Archaeological Surveying at the Artefactual Level: Digital X-Radiography

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Iron concretions, digital X-radiography, CR system, DR system, valuation, objects per square metre.

Aims
Unlike objects in museum collections, which are already regarded as worthy of study and preservation, archaeological excavations produce numerous fragments, corroded lumps and 'things' covered in soil which may or may not be objects, may or may not have value. Archaeological conservators receivingsuch materialfrom excavations have responsibilities for aiding and informing the archaeological process as well as conserving (preserving, revealing [cleaning to restoring] and investigating)[1] any artefacts/objects[2] that are considered worthy of becomingpart of permanentcollections. The conservator's responsibility in the archaeological process requires assessment (investigation and identification)and selection, from this excavated material, of the artefacts / objectsfor retention and conservation. This is normally done in collaboration with archaeological colleagues[3]. The selected objects and their associated information can then be integrated with all the other evidence recovered from the excavation to enable archaeologists to document and understandthe human past. This pre-object existenceprior to assessment in the archaeological process is most apparent when dealing with corroded ironwork, much of which cannot be identified on site by the archaeologist, but requires the conservator to X-ray the ironwork and either the conservator, archaeologist or find's specialist, or a combination of these individuals,to go through the X-radiographs and 'identify' the artefacts/objects[4]. This paper considers thisinvestigation and the methods used to achieve it as well as theassessment and selection processes. It exploresways in which they can be made more effective and efficient.

Archaeological sites can produce many hundreds of lumps of iron oxidesand oxyhydroxides(both natural and human made,hereafter referred to as concretions). These can range from iron objectswith a light coveringof corrosion, through iron artefacts which have become completely corroded and have nothing but mineral left, to natural agglomerations of iron oxides such as iron pan or degraded ironstone nodules. There is an initial selection on the excavation by the 'diggers' who will exclude any clearly natural concretions, only selecting possible artefacts / objects. There is a need to identify meaningful objects from amongst these concretions quickly and cheaply. The costs of conservation and X-radiography have increasingly encouraged archaeologists, especially (but not exclusively) in the commercial sector[5], not to X-ray all their concretions, but to make a selection, removing what they believe areunidentifiable fragments or nails[6] and other ubiquitous objectswhich they perceive as having little archaeological value before giving them to the conservator. They areprimarily seeking to identify informative artefacts such as weapons, tools and similar highstatus objects. This potentially leads to many artefacts remaining unidentified and being discarded.Developments in digital X-radiography and archaeological / conservation decision making can potentially speed up and reduce the cost of the identification process. However, there is a need to recognise this is primarily part of the excavation process[7]rather than a conservation activity andapply archaeological methods, decision making processes and ethics rather than those of conservation,until such time as the concretion is identified as an object of sufficient value to merit conservation.

1 Example

An example of the potential loss of information is provided by bodkin / armour-piercing arrowheads of the 12th and 13th century (Figure 1). Emerging covered in corrosion such objects are visually almost identical to nails and would not be identified or selected for conservation based on visual inspection. Even on X-radiograph (Figure 2) these arrowheads appear visually similar to nails, especially when nails have corroded into hollow tubular forms[8] due to the corrosion process. Consequently many are going unrecorded / unreported. When Jessop discusses these arrowheads; M7, M8, M9 in his typology, he suggests as previous authors[9] that these arrowheads appear in larger numbers in the 13th century sites and thus areprobably a response to the increasing use of armour in the 13th and 14th century[10].However, recent work by Bunning has noted examples of tanged bodkin arrowhead forms in 10th century, Scandinavian contexts in Ireland[11]whilst Jessop noted a couple of socketed examplesrecovered from 12th century contexts such asCastle Acre. This suggests a more complex arrowhead evolution; bodkin formsare developed in the Viking period presumably to pierce mail and leather, married in the 12th century in Britain to the developing use of socketed attachment, all of which preceded the development of plate armour. Work by Stretton and Starley[12] has also raised questions about the penetrative power of these arrowheads, which are only effective when made of appropriately rigid steel.However, with so few examples from well dated contexts,the sequence of development of this weapon, its presence / absence in different cultures andthe evolution of the form all remain unclear due to the lack of well dated examples from excavations.How many have been discarded in the belief that they were nails?

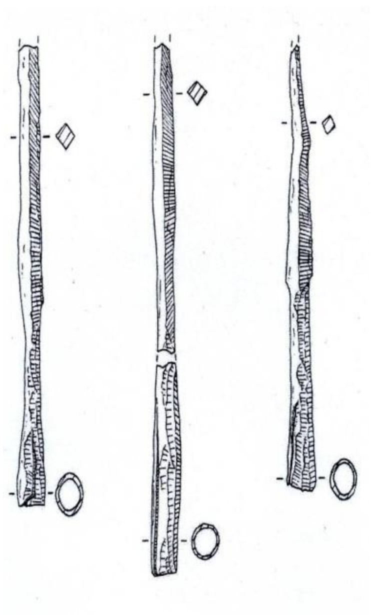

Figure 1: Bodkin type arrowheads from13th century contexts, Dryslwyn Castle (Caple 2007).

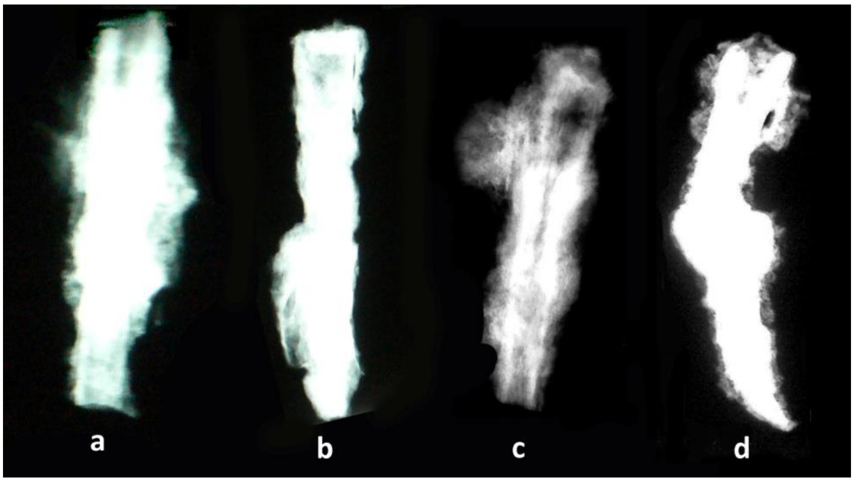

Figure 2: X-radiograph of a bodkin type arrowhead and three nails from 12th century contexts, Nevern castle

There are other examples of simple iron object forms include fragments of chains, lock bolts, barrel padlocks, keys, door furniture and tools all of which frequently go un-x-rayed and unidentified. O'Connor suggested 10% of iron artefacts identified as nails from the Coppergate excavations were in reality parts of more interesting and complex objects[13].

