Science for Historic Industries
Guidelines for the investigation of 17th- to 19th-century industries

ENGLISH HERITAGE
Foreword

The English Heritage Archaeological Science teams have issued multi-period guidelines for particular topics – for example Archaeometallurgy, Environmental Archaeology and Geoarchaeology. With the increase in archaeological work during the redevelopment of brownfield sites, and the research opportunities that these offer, it is appropriate to issue this guideline on the potential of a wide range of scientific methods to contribute to historic urban archaeology. Archaeology has much to tell us about how industrial processes were actually carried out, even those of relatively recent date.

The English Heritage Industrial Archaeology Panel has encouraged the provision of this guidance. It is aware that the pressures of contract archaeology make it crucial for both local authority archaeology officers and contractors to plan for the use of specialised methods, from the outset of a project right through to publication. It is hoped that these guidelines will assist them, not only by explaining the techniques involved, but also by using recent examples to demonstrate their worth.

David Crossley, Chair, English Heritage Industrial Archaeology Panel

Contents

1 Summary .................................................. 3

2 Introduction ............................................. 3

   Case Study 1: Riverside Exchange, Sheffield ...................... 4

2.1 Archaeological approaches to historic industries .................. 5

2.2 The importance of science in understanding the industrial past ............... 5

2.3 But doesn’t history tell us everything we need to know? ................. 5

   Case Study 2: Upper Forge, Coalbrookdale ......................... 6

3 Fieldwork and sampling for historic industries .................... 7

3.1 Project planning ........................................ 7

   Case Study 3: The Beswick pottery, Barford Street, Stoke-on-Trent .......... 8

3.2 The scale of industrial sites .................................. 9

   Case Study 4: Steam-powered cotton-spinning mills in Ancoats, Manchester .. 10

3.3 Site formation processes ..................................... 11

3.4 Contaminated land ......................................... 11

3.5 Historical sources ......................................... 11

   Case Study 5: Leadmill, Sheffield .................................... 12

3.6 Specialists .............................................. 13

3.7 Sampling ................................................. 13

4 Scientific analysis ......................................... 13

   Case Study 6: Percival, Vickers glassworks, Manchester ............... 14

4.1 Locating historic industries .................................. 15

   Case Study 7: Rievaulx Abbey ironworking, Yorkshire .................. 16

4.2 Dating historic industries ................................... 17

4.3 The environmental impact of historic industries .................. 17

   Case Study 8: Silkstone glassworks, Yorkshire ....................... 18

4.4 Investigative conservation ................................... 19

4.5 Understanding historic technologies ............................ 19

4.5.1 Visual inspection ....................................... 19

4.5.2 Low-power microscopy .................................... 19

4.5.3 High-power microscopy .................................... 19

4.5.4 Elemental analysis ........................................ 20

4.5.5 Identifying compounds ..................................... 21

4.5.6 Investigating process temperatures .......................... 21

5 Historic archives .......................................... 22

5.1 Introduction ............................................ 22

5.2 Maps .................................................. 22

5.3 Public records ........................................... 23

5.4 Private records .......................................... 23

5.5 Legal papers ............................................ 24

5.6 Contemporary publications .................................... 24

5.7 Paintings and photographs .................................... 25

6 Summaries of selected industries ............................... 25

6.1 Iron .................................................. 26

6.2 Glass ................................................ 27

6.3 Pottery ................................................. 28

6.4 Textiles ................................................. 29

6.5 Tanning ................................................. 30

7 Where to get information and help ................................ 31

8 References ................................................ 32
These guidelines are intended to aid archaeologists working on sites of historic industries. They provide examples of recent archaeological investigations, which illustrate current practice and show how methodologies from several different disciplines are being combined to enrich our understanding of the industrial past. They also demonstrate the additional information that can be obtained by applying scientific techniques. For the purpose of these guidelines ‘industries’ are non-domestic manufacturing activities (but not the production of foodstuffs) and ‘historic’ covers the period from the early 17th century to the late 19th century. The broader economic and social context of these industries is not addressed here. Some of the issues explored are particularly relevant to urban sites, but the principles have wider application. Despite the crucial contribution that scientific techniques can make to archaeology, their application to the post-medieval and later periods has been rare (Crossley 1998). These guidelines describe some of the techniques that are commonly used and include examples of the ways in which they have been, or could be, applied to the archaeological remains of historic industries.

1 Summary

The first section, ‘Fieldwork and sampling for historic industries’, describes some of the difficulties posed by sites of historic industries – such as their size and contamination – and summarises some solutions to these problems.

The second section, on ‘Scientific analysis’, describes some of the scientific techniques that have been used on historic industrial sites and those with potential for future use. The application of scientific techniques to historic industries is still in its infancy. Nevertheless, there are recent examples that show how a variety of well-established techniques can be used to investigate the types of raw materials consumed and finished products manufactured at a site, as well as the processes involved.

Many sources of ‘Historic archives’ are likely to be unfamiliar to archaeologists who do not normally work on sites of historic industries. These sources can provide detailed information about the layout of a site and the function of individual buildings. Contemporary literature can also provide details of specific industries and processes.

To illustrate the points made in the text, ‘Case studies’ are included throughout. These have been provided by archaeologists active in this field and demonstrate the quality and quantity of data recovery from recent fieldwork. Each focuses on a particular industry but the approaches described can also be applied to other types of industrial site.

The ‘Industrial summaries’ contain information on five common industries, including three using high temperatures (iron, glass and pottery) and two low temperatures (tanning and textiles). These industries were relatively widespread and large scale and so are likely to be encountered archaeologically.

The final section contains information on ‘Where to get help’. The English Heritage Regional Science Advisors can provide advice on the role of science in the archaeological investigation of historic industries. Their contact details can be found at the back of these guidelines, together with those for specialists within the English Heritage Archaeological Science teams. Sources of information on health and safety issues relating to contaminated land are also provided.

These guidelines are intended primarily for curators (for example, local authority archaeological officers and historic buildings officers) who advise on planning and listed buildings applications and write briefs for archaeological investigations, as well as for contractors who undertake such archaeological recording. The guidelines provide useful information for anyone involved with the archaeology of post-medieval industrial sites.

This document is a response to the increasing pace of redevelopment of urban industrial sites in recent years (Fig 1, Case Study 1). Large numbers of new houses are being planned and many of these will be in urban areas (DETR 2000). Urban areas targeted for redevelopment (often referred to as ‘brownfield’ sites) are frequently the sites of historic industries. Until quite recently the post-medieval stratigraphy of urban sites was often removed before archaeologists began their work (eg Barker 1982, 128). The archaeological recording of such sites is now, however, increasingly accommodated through the planning process owing to a greater awareness of the importance of Britain’s industrial heritage (eg Symonds 2005).

When assessing whether a particular industry is likely to be present, account should be taken of the regional nature of many historic industries. Many early industries were located in rural locations where raw materials and sources of fuel and water power were abundant. Many secondary industries were located in urban centres where there was a sufficient market.

Fig 1 Early stages of the excavation on the Riverside Exchange site in central Sheffield (see Case Study 1). The scale of many sites of historic industries can be daunting. (© ARCUS)
The extensive industrial remains at the Riverside Exchange provided an important opportunity to investigate the evolution of the steel-making technology that made Sheffield one of the capitals of the steel industry. The size of the site and the scale of earth moving and deposition provided particular challenges, and the lessons learnt in solving these problems can be applied to other archaeological sites (see Fig 1). The information provided by the excavation enabled some of the archaeological remains to be preserved in situ. Numerous artefacts were recovered that could be sampled for metallography (section 4.5.3), whereas this is often not possible with objects in museum collections.

This four-hectare site, in the centre of Sheffield, next to the River Don, was identified for redevelopment in the early 1990s, by which time there were no visible signs of former industrial activities (Symonds 2005). There are numerous historical sources relating to the site: of particular value are the surveys undertaken by four generations of Fairbanks during the late 18th and early 19th centuries (Badcock and Crossley forthcoming) (see section 5.2). The water-powered town mill had been established in the 12th century, with a number of cutlery workshops set up in the post-medieval period. In the 1760s John Marshall established one of the earliest integrated steelworks, which included cementation and crucible steel furnaces (see section 6.1). His innovative use of technology helped to establish Sheffield as a steel and cutlery making centre, and his works attracted ‘spies’ who tried to discover the secrets of his success. The site continued to develop in the 19th century with the establishment of water-powered rolling mills. Surrounding the steelworks were numerous workshops where the knives and other items that made Sheffield steel famous were manufactured (Fig 2).

The archaeological evaluation of the site faced a number of difficulties related to the scale of past activities and the extensive reworking of archaeological deposits (Symonds 2001). The area identified for redevelopment was large and, like many brownfield sites, had had large quantities of mixed hardcore and domestic refuse dumped on it at various times. While, in some cases, industrial features and structures survived immediately below the modern ground surface, in others they were buried under several metres of overburden, or truncated by 20th-century foundations. A flexible approach was necessary: as demolition contractors revealed deposits they were characterised by the archaeologists, and areas of archaeological significance were targeted for detailed excavation. Owing to the scale of the industrial features, evaluation trenches could not provide sufficient information; instead, careful mechanical excavation of the upper layers identified the extent and depth of archaeological features and deposits over large areas. Greater emphasis was placed on the interpretation of deposits, features and structures as they were encountered, often with specialist input on-site. The developer’s building plans were not finalised until after the archaeological evaluation, so important archaeological remains could be preserved in situ.

The archaeological investigation uncovered the truncated remains of three cementation furnaces, one of which had only a single chest and appears to be a prototype. It is possible that this furnace is the one described and sketched by French industrialist Gabriel Jars after his 1765 visit to Sheffield. The uncovering of the prototype furnace provides an opportunity to see how steel-making technology evolved. The water channels and wheel pits across the site provided many artefacts relating to industrial activity, which were particularly useful in characterising the activities in the smaller workshops.

Many metal artefacts were recovered, including finished and unfinished fragments of cutlery. X-radiography (section 4.4) revealed 18th-century cutlers’ marks on two of the knives. The earlier of the two is a simple cross (+) and belonged to an unrecorded cutler, while the second (+L) was registered in 1750 to Joseph Antt. The similarities between the cutlers’ marks suggest that Joseph Antt had been apprenticed to the earlier cutler. Metallography and hardness testing (section 4.5.3) revealed that the blade marked ‘+’ was made using cementation, rather than crucible, steel. The number of layers within the blade suggests that the steel used was a type known as single shear steel. The knife made by Joseph Antt was more heterogeneous, with abundant slag inclusions and variable carbon content, and was perhaps made from recycled blades. While the differences in metal quality could reflect the skill levels of the two cutlers, it is more likely that the lower-quality knife was from a cheaper range, deliberately made to a price.

### Fig 2
Excavation at the Riverside Exchange, Sheffield revealed wheel-pits and water channels. To the right is a wheel-pit; the area to the centre-left shows the remains of a grinding shop with troughs. (© ARCLUS)
Starting in the 16th century, most industries succeeded in changing from wood (or charcoal) as a fuel to coal. The switch to coal forced many of the rural industries (eg iron) to move from traditional wooded areas (eg the Weald) to the coalfields. Starting in the 18th century, industries increasingly made use of steam power to drive machinery, which allowed some industries to move away from traditional river valley locations. The development of transport networks (especially canal and rail) allowed industries to move even further afield. By the end of the 19th century some industries were beginning to move to coastal sites to enable easy access to international raw materials and markets.

Many industries also developed associations with specific locations. Parts of the West Midlands developed a reputation for producing high-quality puddled wrought iron and had a major share of the national industry. The flat glass industry flourished in Newcastle upon Tyne, in part because it had excellent trade links with London, the principal market for window glass. For transportation there, the uncut crown glass disks were often set into the cargo of small ships carrying coal.

2.1 Archaeological approaches to historic industries
The sites of historic industries frequently differ from conventional archaeological sites (Fig 3; Symonds 2001) in terms of their scale (section 3.2), formation processes (section 3.3), standing buildings and contamination (section 3.4). These sites often yield large quantities of material deriving from the historic industry, which can be divided into raw materials (eg ore, sand, limestone), tools (eg furnaces, crucibles, tongs, rakes), and waste materials (slag, sandever, ‘soaper’s waste’). Such materials are here referred to collectively as ‘process residues’. Most sites yield a high proportion of waste materials and it can be difficult to successfully identify raw materials or tools. The scale of many historic industries can make it difficult to decide how much process residue should be retained for further study, in particular for scientific analysis (section 3.7).

Archaeologists working on sites of historic industries have developed methods for overcoming some of the problems outlined above (Fig 3). In general, archaeologists are using methods from several different disciplines, including traditional archaeological fieldwork (Barker 1982; Cranstone 1992; Roskams 2001), standing buildings recording (English Heritage 2006b), post-medieval archaeology (Crossley 1990), industrial archaeology (Cossons 2000; Palmer and Neaverson 1998) and archaeological science (Bayley and Crossley 2004; Bayley and Williams 2005). Elements of each of these disciplines have contributed to form the current range of methods employed (Cranstone 2004).

2.2 But doesn’t history tell us everything we need to know?
Documentary sources for industries over this period frequently survive and are an invaluable source of information (section 5). It is often difficult to make sense of the remains of an industry until it is placed in its historical context. Nevertheless, documentary sources sometimes omit or simplify details, sometimes to keep industrial secrets from competitors or because the writer did not fully understand the industry. Conversely, those writers that were very familiar with the industry often omitted details that they considered unimportant, or failed to include routine information. Unsuccessful experiments were almost never recorded, and many successful ones have received very limited coverage. Records for a site sometimes focus on a single process or technology and fail to mention the diversity of activities that took place (Case Study 2). Further, ‘even when industries were fully-fledged, surviving records are more concerned with money, building-plans or specifications of large pieces of equipment than with day-to-day details of people and processes’ (Payne 2004).

2.3 The importance of science in understanding the industrial past
Scientific techniques (Brothwell and Pollard 2001) are routinely used to improve our knowledge of the prehistoric, Roman and medieval periods. They provide means of absolute dating, can help reconstruct past environments and reveal the nature of artefacts and how they were made (section 4). English Heritage has issued guidelines on the use of various scientific techniques in archaeology, including archaeometallurgy, environmental archaeology, human bones, geoaarchaeology, geophysical survey and dating (Bayley et al 2001; English Heritage 1995a; 2002; 2004a; 2004b; 2004c; 2006a; Fell et al 2006). The application of scientific techniques to the study of post-medieval and later sites is showing that information not contained in historical accounts can also be gained from these sites.
Case Study 2:
Upper Forge, Coalbrookdale
by Paul Belford and Ronald A Ross

The archaeological excavation at the Upper Forge, Coalbrookdale, Shropshire was initiated to investigate the earliest physical evidence for the production of cementation steel in England (section 6.1). However, it also yielded, from secondary contexts, large quantities of raw materials and process residues relating to other industrial activities in the area. The evidence for copper smelting is of particular importance because there is little physical evidence nationally for this industry.

