, or of individual grains within these layers. These and many more projects will benefit by the use of the upgraded facilities.

Catherine Mortimer

Conservation and Technology

Monitoring archaeological sites

The artefacts and ecofacts found in archaeological excavations have been preserved because they have come into equilibrium with their immediate surroundings. In sites that are not waterlogged the soil is generally damp and oxygenated; metal objects, after initially corroding, reach a stable state soon after burial and thereafter only change very slowly. Organic materials – wood principally, but also skin and leather, antler, horn and ivory, and to a lesser extent bone – are destroyed rapidly by insects and other microorganisms.

Wetland sites

In waterlogged conditions the corrosion of metalwork may be much slower, depending on the chemistry of the water protective coatings of tannates, and phosphates may be formed. The insects and other biological agents that consume organic materials cannot live in wet deposits in the absence of oxygen and in these conditions a good survival of organic evidence can be expected.

Installing monitoring equipment at Market Deeping

Because archaeological sites in wetlands have been less well explored than dry sites, partly in the mistaken assumption that wetlands would have been less attractive to our forebears, and partly because, until recently, the threat to such sites appeared less, the archaeological record is skewed by the absence of the huge quantities of organic materials that would have been used in the past. Nevertheless, it is only from wetlands that we get a picture that indicates the full extent of the utilisation of these materials in pre-industrial times. From the mesolithic wood at Starr Carr, through the bronze age timber structures at Flag Fen, to the wharves of Roman London, the houses of Viking York, and the Elizabethan Globe and Rose Theatres wood and other organics are revealed in their full range and complexity.

These remains are vulnerable. Wetlands are under constant threat: there has been a progressive draining of areas such as the Fens, which has accelerated in the past decade. Sites which until recently were known to be fully waterlogged are now desiccated and their organic component has been lost. Wetlands are a rich source of peat, the extraction of which has again resulted in a lowering of watertables in areas such as the Somerset Levels. As a result, many of the organic finds contained within the peat levels have been lost. Mineral extraction also reduces watertables, by providing sumps into which groundwater can drain. At Etton in Cambridgeshire, for example, the excavator noted the rapid loss of water from the site as gravel extraction progressed over a kilometre away. Mitigation strategies may be adopted when a site is developed, but these are not always appropriate and sites will always be lost to development. The effects of climatic change are as yet unclear, but we might expect to see changes to the watertables that may not necessarily be beneficial to archaeology.

Measuring water levels in the field

Site identification

The greatest problem to be faced with wetland archaeology is that of identification. The wet archaeological deposits may be well below the surface. In the Fens, for example, this may be typically 1.5 metres below the present ground level. Equally, the organic remains cannot be detected by prospecting devices that are commonly used on non-wetland sites. In order to prove the presence of waterlogged material it may be necessary to excavate; however, in excavating we disturb the equilibrium which has thus far protected the remains.

Basic processes

Having found a waterlogged deposit it is then necessary to determine how secure it is from external influences. Here again we have little information about the basic hydrological processes that lead to preservation. We need to know the extent to which the deposit must remain totally within the waterlogged levels or whether it can survive for brief periods as the watertable drops during seasonal fluctuations. We need baseline information about the buried environment so that we can characterise its condition against standard parameters. Research in the Ancient Monuments Laboratory is directed to answering these questions. We have set up an experimental monitoring station at Market Deeping in the Fens, where monthly recordings are made of the watertable level and of the percentage of water content at various levels in the soil profile. We also analyse samples taken from the watertable, recording the pH, the conductivity (as a measure of dissolved salt content), the dissolved oxygen content, and the redox potential (a measure of the ability of the water to support chemical reactions). The data from this monitoring will be set against data from our longstanding monitoring of the Rose Theatre to compare waterlogged urban sites against those in the open country. We will also be utilising data from a major monitoring exercise at Willingham and Over in Cambridgeshire in advance of and during a major gravel extraction. We are beginning to see the seasonal changes in the watertable and how they affect the moisture in the soil above the watertable.

Through these data we are gaining an insight into the effects of agricultural practice on water chemistry; we are gaining an understanding of the microorganisms that destroy wood in aerated soil. We are recognising that the processes taking place in anaerobic deposits are complex and we have commissioned research with Durham University to get a better understanding of these processes.

As a consequence of this research we expect to be able to provide our colleagues with sound advice on the strategies that can be adopted for managing sites in wetlands. We will be able to recommend when mitigation strategies will work and what monitoring should be provided to ensure that they do. This work is a fundamental contribution to English Heritage's Wetland Management Projects and we acknowledge the help and support of our colleagues in Conservation Group in realising our objectives.

Mike Corfield

Head of Conservation and Technology

The health of the elderly at medieval Wharram Percy

Some bone diseases found in the elderly today were either absent or less frequent and less severe among the elderly at Wharram Percy. However, the evidence suggests that osteoporosis was as severe among the medieval women as it is today, despite the vast difference in lifestyles.

Wharram Percy lies in the Yorkshire Wolds, about 20 miles northeast of York. Although no-one lives there now, it was the home of a thriving peasant community in the medieval period (11th–15th century AD). Archaeological excavations of the churchyard at the site have yielded nearly 700 skeletons. Work on this important collection is still in progress, but it has already yielded important insights into the lifestyle of the medieval peasant.
Approximate age at death can be estimated from the bones and teeth of ancient skeletons. This technique showed that at Wharram Percy nearly half of those who survived into adulthood lived to an age of at least 50 years. As well as helping to dispel the commonly held myth that life expectancies were very short in antiquity, the collection from Wharram Percy provides a large group of skeletons of older adults from which to study the health problems of the elderly in medieval times.
Many of the bone diseases to which the elderly fall prey today are rare or absent in the skeletons from Wharram Percy. For example, Paget's disease, a painful softening and swelling of the bones, is absent; and arthritis, in its various forms, is not particularly common. When it does occur it is only of slight or moderate severity. There is only one case of bone cancer.

Reconstruction of medieval Wharram Percy

Osteoporosis

Another disease that afflicts the elderly today is osteoporosis, the loss of bone mineral in older women. It is upon this disease at medieval Wharram Percy that the remainder of this article focuses.
Osteoporosis poses a major health problem for women in the developed world today. The loss of bone mineral weakens the skeleton, leaving the sufferer vulnerable to fractures, particularly of the hip, wrist, ribs, and spine. Hip, spinal, and rib fractures may occur with little or no trauma. In severe osteoporosis even the act of getting up from a chair may result in a hip fracture, rib fractures may be caused by coughing, and collapse of vertebrae may occur when stooping to pick up an object. Even in the less severely affected, trivial falls or other trauma may cause fractures.