Archaeology Assessment and Selection

Archaeology has limited resources and a large range of potential sites[14], consequently all archaeological management processes are now expected to include:

- Understanding of the range, nature and value of material (assessment phase)
- Selection of an appropriate sample for detailed analysis (selection phase)

This selectivity applies not only to excavation, but the equally expensive post-excavation process. In 1989 English Heritage created a formal 'management of archaeological projects' process (MAP), revised by 1991 as MAP2[15], which required a formal assessment phase, after the excavation process was complete, that considered the post excavation work, looking at the value it brought and selecting whether to proceed with it as a whole or only proceed with the parts which delivered high value information, effectively cost vs. benefit analysis. This has now been replaced by 'Management of Research Projects in the Historic Environment' MoRPHE (Historic England 2015), which applies the same cost benefit ideas to all heritage projects. These, or equivalent processes, are widely practised in commercial archaeology. Consequently a quick, cheap, accurate assessment process is required to reveal the nature of the excavated material, especially the iron concretions, to inform the MAP2 / MoRPHE process. English Heritage (later as Historic England) has from the inception of MAP always advocated X-radiography of ironwork[16], the extent to which this has been done has varied considerably.

The informed selection processes continue into the museum.Even where we have identified museum objects, those worthy of investigation, cleaning and preservation, the limited conservation resources available require an object selection or prioritisation process for conservation. These may be made on the basis of the object condition, resulting in collection condition surveys or a combined curatorial valuation process and condition survey[17]. Even within the conservation process a cost benefit approach is often required to cleaning, leading to partial cleaning especially for corroded archaeological iron objects[18].

1 Valuation Processes

To emphasise the level of consideration and judgement which goes into assessment and selectionactivities, the term valuation is increasinglyused in heritage and conservation management. Valuation maydescribe the aspects (tangible or intangible) of the site/objectwhich are most useful / important / functional to individuals, groups or organisations. Valuationeffectively identifies the features or aspects of the site or objects which are most important and thusstarts to define the way in which any conservation process will proceed (to preserve/reveal/investigate the features identified as valuable).The value is used in conjunction withdetailed recording of the object / site, a clear appreciation of the nature and extent of the decay mechanisms and an appreciation of theresources available, as essential elements in formulating the conservation planning process[19]. In almost all cases the limited nature of resources means that the valuation process allows a ranking (of site or object significance) to be achieved. Resources are then made available / applied sequentially to the highest ranked until they are exhausted.

2 Example

A simple example of the valuation process used in archaeology is provided by Startin who describes the process of selecting moated sites to be protected through legislation; the legal instrument of scheduling the site as an ancient monument. Here academic / historic values were the key aspect of the sites which needed consideration. As the cost of excavation prohibits its use on all sites, assessmentswere made using a series of sub-category values; survival, information potential, diversity of features, documentation (archaeological), documentation (historic), associations, group value and amenity value. Simple numerical scales (1-3) or (1, 2) were used, though these numbers were squared to increase numerical separation. Since the sub-category valueswere considered equally important, they could be added and the resultant number used as a basis for selection[20].In this case the valuation was termed the site's 'national importance', in order to meet the terms of the 1979 *Ancient Monuments Amendment Act* and the highest scored sites scheduled.

Published examples of conservation assessment based on valuation have focussed on sites and buildings, few if any examples of simple objects have been published. This is probably because in practice experiencedarchaeologists and conservators have used their expertise to select objects e.g. from X-radiographs, without recourse to slow, formal, numerical systems. However, when training young conservators or making contentious or highly visible decisions to select only a few objects with the highestheritage significance for detailed recording or conservation, a clearly articulated, formalised mechanism is useful, see *Valuation / Identification*.

Assessment Technology: X-Ray Survey Systems

Assessments of excavated artefacts, especially corroded archaeological ironwork, have routinely taken place using X-radiography throughout the 20th and 21st century[21]. Traditionally X-radiographs were taken on film (SF) which required wet development in tanks and then drying, prior to examination. Films are typically taken and processed in batches, depending on the size of the tanks. Typically,at Durham we process batches of 6 plates (each 180mm x 125mm), each developing cycle takes 45minutes (60 minutes including the time taken to lay artefacts out on the plate and pack them away). Though in theory in a working day we can process a maximum of42 - 48 plates, this does not include any marking up of the film[22] or interpretation of the images. In practice, with identification, it would be less than half of this number. The number of concretions/artefactsimaged depends on their size. In practice, around 14 concretions are imaged per plate for the site of Nevern Castle, this means around 588 concretions imaged, or250 - 300 imaged, assessed and marked up,per day. Fell and colleagues[23] suggest 8 plates (180 x 240mm) per day(around 224 concretions) including marking up and interpretation. So around 200-300 concretions imaged and assessed, double this for only imaged. If the film is digitised for reasons of storage or image transmission, there is a loss of image quality and the number of object imaged a day falls further[24].

Film images have excellent quality and are currently the best medium in which to 'read' the image. However, most organisations such as hospitals, veterinary practice, dentists and engineering firms who use radiographs have now moved to digital imaging. Reasons include: saving in time not having to process wet film, saving costs (especially expensive silver compounds), risks and disposal problems of using chemicals (again especially silver compounds), saving space without the need for dark rooms or storing X-ray plates. The speed of obtaining the digital image and the ability to enhance, transmit and store images are also considerable benefits. There are a number of types of digital radiography systems, but given the need for low cost and the relative simplicity of most archaeological objects, 2D X-ray digital imaging systems are normally adequate. The two main types of system are: Computed Radiography (CR) unit and a Digital Radiography (DR)[25].

Computed radiography (CR) units use cassettes containinga plate coated in phosphors which have object placed on them and are exposed to X-rays e.g. in a Faxitron cabinet, as with traditional film. This cassette is then placed into a scanner (Figure 3) and a laser scans the plate, stimulating light emission from the phosphors which is proportional to the X-ray dose received by the phosphor. A photomultiplier reads the light emission level which it converts to an electric pulse giving rise of a digital image, displayed on the screen of an associated computer. The digital image can be enhanced (brightness, contrast, magnification), saved and printed, using appropriate software and devices. CR unit cassettes are sized to be similar to current x-ray film plate sizes. This means they can potentially be used in traditional *Hewlett Packard Faxitron 43806 X-Ray System*units which are present in many archaeology conservation labs[26] as well as with any of the wide range of separate X-ray generators presently available. Organisations such as the National Museum of Wales have purchased a CR system and replaced film for conservation radiography.

