1 THE RESOURCE

Archaeometallurgy is the study of activities associated with the production and working of metals, which are found at most periods and cut across evidence for other contemporary activities. Evaluation and management of the resource is therefore complex, and intersects with many other areas of archaeological activity. The scale of the resource also varies from landscapes, through sites and features, down to individual scraps of waste, to artefacts and documentary records. Although some aspects of the resource are readily identifiable, for instance industrial complexes, others such as a pack-horse trail linking a mine to a smelter, or a metalworking hearth in an otherwise domestic site, may be less so. This part of the Research Framework discusses aspects of the nature of the resource, together with ways in which it may be engaged by the researcher and the manner in which the resource may be protected and managed for the future.

1.1 Geological background

The richness and diversity of the archaeometallurgical resource in Britain reflects the local geological resources that have been exploited over time, as well as the use of imported materials. The distribution of suitable metallic ores plays a dominant role in the location of primary smelting activities. The availability of fuel has also played a part in controlling and locating metallurgical activities, with the production of coal and coke from the Carboniferous coalfields having an especially strong influence in post-medieval times.

The complex pattern of resource generation through geological time leads to enormous variation in style of mineralization, which in turn means that exploitation of the resources often has particular, local features of technology, regulation or social context. Metalliferous geology thus provides both a backdrop to the discussions of the nature of the archaeometallurgical resource, and a context for viewing the variable nature of the resource: the landscapes of mineral extraction, primary metal smelting industries, secondary metal processing and industrial development of the coalfields.

Information on the nature, location and origin of metallic ores is included in recent syntheses of the geology of England and Wales (Brenchley and Rawson 2006) and Scotland (Trewin 2002). Detailed studies of almost all aspects of mineralization are presented by Pattrick and Polya (1993) while more specialized local information can be obtained from the sheet memoirs of the British Geological Survey and its predecessors. The Geological Survey was also responsible for a valuable series of *Special Reports on the Mineral Resources of Great Britain* between 1915 and 1945. Summaries of the distribution of the major groups of natural resources are presented in Figure 2.

1.2 Landscapes

Recognizing landscapes

The interpretation of metalliferous landscapes is a significant issue, despite the tendency for archaeometallurgy to be seen as primarily concerned with production sites and their output. In recent years there has been growing interest in the way in which such landscapes have evolved and developed. This interest has developed in response to threats posed by modern agricultural practices, and in part from development pressures on old industrial sites. In response to the rural threats, changes have been made to the funding support given to agriculture, with emphasis now being placed on protection and regeneration of past landscapes rather than on output. Some of these landscapes have been formed or influenced by metallurgical activities, even though they now give the appearance of being semi-wild and 'natural'. Obvious examples include the tin and copper districts of Cornwall and west Devon (www.cornish-mining.org.uk) or the lead-production landscapes of the Peak District (Barnatt and Penny 2004), but other, more subtle, evidence is contained in areas of woodland managed for charcoal fuel production, and in networks of routeways and settlements that link areas of mineral extraction with sites of primary and secondary production. In urban ('brown-field') areas, recognition of the need for evaluation under PPG 16 (1990) has come from an understanding of the evidence for past industrial, in many

Example: Metalliferous resources in Britain

The oldest significant areas of mineralization in Britain were generated between the Cambrian and the Devonian periods when northern Scotland and southern Britain lay on separate continents. Extensive and prolonged tectonic and igneous activity on the margins of these continents, together with metamorphic processes occurring during and after their eventual collision, led to a range of mineral deposits, which may collectively be referred to as 'Caledonian'. These include vein mineralization in SW and NW Wales, Cumbria and the Scottish Highlands. Some of the most significant are the volcanic-related polymetallic sulphide mineralization at Coed-y-Brenin and Parys Mountain. The latter deposit was exploited from prehistoric times onwards, although little is known about the earlier phases. The gold deposits of south and mid Wales also belong to this period. The sedimentary manganese ores of NW Wales are of Cambrian age. Late Caledonian igneous intrusions are associated with Cu-Mo-(Au) mineralization in northern Scotland, As-Sb-Au in the Southern Uplands and W-Sn-Mo-Li in the Lake District.