Vertebrae from an elderly woman from Wharram Percy showing healed crush-fractures to their weight-bearing parts, typical of those seen in spines of modern osteoporotics

Causes of osteoporosis

The causes of bone mineral loss in women are associated primarily with the hormonal changes that accompany the menopause. However a variety of lifestyle factors do seem to be important in influencing the degree of bone loss. The effects of these various factors on bone loss are difficult to determine in epidemiological studies of human populations since it is impossible entirely to separate the effects of individual factors. Indeed, modern epidemiological studies often produce inconsistent and sometimes mutually conflicting results. However, a survey of the literature suggests that factors including cigarette smoking, alcohol consumption, a calcium-deficient diet, and lack of exercise may increase the rate of bone mineral loss. Conversely, exercise, high calcium intake, multiple pregnancies, and short duration of lactation may act to reduce it.

Methodology

There are many ways to monitor osteoporosis in modern patients. The method selected for this study of ancient skeletons was to measure the thickness (by X-ray) of bone in the second metacarpal, one of the bones that make up the palm of the hand. Modern work has shown that this is a good way to monitor the progress of osteoporosis, and in the present context it has the advantage of producing results from archaeological skeletons that are closely comparable with those obtained from modern patients.

Results

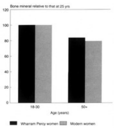
The results from Wharram Percy compared with those from modern women are shown in the bar graph. They suggest that loss of bone thickness among the medieval women from Wharram Percy was similar to that observed in modern women: in both groups, women over 50 years old show a reduction in bone substance to a level of only about 80% of that in young women aged 18–30 years.

This result is perhaps surprising given the great gulf in lifestyles that must have existed between medieval peasants and modern Western people, and the supposed importance of lifestyle factors in influencing rate of bone mineral loss. Tobacco was unknown in medieval England, and the lifestyle of peasants at this time would have involved a great deal of hard physical labour (for women no less than for men) compared with modern day people. Infant mortality was great and methods of contraception were rudimentary, so that numbers of pregnancies were probably high.

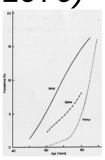
It is also likely that dietary calcium intake would have been high at Wharram Percy. The site lies on chalk geology, so groundwater levels of calcium are high. The element would have been passed up the food chain so local foodstuffs should not have been deficient in calcium. Furthermore, the animal bones recovered during the excavations at the site show that cows were kept, and fragments of pottery vessels used for dairy products (which tend to be high in calcium) were also found. However, despite the presence of these supposedly protective factors, the medieval women seem to have suffered from osteoporosis to an extent similar to that seen in women today.

Fractures

In modern populations osteoporosis is a health hazard because it tends to lead to fractures. This also seems to have been the case at medieval Wharram Percy, although the pattern of fractures differs from that observed in modern women. There were no hip or wrist fractures at Wharram Percy, although there were rib and spinal fractures.



Comparison of bone mineral in women aged 18–30 years with that in those aged over 50 (the amount of bone substance in the younger age category is arbitrarily assigned a value of 100%, and the level in the older category is expressed relative to this), using data from S M Garn, The earlier gain and later loss of cortical bone, *Charles C. Thomas, Springfield, 1970)*



Cumulative prevalence of fractures with increasing age in modern women (from various sources)

Those women showing spinal or rib fractures have much less bone substance than those who do not. This association between loss of bone substance and rib and vertebral

fractures suggests that osteoporosis may have been a precipitating factor in these fractures at a population level.
The question arises as to why the osteoporotic medieval women show fractures of the ribs and vertebrae, but not of the hip and wrist. In modern populations hip fractures are not common until after about 70 or 80 years of age, whereas vertebral fractures become common after about 50 years old, as shown in the linear graph. Despite the fact that many at Wharram Percy survived to at least 50 years of age, perhaps few of these lived to be over about 70 or 80. This appears an attractive explanation for the lack of hip fractures, as in the absence of modern medical care we would expect many fewer to survive into great old age than is the case today.
Nevertheless, we are hindered in investigating this possibility further for the Wharram Percy case, as limitations on skeletal ageing techniques mean that it is at present impossible to distinguish a skeleton of an individual who died in her fifties from one who lived to be 70 or more.
An alternative explanation might be lifestyle differences. Many modern third world populations do not show hip fractures, even in the very elderly. Reasons for this are unclear, but it has been suggested that the less sedentary lifestyle of many third-world populations may have something to do with it.
Today most wrist fractures in the elderly are due to falls onto an outstretched hand. Nowadays falls tend to be onto hard surfaces (eg tarmac, concrete, etc), whereas at medieval Wharram Percy falls would have been onto softer, more yielding surfaces, such as grass, bare earth, or mud. Moreover, peasant dwellings were single storey buildings, so the medieval people would not have been presented with the possibility of falling downstairs. These factors may, at least to some extent, explain the lack of wrist fractures at Wharram Percy.

Simon Mays

Science and Conservation Services, Environmental Studies

To underpin or not to underpin?

Why underpinning should be one of the last resources to deal with cracks and settlement in historic buildings.

Underpinning a building is an expensive business, but it may be vital to its long-term future. Without underpinning, the building may continue to settle and eventually collapse. There are times when there is no alternative. However, underpinning can be often unjustified, a waste of time and money, and can result in a great deal of disturbance to the historic fabric and destruction of the archaeology on which the building sits.

Understanding settlement

All structures settle to some extent when they are built. Initial settlement results when load from a new building is applied to the soil and is due to elastic deformation of the soil mass without volume change, vertical settlement being accompanied by lateral deformation. Consolidation settlement is caused by that same load being applied to the soil mass, thus applying pressure to the water in the soil. The water will drain away at a rate that depends on the permeability of the soil – virtually instantaneously in coarse granular material but very slowly in clays. Drainage reduces the soil volume and causes settlement.
If the whole building settles evenly as a result of initial and consolidation settlements, usually when a building is first erected or in mining areas, there is no serious problem and there will be no need to underpin.