The cementation process for the conversion of iron to steel is thought to have originated in Germany and the Low Countries, and spread to Britain through the efforts of Sir Basil Brooke c 1619. Documentary research strongly suggests that Brooke's first successful steel furnace was located at the Upper Forge, in Coalbrookdale, and this has been confirmed by excavation (Belford 2003; Belford and Ross 2004). A selection of materials and residues related to the operation of furnaces at the site are being studied as part of the post-excavation programme.

A wide range of process residues that appear to relate to other historic industries were also recovered during the excavation, however. Examples of copper ore, copper slag, blast furnace slag and lead slag were found in many later (18th- and 19th-century) contexts; that is, from periods when the use of the site was largely domestic. The examples of copper ore and slag are particularly interesting as there is no documented copper smelting industry in Coalbrookdale. Indeed, while there are good documentary sources for the smelting of copper in Britain from the 16th century onwards (Day and Tylecote 1991), very few copper smelting sites have been excavated and there are no scientific studies of historic copper smelting residues. What little is known about the technologies used by these industries is based largely on late-19th-century accounts (eg Percy 1861) and there is not much information on how these techniques might have changed over the preceding three centuries. Therefore the evidence from Coalbrookdale is potentially of national significance despite the fact that it was recovered from a secondary context.

Samples of both copper ore and smelting slag were examined using a SEM (section 4.5.3). The chemical compositions of the samples were determined using X-ray fluorescence (section 4.5.4). The ore is a sandstone with copper ore (chrysocolla) and barytes (Fig 4). The microstructure and chemical composition of the ore suggest that it comes from the Triassic sandstones of the Cheshire basin. The most famous copper mine in this area is Alderley Edge (Cheshire) but outcrops of similar copper ore were also exploited in Shropshire just to the north of Shrewsbury, far closer to Coalbrookdale.

The examination and analysis of the slag (Fig 5) confirms that it was produced by smelting copper ores. The slag contains enough barium to be consistent with smelting the ore described above. However, the presence of copper sulphides in the slag suggests that other ores were also used. The ‘Welsh process’ of copper smelting (probably introduced at the beginning of the 18th century) relied on mixed charges that contained copper sulphide and oxide ores (Percy 1861). The evidence for copper smelting from Coalbrookdale comes from secondary contexts and almost certainly does not relate to industrial activities on the excavated site. Given the type of ore, however, it is likely that this smelting took place within the area (and probably within Coalbrookdale).

![Fig 4 SEM image of a sample of copper ore recovered from Upper Forge,Coalbrookdale, showing sandstone (silica), copper ore and barytes (scale bar = 0.1mm).](image)

![Fig 5 SEM image of a sample of copper slag from Upper Forge. The bright droplets are copper sulphide and indicate that the ore was smelted using a matte process (scale bar = 0.1mm).](image)
3 Fieldwork and sampling for historic industries

3.1 Project planning
Most archaeological projects are initiated through the planning process when local authority curatorial archaeologists identify the need for work to be done and advise their development control officer colleagues accordingly. The principles they follow are laid out in PPG16 in England (with similar arrangements in other parts of the United Kingdom). PPG16 requires that archaeological remains are, wherever possible, preserved in situ (Corfield et al 1998; Davis et al 2004; Nixon 2004). Where preservation in situ is not possible, it is essential that an adequate record of the archaeological remains is made. The process of recording archaeological sites depends on careful planning and implementation, whether they are small watching briefs or more extensive excavations. The successful management of archaeological projects relies on identifying and managing distinct stages (Table 1; see also Lee 2006).

Having decided that a site needs evaluation, the development control officer produces a brief for the work and the contractors (archaeological units) respond with a written scheme of investigation. Alternatively, work is sometimes commissioned by a statutory body such as English Heritage, in which case the documentation is known as a project design. In either case, a contractor is selected by the developer to undertake the archaeological project.

Table 1 Archaeological science for historic industries: project planning guidance for specialists undertaking scientific work

<table>
<thead>
<tr>
<th>project phases</th>
<th>tasks and products</th>
</tr>
</thead>
</table>
| 1 initiation phase | • Identify core team members and principal contacts.  
• With Project Manager, identify the research aims relating to historic industries.  
• With Project Manager, identify likely requirements (this will depend on factors such as site type, size of excavation, specific needs of receiving organisation, etc). Establish the nature and current state of knowledge of the historic industries likely to be present, in order to inform project budgeting. Additional factors will have to be considered, such as the degree and nature of contamination, likely volume of material to be examined, necessity for soil sampling, etc.  
• Estimate costs for scientific work based on above.  
• Liaise over proposed timetabling.  
• Prepare costed project design.  
• Determine archiving arrangements.  
• Determine mode(s) for the dissemination of results. |
| 2 project execution: fieldwork | • Assist with the identification of features and process residues (provide related training to site staff).  
• Carry out on-site scientific analysis using portable instruments (where agreed at planning stage).  
• Take samples (eg soil and/or process residues, as agreed at planning stage). |
| 3 project execution: assessment | • Carry out initial examination of process residues (with scientific analysis where necessary) to identify the nature of the historic industries.  
• Results of the initial examination to inform assessments and potential for analysis contributions.  
• Establish further scientific examination and analysis requirements through liaison of appropriate specialists and core team members to inform updated project design and additional project costs.  
• Update records accordingly.  
• If review of assessment report shows that an analysis phase is not required, transfer the site archive. |
| 4 project execution: analysis | • Undertake additional scientific examination/analysis as agreed during the assessment, or for other requirements identified during analysis.  
• Update records accordingly.  
• Transfer the site archive. |
| 5 project delivery: dissemination | • Contribute to site publication.  
• Advocacy of project through other agreed media. |
Case Study 3:  
The Beswick pottery, Barford Street,  
Stoke-on-Trent  
by David Barker and Jonathan Goodwin

Stoke-on-Trent is famous for its pottery industry (Barker 2004) and, while some aspects have been recorded (eg Baker 1991), much more has been lost to redevelopment. Before 2002 only five 19th-century or later ovens had been excavated. Since then the increasing pace of development has led to the recording of 14 more sites (Goodwin 2005). The excavation of pottery ovens, and the ‘hovels’ see below that housed them, is providing information that is often absent from historical accounts and cannot always be obtained from intact standing structures (Fig 6).

The redevelopment of an area on Barford Street covering almost 8000m² led to an archaeological evaluation followed by a watching brief. Throughout the 20th century the site was occupied by the Beswick pottery, which produced a range of domestic wares and ornamental ceramics, including flying ducks! Previously, the site had been used by various 19th-century pottery firms including Batkin and Deakin, Deakin and Son, and Hannah and Mary Shubotham. All of the buildings on the site had been demolished in the past but three evaluation trenches, approximately 20m², 200m² and 400m² respectively, located the remains of two circular pottery ovens, as well as a 20th-century tunnel kiln. In certain areas the ovens had been partially or completely truncated by 20th-century activity but sometimes floor surfaces and a few courses of brick walls survived.

The traditional, coal-fired oven consisted of a central oven proper, surrounded by a cover building known as the ‘hovel’, which usually had a distinctive bottle shape. The hovel helped induce a strong and even draught through the oven, necessary to achieve the temperatures required for firing the pottery. Each oven would hold thousands of pieces of pottery in saggars (see section 6.3). At the Barford Street site, the brick floor surfaces inside the hovels survived, at least in part, and in one case four successive hovel floor surfaces had been laid one atop the other (Fig 7).

The foundations of one of the ovens consisted of a mixture of sandy loam, pottery and saggars, seemingly a wholly unsuitable material, but this sort of foundation has been found beneath most of the pottery ovens excavated. Factory records are frustratingly vague about oven construction and operation, but a careful examination of early-20th-century written accounts suggests that the use of this material, called the ‘cork’, for oven foundations was a deliberate policy. The high temperatures achieved in a pottery oven could dry out the subsoil underneath the furnace, leading it to contract, and so weaken the foundations of the hovel wall and possibly causing collapse.

The materials selected for the cork were intended to ensure that this did not happen. The existence of the cork would not be apparent from an examination of a standing hovel and oven; it can only be seen in excavated examples.

The hovel floor surfaces were not associated with any closely dated artefacts. The approximate date at which some of the later ovens went out of use could be estimated by reference to Ordnance Survey maps but this left many structures with rather broad date ranges for their construction and use. More precise dates could have been obtained using scientific methods, such as archaeomagnetic dating for the in situ fired floor surfaces and thermoluminescence dating for individual bricks (see section 4.5.2). The dating of individual floor surfaces could be refined to within a decade or so by applying Bayesian statistical methods to a series of date probability ranges from successive floors (Buck and Millard 2001). Such an approach would have provided a detailed chronology for the construction and use of the ovens and hovels that would not have been obtainable in any other way.
3.2 The scale of industrial sites

The main difficulty posed by sites of historic industries is one of scale: both of the original activities and of subsequent earth moving. Historic industries often used features and structures that were much larger than medieval and earlier counterparts (Fig 8). This can be illustrated by the changes in the furnaces used in the iron and steel industry. Late medieval furnaces were usually simple cylinders built of clay, up to 1m in diameter and probably 1–2m high. Early blast furnaces of the 16th and 17th centuries were square and were built of stone, 4–6m wide and about 6m high. By the mid-19th century, blast furnaces were again cylindrical but were up to 20m high (see Fig 31). Therefore it can be difficult, if not impossible, to recognise significant industrial features in small evaluation trenches. The evaluation of ‘greenfield’ sites often uses long narrow trenches (2m by 30m) or 1m’ test-pits (Hey and Lacey 2001). Such trenches on the site of an historic industry can easily fall wholly within a tank or other large feature and so fail to identify it.

Recent work on many industrial sites has shown that the trench size needs to reflect the scale of the archaeology. This is particularly important at the stage of site evaluation, where trial trenching is most commonly used (Darvill and Russell 2002, 32). Therefore, on the site of an historic industry, the trenches used for evaluation are often larger than typical (Case Study 3). Given the size of many of these sites and the scale of the archaeological features, it is necessary to make use of machinery to excavate many deposits (Fig 9).
Manchester experienced an explosion of factory building at the end of the 18th century, fuelled by a breakthrough in the application of steam power to textile-manufacturing (section 6.4) and the cheap and reliable transport for goods offered by the construction of canals. This led to the creation of a new generation of textile mills, which were built on an unprecedented scale and employed developing techniques of structural and mechanical engineering.

Ancoats evolved as an early focus for these new mills, although the sole survivor of the initial boom in factory building is Murrays’ Mills, which has been the subject of comprehensive archaeological recording. The fabric of this mill complex retains considerable evidence for all stages of its development, and analysis has provided a valuable tool for interpreting the buried remains of other mills in Ancoats. Several of these have been excavated recently, with the remains of the steam-power plants providing a focus for investigation (Fig 10).

An important stage in the transition from water power to steam power involved the use of a pumping engine to furnish a waterwheel with a regular and continuous supply of water. Excavation of New Islington Mill (Fig 11) revealed the key elements of this system, including a narrow waterwheel pit, stone-block foundations for a pumping engine, and a network of large culverts. Excavation also exposed the footings of an engine room that contained stone-block foundations for a beam engine, with square-section iron mounting rods typical of the early 19th century. The walls of the engine room contained sockets for the engine frame and abrasion scars, which helped to determine the size of machinery housed there.

Buried remains demonstrate the evolution of power-plant structures. The first working steam engines had chimneys whose design was based on domestic houses (Douet 1991, 8). The introduction of more powerful engines placed greater demands on the boiler’s steam-raising capacity, as well as on the foundations of internal boiler houses and the very narrow flues taking irregular routes to small, square-section chimneys, which were all typical of the late 18th century. Examples of these structures exposed at Waller’s Mill and Salvin’s Factory were built largely from hand-moulded bricks, with only occasional use of refractory materials. The early 19th-century boiler house and flue at Moore’s Mill showed the increased use of refractory bricks within its build, while the late-19th-century detached boiler house at Murrays’ Mills displayed extensive use of refractory bricks, many bearing makers’ stamps.

All of the excavated mills yielded large quantities of ash and clinker, which offered little potential for analysis, reflecting the lack of process residues generated from cotton-spinning. The 20th-century use of some sites created contaminated ground conditions requiring mitigation prior to excavation. Historic mapping, when integrated with digital records of the excavated features, has consistently proved crucial to the interpretation of sites. The excavations have clarified numerous aspects of the mills’ development that were not clear from documentary sources, including structural details and information on power generation (for example waterwheels, boilers, engines and fuel economisers) during different phases, with implications for the machinery operating within the mill. Social contexts could be established through assemblages of stamped mineral water and botanic beer bottles, which were traced through trades’ directories.

---

**Fig 10** The late 19th-century detached boiler house at Murrays’ Mills, with the circular foundations of a stair tower to the right and the edge of the canal basin at the top of the image. (© Oxford Archaeology North)

**Fig 11** A general view of the engine house for the steam returning-engine at New Islington Mill, showing (on the left, horizontal) one of the iron pipes used to carry water from the underground sump to the waterwheel (the wheel pit in the centre has been backfilled), and the vertical iron restraining rods that tied down the engine. (© Oxford Archaeology North)
3.3 Site formation processes

Archaeologists have recognised that some movement of soil and other sediments has always occurred as features were dug and refilled. The development of canals, the steam engine and railways, however, opened up new possibilities for both the removal and dumping of enormous quantities of material. Dumping was often carried out to level a site and raise it above the water table. Such dumped deposits are often referred to as ‘made ground’ but this term needs to be used carefully as some non-archaeological contractors use this term to refer to all archaeological deposits. Some sites were levelled by removing deposits (truncation), while on others a combination of truncation and dumping was employed.

It should not be assumed, however, that all made ground is of no archaeological value. These deposits can provide information about other sites which have been destroyed by later development. The ‘made ground’ that buries many low-lying sites in town centres often incorporates material from areas of slum housing that no longer exist. In addition, where later redevelopment has completely destroyed in situ evidence for an historic industry, information might still be obtained from process residues dumped on other sites (Case Study 2). Where substantial ‘made-ground’ deposits are identified and assessed as of little archaeological value, however, they can be removed mechanically, thus saving scarce resources for stratified archaeological remains (Case Study 1). This will work best when archaeologists maintain good links with others on site, eg demolition contractors.

In many cases process residues were removed from sites of historic industries. A typical blast furnace at the end of the 18th century was producing around 2000 tonnes of cast iron a year and it is likely that it would have been producing slag at a similar rate (depending on the quality of the ore). If this slag was not removed then the blast furnace would have completely buried itself within a few years; and many blast furnaces continued in use for decades or longer (section 6.1). In some cases waste products were dumped into the pits or quarries that had previously been used to extract raw materials (see Fig 8). In the case of metal smelting industries, slags could be used as road metalling, ‘ballast’ for railway lines (eg Crossley 1995) or, if cast into blocks, as building materials (Fig 12).