The next widespread phase of mineralization was during the Early Carboniferous. At this time large synsedimentary base metal deposits were formed in central Ireland, with smaller areas of Pb-Zn vein systems developing around the margins of the sedimentary basins in Britain. Early Carboniferous Pb-Zn deposits include many of those of the Central Welsh Mining District (although some here may be late Caledonian) and of the Bowland Basin. The Carboniferous period also saw the formation of Britain's coalfields which provide coal, and also synsedimentary blackband and claystone ironstones.

The large Cornubian batholith was intruded during the late Carboniferous–early Permian period. It is associated with the most intensely mineralized zone in Britain. This involves early W-Sn griesen-bordered veins, followed by the main stage with cassiterite (+Cu, As, Fe, Zn sulphide) veins. In some areas the late stage cross-course mineralization (Pb-Zn-Ag-Ba-F) may be due to the movement of low temperature brines from adjacent sedimentary basins. At a similar period Ag-Cu-Co-As-Ba vein mineralization occurred in the Midland Valley in Scotland, with minor base metal sulphide veins occurring elsewhere too.

In the subsequent Permian to Jurassic periods, there was widespread crustal extension across Britain associated with the opening of the Atlantic Ocean. This phase was accompanied by the development of two contrasting, but spatially-related forms of mineralization, iron oxide deposits (Bristol Channel Orefield, NE Wales, Cumbrian Orefield) and the 'Mississippi Valley-type' (MVT) deposits of Britain's major Pb-Zn orefields, including the N Pennines (Askrigg and Alston Blocks), S Pennines (Derbyshire), NE Wales (Halkyn-Minera), and Mendips (including its continuation in South Wales). Probably also related to this phase are the iron ores of N Devon and the Ba-Fe-Cu-Pb mineralization of the margin of the Cheshire Basin at Alderley Edge. These events are poorly dated, but where relationships are seen, the iron mineralization is earlier than the Pb-Zn. An even later stage is demonstrated by Britain's only copper-dolomite association deposit at the Great Orme, Llandudno, which post-dates the local MVT deposits and is therefore later Mesozoic-Tertiary.

The shallow shelf seas which covered much of Britain in the Mesozoic were responsible for the deposition of a wide variety of sedimentary ironstones. Most of the large deposits are ooidal ironstones of Early to Middle Jurassic Age (the Frodingham Ironstone, the Cleveland Ironstone, the ironstones of the Marlstone, the Rosedale Ironstone, the Rassay Ironstone, the Northampton Sands Ironstone and the Dogger Ironstones), with smaller examples continuing through the Late Jurassic into the Early Cretaceous (the Westbury Ironstone, the Abbotsbury Ironstone and the Claxby Ironstone). The Early Cretaceous is also important for development of sideritic claystone ironstones within the Weald of SE England. There are also various localities where oxidized iron-rich sediments, mainly originally glauconitic, have been worked from Early Cretaceous strata, including the Blackdown Hills, Seend and North Norfolk. With the exception of the claystone ironstones of the Weald, these Mesozoic ironstones are generally of low grade, but are very widespread and were worked in early times wherever superficial oxidation raised the grade of the ore. Tertiary sediments of SE England (*eg* in Surrey and Hampshire) also yield sedimentary iron ores of sufficient grade to have been worked in the past.

The most recent ore deposits are bog iron ores which accumulated in various parts of Britain in the Holocene. The former distribution of these deposits is largely unknown, and in many cases it is the recovery of archaeological evidence for iron smelting that is providing that evidence. The best-known areas of of bog ores are the uplands of North Wales, the wetlands of Humberside and E Yorkshire and the Highlands of Scotland.