Problems occur when one part of a building settles more than the rest, ie differential settlement. This can be caused by a hard spot in the ground, either natural or because of some underground structure, such as the wall of an earlier building, or when part of a building has a basement or cellar and part does not. It can also be created by a soft spot being formed as a result of poor drainage or by the washing away of the fine elements of the soil, by a reduction of moisture content adjacent to trees in areas with sensitive clays, or when the structure of soil collapses as a result of flooding.
Initial and consolidation settlements will have ceased a long time ago in the case of an historic building. General settlement to some degree will always occur and is not a problem. Differential settlement causes the problems.

Bristol Temple church: typical church tower that has been leaning for many years

Considering the problems

Before a building is underpinned its problems need a great deal of consideration. How significant are the signs of movement? Are the fractures and distortions signs of continuing movement or are they merely reminders of long-past movements? Is there current or past mining close by? Are any nearby trees close enough to cause problems? What type of soil do the foundations sit on? Is it natural ground or made ground? Was there any wartime bomb damage? What will happen to the building if is not underpinned? Will it become unstable and lose its structural integrity if nothing is done? Can some minor movement be accommodated without action being taken to prevent it? If minor movement can be contemplated will the occupiers accept this?

Example of a detached buttress

Examining the building

A thorough examination of the building and its problems is crucial. Building movements are often indicated by doors and windows jamming, by fractures appearing in walls and ceilings, and by elements of the building being out of level and plumb. It may be necessary to examine the building several times and, if there is any suspicion of live movement, a programme of structural monitoring will almost certainly need to be carried out to determine how significant the fractures and distortions really are. If all the signs indicate that movement has ceased, further action may not be needed.

An example of unnecessary underpinning

Although not an historic building, it had been suggested that a 1930s end-of-terrace house that was about to be sold needed underpinning due to significant cracking. There was movement of the rear external comer of the house, showing itself in cracking over the bathroom window and the window at the top of the stairs, but it became clear that foundation weakness was not the problem. Firstly the cracking pattern was not consistent with settlement, since the cracks did not reach ground level, and more importantly, other houses in the locality showed similar defects. They were unlikely all to suffer from foundation problems in the same corner.
Investigation showed that the wall plates to the roof structure were not continuous but jointed over the window heads, and it was concluded that the problem was caused by

outward thrusting of the roof hip rafter, which was not being properly restrained. An expensive and messy underpinning scheme would have done nothing to solve the problem. All that was needed was a couple of short steel straps fixed to the wall plates to make them continuous and thus able to resist the thrust from the hip rafter. This example shows that proper investigation is vital.

Signs of movement past and present

There are countless historic buildings around the country that show signs of severe past distortions: leaning church towers, twisted windows, doors that have had substantial amounts planed off to allow them to shut properly, buttresses that no longer buttress walls but that have become detached, countless cracks, and so on. Many of these need no action other than structural monitoring as a precautionary measure to check that no significant movements are taking place.

The word ‘significant’ has already been used several times and for good reason. All buildings suffer some movement. It would he difficult to find a building without some minor cracking and it is therefore important to determine which cracks and distortions are significant and which are insignificant. It seems to be a fact of life that cracks get bigger the longer one looks at them, but it may be that the crack appears to get worse because of the build up of dirt and dust in the gap. Perhaps the first thing to be looked for in a fracture is dirt. If it is dirty and has paint partly filling the crack then it has been there a long time. If it is clean, with crisp edges, it is probably new and therefore of more concern. It is also possible that the cracks are actually getting wider, but unless something really dramatic is happening it is most unlikely that the movement will be quantifiable without taking accurate measurements. This is structural monitoring.

Structural monitoring

The most basic level of structural monitoring is checking for changes in crack widths. This has been done traditionally with glass telltales or pats of mortar stuck across the crack. Neither are very satisfactory methods and give little indication of the rate of movement and whether or not movement is cyclic due to climatic changes. An intact glass tell-tale may have become unstuck at one end and therefore not broken despite movement in the crack. Conversely a broken tell-tale may have been broken by external forces, such as frost damage.

The simplest way to measure fractures is to fix three brass screws in plastic plugs in a triangle across a crack and to measure the distance between the shanks of the screws with a vernier gauge. *Demec* strain gauges and stainless steel studs are a better but more expensive method. Readings of the distances between the datum points taken on a regular basis, perhaps monthly or three monthly, will give a clear indication of any movement and will show climatic movements clearly. Crack monitoring can be carried out by anyone with a little understanding of buildings, but if movement is indicated specialist advice should be sought. Good records must be kept, for without these taking readings is pointless. Various electronic devices can be used to monitor crack movements but their cost and level of sophistication is not usually justified.

Changes in levels caused by settlement can be checked using high-accuracy surveyor’s levels and out-of-plumb movements can be checked with a theodolite, but these measurements need to be done by specialist engineers or surveyors. There are numerous other devices, both simple and more complex, available to the specialist for monitoring building structure.

The roots of a tree very close to a building may or may not affect its foundations

Site investigations

It may be necessary to carry out ground investigations by digging trial pits or by having boreholes sunk. As these procedures, particularly boreholes, are expensive there must be good reason to justify embarking on this course. Trial pits adjacent to historic buildings may show that the foundations, as defined by modern standards, are non-existent. Often the wall stops just a few inches below ground level with perhaps only a minimal widening out. Nevertheless, as the building may have stood for several centuries on these 'inadequate' foundations, serious consideration must be given before an underpinning scheme is commenced. It may be much more important to ensure that subterranean drainage is working properly so that excessive moisture is not allowed to build up below the walls, and to ensure that surface drainage, for example from roofs, also works properly, again to ensure that wet areas do not develop.

Underpinning

There are several methods of underpinning. It can be carried out in traditional fashion by excavating beneath the foundations and filling the cavity with concrete or with piles – sometimes large diameter, sometimes so-called 'mini-piles'. In some cases post-tensioning a reinforced concrete ring around the base of the walls can result in less intervention into the historic fabric of a building.

Full underpinning can be expensive and therefore partial underpinning is sometime suggested. This too can have difficulties, because it creates a hard foundation under one part of the building while the remainder is unchanged.

To summarise, it is essential to examine the building carefully, to study its problems in depth, and to investigate its structural history and surroundings. It is equally important to establish a good, accurate monitoring system and to keep good records, to ensure that drainage is working efficiently and that water is being drained away from the building adequately. Finally, it is necessary to carry out a thorough ground investigation. If all this is done and if the monitoring shows significant movements it may be necessary to underpin the building. In most cases it will not be necessary.

Ian Hume

Conservation Engineering Branch, Chief Engineer

Terry Girdler

Conservation Engineering Branch, Geotechnical Works

The enhancement of radiographs through digital image processing

New specialist computer software uses digital image processing to enhance and sharpen X-ray images.