Figure 3: CR System (Carestream, Vita System)

Using a CR digital imaging system at Durham (*Kodak 'Point of Care'CR120 digital x-ray imaging system*) together with a stand-alone X-ray generator (*Merlin Gerin multi 9 C60N X-ray source)*, we can process around 28 digital plates per day. The digital plates we use are 6.8 times the size of the film plates. With similar numbers and sizes of concretions, 952 could be seated on a single plate andthus 2,666 concretionsimaged in a day. Again these figures do not include marking up or interpreting the imagesand thesefigures were achieved with the support of a student volunteer working with the conservator to help load and unload the plates. Careful records need to be made to correlate each object and its unique site code with its image on the plate.

Digital radiography (DR) systems comprise a flat panel detector connected (wirelessly in most modern systems) to a computer (Figure 4). Two types of detector are commonly used; direct conversion systems use selenium compounds to directly convert x-ray photons into electric charge, indirect conversion systems use a scintillator layer and a light sensitive TFT diode to create the digital signal.

Figure 4: DR System (Cuattro Slate 3+)

Objects placed on the flat panel detector will, when irradiated, give an almost instant image of the computer screen. The resultant digital image can again be enhanced (brightness, contrast, magnification), saved and printed using appropriate software and devices. DR systems have been more expensive and were initially less reliable and had poorer resolution than CR systems. Resolution and reliability are increasing and their portability can potentially make them useful (with an appropriate X-ray source) in the field. The archaeologists and conservators working on the excavations at Jamestown Virginia use a DR system to scan their ironwork. At Durham we found that many of the current DR systems are configured for medical use, intended to use low X=-ray doses, and were thus too sensitive to give good images when used with a conventional *Hewlett Packard Faxitron43806 X-Ray System*units.

It is important to note that when using either DR or CR systems it should be possible to import, export and save the original raw digital image file, before any software manipulation. Such manipulation, though usually beneficial, can create artificial effects and images which are potentially misleading and the capacity to go back to the original image is an important safeguard.

In both cases when dealing with a digital unit it is possible to 'label' the resultant image digitally e.g. using Photoshop™. However, this can be a time consuming step, only labelling those concretion images subsequently identified as objects can save time and thus reduce costs, see *Valuation / Identification*. In practice a digital photograph of the bags (or a written list of details) laid out in the same arrangement as the objects on the plate proved a convenient record of the site information.

Thehigh costs of X-ray plates and chemicals meant that the largest large a number of concretions possible were X-rayed on each film. However, the loweroperating costs of digital X-radiography means that only the objects for a single context (or restricted group of archaeological contexts) need be put on a single plate, making it easier to research individual buildings or occupation layers. At present,using CR systems appears to enable between double and triple the number of objects per day to be processed.The use of DR systems could potentially further increase the capacity to bring these costs down further.

X-radiography of archaeological objects serves two aims.

- Observing detail beneath dirt and corrosion to facilitate; cleaning, revealing the method of manufacture, locating original surface, identifying decoration and detail and detecting invisible damage. This can require high quality X-radiographs.
- Swift object identification, which can be done with slightly poorer quality digital x-radiographs.

Improvements in resolution now allow digital to be effectively used by conservators for >99% of requirements[27]. The lower running costs and lower space costs, ease of image storage and reductionin the use of chemicals recommend digital x-radiography systems too many archaeological conservators, only the high initial purchase costs; 20-80K, and potential repair bills, prevent more widespread use of such systems[28]. There is, however, no point in discarding film systems completely if there is still an occasional need to provide a high quality X-radiograph image; it may be appropriate to consider owning both systems, provided they are capable of using the same X-ray generating source. Clearly benefits of space reduction, removing chemicals etc will not be experienced.

Valuation / Identification / Decision Making/Selection Process

Given the need to manage post excavation activities, a rigorous but transparent system for selecting artefacts from X-radiographs is required. It should include clear definition of the factors involved, the weighting they are given, a clear method through which an 'overall' score is reached and a series of actions or activities which can be triggered by the overall score (thresholds). Such a system leads to an analytic deliberative or AD decision making process[29]and facilitates a significant level of transparency and control of the process.Where there are limited resources these can be focussed on the most valued objects.It should be emphasised that that this process acts as a guide to the professional conservator and is not an automatic process of the 'the computer says no' variety. It will aid further development of the system if the reasons for the inclusion of an object scoring poorly, or exclusion of an object scoring well, is recorded, analysed and used to inform the improvement of the system in future versions.Publishing the parameters on which decisions are made and their weighting, permits discussion and recognises that they may vary from site to site, culture to culture and archaeologist to archaeologist. Such discussions lead to enhanced categories and weightings, thus improving the overall decision making system, hence this article. Thresholds triggering action also vary with cultural valuation of the past and the availability of resources. Separation of the assessment and threshold for action elements aids the development of good professional practice,even when there is a poverty (or surfeit) of resources to carry out the work.

The valuation process of corroded iron concretions as objects appropriate for conservation is normally done through appraisal of the X-radiograph image and the actual object. In a number of cases it is be appropriate to turn the object through 90^o and re X-ray, so providing both plan and section X-radiograph images. This greatly increases the capacity to correctly identify the artefact. The value of an objectis based on three criteria, which can be given numerical scores (in brackets) and then totalled:

- F = Form / Shape- the more clearly identifiable an image is as an object with a function or an associated culture or date, the more useful to the archaeologist. A plain unidentifiable piece of metal has little or no value (0), a simple object of widely seen form such as a nail has a limited value (2), a tool or object with similarly identifiable function has some value (4), a clearly identifiable object with specific use which was only produced for a limited time or was associated with a specific cultural group or activity such as a weapon or high status jewellery is very valuable (6). Knowledge about object (identification) based on its shape may come from a finds specialist, archaeologist, the conservatoror researching appropriate publications. Aspects such as looking at the objects in broken cross section may be important for distinguishing between objects such as nails, arrowheads etc.
- % = Completeness – where an object is complete or near complete it reveals any damage or repair or use it has undergoneand this is valuable (2). A damaged but significant part of an object can potentially still provide some information (1) but a fragment which cannot confidently be ascribed to a particular part of the object effectively has no value (0).
- C = Context - the more securely dated the context, the more informative it is for the site the better. The context information comes from the archaeologist, who will invariably use tools such as phased Harris matrices[30] to establish such information. Low value is ascribed to unstratified finds (1). Those re-deposited in later contextsor from contexts built up over a long period of time (2). The highest values are where a deposit is clearly related to a specific event which occurred at a known time (relative or absolute) suchas foundation or destruction of a building or an event such as a siege (3), The value 0 is not used because even an unstratified object may have some value, indicating the presence of a specific group or activity on the site.