Chemical symbols

Ag	silver	Cu	copper	Pb	lead
As	arsenic	F	fluorine	Sb	antimony
Au	gold	Fe	iron	Sn	tin
Ba	barium	Li	lithium	W	tungsten
Co	cobalt	Mo	molybdenum	Zn	zinc

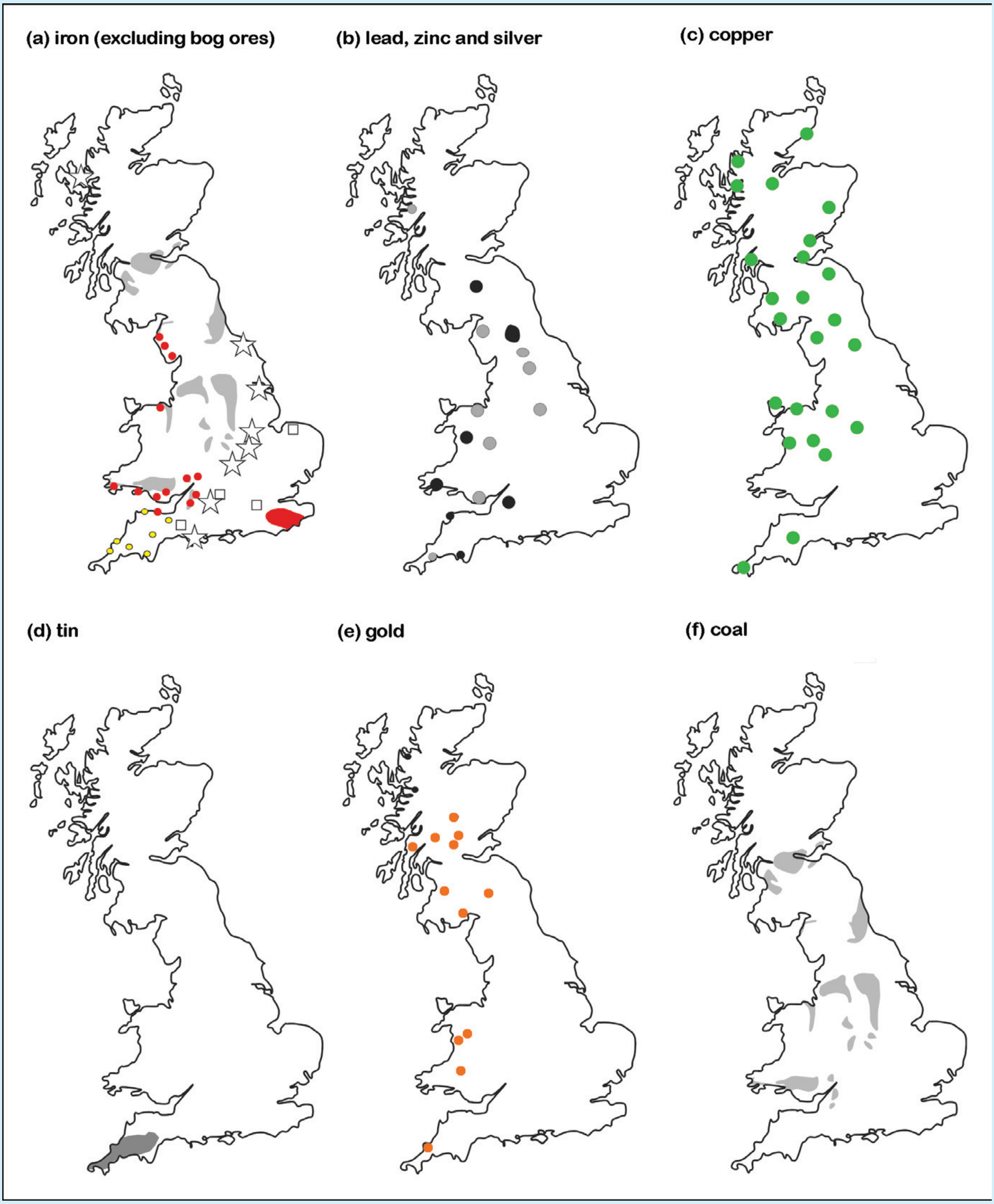

Figure 2: Maps showing the mineral deposits of the British Isles. a) Iron (excluding bog ores): grey tone = the Carboniferous coalfields, with claystone and blackband sedimentary ironstones; red = the Weald, Cretaceous claystone ironstones; yellow spots = oxide iron ores associated with the SW mineral province, including gossan and oxides after siderite; red spotsoxide iron ores associated with epigenetic mineralization on Mesozoic basin margins; stars = sedimentary ooidal ironstones of Mesozoic age; squares = other sedimentary ironstones of Mesozoic–Tertiary age. b) Lead, zinc and silver: areas indicate main lead-zinc orefields. Those in black also produced significant quantities of silver. c) Copper. d) Tin: working of alluvial tin deposits in SW England took place over a wider area than the distribution of the primary mineralization. e) Gold. f) Coal.