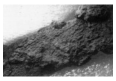
Conservators work closely with field archaeologists and finds specialists to examine and assess artefacts from archaeological excavations. Radiography is a primary tool in the preliminary investigations, particularly for metal objects. A radiograph will provide information on the nature of the artefact, its condition and its technology. Using the radiographs made for the assessment of material from a site, the finds specialist and the illustrator will be able to recognise the shape and approximate dimensions of each item, while the conservator will identify any special features that the radiographs might reveal. The interpretation of radiographs improves with experience but it depends crucially on the quality of each radiograph and the ability of the viewer to detect differences in the image.

Non-destructive examination

Radiography has established itself as an important technique in the nondestructive examination of artefacts, particularly in the examination of iron. To X-rays corrosion products are relatively more transparent than solid metal is. Thus the shape of an object can be seen beneath an accumulation of corrosion and soil. Different metals are more or less opaque to X-rays and therefore, for example, the presence of silver or copper inlay will be detected. It is also possible to assess the internal condition of iron artefacts. Close examination of radiographs has revealed non-ferrous metal coatings and metallurgical details; the weld lines on knives where the steel cutting edges were joined to the back. Furthermore the layers of slag inclusions in iron artefacts has given indications as to how the iron was forged.

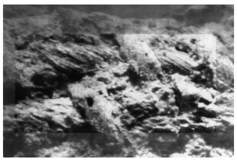
Interpretation

The interpretation of radiographs has improved considerably as a consequence of the precision cleaning of iron with airbrasives. This technique was introduced in the early 1970s, and replaced cruder mechanical cleaning with vibrotools, dental drills, and electrolytic reduction. It was not at first appreciated that more subtle detail could be revealed by careful study of X-radiographs.



Roman knife from a burial at Stansted: encrusted blade has mineral-replaced textile on it

But X-ray plates can be confusing: features overlap, corrosion products create illusionary shapes, and detail is lost in the black and transparent extremes of contrast. Various techniques are used to reveal the features hidden by the encrustations, for example multiple exposures, magnified images and stereo images; however there still remain some X-radiographs where the detail cannot be clarified. When examining X-ray plates taken in the past it was sometimes found that some had darkened, or were incorrectly exposed to begin with. The information may be on the X-ray plate but the detail cannot be resolved by the human eye alone. For these images digital enhancement techniques are proving useful.



The Stansted Roman knife: mineral preserved textile magnified, enhanced, and sharpened in detail when the image was 'captured' from a video camera and printed at 600dpi

Digital enhancement

Following work done in astronomy and medical science, and using specialist software, it was realised that image processing techniques could be used to enhance archaeological radiographs. In a report in *Conservation News* (Lange and Watkinson 1992)* it was shown that a radiograph may have much more information contained in the emulsion than can be discerned by eye, and that this can be revealed by digital image processing. At English

Heritage we realised that having a considerable investment in radiography, both at the Ancient Monuments Laboratory and with our various conservation contractors, we ourselves should investigate the potential of this tool. We commissioned a research project from Durham University to assess the various software packages available and used a selected package to determine the best enhancement techniques for archaeological materials. (Caple and Clogg 1994).**

Information technology and image capture

It is possible to link a video camera and monitor to a personal computer (PC). The image is digitised by the camera and the computer can be used to process and store data relating to the image. 'Frame grabber' boards are used to upgrade the PC for image capture. If the image is saved into the same format as that used by a graphics software package it can be loaded as a graphics image and treated like one. Sophisticated software can be used to manipulate the original image. On screen, rows of pixels seen together create the illusion of a picture. Collectively 768 x 512 pixels form the image.

Each pixel can be one of 256 shades of grey, from white to black. A number proportional to the amount of light shown by a pixel can be allocated to it and the computer, in one operation, can change the grey scales of individual pixels or groups of pixels by adding or subtracting to them. When these operations take effect the image is seen to be lighter or darker.

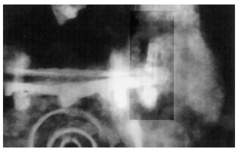
Software packages such as Photofinish, an image processing program, have simple facilities for changing the brightness and contrast of images loaded into the program, performing equalisation, and sharpening routines, and can also be used for printing out pictures.

The mosaic effect of pixel groups can be demonstrated using the zoom function. PC-Image is a much more powerful tool with many facilities that the user can define. A simple feature called Look Up Tables (LUTs) can provide pseudo-colouring in addition to repeatable routines for affecting specific grey scales.

Screen resolution restricts the quality of the pictures produced. Unless high resolution images are used the picture looks blurred. The resolution problem repeats when the image is sent to a printer. Clear pictures start at 600 dots per inch (most printers print at only 300 dpi), and photographic quality printing can only be made using an expensive technique of melting wax onto paper.

The only problem is that when these images are saved onto hard or floppy disks large amounts of memory are used up. Mass storage onto magnetic tape is one solution, but in the future CD-ROM seems most promising. One of the particular benefits of the technique to English Heritage is the ability to incorporate images into our reports. This will enable us to improve the presentation of our reports and to illustrate them with appropriate X-ray images in a way that has previously not been possible.

Image 'grabbed' from radiograph of a lock plate: detail in underexposed (white) area can be enhanced and clarified by digital processing



Part of the underexposed area processed by equilisation, a pixel group function, to increase contrast

The EH system

The system we have set up is based on the Durham report. Our images are grabbed with a CCD video camera and Data Translation DT2867-LC precision frame grabber board. The software is PC-Image Plus produced by Foster Findlay Associates. The computer can enhance the image by means of various mathematical operations. Regions of interest (ROI) can be defined, and either the whole screen or the ROI processed. The contrast of the image can be altered or can be expanded; detail lying close to the boundary between differing contrast ranges can be seen more clearly. The image intensity can be adjusted and fuzzy images can be sharpened. False colour can be used to highlight contrast differences.

We are continuing our research into image enhancement techniques. Our partners in Durham are working on a system for grabbing infra-red images, which may help us to identify organic residues on archaeological objects: writing, dyestuffs, pigments, and so on. We hope that we may use the technique to enhance infra-red images of wall paintings so that we can improve our detection and interpretation of these images too.

Colin Slack

Conservation and Technology

* Lange, E, and Watkinson, D, 1992 Image processing and its application to X-radiography, *Conservation News*, **47**

** Caple C, and Clogg, P, 1994 *An assessment of digital image processing in conservation*, AML Report, **27/94**

Research into the conservation of archaeological waterlogged material

A review of research on waterlogged wood conservation by AML.