Process residues are sometime absent from a site because they could be reused by another industry. A good example of this is bottle glass manufacture which initially used sand and a variety of plant ashes as raw materials. However, cheaper ingredients were sought and, during the 18th century, glassmakers began to use waste materials from other industries, including iron smelting slag and residues from soap and gas manufacture. In its turn, the glass industry regularly produced a waste material called sandever which was sold to brass casters for use as a flux (section 6.2). As a result the residues from some industrial processes are now rather rare. In addition, it is not always certain if the process residues recovered are waste by-products or raw materials.

In industries using organic materials, such as textile production and tanning, some types of residue are rare because they do not survive, save in exceptional circumstances (Case Study 4).

3.4 Contaminated land

The sites of historic industries may be contaminated (Environment Agency 2005) and excavation can pose significant health risks. Contamination was often generated on site as a waste material during periods when environmental controls were absent or less rigorous than today. Contamination can take many forms, but the two commonest types are heavy metals (Case Study 5) and organic compounds.

The problems of contamination may be addressed through the planning process, although some remediation of contaminated land is provided for by the Environmental Protection Act – which does not include archaeological recording. Before working on potentially contaminated sites, it is essential that archaeologists seek professional advice on the risks involved and appropriate mitigation strategies. Desk-based assessments should identify the industries that were present on site, and so indicate the forms of contamination that potentially might be present. Useful information can also obtained where archaeologists (in particular curators) liaise with Local Authority contaminated land teams and relevant contractors, for example geotechnical contractors undertaking a borehole survey. Scientific analysis (section 4) can characterise any on-site contamination, provide information about past industrial activities at the site and establish the existence of regional palaeoenvironmental data that can provide useful information on the local environmental impact of the industry.

The information on the nature and severity of contamination should be used to compile a site-specific risk assessment of the potential risk to the health and safety of site personnel before any site work is undertaken. Often other contractors will undertake chemical testing of sediments as part of on-going assessments of the health and safety risks posed by contamination and, where possible, archaeologists should make use of this information. Further information on contaminated land is included in section 7.5.

3.5 Historical sources

The study of sites of historical industries can frequently benefit from non-archaeological sources of information (section 5). Where detailed maps exist for a site (section 5.1) these should be exploited to help interpret archaeological features and structures. Archaeological features can be recorded digitally using EDMs and the plans superimposed on historic maps using CAD or GIS. While this approach has been used to interpret features at a post-excitation stage (eg Krupa and Heawood 2002) it is increasingly being applied during fieldwork (Case Study 6). The use of GIS allows the application of a wide range of spatial analysis techniques to the sampling strategy. GIS can also be used during post-excitation analysis to examine spatial patterns in data from the scientific analysis of samples.
Case Study 5: Leadmill, Sheffield
by Anna Badcock and Andrew Lines

The Leadmill site in Sheffield illustrates one of the most significant problems inherent in investigating historic industrial sites: contaminated land. As is often the case, the historic industry was the source of the contamination and the modern investigation of the site was only possible once the health and safety risks were addressed. The excavation provided tangible evidence for processes described in historical documents (Fig 13) but also yielded artefacts and process residues that are not described in these sources.

From 1759 until 1903 the Leadmill site was occupied by a works producing pigments (white and red lead). Prior to this, the site was occupied by a cutler's workshop, and in the 20th century it housed a bus and tram depot. During the 19th century, white lead (a hydrated lead carbonate) and red lead (a lead oxide) were used in paints, pigments, glasses and pottery glazes. Both compounds were made from metallic lead but used very different processes. White lead was produced by arranging strips of lead over pots of vinegar, surrounded with dung or spent bark from tanning works (Campbell 1971). Over a period of weeks, the vinegar reacted with the lead to form lead acetate and this was converted to white lead by the fermentation of the organic matter (Cossons 1972). Red lead was produced by roasting metallic lead to form litharge (a lead oxide), which was then ground and roasted to red lead (Muspratt 1860, 476; Percy 1870).

The excavation of an archaeological site that is contaminated with toxic chemicals, such as lead, poses health and safety problems. A risk assessment was carried out before fieldwork started to determine safe working procedures. In order to minimise exposure to lead, everyone working on the Leadmill site wore protective body suits and food and drink could not be consumed on site. Staff received regular medical checks, with two blood tests (one before work started and one at the end of the fieldwork) and urine tests at the end of each week.

Deep features associated with the bus and tram depot had truncated much of the earlier stratigraphy. The features associated with the lead works were overlain by 0.5–1.5m of demolition material and sealed by a layer of clay. The only substantial features associated with the lead works that survived were some foundation walls, a series of flues and floor surfaces (Fig 14). The internal faces of the flues were covered in a sooty deposit. Subsequent analysis of soot samples showed that they contained high levels of lead. The flues probably fed into a chimney shown on the 1896 Goad insurance plan (section 5.2).

The excavation also yielded artefacts and materials associated with the production of the white and red lead: scrap lead, partially oxidised lead spillages, industrial pottery and fragments of furnace. The industrial pottery (unglazed bowls and internally glazed jars) had powdery, lead-rich, white deposits on their surfaces. The glazed jars resemble those mentioned in contemporary accounts (eg Muspratt 1860), but none of these accounts describe the unglazed bowls. The fragments of furnace consisted of pieces of millstone grit that had reacted with lead oxide to variable extents. Some of the partially-oxidised lead corresponded almost exactly with Percy’s description: ‘a dam across the floor of the oven . . . consists of the coarse particles of intermixed lead and protoxide of lead’ (Percy 1870, 512).

The manufacture of lead pigments was confirmed by the scientific study of artefacts and residues recovered during the excavation. XRF analysis (section 4.5.4) enabled inferences to be drawn about the pigments being manufactured and about the operating temperatures. A variety of other scientific techniques could have been used to extract additional information. XRD analysis (section 4.5.5) would have differentiated the lead compounds present, for example oxides, acetates and carbonates, whereas the XRF analysis could not. Such an approach might also have uncovered the function of the unglazed bowls. Further sampling of the features associated with the lead works could have provided information concerning the types of fuel used and environmental evidence for other raw materials or process indicators, such as spent tanning bark and dung (section 4.3). Integration of the scientific analyses into the fieldwork stage (eg portable XRF) might also have aided the interpretation of archaeological features.
The excavation of sites that have been abandoned or that have undergone change of use only recently can be facilitated by referring to oral history records (Howarth 1977), although such accounts are not objective and are best used in conjunction with other sources of evidence. There are also photographic (Stoyel and Williams 2001) and even film records for some industries (Linsley 2000, 123–4).

### 3.6 Specialists

In order to maximise the information recovered as a result of the excavation of industrial sites, the project team should include people with appropriate specialist knowledge, for example of the relevant industrial processes and technologies, particular types of find, sampling techniques and analytical methods. Such specialists can advise on the potential importance of a particular site, what features to expect, the process residues that might be found, what to sample, how much material to retain and what type of analysis is appropriate. Some prior knowledge is particularly useful in instances where the residues may not be easily discernible by eye, for example chemical traces in a tanning pit or at the site of dye works, or parasites and seeds in deposits associated with textile sites. Specialists can provide some indication of the importance of the site since, although some processes and their associated structures are well known, for certain industries and periods there are gaps in our knowledge. For example, several charcoal-fuelled blast furnaces have been excavated (eg Magilton 2003), but there are very few excavations of coke-fuelled blast furnaces, and no typical 19th-century examples have survived as upstanding remains (Gale 1969, 140).

Generally, it benefits all parties if specialists visit the site during the excavation. These visits provide an opportunity to discuss possible industrial uses for features, identify typical finds and review the sampling strategy, depending on what has been recovered. Some specialists will want to take their own samples, or will be able to carry out analyses on site, for example using portable geochemical testing or XRF equipment (sections 4.5.2 and 4.5.4). Many specialists can provide training in recognising and interpreting industrial residues and artefacts and have access to collections of reference material from different industries. When visits are not possible, specialists will need a detailed record of where samples have been taken from, including photographs and plans.

### 3.7 Sampling

Before excavation commences, a strategy should be devised that considers how the different types of evidence likely to be present will be recovered. Relevant information can be present as the remains of structures, artefacts and/or process residues (eg slag and crucibles) and deposits containing remains that are too small to be individually recognised on site (eg environmental evidence or hammerscale). A sampling strategy should aim to recover sufficient material relevant to the historic industries to answer the questions raised by the research aims identified in the project design. Sampling should be done in conjunction with appropriate specialists so that sampling for environmental remains, process residues and artefacts can be integrated (English Heritage 2002, 17–23).

Material should be retained from each spatially and chronologically distinct deposit to ensure that any chronological or spatial changes in the use of the site can be investigated. The fills of flues, water courses, ditches and pits, or destruction layers, are likely to contain the bulk of the material discarded on site. Some features, however, may be more important than others, for example the fill of a tanning pit where anoxic conditions have resulted in the survival of remains that are susceptible to decay, a discrete dump of mould fragments in the corner of a foundry, or a well-preserved workshop floor. In addition, a specialist may require samples to be taken at regular intervals (eg a grid pattern to look at the spatial distribution of material, such as hammerscale (Bayley et al 2001)). Further information on sampling is given in Orton (2000) and in the various English Heritage guidelines (Bayley et al 2001; English Heritage 2002; 2004b).

A rapid visual examination (of a proportion if there are tonnes of waste) should be sufficient to determine how many different types of material are present in a particular deposit (for example some ceramic material, some black slag, some green slag, some magnetic lumps and a grey powdery substance), and then a sample of each can be retained. This will ensure that the overall sample is representative of that deposit. The amount retained should be sufficient for any analysis required and must include examples that show distinctive and diagnostic features, such as details and marks, dimensions, fabrics and forms. Frequently the most informative examples show how different categories of waste were associated in the process (for example a fragment of ceramic material with adhering black and green slag and a grey powdery coating).

It is not necessarily appropriate or possible to retain all of the industrial residues from a context, and the amount that needs to be retained is best decided by the relevant specialist(s). The quantities of material to be retained will vary greatly depending on factors such as the type and scale of deposit, its relationship with the industry, the current state of knowledge of that industry and the analysis planned. In the absence of specialist advice, the guidance above (on which types of deposits to sample and how to obtain a representative sample) will to some extent dictate the amount of material that needs to be retained. Where doubt exists, and only small quantities of a process residue are present, all of the material should be kept. However, where large quantities of material are present (more than 1 tonne), it is likely that it will only be possible to retain a proportion. It is essential that a record is made of the amount of material that is discarded, and also useful to roughly estimate and record the relative amounts of different types of residue (for example, mainly black and green slag with about 10% total of other residues). Once post-excavation assessment and/or analysis have taken place, an informed decision can be made about how much material to retain for the archive.

Consideration should be given to how artefacts and samples are processed, so that important information is not lost. For example, the washing of industrial vessels containing residues might be inappropriate. Also the need for risk assessments does not end with the completion of the fieldwork phase of a project; risk assessments should also be carried out for post-excavation examination of recovered process residues.

### 4 Scientific analysis

The historic archive (section 5) can provide useful information for the investigation of historic industrial sites (such as the date and layout of the site, the raw materials used and the industrial processes carried out), but important details may be lacking (section 2.2); scientific analysis can often fill these gaps. A variety of techniques has been applied to archaeological problems, including locating sites, dating, reconstructing...
The excavations at the Percival, Vickers glassworks provided information on innovations in furnace design, and analysis of the glass recovered is providing information on the wares produced and the types of glass from which they were made, as well as the likely raw materials and process conditions used. Methodologies were developed using pen computers to facilitate the recording and interpretation of the archaeological remains.

The Percival, Vickers and Co Ltd British and Foreign Flint glassworks on Jersey Street, Ancoats, Manchester was established in 1844 with two glass furnaces, an annealing house, and associated buildings (Fig 15). The factory produced a wide range of high-quality tableware and homeware. During the 1860s, the firm began to register designs for press-moulded wares (section 6.2). By 1863, it had become the largest of the city’s glass factories. The development of the site can be traced from a series of cartographic sources, particularly Ordnance Survey maps (section 5.2). The earliest map showing the works, published in 1851, includes two furnaces; subsequent maps show that a third furnace was added (Fig 16).

The remains of all three furnaces, an annealing house and associated workshops were revealed. The furnaces generally survived to the height of the siege foundations, and were approximately 6m in diameter. The flues were almost 3m deep. The furnace erected c 1881 was evidently of an improved design, and incorporated the latest technology, including a Frisbee feeder for replenishing the fuel and an innovative system of air supply. The fire chambers of two of the furnaces were filled with abundant fragments of glass and glassworking waste. More than 100kg of variously-coloured glass were recovered; some of it cut glass, but the majority press-moulded. The forms produced were often intended to imitate the style of cut glass, but the pressing left a surface that was less brilliant. Press-moulding was used to mass produce cheaper versions of cut glass vessels.

In the absence of company records, an eyewitness account of a guided tour of the works provides one of the best descriptions of the glassworks. This mentions the furnaces and various workshops for the storage and mixing of raw materials, the manufacture of crucibles and steel moulds, and the cutting and engraving of glass vessels. Six catalogues survive (see section 5.6), and the final catalogue includes an engraving of the glassworks showing the three large chimneys of the glass furnaces (Fig 15).

Excavation started with five machine-dug trenches covering 500m², targeted on the furnaces and their associated flues. This work led to more detailed excavation, exposing and recording an area of approximately 2030m². A total station (a surveying instrument that combines an electronic theodolite and an electronic distance measuring device) was used during the excavations to record all structures three-dimensionally on to a pen computer (Fig 17). This computer was loaded with Ordnance Survey data that allowed archaeological detail to be overlaid on to historic maps, which proved valuable in interpreting features. The survey data was used as the basis for a manually-drafted plan of the entire site. This ensured accuracy and dispensed with the need for a site grid, as getting grid pegs into thick deposits of rubble is difficult if accuracy is to be maintained. The total station was also used in reflectorless mode to record elements of the site that were difficult to access, such as the underground flues, and to generate accurate cross-sectional profiles.

Samples of glass, including some of the working waste, were analysed using inductively coupled plasma spectrometry (ICPS) (section 4.5.4). The preliminary results suggest that there are six broad compositional groups, dominated by lead- (and potash-) rich types of glass and others that are soda-rich. The soda-rich glass appears to have been used for the press-moulded vessels and contained relatively low concentrations of lead, although there was probably sufficient lead to influence the melting properties of the batch.
environments, identifying raw materials and understanding how artefacts were made. Sediments, materials and residues adhering to features or artefacts can be sampled for scientific analysis. This section includes brief summaries of the scientific methods commonly used to address these problems.

The single most important issue when considering whether or not to use scientific techniques is the nature of the archaeological question (section 3). Limited resources should be used to undertake the most appropriate scientific analysis with the best prospect of succeeding. No one scientific technique can answer all questions, and there are many issues to consider before selecting an analytical method. Important factors include the type, size, number and heterogeneity of the objects or samples; whether it is acceptable for objects to be sampled or for samples to be destroyed; whether the technique can be used on site; and the speed and the cost. Analytical methods will vary in terms of their sensitivity for different elements and the accuracy, reproducibility and presentation of the results. Expert interpretation of the analyses may also be necessary. If these issues are raised with the analyst in advance, well-informed decisions can be made about the best way to proceed. Further advice can be obtained from a number of sources (section 7).