It will be noted that the relative worth of these numerical values are not equal;theweightings derive from the author's experience and that of colleagues at Durham. The form or shape of an artefact is the principal method of identification, hence the enhanced numerical weighting. It alsorecognises that objects such as tools and weaponsfrom well dated contexts are far more archaeologically valuable than complete or well contexted simple artefacts such as nails. Consequently the product (F x % x C) of the weightings is used. A well contexted complete tool or weapons would thus score36 (6 x 2 x 3). Arguably there may also be additional valuation where there are features such as decoration or plating are present, though such features devoid of the essential elements would mean little and thus a value of 0-4 might be added to the score giving a maximum score of 40. Interesting and only partially damaged objects even from unstratified contexts would score 6(6 x 1 x 1) as would fragments of simpleobjects from good contexts(2 x 1 x 3). Largely completesimple objects such as hinges in a redeposited[31] context would score 8 (4 x 2 x 1). All of these may be worthy of further observation, even drawing or partial cleaning. Thus conservation and retention as an object, part of the collections from the site, may occur for an object with a combined values as low as 6, but the level at which concretions are classified as 'objects'and retained for conservation, will depend on the site, level of funding etc. Higher valued objects are likely to require significant specialist reports. Experienced conservators, finds researchers and archaeologists,when looking at X-radiographs and objects, perform these assessments in fractions of a secondand for them it is a heuristic decision making process[32] However, when explaining the process e.g. when teaching, or when you are learning, it is important to be able to break this process down into its component steps so young conservators and archaeological colleagues can understand how decisions are arrived at, as an analytic, deliberative decision making process.

Interpretation

It is not the production of the cleaned object which is of primary importanceto archaeology but the information it provides about the past. It is thus important for the conservator to be aware of thetype of information which is created and published about ironwork in archaeological reports.Objects providearchaeologists with information on date, culture, function, symbolism (ideas and beliefs such as wealth, fashion, taste and religion), recycling, repair and reuse (object biographies). Their distribution through time and space informsabout changes in activity, peoples present, belief etc. The valuation process identified above gave higher scores for objects with more complex and specific function and higher levels of decoration, objects which are more readily datable and often culture specific. It has been found convenient, when working with artefacts, to consider them in three forms: bespoke, crafted and mass produced[33] which refers to their method of production, but which also effectively maps onto their values, their conservation treatment as well as the approach taken by archaeologists to their research and reporting:

- Bespoke – complex objects, often made to order, valuable materials and having highly decorative character. Objects such as highly decorated jewellery, weaponsor pieces of sculpture reveal much about the date, culture, biography, change in fashion and luxury trade.
- Crafted Objects – usually involve specific materials, some decoration, careful control of form, value etc. Objects such as coins, tools such as armour-piercing arrowheads, decorated ceramic and glass vessels, they reveal information about date, culture, activities on site, technology of processes, wealth etc, though their high functionality means they are used for long periods and some objects change form very little over time.
- Mass produced objects such as course pottery, pins, nails and spindle whorls. Here any one individual object indicates little other than its function / associated activity and since they do not change much over time, they have minimal use for dating. However, with low value they are frequently lost and are not recycled, so they are a good indicator of the presence of specific activities, trades or groups or cultures. They are often studied as the product of an industry; changes in the industry are tracked through the changing product.

Bespoke objects are invariably X-rayed,selected, cleaned, drawn, researched, published and preserved. Craftedobjects are often X-rayed, (though some are not initially identified as such due to obscuration by corrosion and are only picked up with mass X-radiography) selected, either cleaned or often partially cleaned, drawn, researched and published. Some effort is made to preserve them. Mass produced objects such as roves, chain links or nails are only occasionally X-rayed and rarely if ever even partially cleaned. Only occasionally are they published and only occasionally are even a selection preserved due to the high cost of storage and perceived low value of the objects. If they are researched and recorded, it is when there are large numbers and distribution patterns can be seen across the site, across time or between sites and periods. Goodall has shown the value of being able to identify these relatively plain mass produced objects[34]. Thompson for examplehasshown that by noting the types of nail present you can identify the type of roofing present on a building[35]. These artefacts will, however, never provide information about the past if they are not recorded in detail or retained for further study;but the cost is high. The solution may be not be retaining the object, but its digital X-radiograph. Not as informative as the actual object, like much of the site record[36] it is a proxy, and does ensure that some permanent record survives and permits the possibility of future study.

Interpreting Iron Objects

Archaeological objects have normally been recorded, researched and reported from archaeological excavations such as Dryslwyn Castle[37] or published in museum catalogues[38]. Increasingly organisations such as YAT (York Archaeological Trust) and MOLA (Museum of London Archaeology) are publishing monographs on objects from groups of sites within a city to maximise the research potential of these objects[39]. Recently the information on widely dispersed single finds recovered by metal detecting and reported through the PAS has created a new research resource for archaeological object research[40]. Individual objects continue to be studied in detail[41] and groups of specific object types subject to typological study and published in academic journals[42].

The presence, absence or concentration of objects around a site is a key part of the interpretation, as are the differences and similarities in object types and concentrations between sites. However, variations in object numbers between sites are highly influenced by the size of the excavation. To overcome this bias Morgan[43]has recorded the presence of object as ‘numbers of objects per square metre excavated’, Figure 5. This allows concentrations of the object to be identified independent of the size of the excavation.