The Ancient Monuments Laboratory (AML) first became involved in conservation of waterlogged artefacts as a consequence of the late Dorothy Charlesworth's excavations in Carlisle in the 1970s, which produced quantities of leatherwork, basketry, and small wooden items. During that time most conservators and conservation students passing through the laboratory experimented on this, trying out various suggestions for treating waterlogged material. The results were highly variable, with few, if any, being outstanding and most being barely acceptable or just short of disastrous. Probably as a result of this mixed experience, many conservators later avoided working on wet organics if at all possible, so that few other laboratories were able to provide either advice or facilities. At the same time, however, archaeologists throughout the country were becoming increasingly involved with waterlogged sites producing vast quantities of material in urgent need of quick, inexpensive, and reliable conservation.

Freezedrying

By 1979 the AML had acquired a small freeze-dryer. At the same time the Central Excavation Unit (now the Central Archaeology Service, CAS) were conducting excavations at Fisher Street, Carlisle, where they were producing a small quantity of waterlogged leather and wooden objects. Two wooden bowls and a gaming board were the first items freeze-dried by the laboratory, and the results encouraged us to develop the technique further.

The structures of all waterlogged archaeological materials are highly degraded and cannot withstand the stresses that occur when the water in their cells freezes. To overcome this problem, simple experimental programmes were set up to assess the best pretreatment regimes for both wood and leather. In the case of wood this involves the use of polyethylene glycol (PEG), a water-soluble wax, which compensates for the volume change when water freezes and also consolidates degraded parts of the objects. From this time onwards freeze-drying has dominated the conservation of waterlogged organic materials as it produces the most consistently reliable results, quickly, and is less labour intensive than the methods that had been tried before. The only limitation to the use of the method seemed to be the size of the facilities required: the AML now has a 2m freeze-dryer at Savile Row and a 4m one at the York Archaeological Wood Centre. These two installations provide the core of facilities for waterlogged material from English Heritage funded projects.

Freeze-drying equipment at the AML

Two freeze-dried wooden bowls from Carlisle, CEU excavations at Fisher Street

New lines of research

Now, after many years of using freeze-drying we feel we have to review our methods, particularly for wood, which does not always respond well to the basic treatment. More importantly, the existing facilities cannot cope with the growing demand. To tackle these problems we need to study the behaviour of the wood structure and pretreatment solutions during the actual freeze-drying process. This would seem an obvious line of inquiry but, in fact, research into the freeze-drying phase of the process has not been addressed before in conservation, and can only now be attempted because of our recent collaboration with scientists from other disciplines. Of particular importance is access to a freeze-drying microscope at Porton Down, which allows us to view the physical changes under variable freeze-drying conditions.

In addition to our own freeze-drying programme we are assisting St Andrews University with the development of supercritical drying (SCD) for waterlogged wood. This method replaces water in the wood structure with methanol, which is in turn replaced by carbon dioxide at increased temperature and high pressure. Surprisingly the wood is not subjected to the normal drying stresses, avoiding serious shrinkage and cracking. It is hoped that this method may provide an alternative to freeze-drying for some types of wood, but, more importantly, for composite metal and wood objects, for PEG encourages the corrosion of most metals. At the time of writing this method is restricted to small items because of the size of available equipment.

We are also looking into the assessment of the condition of waterlogged wood. The current condition of the wood that has been degraded during burial has to be assessed; we need to determine how much of the wood structure survives, as well as its composition. This is particularly important both from the point of view of choosing a suitable conservation programme for excavated material and for monitoring the preservation of structural timbers left *in situ.*

Increased needs

The increasing emphasis on wetland archaeology, along with the proposal that English Heritage should take on responsibility for wrecks and coastal sites, will mean the location of more waterlogged sites with both *in situ* and archive conservation needs. Even if the conservation is not undertaken by AML or by its regional contractors we are often asked to advise archaeologists on the conservation potential of their waterlogged materials, what the conservation requirements are, and how these will affect other specialist studies. It is hoped that the integrated research programme we are working on will enable the AML not only to produce objects conserved to an acceptable standard for study and display but also to provide reliable advice for archaeologists on the conservation and *in situ* preservation of wooden structures.

Jacqui Watson

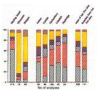
Conservation and Technology

Use of copper alloys in Roman Britain

Recent work on the precise composition of alloys used in Roman Britain reveals a wider range than thought.

Archaeologists are becoming more aware that a whole range of metals and alloys were in use in Roman Britain and, in particular, that bronze (an alloy of copper and tin) was not the only copper alloy used. This is due in large part to research carried out in English Heritage's Ancient Monuments Laboratory. Copper alloys were used to make a wide range of decorative and utilitarian objects, from brooches and bracelets to tweezers, spoons, handles, keys, coins, and fittings for armour.

The alloys were macle by adding tin, zinc, lead, or combinations of these to copper. The common Roman alloys were bronze – mainly copper with 4–12% tin, brass – mainly copper with 8–25% zinc, and gunmetal – copper with more than several percent of both tin and zinc. Leaded alloys contain more than a few percent lead, and some as much as 25%.

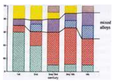


Proportions of different alloys used in Roman Britain; key (to all graphs): green = bronze, red = leaded bronze, blue = leaded gunmetal, purple = gunmetal, yellow = brass, brown = other copper alloys

Analysis of first century objects

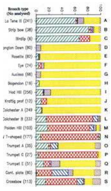
Analytical results for objects, other than brooches, from eight sites illustrate a number of general trends. Most of the objects from Hayling Island (Hampshire) date to the pre-Roman Iron Age when bronze was the normal alloy used; some leaded bronze was used for cast object while the few brasses are 'ritual' objects, possibly imported from Romanised Gaul. The Gloucester and Sheepen. (Essex) finds just post-date the Roman Conquest of AD 43 and include much military metalwork, the majority of which is brass. The objects from the other five sites come from all over England and span the first to fourth centuries A.D. The average of these columns gives a good idea of the overall pattern of alloy use in Roman Britain. The brooches from these five sites show a similar pattern but with more brasses.