Figure 3: A rake (an opencast mine following a vein containing lead ore) from which the minerals have been removed, at Dirtlow, Castleton, Derbyshire.

cases metallurgical, activities. Many of these issues are discussed in the edited conference proceedings *Mining before powder* (Ford and Willies 1994) and *Mining and metallurgy in south-west Britain* (Newman 1996), which within their respective themes provide a benchmark for recent understanding of the subject.

Surface landscapes

The key to the understanding of landscapes shaped by metal industries is the inter-relationship between mining, primary production and secondary occupations. When dealing with the history and archaeology of mining there are two distinct but symbiotic landscapes to consider, the surface and the underground which should be treated as one. Underground ore-mining (see below) also leaves surface traces, such as shafts, adits, spoil dumps, haulage and drainage equipment, and industrial and domestic buildings (for lead in particular, the distribution of metal-tolerant vegetation can help locate overgrown spoil); underground fieldwork is therefore adding a valuable new dimension to the study of surface mining landscapes. A key to understanding mining landscapes is the role of local geology and the properties of the mineral veins. Most of the landscape features seen in metalliferous mining areas are expressions of these geological patterns (Fig 3). The relationship between the ore-field and smelting operations depended on markets, fuel supply and the availability of labour. In some cases, notably in the tin-districts of SW England, the operations were often adjacent. In the Pennines, lead smelters were often sited in the direction of market outlets, and adjacent to the coppice-woodlands or Coal Measures which produced the necessary fuel. Road networks assist the understanding of such patterns. By contrast, post-medieval smelting of the copper ores of SW England was overwhelmingly concentrated in south Wales, the ore being taken to the fuel and the smelted metal then being transported to markets.

In the West Midlands and Yorkshire, iron-mining and smelting thrived adjacent to settlements where land-shortage made employment in the secondary metal trades an attractive supplement or alternative to farming. In Sheffield and its surroundings, ore deposits, coppiced woodlands and water power served the iron industry, while upland agriculture was characterised by the need for industrial by-employment, which gave rise to secondary specialisms that in the end dominated and urbanised the local economy, and provided a base for the emergence of heavy metal industries. In the relationship between metallurgy and other economic activities, as exemplified by both rural and urban landscapes, the farmer-miner or farmer-smith is a key concept, connecting agriculture with industry, especially in areas where the agrarian resource was limited. The archaeological evidence for such activities is often indistinct and unexpected which frequently means that it is overlooked in watching briefs; further studies are required. Economic historians have made much progress in the study of this dual economy, in relation to both metal and other manufactures, partly with the object of examining theories about proto-industrialization (*eg* Thirsk 1961; Hey 1972; 1990; Rowlands 1975; 1989, 114). However, the considerable archaeological potential of former rural-industrial buildings and the associated residues and land boundaries await identification and survey (Fig 4). Craft workshops existed in many areas, and at various periods, beyond districts renowned for their specialism. For example Tyneside hosted the manufacturing centres

Figure 4: Farmhouse with attached smithy (second building from the right) at Dungworth, near Sheffield, Yorkshire.

Figure 5: Remains of 18th-century blast furnaces at the World Heritage Site at Blaenavon, Gwent, South Wales.

of the Crowley and Hawkes families in the 18th and 19th centuries (Flinn 1962; Evans 1993a), and the fringes of the Forest of Dean had significant numbers of smiths at the end of the medieval period (Evans 1993a).

Research into the metal industries of the 18th century and later has concentrated on large units (Fig 5), the blast-furnaces and forges, and rolling mills together with factory-units, rather than the small craft-based workshops. However, the identification of small workshops and the crafts that were practised within them is important in recreating the landscape of the past (Fig 6). The study of the standing remains is one method, where such evidence survives. Additional information can be retrieved by excavation (and by the application of some of the methodologies discussed in Part 2), though often the residues of small craft processes are limited and difficult to retrieve and understand. Routine sampling of soils from sites that may have been the location of small craft workshops can reveal the nature of the craft; see the adjacent example.