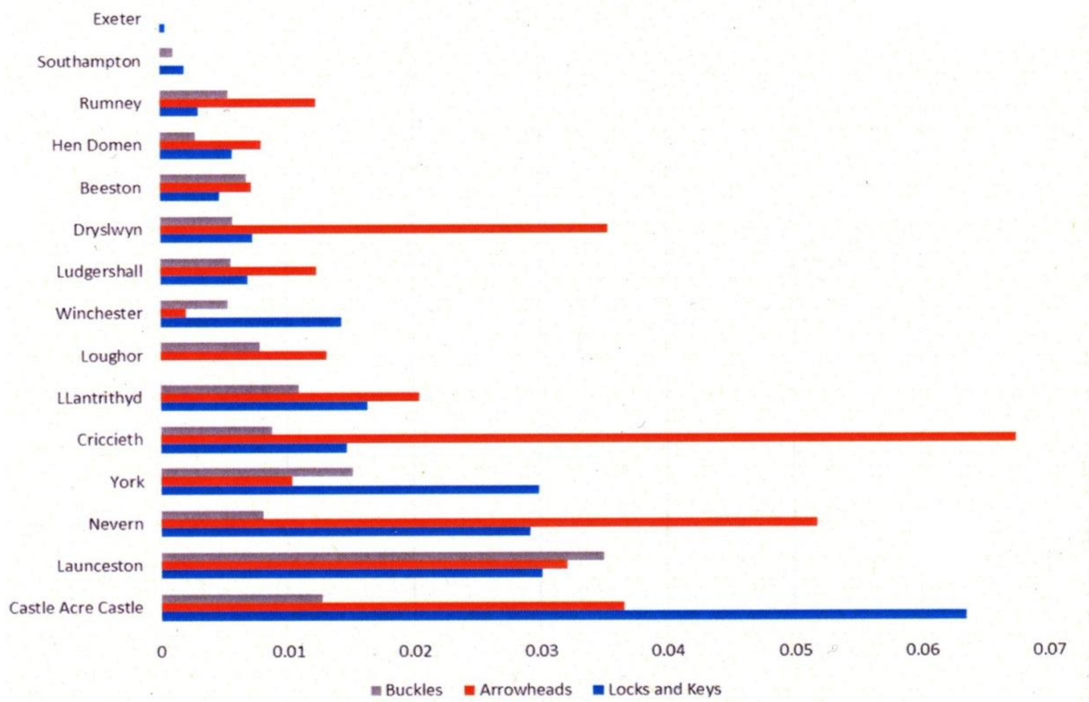

Figure 5: number of arrowheads, buckles and locks/keys per square metre from a range of medieval sites[44]

Whilst it may be imagined that many factors such as the rate of corrosion, and the nature of the excavators may bias the recovery of artefacts, thus far two reasons dominate:

- Publication: some excavations are highly selective and appear not to identify or publish information on many of their iron finds. As Figure 5 shows both Southampton / Exeter – excavated hundreds of square metres but have published few iron finds. This reflects publication policy and in most cases the extremely low values of objects/m^2 result from incomplete publication. It may be appropriate to exclude such sites / regions from detailed regional or national pictures of artefact assessments as a result of the nature of the bias it produces.
- Sites which have X-rayed 100% of the iron artefacts recovered from the site, such as Dryslwyn and Nevern Castle excavations generally have high numbers of objects/m^2 recorded.

Current experience suggests that corrosion rates do not denude a site of ironwork, just leave it in a highly corroded condition. This is exemplified by Nevern Castle which is barely three miles from the sea and possesses a highly acid soil on slate geology, yet it still produces a good volume of ironwork, even if it is in a highly corroded condition. Historic sites devoid of ironwork are a result of stripping the metal from the site and its recycling, by human beings.

Beyond the biases, the intensity of occupation is revealed by high concentrations of ubiquitous objects required by a wide range of people for a wide range of activities. Objects such as knives and buckles are not specific to a single activity type or group and thus reveal the extent of occupation. Levels of buckles 0.004-.014/m^2appears normal for medieval town and castle sites. Launceston appears much higher suggesting either buckle using activities were practised on site, such as the use or manufacture of armour, or there may be errors in the reported area of excavation. Crucially, as might have been expected, finds related to specific activities do vary with site type, it is no surprise that large numbers of arrowheads were recovered from castles which experienced a lot of military activity such as Criccieth, Dryslwyn and Nevern.

However, objects such as locks and keys are more complex to interpret. Locks are frequently found in locations where there is a concern about theft; locations such as towns and markets (York, Winchester) with large number of strangers, whilst the levels are low in rural communities (Hen Domen, Llantrithyd) where everyone knows everyone else. The rich castles of England (Acre and Launceston) have amuch higher number of locks than castles in active war zones, such as Hen Domen andDryslwyn. Presumably locks provided little security in a war zone where a locked door might be kicked in, indicating that Acre and Launceston castles had more social than military functions from the 13th century onwards. High levels of locks at Nevern Castle (c.f. Hen Domen or Dryslwyn) or at York (c.f. Winchester) need more detailed explanation, but such potentially interesting research is highlighted by this method.

The use of the 'number of artefacts / objects per m^2 excavated' allows relative concentrations of artefacts from sites of different sizes and different volumes of excavation to be compared. Though an imperfect measure it gives an indication of:

- those sites where publication even research and recording of objects is incomplete
- what occurred on small and partially excavated sites in comparison to larger more fully excavated sites
- unusual concentrations and omissions allow us to better interpret where activities took place on sites and how activities changed over time.

Conclusion

Most publications on X-radiography and conservation focus on improving the quality and legibility of X-ray images[45]. However, for archaeological conservators there exists, for that period of time before the archaeological finds have become identifiably objects, a clear need for relatively quick and cheap X-radiograph images upon which object identification decisions can be made, in order to complete the archaeological process. Whilst in museums and private collections unexamined artefacts wait, still stored, for future examination and analysis, if archaeological finds are not identified as objects,at the point of site assessment, they are not retained but discarded.

Shorn of naive notions of the value of the past by the realities of commercial archaeology archaeological conservators in the UK are only too awarethat the value of the past is what local politicians, private individuals and businesses will actually pay for. On waterlogged city centre sites, planning authorities consider 5% loss of archaeological deposits through piling, without any archaeological recovery or record, as acceptable[46]. Of the excavations carried out, some are not published and those which are, havebeen assessed to establish whetherthe cost of conserving theobjects represents ‘value for money’. In some reports objects are drawn and reported-on uncleaned, in others they are drawn straight from X-rayand in some cases conservation labs are paid only to take X-radiographs they are not consulted over interpretation of the image[47].

Costs of long term storage of ironwork, at reduced RH levels to ensure the stability of the ironwork[48], in museums are substantial[49]. Increasingly artefacts must have a value sufficient,not just to be identified and recorded (possibly cleaned and conserved), but also to justify such museum preservation. Many museum suffering cuts in central or local government funding are now refusing to accept anything than high value finds[50]. In many cases the preservation of a digital image may be all that can be afforded, especially for mass produced iron objects. This is a poor proxy to the actual artefacts, but given the focus now given to digital archiving it may be realisticallywhat needs to be done to ensure that something survives.