The first figure shows that the common copper alloys in Roman Britain were tin-rich ones but also that a significant minority of objects were made of brass. Brass was widely used for coins and military metalwork, particularly in the first century AD, and was used to make about 20% of other copper alloy objects. The proportion is higher for brooches (30%) but this may be at least partly because brooches were far commoner in the first century than later. This is the period when brass was commonest, a direct reflection of Britain's increased contact with the Romanised world.

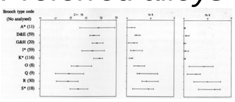


Composition of objects from well-dated contexts at Gorhambury

Groups of objects from well dated find spots at Gorhambury (Hertfordshire) were analysed to see if there were any changes in the alloys used from the first to fourth centuries. The sample size is small but still shows, as mentioned above, both the decline in the proportion of brass objects and an increase in the use of mixed alloys (gunmetals), which suggests that recycled metal became increasingly important later in the Roman period. The proportion of gunmetals continues to increase in the post-Roman period, rising to about 40% on some early Saxon sites. It is also noticeable that the quality of the brass used declines with time, the average zinc content of brass brooches decreases, and the tin and lead content increases.



Preferred alloys used to make individual brooch types



*Zinc, tin, and lead contents of brass brooch types, showing the median and interquartile ranges; values for types marked * were calculated omitting the obvious non-brass examples: top five types – mid first century, next two – later first–second century, last two – second and third fourth centuries respectively*

Type R Roman brooch, made on the Continent and decorated with enamel, maximum length 4.9cm

Alloys of the first to fourth centuries

Unlike most other classes of objects, brooches show clear typological changes, which are relatively well-dated. Changes in alloy use and alloy composition with time can therefore be examined, even when find contexts are not themselves well dated. Native British types of the early to mid first century AD (types A–C) were mainly bronzes, like other Iron Age metalwork. Just before the Roman Conquest in AD 43 types D–K, made of brass, began to appear, many of them imports from the continent. Brass brooches became more common immediately after the conquest and continued in use until the third quarter of the first century and occasionally later. Although some later first-century types were still made of brass (types O and Q), the bulk of late first- to early second-century brooches were leaded bronzes (types L–N and P).

Brooches became less common from the second century. The information about their composition does not present a clear picture as insufficient numbers of most of the types have been analysed. However, a range of enamelled plate brooches were imported from the continent (type R), and these show a wider compositional range than earlier imports. Late third- to fourth-century crossbow (type S) and related brooch types are mainly leaded bronze, but with some brasses and some other low lead alloys. The reason for this range of compositions is that all the brooches made of relatively lead-free alloys were probably originally mercury gilded, a decorative finish that could only be applied to unleaded alloys.

Justine Bayley

Conservation and Technology, Head of Technology Section

Understanding and managing the environment of historic buildings

A greater understanding of the effects of the environment on buildings and their contents is leading to better monitoring and control methods.

The fabric of buildings and their contents react to changes in their environment. In low humidities organic materials such as wood will lose moisture to the atmosphere and as a result will split and crack; in high humidities organic materials will absorb moisture and swell. If the item is part of a structure or is fixed in any way it may be damaged by such dimensional changes. High humidities also encourage biological organisms, which draw their food from the organic materials, to grow. For example fungi, such as dry rot, and insects are capable of totally consuming timber. In high humidities metals will corrode, dyes will fade, textiles will be weakened, and unstable glass will break down. Some of these processes of deterioration are accelerated by the effects of ultra violet light. Practitioners of conservation have been aware of these changes and have sought to modify environments in an attempt to prolong the life of vulnerable objects or decorative features on buildings.

Understanding the existing environment

Before any attempt can be made to change the environment it is first necessary to have a full understanding of the existing environment; this means that the environment should be monitored for at least 12 months so that the full effect of seasonal changes can be seen. In general the two principal environmental factors that are monitored are relative humidity and temperature. These two factors are interdependent: the higher the temperature the more moisture it can hold. The *relative humidity (RH) is* the ratio of the absolute volume of water held by a given volume of air and of the maximum volume of water that volume could hold *at that temperature*.
We have recently become conscious of the fact that simply to measure these two parameters is insufficient. This is particularly the case when we are dealing with features such as wall paintings, where the painting will be affected by a variety of other factors, for example the temperature of the structure, the movement of moisture within the structure, the salts that may be dissolved in structural moisture, and the surface temperature. If the surface temperature is below the dew point for the room concerned then moisture from the air will condense on the surface of the painting, a phenomenon often seen on windows when the outside temperature is lower than that indoors, with a moderately high humidity. Similarly, if the room humidity is low and the structure is loaded with salt rich moisture the salty solution will be drawn to the surface, the moisture will evaporate and the salt will crystallise on the surface. If there is any barrier to this process, for example, a painting executed in tempera or a varnish applied over a surface the salts will crystallise below the surface and will disrupt it and cause it eventually to flake off. This can often be seen when churches are decorated with modern emulsion paints.

Monitoring the environment

The means for monitoring the environment have become more sophisticated. In the past the principal method for recording changes to the environment was by means of a thermohygrograph. This uses the fact that human hair is especially sensitive to changes in relative humidity, increasing in length in higher humidities. Temperature is recorded by measuring the change in a bimetallic strip. Although thermohygrographs are still extensively used they are limited in their ability. Information on charts cannot be manipulated and the instruments need to be sited on a solid shelf. The charts have to be changed daily, weekly or monthly. To overcome these deficiencies the environment is increasingly monitored using solid state logging devices with suitable sensors for *RH*, temperature, light, surface temperature, conductivity (for salt content), and so on. The sensors are small and are easily located in unobtrusive places.

The information stored by these loggers must be downloaded into a computer, and once there, using the manufacturer’s software, can be presented in graph form and manipulated to give expanded scales so that changes can be examined in detail. Limits can be set so that only the occasions when the conditions measured fall outside the limits are recorded. For example, if it is known that no harm will result as long as the *RH* remains between 45% and 65%, then all we may need to know is when the *RH* fell outside that range, how far it deviated, and for how long. This considerably reduces the data held.

Telemetric downloading

A recent development of logging has been telemetric downloading. Systems are now available where the sensors are attached to a miniature radio transmitter; the transmitter sends the signal to a central computer where the data is stored and may be used to trigger alarms when the parameters stray from the set limits. For monitoring conditions in historic houses these systems have considerable advantages, particularly in that no hard wiring that would intrude into the decoration is needed. A further advantage is that the data can be interrogated remotely via a modem so that a number of sites can be monitored from a central office.