The finds and samples from historic industrial sites will include a range of materials, and advice on sampling (section 3.3), assessing, analysing and reporting on these is also available in the EH guidelines series (Bayley et al 2001; English Heritage 2002; 2004a; 2004b and 2004c).

4.1 Locating historic industrial activities

by Ken Hamilton

Geophysical survey is a well-established technique for the exploration of archaeological remains on rural sites, but it has rarely been applied successfully to urban sites owing to the depth and complexity of the stratigraphy, and interference from metallic objects, services and adjacent structures. Nevertheless, under favourable conditions geophysical survey can provide useful indications about the nature and location of subsurface features relating to historic industries (English Heritage 1995a, and forthcoming; Gaffney and Gater 2003).

The use of earth resistance survey is difficult on most urban sites, as the ground cover (such as tarmac or rubble) usually prevents the insertion of the electrodes. Electromagnetic surveys can work well in detecting large features or those with significant contrasts between their conductivity or magnetic susceptibility and the surrounding deposit; however, these instruments are affected by the presence of extraneous metal structures.

The performance of magnetometers is variable: in some cases the response can be related to historically known industrial structures but in other cases the significant anomalies are obscured. Fluxgate gradiometers measure variations in the Earth’s local magnetic field and are strongly influenced by the presence of iron objects. Historic industry sites frequently contain large numbers of iron objects that can mask the presence of archaeologically significant features. Some urban sites also contain very large iron objects, which can produce extreme anomalies that extend across the entire site. Nevertheless, where anomalies are produced by large iron objects that are in situ remains (such as machine bases and frames for buildings), a low sensitivity fluxgate gradiometer survey can show the extent and location of such features.

Ground penetrating radar (GPR) survey has been applied to urban archaeology using individual transects and can image targets through a variety of surface layers, such as asphalt or concrete (Reynolds 1996). A better approach is the collection of data in closely spaced, parallel transects (certainly no coarser than 0.5m, for a sampling interval of 0.1m), from which a three dimensional block of data can be compiled. This can then be used to create amplitude ‘time slices’ (Figs 18 and 19) which provide a series of horizontal plans mapping the strength of GPR reflectors at a particular depth (eg Conyers 2004). The signal from GPR will be heavily attenuated in high conductivity soils or by the presence of ferrous reinforcement bars within concrete, which may limit its application on some sites.

Filters are used to process the geophysical survey data from archaeological sites and may suppress unwanted signals, such as large-scale trends due to geology or small-scale anomalies, especially those produced by near-surface iron objects. Data from sites of historical industries, however, often require extensive processing and this may also remove archaeologically-significant anomalies as well as the unwanted signals.

In contrast to geophysical survey, geochemical survey, which identifies and maps the distribution of elements or compounds, is at present not much used in archaeology. There is, however, potential for its application to sites of historic industries, for example to locate activities by detecting increased levels of...
Case Study 7: Iron-working sites at Rievaulx and Bilsdale, North Yorkshire
by Jane Wheeler

Iron-working sites have been located within the environs of the ruins of Rievaulx Abbey in North Yorkshire and at a number of locations throughout Bilsdale, immediately to the north. The aim of this project was to investigate the environmental effects of human industrial activities and evidence for woodland management in relation to the fuel requirements of the iron industry between the 12th and 17th centuries. This has been achieved by using a variety of scientific techniques to extract data from off-site core samples (English Heritage 2002). The sites of interest are in a rural location and contemporary land use is pastoral. As the study area is large (28 hectares), a systematic approach was used to locate the archaeological remains of furnaces for excavation, and to identify suitable sites for the retrieval of cores. This approach made use of a variety of evidence, including surface scatters of slag, field name evidence and the results of geophysical survey (Vernon et al. 1998).

Using a Russian corer, pollen cores were taken at sites slightly distant from the ironworking furnaces. The cores were assessed for their pollutant content by ascertaining whether the sediment sequences contained a magnetic record of airborne pollution (specifically iron and burnt charcoal) generated by the iron-smelting processes. This was done in a laboratory using a Bartington dual-frequency magnetic susceptibility sensor (model MS2B) to scan the cores. In each case, the preliminary magnetic susceptibility results appear to reflect the accumulation of atmospheric pollutants in quantities that can be associated with phases of ironworking activity, and act as an environmental marker for iron smelting (Fig 20).

The ironworking sites included in the project date to different periods (according to the results of archaeomagnetic dating and historical records), and there is evidence that the technology developed over time from bloomery furnace to blast furnace, with implications for the utilisation of natural resources, fuel consumption and metal output. When this study is complete, the data from the cores will be linked in more detail to the results from the excavation, for example correlating the local pollen data with the wood types found in the archaeological charcoal assemblages. It will also be possible to compare the environmental impact of the ironworking at different types of furnace site.

However, this case study focuses only on preliminary results for a core from the vicinity of the charcoal-fuelled blast furnace at Rievaulx village, which operated from c. 1570 to c. 1647 (McDonnell 1963; 1972; 1999). The site is contained within an area designated a Scheduled Monument, and a licence was obtained to conduct field-walking and environmental sampling, and to conduct an investigatory excavation in the refectory building of the abbey ruins.

The preliminary results from the pollen core (Fig 20) taken from the meadow immediately west of the blast furnace site, show high charcoal, spheroid (SCPs) (cf section 4.3) and magnetic susceptibility values between points 1 (0.58m) and 3 (1.22m). The pollen data show the local arboreal pollen to be very low and a dominance of grass and sedge reflects the pastoral nature of the surroundings. The low counts for arboreal pollen suggest either there were few trees present, or that the trees that had survived into the late medieval and early modern period were being tightly managed using traditional strategies such as coppicing and pollarding. The correlated peaks for charcoal and spheroids have been interpreted as representing the period of blast furnace operations, beginning c. 1570 until closure of the ironworks c. 1647. Point 2 (0.9m) reveals a reduction in the output of spheroids and a slight decline in charcoal, yet relatively stable (elevated) magnetic susceptibility values. This decline in spheroidal output recorded between 0.98m and 0.74m may be indicative of reduced iron production, although the furnace continued to be operational, a fact that is supported by the consistently high charcoal values.

Fig 20 Selected taxa pollen diagram from Rievaulx Abbey, including spheroidal and microscopic charcoal data, and magnetic susceptibility values. (© Jane Wheeler)
chemicals associated with that activity. In most cases, samples of soil are taken for later analysis in a laboratory (Wild and Eastwood 1992), but recent improvements in the accuracy and robustness of portable instruments now enables on-site analysis of soils for some elements. The most useful elements in such situations are ones that can be associated with particular historic industries (these will vary from industry to industry, and chronologically). Geochemical survey and testing has been most widely applied to metals industries. However, there has been some successful application of geochemical testing to the textile (Russell 2001) and tanning industries (Shaw 1996), primarily to understand the function of excavated features (section 6 and below).

4.2 Dating historic industries with contributions by Derek Hamilton, Paul Linford and Cathy Groves

It is often possible to obtain very precise dating for sites of historic industries from documentary sources (section 5) or from excavated artefactual evidence (domestic pottery, clay pipes, etc). In some cases, however, scientific techniques may offer the only way of dating a site, feature or artefact. The most widely used scientific dating technique in archaeology as a whole is radiocarbon dating, but this is of limited use for the period 1650–1950, as there is a plateau in the calibration curve (Stuiver and Pearson 1986), and so errors are generally larger than can be obtained from archaeomagnetic or thermoluminescence dating (Aitken 1990).

Directional archaeomagnetic dating can date in situ fired features (typically composed of baked clay or stone) that have acquired a thermoremanent magnetisation (Aitken 1990; English Heritage 2006a). The technique is at its most precise for the post-medieval period, as direct observations of variations in the direction of the Earth’s magnetic field have been made in Britain since 1650. Furthermore, the change in field direction has been rapid throughout this period. Hence, it is often possible to date the last firing of features at 95% confidence to within 35 to 50 years, and possibly to about 20 years for dates after 1700 (English Heritage 2006a). Unfortunately, it is often not possible to date iron-working features because iron metal or iron-rich slag become strongly magnetised as they cool. Any parts of the structure cooling in the vicinity will become magnetised in the direction of this strong local field rather than in the direction of the Earth’s field.

Ceramic structures and artefacts can also be dated using thermoluminescence (TL), which is not limited to in situ fired features (Aitken 1990). TL has great potential for dating artefacts or features of historic industries, as the errors are a percentage (typically 28–10 %) of the central date. Thus, a TL date indicating that a sample is 200 years old gives an error of ±20 years. However, moisture content and burial history, which vary from site to site, can have a strong influence on both the central value and the error.

Dendrochronology is an accurate and precise dating method for wood (English Heritage 2004c), which can be used to date some industrial structures. The type and origins of the wood are important factors: in England oak is most commonly used for dating purposes, but in the post-medieval period there was a noticeable rise in the use of native hardwood species other than oak and a dramatic escalation in the use of conifer timbers, the vast majority of which are presumed to have been imported (Groves 2000). It is rarely possible to produce a long chronology for each species under consideration, but some species, such as elm, have been dated by producing a site master curve and comparing this with native oak reference chronologies (English Heritage 2004c). The ability to date conifer timbers relies on the availability of reference data from the relevant source areas.

The rapid pace of technological development and changes in many materials in the 17th to 19th centuries means that knowing the chemical composition of a sample can occasionally help to date it, providing similar materials of known date have already been analysed for comparison (Bowman 1991). Sometimes the date when a particular element or compound was first isolated is known, and this provides a terminus post quem for the manufacture of this material.

4.3 Environmental impact of historic industries by Gill Campbell

‘For several miles before they reached Milton, they saw a deep lead-coloured cloud hanging over the horizon in the direction in which it lay.’

North and South, Elizabeth Gaskell, 1854–5 (Gaskell 1994)

This quote provides a reminder that one of the major effects of industry on the environment is the pollution of air, earth and water, and that this pollution can spread well beyond industrial sites and affect the wider environment. When investigating industrial sites it is important to consider these effects at both a landscape and a local scale. Contaminated ground reflects local pollution of the soil, but increased concentrations of heavy metals are also found in sediments bordering industrial sites as a result of airborne pollution (Mighall et al 2004).

This evidence, along with the presence of microscopic charcoal, spherical carbonaceous particles (SCPs) and different types of fly ash (for example inorganic ash spheres – IAS), in such sediments will reflect the location, type and intensity of industrial activity (Case Study 7) (Smol 2002). SCPs, in particular, are associated with the use of coal, and their appearance in a palaeoenvironmental sequence is often taken as marking the onset of the industrial age (Renberg and Wik 1985).

Studying pollen assemblages from the levels where SCPs first appear gives an immediate insight into how vegetation cover was affected, especially as regards the extent of woodland. While in some cases decline in woodland cover is seen (Mighall et al 2004), it is argued that industrial use of woodland led to careful management and conservation (see Fig 30) rather than destruction (Rackham 1990).

Here, one of the problems may be that the effects of pollution causing vegetation to die out are difficult to distinguish from exploitation for fuel.

Heavy metal pollution is also seen in river sediments. Lead levels in dated flood sediments in York have been shown to relate to lead working in the Yorkshire dales (Hudson-Edwards et al 1999), while increased levels of lead, arsenic, zinc and copper in a palaeochannel at Sexton, Dartmoor, against a background of tin contamination, are thought to reflect the exploitation of silver-lead lodes at Loddiswell mine in the mid-19th century (Thornycraft et al 2003).

Processing of textiles, tanning and horn working are also highly polluting of the water supply and tend to be situated downstream and on the edges of settlements. Waste from these processes leads to oxygen depletion, and if anoxic conditions are maintained, fragile biological remains will be preserved. These remains
Case Study 8: 
Silkstone glassworks, Yorkshire 
by David Dungworth and Tom Cromwell

The investigation of the site of a glassworks at Silkstone was driven by the need to identify the site and inform decisions about designation and preservation. However, the evaluation also provided the opportunity to develop both field- and lab-based methodologies for industrial sites. The scientific examination was intensive and aimed to test which methods would be most effective.

Documentary evidence suggested that a glasshouse had operated in the Yorkshire village of Silkstone from the middle of the 17th century into the early 18th century. A small evaluation trench revealed floor surfaces and dumped layers extending to a depth of about a metre. As the stratified sequence was finely dated by clay pipes, the assemblage provided a good opportunity to test various sampling strategies and scientific techniques for investigating post-medieval glasshouses. Soil samples (10 litres) from selected contexts were sieved to recover small fragments of debris normally missed during excavation, such as fine glass threads (Fig 21). More than 400 of these small fragments of glass and glass-working waste were analysed to determine the chemical composition of the glass produced and how this changed over time (Dungworth and Cromwell 2006).

The detailed examination and analysis of a large number of samples from a single site has provided important information about the sorts of samples and scientific techniques that can provide the most useful information. The scientific work has shown that many categories of glassworking waste had been subjected to transformations and reactions with other process residues (eg clinker from the coal ash) and so provide only limited information about the types of glass that were manufactured. However, some types of waste, in particular the fine threads (Fig 21), provided reliable information on the composition of the glass made at the site.

Prior to phase 4 (c 1680–c 1700) the glasshouse produced a dark green bottle glass (high-lime low-alkali type) and pale green glass (mixed alkali type) probably used for tablewares (Fig 22). This corresponds with the documentary evidence (section 5) for two glasshouses at the site: a ‘greenhouse’ and a ‘whitehouse’. The glass composition also indicates the raw materials used; the bottle glass composition is consistent with the use of plant ashes, such as the rape ash recorded in a will as being part of the stock of the glasshouse. The composition of the pale green (mixed alkali) glass changed over time (Fig 22). During phase 1 (c 1660–c 1670) it was probably made from kelp or seaweed ash (indicated by the high strontium content of the glass) and during phase 2 (c 1670–c 1680) it was perhaps made from the ashes of a relatively soda-rich coastal plant such as glasswort. The low strontium content rules out seaweed.

About 1680 the glasshouse underwent major alterations, indicated by a thick layer of demolition rubble. The bottle glass production continued, but a clear lead glass replaced the mixed alkali glass. Lead crystal glass was developed in the 1670s in London and it displaced most other tableware glass recipes by the end of the 17th century (Dungworth and Brain 2005). The evidence from Silkstone shows that the new technology was rapidly adopted outside London.

The intensive scientific study of glassworking process residues from Silkstone has provided insights that are not available using other approaches. The historic record for Silkstone gives no impression of the ways in which glassmaking recipes changed over time. The scientific results show that at least some of the raw materials had been transported long distances; Silkstone is more than 80km from the nearest source of seaweed. The quick adoption of lead crystal shows that this provincial glasshouse was dynamic and open to new ideas.