The advent of digital X-radiograph systems, the increasing awareness of ‘an assessment and selection phase’ in post excavation work, the potential of many mass produced objects to provide informationargues that archaeological conservators should urge archaeologists to X-radiograph ALL iron artefacts. Given the realities of limited budgets and the high cost of object retention for museums and units we should then consider retention of the digital X-radiographs and four outcomes (fates) for the artefacts:

I. Clean, conserve and retain all bespoke and many crafted objects.
II. Partially clean discerning key features such as cross sections for many of the crafted objects, recognising that x-radiographs do not provide the whole story[51]. Objects are recorded and then discarded or retained as appropriate.
III. Identify mass produced / ubiquitous objectsthrough their x-ray image. The object itself is normally discarded but a sample number of objects may be retained from well dated contextsto demonstrate the object type.
IV. Not discernible as an artefact and discarded.

The digital X-ray imaging systems now starting to be used make total assessment surveys of site ironwork more affordable, meaning that in the future archaeological artefacts such as nails and armour piercing arrowheads need not be completely lost to archaeological researchers.Retention of a digital X-radiograph image creates a potentially permanent record which could be; reinvestigated in future, shared almost instantly with anyone else around the world and is readily incorporated into the archaeological excavation archive. It should be remembered storing digital data is not without its own risks and digital X-ray systems are not cheap. Where there is need for high quality X-radiographs, it is perfectly possible to retain and use film alongside the digital should the need arise.

Footnotes

1 – Caple, C. (2006) *Objects Reluctant Witnesses to the Past*, Abingdon: Routledge, 33-35

2 - The term artefact is widely used to by the archaeological community and refers to 'things which have beenworked by human beings', literally anything which is not natural and attests in some way, even through arrangement or selection the hand/choice of human beings (Caple 2006, 1). The term isused in this paper to refer to any corrosion or fragment of metal. Even if it is not discernible as an object now, it was once metal and thus evidence of human activity.The term object can be defined as 'things capable of being presented' - Chambers 20th Century Dictionary (1972) and is used in this paper to mean some whole or fragment of an artefact whose function can be identified and is of sufficient value for display or research i.e. worthy of collection.

Concretions - all lumps of iron and iron minerals natural and human-made.
Artefacts - all lumps of iron and iron corrosion minerals which derive from human activities.
Objects - all lumps of iron and iron corrosion mineral which can be identified as having a specific function and are worthy of retention.

3 – A version of this paper will also be submitted to professional archaeology journals to attempt to raise this issue with the archaeological community.

4 – The issues of assessment of ironwork from archaeological excavations at York Archaeological Trust were described by Sonia O'Connor (O'Connor, S. (1996) 'Developing a conservation strategy in a rescue archaeology environment', in A. Roy and P. Smith (eds) *Archaeological Conservation and its Consequences, 1996 IIC Copenhagen Congress*, London: IIC , 133-136). She also discussed the specific details of the selection process for the ironwork from the site of Coppergate, York (O'Connor, S. (1992) ' Conservation of the Coppergate ironwork', in P. Ottaway*, Anglo-Scandinavian Ironwork from Coppergate*, The Archaeology of York 17/6: 466-471, London: CBA) where full X-radiographic assessment was carried out; a total of 650 iron objects received conservation treatment out of a total of 4700 iron artefacts.

5 – In England there is a legal obligation for developers to assess the impact of any building on potential archaeological remains (from March 2012, The National Planning Policy Framework). If present such remains must be identified and recorded prior to loss or, if sufficiently valuable, appropriately preserved. This has resulted in a commercial archaeology sector generating a large amount of excavated material which often comes from partially excavated sites (excavating only to the depth of the proposed building foundations). Such sites often have only limited stratigraphy and dating evidence and are consequently only published in grey literature or online (Roth, B. (2010) An Academic Perspective on Grey Literature, *Archaeologies* 6:2, 337-345). For this sector a cheap, quick assessment and selection process is required to reveal any important excavated artefacts; islands of valuable information in this sea of material with limited archaeological and historical value.

6–Nails are so numerous on Roman and medieval sites that they are not normally conserved. A selection may be retained, but only rarely are they recorded, researched and published in any detail (Thompson 2007). They are often considered not to provide sufficient information to warrant publishing or retention.

7 - Fell, V., Mould, Q. And White, R. (2006) *Guidelines on the X-radiography of Archaeological Metalwork*, London: English Heritage

8 - Watkinson, D. and Neal V. 1998 (3nd Edition)*First Aid For Finds*, Hertford: RESCUE, British Archaeological Trust, UKIC, 35

9 - Ward-Perkins, J.B. (1940) London Museum, Medieval Catalogue. London: HMSO, 68

10 - Jessop, O.M (1996)'A New Artefact Typology for the Study of Medieval Arrowheads', *Medieval Archaeology* 40, 192-205, Jessop, O.M. (1997)*Medieval Arrowheads*, Medieval Finds Research Group 700-1700, Datasheet 22, Jessop, O. (2007), Weapons, in C. Caple 2007 *Excavations at Dryslwyn Castle 1980-1995*, Society for Medieval Archaeology Monograph 26, Leeds: The Society for Medieval Archaeology, 201.

11- Bunning, S.J. (2015) Image and Reality in Medieval Weaponry and Warfare: Wales c1100-c1450, unpublished PhD thesis, Bangor University, notes the presence of early bodkins forms reported by Viking Ireland quote d by Halpin: Halpin, A. (1997) 'Archery Material', in M.F. Hurley & B.O. Scully (eds.) *Late Viking Age and Medieval Waterford: Excavations 1986-1992*, Waterford: Waterford Corporation, 538-552, Halpin, A. (2008) Weapons and Warfare in Viking and Medieval Dublin, Dublin: National Museum of Ireland.

12 - Stretton, M, (2010) 'The development and manufacture of military arrowheads', in H.D.H. Soar, *Secrets of the English War Bow*, Yardley-Pennsylvania: Westholme, Starley, D. (2005) 'What's the Point? A metallurgical insight into medieval arrowheads.' In R. Bork (ed.) *De Re Metallica: The Use of Metal in the Middle Ages*, Surrey: Ashgate Publishing Co.