RPS research

Members of Research and Professional Services are using modern monitoring technology to help us to understand the way in which objects, buildings, and decorative features react to changes. The results of this monitoring are currently being used to find defects in buildings and their environmental control systems. We have made investments in humidification and dehumidification equipment in order to manipulate the environment to the advantage of objects displayed; but we have not yet investigated the effect of this equipment on the building. Are we drawing too much moisture from the building fabric or are we putting too much moisture into it? What is the effect of heating on the movement of moisture through the structure? Can we maintain a satisfactory environment by the intelligent use of air movement alone? These are some of the questions that we will address through our research programmes. The answers to these questions will help us to provide the right environment to suit the building and its contents in a cost effective manner.

Brough Skingley

Head of Building Services Engineering

Animal bones from Launceston Castle

Careful examination has revealed evidence of food for the aristocracy and new evidence for the beginning of the Agricultural Revolution.

The castle at Launceston, Cornwall, lies near the Devon border about 14 miles from the coast. It was first built in the early years of the Norman conquest and remained in use until the 1840s. The castle underwent a substantial decline in status in the course of the thirteenth to seventeenth centuries, from dense occupation by people of both high and low status to episodic use by the justices' circuit. Finally, in the period between 1660 and 1840, occupation of the castle was limited to a gaoler, his family, and a few prisoners. By this time it had fallen into ruins and may even have served as a town tip. Today it is in the care of English Heritage and excavations have been undertaken between 1961 and 1982 by Andrew Saunders, until recently Chief Inspector.

Bones tell tales

Over 9000 animal bones and teeth from his excavations have been studied and recently published in an Ancient Monuments Laboratory report (AML Report 18/94). These included some rather unusual animals such as sea mammals and rare birds, and provide us with an interesting new perspective on the beginning of the Agricultural Revolution.
Four periods produced especially large assemblages of animal remains: Period 6 (late thirteenth century), Period 8 (mid to late fifteenth century), Period 9 (sixteenth and seventeenth centuries), and Period 10 (eighteenth century to 1840).
Like most archaeological remains of animals these bones are the leftovers of meals eaten in antiquity. They tell us not only what the people were eating but also something about the people who were doing the eating and about the animals themselves. For example, the castle's historically documented decline in status during the course of its occupation is reflected in a decrease in the amount of fish and birds compared to the mammals, ie a shift from a varied diet to a restricted diet.
As in most archaeological sites in England the majority of the animal remains belong to cattle, sheep, and pig, with some horse, fallow deer, and dog. Most of the fallow deer bones were found in the medieval levels and were from the hind limbs, where the choice cuts of meat are situated. Haunches of deer venison were presumably brought in and offered to the diners at Launceston. Similar over-representations of deer hind-limb bones are known from other castles in England.

Launceston Castle: dolphin mandible and teeth from Period 8 (fifteenth century) maximum width 15. 6cm

Launceston Castle: small cetacean vertebrae (dolphin?) from period 8 (fifteenth century) maximum height 7.8cm

Launceston Castle: whale vertebra with chop marks from period 8 (fifteenth century) maximum width 18.7cm

Medieval layers

The remains of other mammals and of several species of birds also attest to Launceston's high status in medieval times. For example, a number of kid bones were found. Kid meat was considered a great medieval delicacy and many great banquets of the period included it on their menus. Perhaps most unusual among the mammal bones from Launceston were those of whales and dolphins, which, like the fish and sea birds, indicate a strong maritime connection. Several whale vertebrae were found, which, when compared to whale skeletons in the Natural History Museum, London, come from individuals of up to 150 tons. Whether they can be interpreted as evidence of whaling or merely of the scavenging of odd bones from beached animals is impossible to determine. These vertebrae bear chop-marks, and so may have been brought inland for use as chopping boards.

Dolphins and birds

The medieval levels also contained a mandible and several other bones of dolphins. According to early cookery writers whale and dolphin livers ‘smell like violets’ and ‘taste most pleasantly being salted, and give competent nourishment...’. Marine mammal meat is said to have gone out of fashion in the late sixteenth century.

A wide range of birds was also represented in the Launceston assemblage, giving further evidence of a varied diet among the medieval aristocracy. The assemblage includes swan, heron, partridge, woodcock, plover, curlew, snipe, lapwing, crane, gannet, and shearwater. The last may have come from the Scilly Isles, which formed part of the Earldom of Cornwall.

Cattle, pigs, and sheep

The bulk of the faunal assemblage from Launceston, however, comprises bones from common animals: cattle, sheep, and pig. Careful comparisons of the measurements of these three species show that between medieval and post-medieval times (between periods 8 and 9, some time during the fifteenth to sixteenth centuries) the sizes of individuals underwent a significant increase. In the case of cattle this size increase coincided with a change in shape of some of their bones and with the disappearance of a possibly inherited dental anomaly. There were too few complete bones of sheep and pig to make a similar study of the shapes of their bones.

All of these changes, including the size increases of the sheep and pigs, may reflect local improvement and/or the import into Cornwall of new breeding stock. Various contemporary sources mention that in the seventeenth century and possibly earlier, a pied strain of cows of considerable size and possibly of Dutch origin begins to be noted among English cattle. If so, these changes could reflect the greater sophistication of sixteenth–seventeenth century farming methods.

Agricultural revolution

There is some debate among historians as to when the Agricultural Revolution began. One view links it with the accession of King George III (also known as ‘farmer George’). However an increasing number of historians now accept that agrarian improvements were under way much earlier. The changes at Launceston, together with reports of similar size increases in the bone assemblages from other sites in England, represent an independent source of data in support of the early onset of the Agricultural Revolution. Thus the Launceston animal bones not only play an important role in understanding the people who occupied the castle but also contribute towards the understanding of the economic and social history of England.

Umberto Albarella

Simon Davis

Science and Conservation Services, Environmental Studies

Current building materials research

This brief summary of the current research projects of the Architectural Conservation Branch will be followed by a further, more detailed report in Conservation Bulletin issue 25 for March 1995.

Research into the decay and treatment of historic building materials is the province of Architectural Conservation Branch within English Heritage’s Science and Conservation

Services Division. Its extensive programme of scientific testing and development, now worth more than £0.5m per year, is organised through agreements and contracts with over 15 national and international groups of collaborators, consultants, and contractors, and indirectly employs more than 30 specialists on 18 projects in the service of better building conservation.

Most of the projects are of two to five years duration and involve substantial programmes of monitoring and testing to establish scientific facts. Unless stated specifically in the text, there are no official published outputs yet available, but all the work *will* be published when tests are complete and the results are finalised.