The nature of the glass produced at such sites can only be understood by analysing a large number of samples and these need to be selected with reference to the stratigraphy. The small-scale excavation did not locate any structures associated with glassworking, such as a furnace. Nevertheless, the excavation showed that c 0.5m of stratified deposits associated with glassworking survived and the site has since been scheduled as an Ancient Monument.
can be used not only to elucidate the types of activity that are taking place at a site but also to investigate water quality. Cladocerans (water fleas) and chironomid (non-biting midge) larvae may prove particularly useful for this purpose (Hall and Kenward 2003; Ruiz et al 2006).

However, diatoms (single-celled algae) and ostracods (small crustaceans), which are found in all types of water, are particularly sensitive to changes in water quality and will survive in less favourable conditions; both deserve more attention. Sampling water features, such as drains and culverts, for these remains should help in discovering whether these features contained clean water or effluent and thus establish function and help in understanding site layout (English Heritage 2002).

Another aspect of industry in the past was the vast consumption of raw materials. In addition to studying the types of fuel used, from sources of coal (Smith 2005) to types of charcoal (Gale 2003), studies of plant and insect remains from sites can also provide information on the sources of different components, such as raw textile materials. It has long been known that certain alien species arrived in this country with imported wool. Nearly 350 species were recorded in the early 20th century growing by the side of the river Tweed (Salisbury 1964, 138) but as yet few archaeological deposits have been investigated for evidence of this kind.

Waste deposits represent unique environments for plants. Plants that can tolerate contamination by heavy metals are known as metallophytes and form a distinctive flora, more common in the north Pennines than anywhere else in Britain (Buchanan 1992). Typical species are alpine pennycress (Thlaspi caerulescens), spring sandwort (Minuartia verna) and thrift (Armeria maritima) (Lunn 2004). Coal tips can also support distinctive florae. American cudweed (Anaphalis margaritacea), an early New World introduction, is a common sight on Welsh coal tips, along with native colt’s-foot (Tussilago farfara) and birch trees. One spectacular example of a waste deposit that has developed a unique flora is a 1km-long ridge known as the Spetchells, on the south side of the Tyne at Low Prudhoe (Fig 23). The site is a dump of calcium carbonate produced as a by-product of the synthesis of ammonium sulphate fertiliser during the Second World War. The dump was turfed over to make it less obvious to German bombers and now supports plants typical of the ungrazed chalk grassland of southern England (Lunn 2004, 191). Again, these artificial environments, and their development, could be investigated by sampling during archaeological investigations of industrial sites.

4.4 Investigative conservation

Investigative conservation uses a range of techniques (section 4.5) to understand how materials are preserved or altered in the burial environment. Conservators can provide advice and expertise that will ensure that the maximum information is obtained from excavated artefacts and materials. In some cases, special techniques (eg X-radiography, see Fell et al 2006 and Case Study 1) can be used to understand artefacts and materials that have undergone significant post-depositional alteration. In other cases, organic materials that have been preserved in anoxic burial environments require particular treatment to prevent deterioration (English Heritage 1999b; 1995c; 1999). The requirement to preserve archaeological remains in situ, wherever possible, has lead to increasing research by conservators and other scientists into the burial environment (Corfield et al 1998; Nixon 2004).

4.5 Understanding historic technologies

A wide variety of scientific techniques can be used to investigate the technologies employed in historic industries. It important that the scientific techniques selected are the most appropriate to answer the archaeological questions. Common questions include:

- What were the industrial processes, conditions and environment?
- What materials were consumed in the process?
- Where did these materials come from?
- What products and wastes resulted?

The range of materials recovered from historic industrial sites can include raw materials, fuel, fragments of structures (eg furnaces, pit linings, cementation chests), industrial ceramics (eg crucibles, moulds, saggars), waste (eg slag, chemical residues) and products. Scientific techniques can help identify these materials and link them with a particular industrial process and/or environment. Occasionally they can be traced to a specific source. Even when some of the materials do not survive, they can often be inferred by analysing those products and/or by-products that do survive.

The amount of material required for scientific examination or analysis varies depending on the nature of the technique, but often this can be very small (eg <0.1g). In many cases, however, the heterogeneous nature of the materials being studied (eg slag, crucibles with adhering glass) makes larger samples advisable (eg 1–10g) in order to obtain results that are representative. The techniques described below are grouped by the method of investigation: visual inspection, low-power microscopy, high-power microscopy, elemental analysis, analysis of compounds and physical testing.

4.5.1 Visual inspection

The first stage of any scientific examination of archaeological material is its systematic visual examination and comparison with reference collections. The size, shape, colour, density, texture and other properties of materials can be assessed without the need for complex instruments. This approach for metalworking slags and other residues is detailed in the English Heritage Archaeometallurgy guidelines (Bayley et al 2001).

4.5.2 Low-power microscopy

Low-power microscopes (magnification in the range x4–x50) are frequently used to extend the range of visual examination. Low-power microscopes require no sample preparation and are used to detect finer details on the surface of objects.

4.5.3 High-power microscopy

At magnifications greater than x50, optical microscopes have a small depth of focus and so are usually used with polished specimens. These provide information about the small scale internal structure (microstructure) of materials (Fig 24). To obtain a polished specimen it is necessary to cut a sample from the object. High-power microscopy is routinely applied to stone, ceramic and soil samples (petrography) as well as specimens of slag and metal (metallography).

Fig 23 The Spetchells, a dump of process residue (calcium carbonate), which has provided an isolated example of chalk downland in the North East. (© Jacqui Huntley)
Petrography is the study of the minerals present in geological materials and ceramics. Sometimes the origins of the material can be determined by identifying the combination of minerals present. A slice from the sample is ground until it is thin enough to allow light to pass through (usually 30 microns). When these thin sections are examined using a suitable microscope, the minerals in them display optical properties that enable them to be identified. As well as being widely applied to geological materials (eg stone and coal), this technique is routinely used to study archaeological ceramics (Whitbread 2001). It is more likely to be successful on coarse ceramics, rather than on fine ones, as large mineral grains are easier to identify.

Metallography is the study of the structure of metals and slags on a microscopic scale (macrostructure). The technique provides information on how the materials formed and also on the composition of alloys (Scott 1991). Samples are polished flat so that they can be examined using a high-power microscope (Fig 24). The shape of crystals in the object will show whether it has been cast or hammered into shape, and if it has been heat treated. The common alloys of iron, such as steel and cast iron, contain different levels of carbon, which are hard to differentiate with many analytical techniques. Crystals with different carbon contents, however, can be distinguished by metallographic examination. In addition weld lines and other features associated with fabrication can be detected. The microstructure of slags can be examined in a similar way, to obtain information about the ores smelted, the metal produced and the smelting conditions used (such as furnace temperature) (Bayley et al 2001).

When a specimen has been prepared for metallographic examination, the same sample can then be hardness tested.

A small, pyramid-shaped diamond is pressed into the sample surface and the hardness is calculated from the width of the impression. Hardness testing provides information about the strength of a sample, which can reveal how an object has been fabricated and can help distinguish different iron alloys.

The scanning electron microscope (SEM) can be used to form images at much higher magnifications (up to x50,000) than can be achieved with an optical microscope, and has a superior depth of focus (Fig 25; José-Yacamán and Ascencio 2000). SEMs can provide many different sorts of images: the two commonest are secondary electron and back-scattered electron images. Secondary electron images provide a detailed picture of the surface topography of a sample (see Fig 21) and are widely applied to the recognition of a range of materials, but especially to organic ones (eg plant macrofossils, pollen, bone, shell, wood and mineral-preserved organics). Back-scattered electron images are used to look at the microstructure of a material and to obtain some chemical information. Inorganic materials (eg slags, ores, metals, glasses and ceramics) are often examined in this way (see Figs 4 and 5). When an X-ray spectrometer (section 4.5.4) is attached to a SEM, selected areas of a polished sample can also be analysed. Overall, SEM, combined with X-ray spectrometry, is one of the most useful analytical tools for archaeological materials. It allows the determination of chemical composition, but this can always be related back to aspects of the microstructure, which is particularly useful for heterogeneous or composite materials (Freestone 1982) such as the smelting slag analysed in Case Study 2.

4.5.4 Elemental analysis

The goal of elemental analysis is to determine the proportion of different elements present in a material, and it is generally used for characterising inorganic materials (eg metals, glasses and ceramics). As organic materials are mostly made of carbon, hydrogen, oxygen and nitrogen in proportions that vary only a little, elemental analysis is of little value, and it is the nature of the compounds present that is important (section 4.5.5). Many different analytical techniques have been applied to archaeological materials (Brothwell and Pollard 2001, Ciliberto and Spoto 2000; Pollard and Heron 1996) and only the most commonly applied techniques are described here: inductively coupled plasma spectroscopy and different types of X-ray spectrometry.

The inductively coupled plasma spectrometer (ICPS) heats samples in solution to extremely high temperatures until they emit radiation as visible light. Samples are destroyed by analysis and the results are for the entire sample, rather than for specific parts of it. The proportion of different elements present can be determined from the wavelength and intensity of the emitted light. The main advantages of ICPS are that it is very sensitive (most elements can be detected in parts per million) and large numbers of samples can be analysed quickly (Pollard and Heron 1996, 36–53). However, it is useful to already have a rough idea of which elements are in the sample, because the analyst has to choose the ones that are going to be measured (usually about 20) in advance of analysis. A disadvantage is that, although ICPS is commonly used for glasses and ceramics, the sample preparation procedure removes silicon (a major component of these materials), which then cannot be measured. Consequently, the results do not add up to 100% and so the analytical total cannot be used as a check that nothing significant has been missed.

Another commonly used technique is X-ray spectrometry (Moens et al 2000; Pollard and Heron 1996, 36–53). There are various types of X-ray spectrometer but in each case the sample is made to emit X-rays, and their energy and intensity are used to work out the composition of the sample (Fig 26). Some of these techniques, known as EDS (energy dispersive X-ray spectrometry), WDS (wavelength dispersive spectrometry) or EPMA (electron microprobe analysis) are used in conjunction with an electron microscope (section 4.5.3), which allows the user to analyse small features selectively, a few microns across, or to look at changes over a larger area or along a line. Weathered areas can also be seen and avoided. Another advantage is that even unexpected elements...
For example, shell and XRF spectrum: the positions of the peaks indicates which elements are present and the height of a peak indicates the abundance of that element. Many analytical methods will measure the amounts of different elements present in a sample, although they cannot detect as many elements as laboratory-based instruments. Identifying compounds

Many analytical methods will measure the amounts of different elements present in a sample (section 4.5.4), but this is not always enough to identify a material conclusively (Case Study 5). For example shell and limestone are chemically the same (calcium carbonate), but the atoms are arranged differently in each. It would be difficult to tell the materials apart using elemental analysis. Some techniques, however, such as chromatography, Fourier transform infra-red (FTIR) spectroscopy, Raman spectroscopy and X-ray diffraction (XRD), provide information on the way atoms are arranged in a sample. These techniques are able to distinguish different materials, even when they are chemically similar.

Chromatography is a technique for identifying organic compounds (Pollard and Heron 1996, 66–72). The sample is passed through a column as a gas (gas chromatography) or a liquid (liquid chromatography). The various components of the sample are separated because they flow through the column at different rates depending on their size; small ones move more quickly than large ones. Chromatography can be used to analyse very small samples and is extremely sensitive. Gas chromatography can only be used on samples that are both thermally stable and volatile. However, liquid chromatography, and high-performance or high-pressure liquid chromatography (HPLC), can be used to analyse a wider range of materials. The chromatogram generated is compared with those of known reference materials. In addition, chromatography can be used in combination with a mass spectrometer (MS), which provides extra information to help identification (Evershed 2000).

Chromatography is widely used to examine the remains of foodstuffs in pottery but has also been applied to a variety of resins, waxes, dyes and other organic compounds. Fourier transform infra-red (FTIR) spectroscopy provides information about the chemical bonds in a sample, and their molecular environment (Bacci 2000; Cariati and Bruni 2000). Bonds between different types of atom can be distinguished because they absorb in different regions of the infra-red spectrum. Raman spectroscopy uses a laser beam, which is shone onto the sample and scattered by it. The resulting spectrum is matched against ones from reference materials. FTIR and Raman spectrometers can be combined with microscopes to analyse small samples or to target a specific area. These techniques have been applied to a range of materials including paint binders, plastics, corrosion products and minerals.

In X-ray diffractometry (XRD), X-rays are passed through a sample at different angles. The intensity of the emerging X-rays varies over the angle range, and is dependent on the spacing between the atoms of the sample. The results are compared against reference XRD plots for known materials to identify the compounds present. XRD analysis is usually carried out on a powdered material, and many machines can use very small samples. Any type of material (organic or inorganic) can be identified except non-crystalline ones, such as glass. The technique is commonly used for corrosion products, minerals, pigments, efflorescent salts and chemical residues.

4.5.6 Investigating process temperatures

Many industries use heat to transform raw materials into finished products, and there are a number of different methods for determining the temperatures achieved (Odlyha 2000). Sometimes samples of the product itself can be tested, for example reheating a glass to see when it becomes fluid. The temperatures achieved during the production of a material can also be estimated from the composition of the material itself. Various different methods have been used, including phase diagrams and models (Freestone 1988).

Alternatively, replica materials can be made up and their properties measured (Cable and Smedley 1987). There are also a number of methods for testing ceramics to see what temperatures they have been exposed to. These methods have been used for domestic pottery but can also be used for industrial ceramics, for example crucibles and furnace linings.

Dilatometry measures the dimensional changes of a sample during heating and cooling: ceramics generally expand as they are reheated but start to shrink as the previous firing temperature is approached (Tite 1969). Changes to archaeological ceramics over time, however, including the absorption of water, can affect the results. The firing temperature of a ceramic material can also be estimated by looking for microscopic changes in the structure of the ceramic after it has been reheated (Tite and Maniatis 1975; Dungworth and Cromwell 2006). Samples are reheated to increasingly higher temperatures and then examined using scanning electron microscopy. The structure alters little (compared to that of the sample prior to reheating) until the original firing temperature is exceeded, at which point changes are observed.
5 Historic archives
by David Crossley

5.1 Introduction
Historic archives can provide detailed information about the range of activities and structures that were present on a specific historic industry site (see for example Case Study 1 and Case Study 6). In addition, archives can provide generic information about the processes and by-products of historic industries. This section provides a guide to the most commonly-found classes of archive material, and those likely to give the best yield to researchers, particularly those with little background in work on historical records.

5.2 Maps
Cartographic evidence provides the most effective starting-point, and it is usually best to work back from modern surveys, to seek indications of phases of development that may correspond with stratigraphic and structural evidence (often referred to as ‘map regression’). The Ordnance Survey 6-inch and 25-inch to the mile maps (now 1:10000 and 1:2500) are the essential starting point (Oliver 1993); the former appeared from the middle of the 19th century, the latter from about 1890, and both have gone through numerous editions (Case Study 6). For the major conurbations there are also large-scale plans (1:1056 and 1:500); the former start in the 1840s, the latter in the last quarter of the 19th century. They are valuable for the precise establishment of property boundaries and frequently indicate the uses to which land and buildings were put (Fig 27). The 1 inch:mile OS maps are useful for the first half of the 19th century, but the recording of detail is apt to be selective, and not always predictably so.