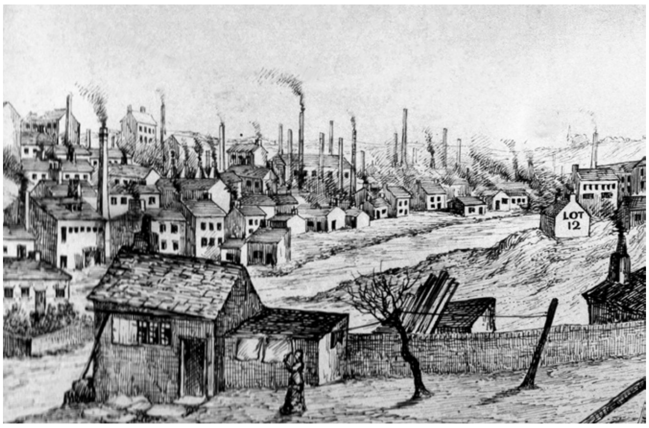

Figure 6: View of the Sheaf Valley, Sheffield, in the mid-19th century showing many small workshops with their forge chimneys.

Townscapes and communities

The separation of town and country is relatively recent, characterised by the urbanization of the Industrial Revolution, as is the distinction between the industrial and the agricultural workforce. In urban districts, landscape evidence relating to industries producing and working metal in the last two hundred years is often still quite evident. In Sheffield there has been a growth of interest in the city's industrial past, where items such as cutlery, silver-ware and silver plate, engineers' tools, pins and needles and agricultural implements were made. These industries declined through the 20th century, but their importance was realized, and an attempt was launched in 2001 to encourage the re-use, rather than demolition, of their buildings (Wray *et al* 2001). An English Heritage press release at the time stated: 'Humble workshops as well as the great integrated works buildings played a crucial role in the metals trades. The surviving buildings are a powerful symbol of Sheffield's industrial past. Equally, they are components of the city's regeneration, providing and reinforcing its distinctiveness and unique sense of place' (Symonds 2002, 3).

The Jewellery Quarter in Birmingham is a similar entity with different industries working next to each other in tenement workshops (Fig 7). The inter-relations between crafts in such environments have been the subject of study (Cattell *et al* 2002). These were arguably more complex than in Sheffield, as both ferrous and non-ferrous trades worked in close proximity and a wider range of goods

Example: Making fish hooks in Kings Lynn

Excavation of what seemed to be 13th- and 14th-century workshops on Norfolk Street, Kings Lynn revealed a rubbish pit containing evidence for small-scale iron-working, the complete contents of which were subjected to wet-sieving. This is a fairly new approach to dealing with metalliferous residues and involved washing the soil through a 1mm mesh sieve, a process that was thought by some to be too damaging for the iron (Cowgill 2003). Initial examination produced some fascinating insights into the occupation of the workshop's inhabitants. Iron wire was being made by drawing strips of annealed metal cut from sheet through a steel draw plate. The wire was then made into fish-hooks, by first splaying the end of a length, forming a barb from the splay, then bending the wire into the hook shape and finally splaying the other end (ibid). The sequence and likely speed of this process was recreated from careful study of the waste with the co-operation of a skilled blacksmith. The range of fish-hook sizes recovered has also allowed comparison with the fish-bones retrieved and has fed into a study of medieval fishing and the coastal economy in Kings Lynn.

Example: Evidence for urban metal industries

In Sheffield the existing evidence has been categorized; similar headings would be applicable in other industrial cities:

- Standing remains: *eg* small workshops (often joined to domestic structures), large cutlery and steel works, cementation and crucible furnaces (rare), water-powered sites (for grinding and forging), water management features (leats, wheel pits etc); housing adjacent to these industrial sites. These are mainly of the 18th–20th centuries. Walls may contain materials such as grindstones and 'crozzle' — the clay crust from cementation chests.
- Buried remains (often well-preserved below later structures): Cementation and crucible furnaces, building foundations, water-powered features, waterlogged timbers (*eg* tilt hammers), grinding hulls, artefacts (representing various stages of production), residues and palaeo-environmental evidence. Some features (*eg* deep wheel pits, grinding troughs, water channels) act as catchment zones for artefacts and residues.
- Archives and/or collections from companies: trade catalogues, tools, finished and unfinished artefacts. For example, the 18th–19th century Fairbank collection of finished maps, notebooks and survey books. Old photographs and other records. The Hawley collection in Sheffield University has sought to salvage and bring together much of this sort of evidence from the Sheffield region (www.shef.ac.uk/hawley), but initiatives of this type are rare.
- Oral history.
- Working craftsmen; there is an extremely limited number of craftsmen continuing traditional working practices which all badly need documenting.