13 - O'Connor, 'Conservation of the Coppergate ironwork', 1992, 467

14 - In the 18th and 19th century archaeological remains such as Pompeii and Stonehenge were regarded as rare isolated examples of the distant past. However, the advent of aerial photography in the 1920's and 30's by pioneers such as O.S. Crawford led to an appreciation that the British archaeological past was not confined to the obvious monuments such as castles and villas but was a landscape filled with ancient settlements, field systems, trackways and barrows. Subsequent developments in survey techniques such as LIDAR and most recently satellite imaging, have shown that the whole world, from the Amazon jungle to the Sahara desert, is filled with extensive traces of the ancient past. An appreciation by archaeologists of the widespread presence of the archaeological past in the world around us has meant that where sites are chosen for excavation or preservation they are selected from a wide range of known and carefully assessed possibilities. Excavation is now such an expensive process that clear, evidence based decisions must be made about which sites to excavate and even where within them to excavate. Geophysical techniques such as resistivity, magnetometry and ground penetrating radar are now routinely used, enabling us to survey beneath the soil surface and assess the archaeological value of the site, so aiding selection processes for either excavation and / or preservation.

15 - English Heritage (1991) *Management of archaeological projects: MAP2*, London: English Heritage.

16 - Fell, et al. *Guidelines on the X-radiography of Archaeological Metalwork,* 2006

17 - Keene, S. (1996) Information for Preservation, *Managing Conservation in Museums*, Chapter 8, 112-135, Dollery, D. (1994) 'A Methodology of Preventive Conservation for a Large, expanding and Mixed Archaeological Collection', in A. Roy and P. Smith (eds) *Preventive Conservation Practice, Theory and Research: 1994 IIC Ottawa Congress*, London: IIC, Dollery, D. and Henderson, J. (1996) 'Conservation Records for the Archaeologist?', in A. Roy and P. Smith (eds) *Archaeological Conservation and its Consequences, 1996 IIC Copenhagen Congress*, London: IIC

18 - Caple C. (2000)*Conservation Skills: Judgement, Method and Decision Making*, London: Routledge, 170-174. O'Connor ' Conservation of the Coppergate ironwork' 1992

19 - Clark, K. (2001). *Informed Conservation*. London: English Heritage. Demas, M. (2000). 'Planning for Conservation and Management of Archaeological Sites: A Values Based Approach.' In J.M. Teutonico and G. Palumbo (eds), *Management Planning for Archaeological Sites*. Los Angeles: GCI, 27-54.

20 - Startin, W. (1993). 'Assessment of Field Remains.' In J. Hunter and I. Ralston (eds), *Archaeological Resource Management in the UK*. Stroud, Alan Sutton Publishing, 184-196.

21 - Caple, C and Clogg, P (1994) *An Assessment of Digital Image Processing in Conservation*, Ancient Monument Laboratory Report 27/94, London: English Heritage. Cronyn, J. (1990) *The Elements of Archaeological Conservation*, London: Routledge. English Heritage (2008) *Investigative Conservation*, London: English Heritage. Fell, V., Mould, Q. and White, R. (2006) *Guidelines on the X-radiography of Archaeological Metalwork*, London: English Heritage. Corfield, M. 1982 Radiography of Archaeological Ironwork, in .W. Clarke & S.M. Blackshaw (eds) *Conservation of Iron*, National Maritime Museum Monographs and Reports No. 53, 8-12. London, Lang, J. and Middleton, A. (2005) *Radiography of Cultural Material*, Elsevier.

22 – Adding details of the site, context and small finds numbers, or similar unique alphanumeric identifier, is added to each plate and where appropriate to each identified image.

23- Fell, et al. *Guidelines on the X-radiography of Archaeological Metalwork*, 2006

24 - O'Connor, S. & Maher, J. (2001) 'The digitization of X-radiographs for dissemination, archiving and improved image interpretation', *The Conservator* 25, 3-15.

25 - Lanca, L. and Silva, A. (2009a) Digital radiography detectors -A technical overview: Part 1', *Radiography* 15, 58-62. Lanca, L. and Silva, A. (2009b) Digital radiography detectors - A technical overview: Part 2', *Radiography* 15, 134-138

26 - O'Connor, 'Conservation of the Coppergate ironwork', 1992, 468

27 - Questions regarding the quality of radiographic image (sharpness, contrast and noise – graininess) and the associated IQI testing devices (image quality indicators) are not discussed here. At Durham we used a series of objects, (dressed doll, corroded coin etc) relevant to archaeology and conservation to compare a small number of systems. IQI devices invariably reveal film as generating higher quality images than digital, though they can be useful for distinguishing between digital systems.

http://www.cmarques.com.br/dbimg/pdf/85_115.pdf https://www.nde-ed.org/EducationResources/CommunityCollege/Radiography/TechCalibrations/controllingquality.htm

When looking at either CR or DR systems, 'signal to noise ratio, bit depth and detector resolution' are all crucial elements in determining the quality of the image(O'Conner pers. comm.)

28 - Equipment can often be purchased through separate capital or equipment funds and/orattracting grants for such improvements. True costing would require that charges for subsequent commercial work sought to recover the cost of replacement systems over an appropriate (10year?) period. In which case operating costs would be higher and the benefit over film reduced, though it may be offset with an increased volume of work being processed.

Since archaeologists usually only sample excavate part of the site, only recover the iron artefacts during the digging process (sieving all recovered soil is a luxury they cannot afford) they are quite prepared to accept a further loss of objects from unrecognised concretions in post-excavation assessment. Unless cheap, fast,digital X-radiograph imaging is available, they will increasingly continue to select 'known' objects for x-radiography and conservation. Where we are not getting ironwork in at all, it may be digital or nothing.

29 - Henderson, J. and Waller, R. (2016) effective preservation decision strategies, *Studies in Conservation* 61, 61, 308-323

30 - Harris matrices are charts showing the relative stratigraphic position of contexts and key relationships against a vertical scale. Geographic relationship is not important, the relative stratigrahicposition is the key factor. Bands in these matrices can be ascribed phases which can be given dates (Harris, E.C.(1989)*Principles of Archaeological Stratigraphy*. London & New York: Academic Press)

31 - Redeposited - object from an earlier period which has been found in a later layer (context) – this frequently occurs, the soil is filled with artefacts of earlier periods, both now and then.

32– Henderson and Waller 'Effective preservation decision strategies' 2016,

33 - Caple, C. (2006) *Objects Reluctant Witnesses to the Past*, Abingdon: Routledge, 18

34- Goodall, I. (2011) *Ironwork in Medieval Britain: An archaeological Study*, Society for Medieval Archaeology Monograph 31. London: Society for Medieval Archaeology

35 - Thompson, A. (2007) Nails, in C.Caple, *Excavations at Dryslwyn Castle 1980-95*, Society for Medieval Archaeology 26, London: Society for Medieval Archaeology,175-182

36 - Excavations remove evidence as they excavate, so once excavated site often only exists from the records: the drawn plans& sections, photographs and context sheets created as the site was dug away. Thus nails and other mass produced objects would be treated no better or worse than any other piece of site information existing only in image or descriptive form.