Before the 19th century, there are national or regional maps (Wallis and McConnell 1994). These start late in the 16th century with county maps of England by Saxton, followed by Speed’s series early in the 17th century, and continue in the 18th century with, for example, those of Burdett for Derbyshire, Dury and Andrews for Hertfordshire, and Jefferys for Yorkshire. Detailed maps were largely made by local surveyors. Their skills developed over the 16th and 17th centuries when active land-markets made accurate recording of boundaries essential. The convention of representing buildings in bird’s-eye-view (Fig 28) was replaced by the measured plan, and this became standard on maps by the second quarter of the 18th century (Fig 29). The earlier convention, however, was much used for panoramas, such as those of the Bucks in their series of views of towns (eg Bristol or York). With few exceptions, surveyors’ output is to be found in the archives of their landowner-clients (Fig 30), rather than in those of the surveyor firms themselves, of which very few collections survive, examples being Fairbank for Sheffield, Bell for Tyneside or Kyle, Denniston and Frew for Glasgow (Crossley 1997). Some surveys were widely circulated, particularly if they accompanied projects such as land-enclosure, turnpike-road building or canal or railway construction, which required Parliamentary authority in the form of a private Act. Many surveyors operated a commercial side-line in combining information from their property surveys to compile town maps for sale.

There are non-Ordnance Survey maps and plans, made in the 19th century for specific uses, which are also worth seeking out, but whose universal compilation, or survival, cannot be assumed. Some Poor Law Unions commissioned maps of their territories, frequently emphasising properties such as mills, factories and mines, which were properties with rating...
potential. Fire-insurance companies required plans, and many towns were mapped for this purpose by the firm of Goad, who recorded valuable details of building-use. Goad plans continued to be produced well into the 20th century. Equally valuable are sale-plans, which were commonly made by local surveyors for auctioneers.

Mining for coal and iron ore is well covered by maps produced by the pre-nationalisation companies, often going back to the 19th century. These were preserved by the former National Coal Board as a safety measure, showing where potentially hazardous workings lay, and much of this collection has been safeguarded by deposit in record offices. Particularly important are Abandonment Plans, which from 1872 were required to be made and deposited under Home Office legislation when workings were closed down.

5.3 Public records
Public bodies, especially local and national government, have made numerous records that contain information relevant to understanding historic industries, including Rate Books, Bye-laws, and Parliamentary records. Local rates were paid for maintenance of the parish facilities; originally just the church but from the 17th century onwards the rates were used to support the local poor and maintain roads. Rate Books, which survive to a varying extent for many urban areas, comprise assessments of property values on which rates were charged to cover growing municipal commitments. Their detail is variable, some assessors being meticulous in recording the purposes to which buildings were put, for example showing power generated by steam engines or by the fall of water over mill-wheels. Bye-laws concerning building standards go back as far as London’s Great Fire of 1666, but were commonly introduced over the middle quarters of the 19th century. Survival of related material is variable but, at best, plans and structural descriptions can be found.

The records of central government can provide information about historic industries, especially from the early 19th century onwards. Private Acts of Parliament often dealt with land-enclosures, road, canal and railway building and reservoirs for municipal water supply. The proceedings themselves include material such as maps and surveys, and also descriptions of works and, in particular, petitions for and against such schemes and their proposed routes, which include contextual information, such as the industries that would be served. In some cases, opposition was considerable over long periods, for example by mill owners against reservoir schemes. Royal Commissions reported on numerous relevant topics, such as the Health of Towns or Children’s Employment. For example, the enquiry into the ‘Sheffield Outrages’ of 1867 contains witnesses’ statements that shed light on local industries and their processes, particularly where these were injurious to health. The Royal Commission on the Board of Excise reported on the state of a number of industries, including the glass industry in 1833 (Brown 1980).

5.4 Private records
The survival and availability of archive material from private records is unpredictable, although, at its best, rewarding. When assessing an archive
collection in a record office, the quality of cataloguing is all-important. The Access to Archives project (www.a2a.org.uk) provides for on-line searching of more than 300 archive repositories in the United Kingdom, as well as those of the National Archives.

Directly-managed industry was rare on great landed estates after the middle of the 18th century. Where this was the case, however, estate accounts include material for coal mines or ironworks along with the corn mills and farms. Woodland management was apt to remain in estate hands, and long-term contracts for charcoal with neighbouring ironworks were often recorded. More usual were tenanted works, identified from leasebooks and rentals. The former are important for construction, where the landowner and tenant shared costs, sometimes by a rent-reduction over an initial period. The rentals confirm identity and continuity of occupation.

During the 18th and 19th centuries, certain industries generated and preserved significant archives. The survival rate does not match papers of landed estates, where there was often a pride in the keeping of long-term records. In many industries, changes of ownership have been the occasion for wholesale destruction of papers. Many business archives have been catalogued by the National Register of Archives of the Historical Manuscripts Commission (now part of the National Archives).

5.5 Legal papers
Legal documents are particularly significant for the immediate post-medieval period. In the 16th and 17th centuries, in the absence of several key sources referred to above, court cases involving or peripheral to industrial activities can be important. Access to justice was a key policy of Tudor government, and the records of the national Equity Courts (Chancery, Requests, Star Chamber) are well preserved in the National Archives (formerly Public Record Office), although not yet fully calendared or indexed. The facts of legal cases can be valuable contributors to the history of industrial concerns, but it is among the depositions of witnesses that information can often be found, particularly where the witness digresses into the context of a dispute. At the local level, records of proceedings in Quarter Sessions or magistrates courts can be relevant, where disputes or disorder involved industries or those identified as working within them.

The study of vernacular architecture has proved the value of inventories of goods compiled to secure probate of wills. It was common in the period 1550–1750 for appraisers to list goods on a room-by-room basis, their record thus comprising an impression of houses and workshops, sometimes listing materials (Case Study 8). Written evidence of ownership of property comes from deeds, whose survival is variable. Private deeds can contain descriptions of property, often concealed within a conventional wording. In some cases Abstracts of Title have been compiled by lawyers, listing and consolidating past changes. These are a mixed blessing, for although convenient, they often accompanied the destruction or dispersal of original deeds, with the loss of the valuable incidental information that these can contain. Sales of lands generated significant records, whether new deeds, sale-plans, or, in cases of estates where there were long-term legal restraints on disposal, private Acts of Parliament permitting this to happen.

5.6 Contemporary publications
Contemporary publications can be divided into two categories: those that provide information about a specific site and those that provide generic information about particular industries.

The investigation of a specific site can benefit from the examination of a number of local resources, such as street directories and newspapers. Street directories exist year-by-year for large towns from late in the 18th century, and in many cases the publishers included surrounding rural townships. Early directories may not be comprehensive, as there was no obligation for the occupier of

![Fig 31](A mid-19th century blast furnace from Muspratt (1860).)
property to be included. However, by the 1820s most give a complete listing of occupants and uses of urban property.

Newspapers, such as the *Penny Magazine*, occasionally contain useful information, for example descriptions of factory tours (Case Study 6), but can be a frustrating source, as local paper collections are rarely indexed. External evidence of the date of a key event, such as the passing of a private Act of Parliament, local agitations against such schemes or bankruptcies of prominent firms can lead to reports that include descriptions of industrial premises and activities. Advertisements and catalogues are useful for their engravings of works-views taken from firms’ billheads (Case Study 6), although such illustrations are not always accurate.

In the 18th century, descriptions of industry in Britain were compiled by observers from overseas. A recently published example is Angerstein’s *Diary* (Berg and Berg 2001), which describes numerous English industrial sites. During the 18th and 19th centuries lists of ironworks were compiled and, although not published at the time, have been reviewed (Riden 1994; Riden and Owen 1995). Forerunners were the lists of Wealden ironworks of 1574 and 1588, drawn up by Crown officers in the face of a perceived threat of illegal export of ordnance to Spain. Another national record of an industry is Houghton’s list of glassworks of 1696 (Vose 1980).

Accounts of specific industries can be found in various contemporary encyclopaedias and textbooks. Particularly useful early accounts are Agricola’s 16th-century *De Re Metallica* (Hoover and Hoover 1950) and Diderot’s *Encyclopedia* (Gillispie 1959). Technical textbooks became increasingly popular in the 19th century, from early examples such as Rees’ *Cyclopedia* of 1819–20 (Cossons 1972), and developed to rigorous descriptive works such as Percy’s *Metallurgy* (1861; 1864; 1870). The dictionaries compiled by Andrew Ure (1843) and James Muspratt (1860) contain much useful information (Fig 31) and were published in such large numbers that they are both commonly available. In the 19th century technical journals became important, examples being the *Journal of the Iron and Steel Institute*, the *Proceedings of the Institute of Mechanical Engineers* and the *Journal of the Society of Chemical Industry*.

**5.7 Paintings and photographs**

An often-ignored source is the work of landscape artists, from the 18th century onwards (Fig 32). Paintings need to be treated carefully, as composition or convention could take precedence over strict accuracy of detail and they should be interpreted in their historical and artistic contexts (Klingender 1972). At the very least, the inclusion of a feature, however portrayed, seen to exist at a particular time, has its value. The attraction of railways to artists is well known, from the mid-19th century paintings and engravings of newly-built railways to the portrayals by French Impressionist painters visiting England in the 1870s. Architects’ drawings of such schemes are important, although use of them should include verification that buildings were finished as projected.

The more modern counterpart is the photographic collection, and the value of the widely-disseminated work of commercial photographers such as Frith of Reigate, Mottershaw of Sheffield or Frank Sutcliffe of Whiby cannot be overstated. Many towns had firms whose work survives, and the recent interest in publishing selections has emphasised the value of such sources.

**6 Industrial summaries**

The primary aims of an archaeological investigation into a site of past industrial activity include identifying the processes and human activities that took place, and when and where on the site they occurred (Badcock and Malaws 2004; Cranstone 2001). These aims can be difficult to achieve, even at sites where buildings survive and the industrial activity ceased relatively recently. Some prior knowledge of the processes that took place is essential in order to develop the most appropriate strategy for investigating the site, and to interpret the results to their full potential.

Numerous significant industries have not been included in this summary for reasons of space, notably the non-ferrous industries (eg lead and copper), chemical industries (eg acids, alkalis and organic chemicals), industries producing gas, tar and coke from coal, and so on. Although the sites of these historic industries have great potential for archaeological investigation, as yet there are few examples where this potential has been realised. However, general information on these, and on other industries, can be found in Buchanan (1972), Campbell (1971), Cossons (1972), Crossley (1990), Jones (1996), Newman (2001), Raistrick (1972) and Russell (2000). Case Studies 2 and 5 also describe archaeological evidence of non-ferrous industries.

The five tables in this section cover the iron, glass, pottery, textile and tanning industries. Each table includes a brief summary of the processes and a chronology of developments in that industry (17th to 19th centuries), the types of materials, structures and waste involved (any of which might be encountered archaeologically), the analytical techniques that potentially could be employed and, finally, sources of further information. These industries have been chosen because they were relatively widespread and large scale and so the remains are likely to be encountered by archaeologists. This selection also encompasses relatively low temperature industries using organic materials as well as high temperature industries using largely inorganic materials. Therefore, although this list is far from comprehensive, many of the same principles, in terms of the types of archaeological evidence likely to survive and the scientific techniques that might be used, are likely to apply for other industries. The case studies relevant to each industry are highlighted at the top of each table.

The analysis section of each industry table is intended as a guide to the types of deposit and feature that might have the most potential for analysis, and the techniques that could be applied to address certain questions. Not all of the techniques will be necessary or practicable in every situation. More information on analytical techniques and sampling, including sample sizes, is provided in section 4, as well as details of the relevant English Heritage guidelines.
Processes
Iron ore was reduced to iron metal by smelting. The product of blast furnace smelting was molten cast iron (a carbon-rich iron alloy). A limestone flux was used in the process, resulting in a lime-rich slag by-product. The iron could be cast in a casting house next to the blast furnace, using moulding sand (eg for ‘pig’ ingots) or clay moulds (eg for vessels and cauldrons). Foundries specialised in casting and could be separate from blast furnaces. They used reverberatory furnaces to re-melt cast iron.

Plain (or ‘wrought’) iron was shaped by smithing. Plain iron, steel and cast iron have different properties and applications, so a variety of processes were used to convert one to another. Cast iron was refined to make plain iron using the fining process. Cast iron from coke-fuelled blast furnaces was more difficult to refine, and a number of processes were developed to do it, including potting and stamping; but the reverberatory puddling furnace method was more common. There were also a number of methods for converting plain iron into steel. The cementation process resulted in heterogeneous steel bars, known as blister steel. The Huntsman crucible steel-making method, however, produced more homogenous steel ingots by melting the steel. The Bessemer converter and Siemens regenerative open hearth furnace also produced steel ingots, but with fewer impurities.

Chronological summary
Blast furnaces were introduced in Britain from the 15th century onwards. Early ones had water-powered bellows and were charcoal-fuelled. Coke was used from the beginning of the 18th century but was not widely adopted until the later 18th century. Leather and wood bellows were replaced with cast iron blowing cylinders, and pumping engines were used to return water to mill ponds. From the late 18th into the 19th century waterwheels were superseded by steam engines, and stoves preheated the air blasted into the furnace, allowing different ores and fuels, for example anthracite and coal, to be used.

Before the late 17th century a large amount of steel was imported. This changed when cementation steel was developed, followed by Huntsman crucible steel in the 18th century. The Bessemer converter was used for steel production from the mid-19th century, followed by the Siemens regenerative open hearth furnace. From the end of the 18th century, with the invention of the cupola furnace, cast iron was used directly in more applications, such as bridges, architectural components and industrial machinery. Until the end of the 18th century, a large proportion of cast iron was converted to plain or ‘wrought’ iron, using refining, potting, stamping and, from the 18th century, Cort’s puddling process. An increasing amount of puddled wrought iron was used in civil engineering and railway work. The puddled iron was hammered and rolled through grooves to form bars, which could subsequently be shaped into sheet, rods and rails. Steam hammers were widespread by the second half of the 19th century, and continuous mills were also introduced. Ironworking processes were increasingly mechanised over time. Water was used to power mills for slitting, drawing wire, making sheet, grinding blades and reaming or boring. Later, pumping engines and, in the 18th century, steam power were introduced. In some ‘hand trades’, however, power was rarely used.

Materials
Ore, fuel (charcoal/coke), flux (limestone), iron alloys, clay, sand and stone (eg for moulds, casting floor, furnaces, crucibles).