Project summaries

AC1 Mortars (Smeaton project). This research is investigating factors affecting the properties of lime-based mortars used in conservation and the results of the first of three phases of the project have just been published.[1]

AC2 Masonry consolidants. We are currently writing the conclusions of unique long-term field reviews of Brethane alkoxysilane consolidant trials and are now attempting to establish laboratory-based methods for proving exactly where and in what condition residual consolidating material remains in weathering subject stone to tackle the question of re-treatment.

AC3/4 Floor wear and tile pavement decay. This work seeks to find ways of measuring the rate of wear and decay in historic floors, especially of encaustic tile pavements. It is also concerned to define decay mechanisms and find ways to ameliorate their effects.

Anti-graffiti wax barriers and their multiple removal and reapplication are the subject of a study with the Building Research Establishment

AC5 Polishable limestone decay. Decay in Purbeck marble and other stones is being monitored at several cathedral sites, together with laboratory testing to help us to understand the causes and processes involved.

AC6 Sandstone decay. This programme seeks to define and explain decay in sandstones with a view to preparing appropriate treatments. A literature review and decay survey mapping system will be published as a culmination to the first phase of the work.

AC7 Anti-graffiti barriers. This research is assessing whether wax-based anti-graffiti barriers, and their regular removal and reapplication, can be recommended for use to protect friable historic masonry.

AC8 Structural fire protection. Phase I has established the performance of historic, panelled timber doors in fire and the results will be published early in 1995. Other publications will include advice on fire engineering principles and a model fire safety manual.

AC9 Lime and lime treatments. This project seeks to characterise all currently available building limes for the publication of a directory. The second stage will look at lime treatments – lime watering, lime repairs, and lime shelter coating – and their effectiveness, following on from the work of Dr C Price at the Building Research Establishment.[2]

AC10 Underside lead corrosion. This long-term programme aims to determine all the parameters affecting underside lead sheet corrosion in historic roofing. A state-of-the-art summary of progress will be published soon.

AC11 Timber decay and moisture ingress. This project completed its third and final stage in 1993/4, assessing the interrelationships between environment, fungi, and beetles in cathedral roof spaces, with special attention to moisture ingress.

The results are to be assembled in a book to be launched in spring 1995 by SPONS Publishers. We have also arranged a partnership with Historic Scotland to sponsor the programme and a supporting campaign of public awareness.
AC12 Masonry cleaning. This project updates our assessments of currently available masonry cleaning systems so that we can establish policies and guidelines on them. Our consultants are redrafting the British Standard Code of Practice for the Cleaning and Surface Repair of Buildings (BS CP 6270 Pt I: 1982) and they have commenced work on a priority list of cleaning problems where additional research might assist in making recommendations to specifiers and practitioners.
AC13 Fire safety in cathedrals. Our consultants from the Warrington Fire Research Consultancy, London, recently completed a two-year study of the fire safety provisions in cathedrals, measured in the light of the recommendations in the Bailey Inquiry Report following the fire at Windsor Castle in 1992. Their report has been submitted to peer review and final revisions to the text are now being made before publication.
AC14 Terracotta decay and conservation. This project runs over two years and seeks to understand the special sensitivities of architectural terracotta to soiling, decay, and treatment, thereby to devise better care for the material. The first phase involves testing methods to assess the cleaning sensitivities of terracotta surfaces and substrates and includes a general literature review on terracotta decay and conservation.[3]
AC17 Stained glass. This two-and-a-half-year project in three phases seeks to discover the factors affecting the durability of mastics, lead cames, and Paraloid B72 adhesive in stained glass repair and conservation.
AC21 Mosaic clad concrete. This project, just begun, will bring together a team of building pathologists and mosaic conservators to elucidate how and why glass mosaic cladding decays on modern concrete buildings.
AC23 Stone slate roofing. This work is concerned with the technical and economic issues surrounding the decline in the production of non-metamorphic fissile stone roofing slates and flags (eg Cotswold and Collyweston tiles, and northern sandstone/gritstone flags).

Application of the lime watering treatment to consolidate the surfaces of decaying limestones

Rigging up environmental monitoring equipment on the medieval encaustic tile pavement of Westminster Abbey Chapter House in order to ascertain climatological data and pollutant levels

Experimental treatment with Brethane alkoxysilane at Goodrich Castle, a project started in the mid 1970s
The latter exercise is cosponsored by Derbyshire County Council and the Peak Park Planning Board.
AC204 National sand and aggregates library. Undertaken originally as a student intern's exercise, this project has developed a national reference collection of sands and aggregates for building mortars for English Heritage.
AC207 Earthen structures. This study has fostered research and other technical studies in the decay and conservation of earthen architecture. We helped to set up the Earth

Structures Committee of the International Council on Monuments and Sites and encouraged the establishment of the National Centre for Earthen Architecture at the School of Architecture at Plymouth University. Through advice with others to the university's architecture and material science departments we enabled the centre to win several university research fellowships.[4]

Current practices

Because of limitations on our resources, we are unfortunately not able to discuss our current findings in detail on a one-to-one basis until the work is complete. Technical advice to local authorities and to historic building owners and their professional advisers remains the responsibility of the regional teams in our Conservation Group and their technical policy stance to material recipes and practice remains unchanged until research findings are ultimately debated and corporate advice is announced.

John Fidler

Science and Conservation Services, Head of Architectural Conservation

Notes

1 Teutonico, JM, *et al*, 1994 The Smeaton Project: factors affecting the properties of lime-based mortars, *Bulletin of the Association for Preservation Technology (APT)* Albany, NY; off-prints available from English Heritage, Architectural Conservation Branch, Room 528, 429 Oxford Street, London WIR 2HD; price £10.00 including post and packing.
2 No scientific proof has been found for the evidence of surface consolidation of friable stonework often reported by experienced conservators; see Price, C, *et al*, 1988 Further appraisal of the lime technique for limestone consolidation, using a radioactive tracer, *Studies in conservation*, **33**, 178–86.
3 The work was presented at a national Architectural Ceramics Conference in September 1994, set up by English Heritage and the United Kingdom Institute for Conservation and held at the Ironbridge Institute, Telford, Shropshire; the proceedings will be published shortly.
4 Publications include the proceedings of a conference on the Conservation of Earthen Architecture held at Dartington Hall, Tomes, Devon (available from Plymouth University) and the creation of a national travelling exhibition called 'Out of earth', at English Heritage.