37 - Caple, C. (2007) *Excavations at Dryslwyn Castle 1980-95*, Society for Medieval Archaeology 26, London: Society for Medieval Archaeology

38 - Ward-Perkins, London Museum, Medieval Catalogue, 1940

39 - Egan, G. 2005, *Material Culture in London in an Age of Transition, Tudor and Stuart period finds c1450-c1700 from excavations at riverside sites in Southwark*, MOLAS Monograph 19, London: MOLAS, English Heritage. Egan G. and F. Pritchard (rev. ed.) 2002 *Dress Accessories 1150-1450*, Medieval Finds from Excavations in London 3, London: Boydell Press. Ottaway, P and P. Rogers 2002*. Craft Industry and Everyday Life: Finds from Medieval York*, The Archaeology of York: The Small Finds17/15, York: CBA.

40 - Kelleher, R.M. 2012. *Coins, Monetisation and Re-use in medieval England and Wales: new interpretations made possible by the Portable Antiquities Scheme*. Unpublished PhD thesis, Durham University. Leins, I.M.R. 2012. *Numismatic data reconsidered: coins distributions and interpretation in studies of Late Iron Age Britain*. Unpublished PhD thesis, University of Newcastle

41 - Harkel, L.T., Weetch, R. and Sainsbury, V. (2016) 'An Early Medieval Polychrome-Enamelled Brooch from Flaxengate, Lincoln: Continental Fashions in an Anglo-Scandinavian Town, Medieval Archaeology 60/1, 57-71

42 – Jessop 'A New Artefact Typology for the Study of Medieval Arrowheads', 1996

43 - Morgan, K. 2013 '*Locks and Keys Excavated from Nevern Castle, Wales*', unpublished Research Project, Dept of Archaeology, Durham University

44 - Morgan '*Locks and Keys Excavated from Nevern Castle, Wales*', 2013

45 - O'Connor, S. and Brooks, M. (207) X-Radiography of Textiles, Dress and Related Objects: techniques, Applications and Interpretation. London: Routledge.Lang, J. and Middleton, A. (2005) *Radiography of Cultural Material*, Elsevier

46 - Davis, M.J., K.L.A. Gdaniec, M. Brice et al. (2004). *Mitigation of Construction Impact on Archaeological Remains*. London: English Heritage. Biddle, M. (1994) *What Future for British Archaeology?*, Oxbow Lecture 1, Oxford.

47 - Ian Panter and Mags Felter (York Archaeological Trust) pers. comm.

48 - Rimmer, M., Thickett, D., Watkinson, D. and Ganiaris, H. (2013)*Guidelines for the Storage and Display of Archaeological Metalwork*. Swindon: English Heritage.

49 - The problems with storage of archaeological finds are exemplified by the refusal of some museums to accept more finds and the limitations placed by others (no ceramic body sherds - Durham County Council museums) and similar. Corroded archaeological ironwork perhaps represents the greatest challenge to museums in the current age. A recent survey of museums in the north east in England showed that more that 50% have no form of control of relative humidity for the archaeological ironwork in storage. (Harder, S. 2007*The Current State of Archaeological Ironwork Storage in North East England*, unpublished MA Dissertation).This is almost certainly typical. Given our understanding of iron corrosion, see Rimmer above, it is clear that such items will not last in perpetuity, survival to a more aware period where resources are more plentiful, is their best hope. This seems unrealistic, consequently either the cost of their survival must be reduced or their value raised. Existence in digital X-ray form, though not ideal, would make them a viable

research tool. The problem then becomes one of acquiring digital X-radiography imaging systems, and, if they cannot be used with existing X-ray generator systems such as existing Faxitronunits, new X-ray generating sources.

50 - Jennifer Jones pers. comm..

51 - Caple, *Conservation Skills: Judgement, Method and Decision Making*, 2000

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Abstract

Archaeological conservators do not start with objects, but a range of iron concretions and other lumps of material covered in soil recovered from archaeological sites. Working in conjunction with archaeological colleagues the initial requirement isto assess this material and identify the artefacts/objects. This is part of a wider assessment and selection process which occurs throughout archaeology and is seen in thepost-excavation process (in the UK) as systems such as MAP1, MAP2 or MoRPHE. Experience has shown that the high cost of film based x-radiography is leading archaeologists to pre select objects for X-radiography rather than X-radiograph all ironwork.This is resulting in missing artefacts. The recent development and improvement of digital X-radiography, often divided into CR (computed radiography) and DR (digital radiography) systems,now provides a quicker and potentially cheaper, if slightly lower quality,alternative to film. The actual assessment or valuation process is normally only discussed in print in the case of large building conservation projects. It can usefully be applied to the valuation of individual iron concretions, factors such as form, completeness and archaeological context are seen to be crucial. There is benefit in considering this as an analytic deliberative decision-making process to those learning conservation and those seeking to improve the process. For experienced conservators it is often a heuristic decision making process. There is also benefit of X-radiography of all ironwork from an excavation to record the extent of objects recovered from the site (objects /m^2 excavated) aiding research into artefact use and site interpretation. It is noted that the extent of conservation and research applied to objects is usually related to their means of production; bespoke, crafted and mass produced. Given the high cost of ironwork storage and due to recent funding cuts, museums in the UK are exhibiting increasing reluctance to store lower value iron objects, mass produced and some crafted items appear increasingly likely only to be retained in digital X-radiograph image form or not at all.

Biographies

Vicky Garlick originally completed an undergraduate degree in English Language and Linguistics at Lancaster University before deciding on a career in the museums sector. She completed her master's degree in the Conservation of Archaeological and Museum Objects at Durham University, where she

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Chris Caple graduated from Cardiff with a BSc in Archaeological Conservation and was awarded his PhD from Bradford University on the composition and manufacturing technology of medieval copper alloy pinsin 1986. Between 1984 and 1988 he was the artefacts conservator at the York Castle Museum. From 1988 he was lecturer in Archaeological Conservation at the Dept. of Archaeology, University of Durham, becoming a senior lecturer in 1996. As an archaeologist he directed excavations at Dryslwyn Castle in Dyfed 1980-1995, published in 2006, and Nevern Castle, Pembrokeshire 2008-present. He wrote *Conservation Skills: Judgement, Method and Decision Making* (2000) followed by *Objects: Reluctant Witnesses to the Past* (2006) and most recently *Preservation of Archaeological Remains in Situ* (2016). He is an Accredited Conservator Restorer (ACR), Fellow of the International Institute for Conservation (FIIC) and Fellow of the Society of Antiquaries (FSA).