Structures
Building foundations, furnaces (smelting and foundry), timber, or stone-lined casting pits (foundry), anvil and hammer foundations (smithing), wheel-pits, culverts, dams, mill ponds, gear pits and shafts, engine houses, boiler houses, flues and chimneys, placements for machinery (engines, stoves) and pipe work, gun carriages (gun boring), and grindstones and troughs for them (blade production).

Waste
Slag, including hammerscale (smelting and smithing), furnace materials, moulds (foundry), pots (potting), crucibles (crucible steel), cementation chests (cementation steel) and metal (eg spills, offcuts, turnings, failed castings).

Sampling and analysis
Specialist examination of slag, crucibles, etc (see Waste). Analysis of raw materials, slag, metal etc (eg by EDS/XRF/metallography) to identify processes, raw materials and products. Investigate process temperatures by testing associated ceramics, such as crucibles (eg SEM/EDS/reheating). Sample deposits of materials (eg clay, casting sand) for analysis (eg by XRD/ICPS) and identification. Sample preserved working surfaces and test for evidence of processes eg magnetic hammerscale from smithing, turnings from gun boring. Sample fuel for identification. Off-site sampling for environmental and chemical evidence of pollution and land use. TL dating of ceramic materials.

Information
Processes
To make glass, a source of silica, such as sand, flint or quartz pebbles, was combined with fluxes, for example lead oxide or alkalis (soda/potash). Before the development of synthetic soda, alkali fluxes were commonly derived from the ashes of plants such as bracken, kelp or beech. Glass was made in a variety of colours, opaque or transparent, by controlling the production conditions and adding colorants or opacifiers. Colourless glass was made using pure raw materials and/or by adding de-colourisers.

The raw materials (batch) were ‘fritted’ at ~700ºC then melted at higher temperatures (1200–1300ºC) in the furnace. Generally the glass was contained in crucibles, situated on platforms (sieges) in the furnace. In contrast, in tank furnaces raw materials were charged (added) at one end and melted glass taken from the other. Siemens’ regenerative furnace incorporated a method of preheating air and gas before they were used.

The shaping of glass mostly took place at production sites. Windows were made from crown glass, in which a blown glass bubble was opened out and spun to produce a circular ‘table’ of glass, or from broad or cylinder glass, in which a glass bubble was elongated to form a cylinder and then cut open and laid flat. Tablewares and bottles could be ‘free-blown’, blown into moulds, or press moulded. Tablewares were often cut and engraved.

Chronological summary
Earlier furnaces comprised a long fuel trench flanked by parallel sieges, where the crucibles holding the glass were placed. Coal was used from the early 17th century and glass furnaces were rapidly adapted to incorporate underground flues, ash pits and grates. The characteristic conical cover building first appears in the late 17th century (see Fig 28) and, during the 18th century, some furnaces used a circular hearth with six or eight crucibles surrounding it. Nineteenth-century developments included the transition to gas fuel and the use of large tank furnaces, and later Siemens’ regenerative furnace.

Both crown glass and broad glass were used for windows up to the mid-18th century. Subsequently crown glass was favoured until the mid 19th century, when broad glass (or German sheet glass) was reintroduced, and ground and polished to improve the finish (patent plate). Initially the glass used for windows had a high-lime, low-alkali (HLLA) composition, made from plant ashes. Kelp ashes were widely used through the 18th century and, from the 1830s, synthetic soda (saltcake) was commercially produced and commonly used in window glass.

In the 17th century, tableware was mainly free-blown, generally from ‘ordinary’ HLLA-type glass or a colourless, purer alkali glass known as crystal. Crystal glass was revolutionised in the later 17th century by the development of lead crystal (flint glass) made with lead oxide. In the 19th century, some tablewares were produced by blowing glass into moulds and later press moulding techniques were widely used.

Container bottles, such as wine bottles, were made from about the mid-17th century, initially free-blown but, during the 18th century, they were increasingly mould-blown in two-part moulds. In 1821 a three-part mould for bottles was patented. The earliest bottles were made from ordinary (HLLA) glass but from the mid-18th century, other, often cheaper, ingredients were added, for example blast furnace slag, kelp ash, soapers’ waste, bricks, clay and stone.

Materials
Sand/flint/quartz, potash/plant ashes (and plants from which potash derived, eg kelp), lime/slag/lead oxide (red lead), colorants, clay, sand and stone (eg for crucibles, furnaces), metal (eg moulds), fuel (eg coal).

Structures
Building foundations, furnaces (eg sieges, foundation of cone, tank, swing pits), fritting oven, annealing oven or channels, pipes and chimneys, ash pit, fuel grates and fuel delivery systems (eg Frisbee feeder).

Waste
Glass (working waste, fragments of products, devitrified glass), crucibles, moulds, furnace materials, sandever (scum from surface of glass), tools (eg blowing iron, shears, wooden tools).

Sampling and analysis
Specialist examination of glass, crucibles, etc (see Waste). Sieve samples from working surfaces to recover small glass fragments if little survives otherwise. Analysis of glass to identify types made and probable raw materials (eg EDS/ICPS). Sample deposits of material (eg clay for crucibles, glass raw materials – see Materials) for identification (eg by XRD/ICPS). Sample fuel for identification. Off-site sampling for environmental and chemical evidence of pollution and land use. Investigate process temperatures by testing glass or associated materials (eg crucibles, furnace materials). TL dating of ceramic materials or archaeomagnetic dating of furnaces.

Information
### Processes

The raw materials for ceramics were prepared, for example, by weathering, levigation, working, milling, mixing and sieving. Materials were often combined, for example different clays, temper (a non-plastic material added to clay to modify its properties) and fluxes (to modify the fusing temperature). Strongly-coloured ceramic bodies were made by adding colourants (e.g. Wedgwood Jasper ware) or by using materials with a naturally high concentration of colourants. ‘Hard-paste’ porcelain bodies were made using china clay and china stone. Bone china was produced using bone ash.

Pottery was formed by a variety of methods, including hand forming, throwing, slip casting in moulds, press moulding and lathe turning. After drying, objects were fired in kilns using fuels, depending on availability, although coal was used increasingly. The firing temperature depended on the ceramic: for earthenware clays 800–1100°C, and higher for stoneware and porcelain. Often pottery underwent more than one firing; for example an initial biscuit firing, after which the decoration and glaze were applied, followed by a glost firing. Wares could be protected in the kiln by stacking them in sealed ceramic vessels (saggars), with various types of divider supporting them (spurs, stilts, etc). The firing atmosphere (oxidising/reducing) also influenced the resulting appearance of the ceramic, glaze and decoration.

Types of decoration include slips (coloured, fine clay suspensions), which were applied to vessels before they were fired. Glaze raw materials could be fritted and ground before application, or applied in the raw state. Glaze mixtures were applied as a powder, or from a suspension in water, by pouring, dipping, splashing, etc. Glaze compositions were tailored to ‘fit’ the ceramic body and for decorative effect. Salt glazing was used on stonewares; the salt decomposed at high temperatures and reacted with the ceramic to form a thin glaze layer. Delftware was earthenware covered with a white glaze, opacified with tin oxide. Decoration could be painted on top of the glaze (overglaze) using pigments.

### Chronological summary

Although single-flue and double-flue kilns are known from small-scale production sites in the 17th century, kilns with three or more stokeholes were the common form, being better suited to coal fuel. Brick-built kilns with a permanent structure were standard by the early 18th century in major pottery-producing centres and the characteristic, large, conical chimneys developed over the late 17th and early 18th centuries. These kilns were permanent and brick-built with a bottle-shaped casing and multiple flues. Rectangular continental-style kilns were used for producing some wares (e.g. delft and stoneware). From the 18th century, steam engines were used, for example for flint mills, grinding ceramic colours and mixing clays.

Delftwares were produced in England from the early 17th century, or a little earlier, declining towards the end of the 18th century. Large-scale production of English stonewares began in the late 17th century, together with salt-glazing. In the mid 18th century, the scale and specialisation of English ceramic production increased significantly, together with the exploitation of white-firing clays for refined earthenwares and stonewares (significantly ball clay from Devon and Dorset). Coloured earthenware bodies were popular in the mid-18th century but less so throughout the 19th century, whereas coloured stoneware bodies became increasingly important from the mid-18th century onwards.

Transfer-printed earthenwares were produced on a significant scale from the late 18th century. Hard-paste porcelain was produced from the mid-18th century, although types of soft-paste porcelain were previously made in England. Bone china was made from the early 19th century.

### Materials

Clay, sand, bone, flint, glaze materials (e.g. lead oxide, tin oxide, salt, colouring pigments), fuel (e.g. wood, coal).

### Waste

Pot wasters, kiln furniture (saggars, strips or wads of clay for sealing saggars, bars or pegs for supporting wares, stilts, spurs, cranks, placing rings, re-used wasters), kiln fragments, kiln bats, coal, ash and slag, miscellaneous small coarse vessels containing residues of glazes and pigments, moulds (fired clay and plaster of Paris), ribs and profiles for shaping wares (usually ceramic, sometimes slate), other tools (e.g. from bone or wood).

### Structures

Building foundations, kilns, fireboxes, hovels, flues, stoking pits, stoves or hearths (e.g. pot drying), engine house, flues, chimney (e.g. for steam-powered flint mill), troughs, pits, tanks.

### Sampling and analysis

Specialist examination of wasters, moulds, etc (see Waste). Analysis of wasters at different stages of production to identify the raw materials and firing regimes (e.g. SEM/EDS/reheating). Analysis (e.g. by XRD/EDS/XRF) of residues in coarse vessels and saggars to identify origins and function of glaze and pigment preparation/flow powder for transfer printing. Sample tanks and pots for evidence of function and also sample distinct deposits (e.g. clay, glaze raw materials – see Materials) for identification (e.g. by XRD/ICPS). Sample fuel for identification. TL dating of ceramics or archaeomagnetic dating of furnaces.

### Information

**Processes**

Many similar processes were involved in textile production, whether of silk, cotton, hemp, wool or flax. The material was cleaned and prepared by carding (aligning the fibres). Short wool fibres were separated from long ones by combing, and the latter were made into fine yarn for ‘worsted’ cloth whereas the short fibres were used for ‘woollens’. The fibres were spun into thread.

Woven fabrics were produced on a loom. The longitudinal warp threads were held on a frame and the horizontal weft threads were passed over and under these. The threads were often coated in a mixture called a ‘size’.

The finishing of woven cloths included ‘fulling’, where the fabric was pounded in water with fuller’s earth and stretched out to dry on tenter hooks. Bleaching and dyeing required large amounts of water. The alkaline solutions used in bleaching were derived from plant ashes and the fabric was pegged out in the sun for up to several weeks. Dyes were also plant-based. Later, faster-acting chlorine bleaches and synthetic dyes were used.

**Chronological summary**

The development of powered machines for many textile processes, particularly in the 18th and 19th centuries, had a profound impact on the organisation and output of the industry. The evidence for textile industries prior to these developments is often scant.

Carding was mechanised from the later 18th century whereas combing was the last section of the process to be mechanised.

In the second half of the 18th century, the introduction of the hand-driven ‘spinning jenny’, with multiple spindles, revolutionised the spinning process. This was followed by the development of a ‘water frame’ for spinning cotton, driven by horse- then water-power. The ‘spinning mule’ incorporated the attributes of both inventions and was water-driven by the end of the 18th century. Ultimately spinning machines with more than 1000 spindles were employed.

Textile mills were erected from around the mid-18th century. Mills had multiple storeys and bays accommodating rows of machines drawing power from a waterwheel or, later, a steam engine. Wooden shafts and gears were replaced by iron ones and then, in the second half of the 19th century, with a system of ropes attached to the flywheel of a steam engine. Catastrophic fires stimulated the development of fire-proofing measures, such as cast iron beams in place of timber ones.

Handlooms were located in the weavers’ homes. Powered looms increased in use from the end of the 18th century, becoming widely employed in the first part of the 19th century. The processes for producing knitted fabrics, hosiery and lace were also mechanised over this period. Powered weaving frames were generally heavy, with a strong reciprocating action, and were housed in single story weaving sheds.

The hammers of fulling mills were water-powered from an early date. Before the Industrial Revolution, bleaching and dyeing processes probably made use of wooden- or stone-lined troughs and pits, vats and cauldrons. Later, heated dyeing houses were employed and the processes used massive equipment housed in sheds. In the late 18th century, chlorine bleaches were used, and in the 19th century, synthetic dyes were developed.

**Materials**

Silk, cotton, hemp, wool, flax, fibre sizing materials (flour/tallow/china clay), fulling materials (eg fuller’s earth, fuller’s tease: *Dipsacus sativus*), bleaching materials (eg alkalis from plant ashes, chlorine bleaches), dyeing materials (eg dyers greenweed, synthetic aniline dyes), mordants (eg alum), water.

**Structures**

Building foundations, vat bases, pits and drains (dyeing), engine room, boiler house, machine bases and restraining rods, culverts, flues, chimneys and pipe work (all textile mills), wheel-pit (fulling mills, textile mills).

**Waste**

Fibres, propagules or, for flax, seed capsules and flax field weeds in waterlain deposits (water-retting of hemp and flax), sheep keds, lice and possibly types of dung beetle (wool cleaning), remains of plants used in dyeing and mordanting, for example dyers’ greenweed, or chemicals used in these processes, clinker/ash from engine/boiler houses, artefacts (eg bobbin, loom weight, cauldron, weaving reed, pegs and pins).

**Sampling and analysis**

General industry: Sample waterlain and waterlogged deposits, preserved working surfaces and cut features near to structures for evidence of the textile processes taking place and raw materials used. Identify environmental evidence (plant and insect indicators – see Waste, and Materials). Specialist examination of surviving textiles.

Textile mills: Sample at intervals across excavated area or structure (to locate activity), or in water features and sediments (to investigate pollution and water quality). Analyse for high levels of organic chemicals, such as synthetic dyes (eg test for toluene soluble material), and other elements (eg aluminium/tin/lead) that might be associated with bleaches, dyes or mordants for the period in question.

**Information**

Cossons 1975; Hall and Kenward 2003; Schelvis 2003; Crossley 1990; Calladine and Fricker 1993; Baines 1966.
6.5 Tanning (also tawing and fellmongering)

Processes
Cattle hides were tanned in a time-consuming, multiple-stage process. The horns, upper part of the skull, feet and tail, which were varyingly left attached to the hide as received by the tanner, were later removed and the hides were washed. The removal of flesh and hair was accelerated using a lime or ash suspension (liming), or urine. In the mastering process, hides were immersed in an alkaline mixture made from bird droppings, dog faeces, or vegetable matter (e.g., barley, rye, or ash bark). Hides were tanned in pits, sandwiched between layers of oak bark, filled with water or oak bark solution for between nine months and several years. The tanned hides were rinsed, smoothed, dried and sometimes hammered or rolled.

The skins of other animals, such as goats, sheep and horses, were also used, some ‘casualty’ animals and others butchered. Although traditionally these skins were processed using mixtures based on alum or oils, known as tawing, in this period these animal skins were also tanned, often at the same site as hides. The skins were softened by working and cut to the desired thickness before being dyed.

Skinners or furriers prepared the skins of animals such as cats and squirrels. The hair was retained and the skin was preserved by tawing methods. Fellmongers removed and sold wool from sheep skins and sold the pelt on to whittawyers (or glovers). Curriers dressed leather, producing a uniform and flexible material with an appropriate thickness.

Chronological summary
Industries became increasingly centralised in the post-medieval period. The first aspect to be powered was grinding the tanning bark, then powered stocks, mills or kickers were introduced for re-hydrating dried hides or impregnating skins with oils. In the 18th century, machines were developed for splitting hides to the desired thickness. In the 19th century, a revolving drum system was widely adopted to speed up the penetration of tanning solutions into light leathers. Also in the 19th century, a process using chromium salts for tanning was developed.

Materials
Cattle hides, skins or carcasses of other animals (e.g., sheep, goats, horses, cats), oak bark (tanning), lime/ash/urine (liming), bird droppings/dog faeces or barley/rye/ash bark (mastering), water.

Structures
Building foundations, numerous large pits (e.g., 0.7–2m diameter), predominantly round but some rectangular, generally lined with clay and wooden staves, also ditches, troughs, drains and wells.

Waste
Bone (typically from only one or two species), cattle horncores common and abundant, sheep and goat horncores and sheep foot bones also common, horse bones from all parts of the skeleton, deposits of cat paw bones known, regular or consistent sharp cut or chop marks, particularly at extremities of skeleton), oak bark, bark scleroids, increased number of scarabaeid beetle T. Scaber, leather, residues (lime, ash, tannins), tools (e.g., knives).

Sampling and analysis
Sampling from pits, water features, waterlain deposits and preserved working surfaces to identify function of features and materials used. Test for residues (e.g., phosphate and uric acid from mastering stage, carbonates from liming stage and humic acids and tannins from tanning stage). Identify environmental evidence for nature of activity and water quality (plant and insect indicators – see Waste, and Materials). Specialist examination of bone assemblages and surviving leather.

Information
Where to get information and help

Monuments Protection Programme reports
Information about historic industries can be obtained from a number of sources. As part of English Heritage’s Monuments Protection Programme (English Heritage 2000) surveys of major historic industries were undertaken and a series of ‘step’ reports compiled. The step 1 reports contain overviews of each industry while the step 3 reports include a list of all sites that are potentially of national importance, in order of significance. The completed step 1 and step 3 reports (see Table 2) are available for consultation at the National Monuments Record (Swindon), the Council for British Archaeology (York), Leicester University and the Institute for Industrial Archaeology (Ironbridge).

Table 2. Details of completed MPP reports

<table>
<thead>
<tr>
<th>Step</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALUM</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ARSENIC</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>BRASS</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>CHEMICALS</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>CLAY</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>COAL</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>COPPER</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>DOVECOTES</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ELECTRICITY</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GAS</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>GLASS</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>GUNPOWDER</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ICEHOUSES</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>IRON/STEEL</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>LEAD</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>LIMESTONE</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>MINOR METALS</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>OIL</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>SALT</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>STONE</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>TIN</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>WATER SUPPLY</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ZINC</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Regional Science Advisors
The English Heritage Regional Science Advisors can provide advice on the role of science in the archaeological investigation of an historic industry. The nine regional advisors are available to provide independent non-commercial advice on aspects of archaeological science. They are based in universities or in the English Heritage regional offices.

East of England
(Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, Suffolk)
Dr Jen Heathcote
English Heritage Regional Office
24 Brooklands Avenue
Cambridge CB2 2BU
tel: 01223 582700
e-mail: jen.heathcote@english-heritage.org.uk

London
Dr Jane Sidell
University College London
Institute of Archaeology
31–34 Gordon Square
London WC1H 0PY
tel: 0207 679 4928
e-mail: j.sidell@ucl.ac.uk

North East
(Northumberland, Durham, Tyne & Wear, all of Hadrian’s Wall)
Mrs Jacqui Huntley
Department of Archaeology
University of Durham Science Laboratories
South Road
Durham DH1 3LE
tel: 0191 334 1137
e-mail: j.p.huntley@durham.ac.uk

Yorkshire Region
(North Yorkshire, South Yorkshire, West Yorkshire and former Humberside)
Dr Andrew Hammon
English Heritage
37 Tanner Row
York Y01 6WP
tel: 01904 601983
e-mail: andy.hammon@english-heritage.org.uk

South West
(Cornwall, Isles of Scilly, Devon, Somerset, Dorset, Wiltshire, Gloucestershire, Bath and NE Somerset, Bristol, South Gloucestershire, North Somerset)
Ms Vanessa Straker
English Heritage Regional Office
24 Queen Square
Bristol BS1 4ND
tel: 0117 975 2289
e-mail: Vanessa.straker@english-heritage.org.uk

North West
(Cheshire, former Greater Manchester, former Merseyside, Lancashire, Cumbria (excluding Hadrian’s Wall: see North East)
Dr Sue Stallibrass
University of Liverpool

School of Archaeology, Classics and Oriental Studies (SACOS)
William Hartley Building
Brownlow Street
Liverpool L69 3GS
tel: 0151 794 5046
e-mail: sue.stallibrass@liv.ac.uk

Department of the Environment Industry Profiles
Further information about particular industries can be found in the Department of the Environment Industry Profiles (www.environment-agency.gov.uk). The primary aim of these reports is to identify the range of possible contaminants on sites of historic industries, but in so doing they provide information on the processes, materials and wastes associated with individuals industries.

Regional Science Advisors
The English Heritage Regional Science Advisors can provide advice on the role of science in the archaeological investigation of an historic industry. The nine regional advisors are available to provide independent non-commercial advice on aspects of archaeological science. They are based in universities or in the English Heritage regional offices.

East of England
(Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, Suffolk)
Dr Jen Heathcote
English Heritage Regional Office
24 Brooklands Avenue
Cambridge CB2 2BU
tel: 01223 582700
e-mail: jen.heathcote@english-heritage.org.uk

East Midlands
(Derbyshire, Leicestershire, Rutland, Lincolnshire, Nottinghamshire, Northamptonshire)
Dr Jim Williams
English Heritage Regional Office
44 Derngate, Northampton NN1 1UH
tel: 01604 735400
e-mail: jim.williams@english-heritage.org.uk

North West
(Cheshire, former Greater Manchester, former Merseyside, Lancashire, Cumbria (excluding Hadrian’s Wall: see North East)
Dr Sue Stallibrass
University of Liverpool

7.2 Department of the Environment Industry Profiles
Further information about particular industries can be found in the Department of the Environment Industry Profiles (www.environment-agency.gov.uk). The primary aim of these reports is to identify the range of possible contaminants on sites of historic industries, but in so doing they provide information on the processes, materials and wastes associated with individuals industries.
7.4 English Heritage Archaeological Science teams
Further advice can be obtained from the English Heritage Archaeological Science teams.

Scientific dating co-ordinator:
Dr Alex Bayliss
1 Waterhouse Square
138–142 Holborn
London EC1N 2ST
tel: 020 7973 3299
e-mail: alex.bayliss@english-heritage.org.uk

Archaeomagnetic dating:
Dr Paul Linford
Fort Cumberland, Fort Cumberland Road, Eastney,
Portsmouth PO4 9LD
tel: 02392 856700
e-mail: paul.linford@english-heritage.org.uk

Environmental science:
Mrs Gill Campbell
Fort Cumberland (see details above)
e-mail: gill.campbell@english-heritage.org.uk

Investigative conservation:
Mrs Jacqui Watson
Fort Cumberland (see details above)
e-mail: jacqui.watson@english-heritage.org.uk

Technology:
Dr Justine Bayley
Fort Cumberland (see details above)
e-mail: justine.bayley@english-heritage.org.uk

Geophysics:
Dr Paul Linford
Fort Cumberland (see details above)
e-mail: paul.linford@english-heritage.org.uk

7.5 Health and safety issues relating to contaminated land
The investigation of sites of historic industries poses many potential risks to the health and safety of the personnel involved. Before any fieldwork begins it is essential that a site-specific risk assessment is drawn up. This should set out the risks in terms of the likelihood that personnel will be exposed to a hazard as well as the outcome of that exposure. Desk-based assessments, site evaluations and data from non-archaeological contractors will all provide information about potential hazards. Risk assessments should be carried out with reference to appropriate legislation, for example the Health and Safety at Work Act (1974), the Management of Health and Safety at Work Regulations (1999), the Control of Substances Hazardous to Health (COSHH) Regulations 2002, and the Personal Protective Equipment at Work Regulations (2002).

More detailed information on the hazards posed, and how to carry out risk assessments, can be obtained from a number of sources, in particular the Health and Safety Executive (www.hse.gov.uk), as well as local authority health and safety teams. Further guidance is available from the Department of the Environment, Food and Rural Affairs (www.defra.gov.uk) and from the Environment Agency (www.environment-agency.gov.uk). Specific guidance for land contamination and archaeology can be obtained from the Institute of Field Archaeologists (www.archaeologists.net), the Construction Industry Research and Information Association (www.contaminated-land.org) and the Association of Geotechnical and Geoenvironmental Specialists (www.ags.org.uk).

8 References
Aitken, M J 1990 Science-Based Dating in Archaeology. Longman: London


Barraclough, K C 1984 Steel Before Bessemer, (2 volumes). London: Metals Society


Cable, M and Smedley, J W 1987 ‘Liquids temperatures and melting characteristics of some early container glasses’. Glass Technol 28, 94–8


Conyers, L B 2004 Ground Penetrating Radar for Archaeology. Walnut Creek, CA: AltaMira Press


Cossins, N 1975 The BP Book of Industrial Archaeology. Newton Abbot: David and Charles


Crossley, D 1990 Post-Medieval Archaeology in Britain. Leicester: Leicester University Press

— 1995 ‘The blast furnace at Rockley, South Yorkshire’. Archaeol J 152, 381–421


Dungworth, D B and Cromwell, T 2006 ‘Glass and pottery production at Silkstone, Yorkshire’. Post-Medieval Archaeol 40


English Heritage 1995c Guidelines for the Care of Waterlogged Archaeological Leather. London: English Heritage


English Heritage 2002 Environmental Archaeology. Centre for Archaeology Guidelines 2002/01. Swindon: English Heritage


English Heritage 2004b Geoarchaeology. Swindon: English Heritage

English Heritage 2004c Dendrochronology. London: English Heritage

English Heritage 2006a Archaeomagnetic Dating. Swindon: English Heritage


Freestone, I C 1988 ‘Melting points and viscosities of ancient slags: a contribution to the discussion’. Historical Metallurgy 22, 49–51


Gillispie, C C (ed) 1959 A Diderot Pictorial Encyclopedia of Trades and Industry. New York: Dover


Goodwin, J 2005 ‘Piecing together the Potteries’. British Archaeol 82, 47–51


Hayman, R 2005 Ironmaking: the history and archaeology of the iron industry. Stroud: Tempus


Lunn, A 2004 Northumberland. London: Collins

Magilton, J 2003 Fernhurst Furnace and Other Industrial Sites in the Western Weald. Chichester: Chichester District Council

McDonnell, J G 1972 ‘An account of the iron industry in upper Ryedale and Bilsdale, c1150–1650’. Ryedale Historian 6, 23–49

— 1999 ‘Monks and miners: the iron industry of Bilsdale and Rievaulx Abbey’. Medieval Life 11, 16–22


Mighall, T, M, Dumayne-Peaty, L, Cranstone, P 2004 ‘A record of atmospheric pollution and vegetation change as recorded in three peat bogs from the Northern Penines Pb-Zn orefield’. Environmental Archaeol 9, 13–38


Muspratt, S 1860 Chemistry, Theoretical, Practical and Analytical. Glasgow: Mackenzie

Newman, R 2001 The Historical Archaeology of Britain, c1540–1900. Stroud: Sutton


Oliver, R 1993 Ordnance Survey Maps — a concise guide for historians. London: Historical Association


Payne, S 2004 ‘Contaminated land or human history?’. British Archaeol 79, 32

Percy, J 1861 Metallurgy. Fuel; Fire-clays; Copper; zinc; Brass, Etc. London: John Murray


— 1870 Metallurgy. Lead, including the extraction of silver from lead. London: John Murray

Pollard, A M and Heron, C 1996 Archaeological Chemistry. Cambridge: The Royal Society of Chemistry


Riden, P 1994 ‘The final phase of charcoal iron-smelting in Britain, 1660–1800’. Historical Metallurgy 28, 14–26


Roskams, S 2001 Excavation. Cambridge: Cambridge University Press


Stoyel, A and Williams, P 2001 Images of Cornish Tin. Ashbourne: Landmark


Tite, M S 1969 ‘Determination of the firing temperature of ancient ceramics by measurement of thermal expansion: a reassessment’. Archaeometry 11, 131–143


Ure, A 1843 A Dictionary of Arts, Manufacturers and Mines; containing a clear exposition of their principles and practice. Longman, Brown, Green and Longman

Vose 1980 Glass. London: Collins


These Guidelines were written and compiled by David Dungworth and Sarah Paynter, with contributions by Anna Badcock, David Barker, Justine Bayley, Alex Bayliss, Paul Belford, Gill Campbell, Tom Cromwell, David Crossley, Jonathon Goodwin, Cathy Groves, Derek Hamilton, Ken Hamilton, Andrew Lines, Paul Linford, Roderick Mackenzie, Ian Miller, Ronald Ross, James Symonds and Jane Wheeler.

Acknowledgements
We are very grateful to all those who commented on previous drafts of these Guidelines, including contributors and also Jon Brett, Jon Cattell, Wayne Cocroft, Andrew David, Dominique de Moulins, Keith Falconer, Shane Gould, Karla Graham, Andy Hammon, Jen Heathcote, Jon Hoyle, Jacqui Huntley, Bob Jones, Ian Panter, Jane Sidell, Sue Stallibrass, Vanessa Straker, Jim Williams, Mike Williams and Jan Wills.

Cover figure
The cover was designed by John Vallender and shows (top left to bottom right): 19th-century bottle kilns in Staffordshire; applying glaze to ceramic plates in the 19th century (Muspratt 1860, 484); an early 20th-century photograph of Daisy Bank marl pit in Staffordshire (© The Potteries Museum and Art Gallery, Stoke-on-Trent); the Red Lane glasshouse, Bristol, shown by Millerd in c.1711 (© Bristol Museums, Galleries & Archives); an excavator on the site of the boiler house at Murrays’ Mills, Manchester (© Oxford Archaeology North); excavating at the Leadmill, Sheffield (© ARCUS); furnace 3 during excavation at Percival, Vickers glassworks, Manchester (© Oxford Archaeology North); mechanical excavation at Portwall Lane glasshouse, Bristol (© David Dungworth); reflected light microscopy; SEM image of a fine glass thread from Silkstone glasshouse, Yorkshire; an early 18th-century glass bottle waster from Lime Kiln Lane, Bristol and an SEM image of the head of the scarabaeid beetle Trox Scaber (© Harry Kenward).