Steelmaking continues, although much of Sheffield's output now is 'speciality' steel. There has been a shift in the pattern of production in recent years that itself needs documenting whilst the information still exists.

Figure 7: A tenement workshop in the Birmingham Jewellery Quarter.

was manufactured (Belford 2006). As well as jewellery, Birmingham was also highly regarded for the manufacture of 'toys', a term which covered small articles including buttons and buckles (rather than children's toys, in the modern sense). Such articles required a range of inputs, from glassmakers and enamel workers as well as the metal trades. A number of trades developed out of this, including silverware, jewellery, and the production of pen-nibs, coins and medals. Birmingham was also important as a source of tools of all kinds. Except for some production during the Civil War, the origins of the Birmingham gun trade (making muskets and pistols) probably lie in the 18th century. Some aspects of production were purely manual, but water mills were used to produce the strips that were forged into gun-barrels, and then to bore out and grind off the barrels. Other components were produced in domestic workshops. During the 19th century the industry was centralized in factories, and it also branched out into making tubes (such as gas pipes), bicycles and machine tools. The wide range of metalworking skills in the region was exploited with the advent of new industries. For example, component manufacture for the motor vehicle and aircraft industries in the 20th century developed out of the skills gained in the mechanization of the 19th-century gun trade. Many 17th, 18th and 19th-century industries — and the lives of those that worked within them — have remained little-studied archaeologically. Such explorations require a holistic approach that examines the wider landscape of houses, pubs, shops and streets, as well as the workshops themselves (Belford 2001; 2003; 2006).

In the 19th century the Black Country, outside Birmingham, possessed many examples of urban landscapes characterized by small workshops. At Cradley Heath there were around 900 chain-makers' shops, most very small-scale family enterprises (Belford 2006). Despite the small scale of production, Cradley Heath produced most of the chain used in Britain and its overseas territories during the 19th century. The industry remained dominated by hand forging, and by a tightly-knit and closely-demarcated workforce. Several small concerns might join forces for a particularly large order, but independence was valued and the industry never developed the tenement workshops that became a feature of the 19th-century Sheffield trades (*ibid*). Such approaches to the social aspects of metalworking can also be used to inform the interpretation of the archaeometallurgy of more distant periods (see Part 3).

Below-ground features

The commonly-held view that certain forms of mining are primitive, and must therefore be evidence of

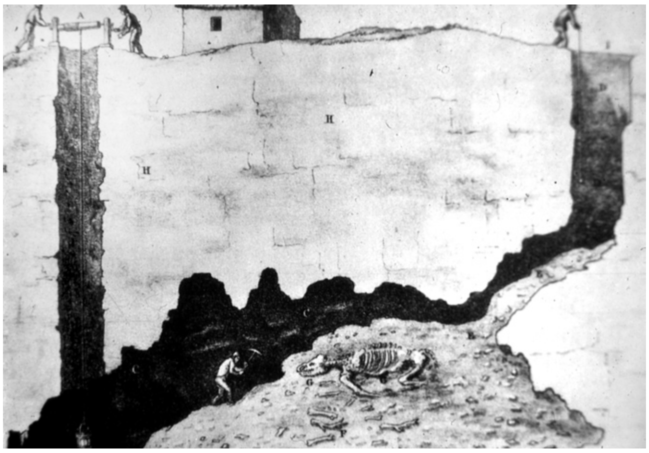

Figure 8: Drawing of Dream Mine, Wirksworth, Derbyshire, showing two shafts, the one to the left with a windlass. After Buckland 1823.

Figure 9: The sub-surface of a lead-mining landscape at Gunnerside Gill, North Yorkshire. This engine house is on Sir Francis Level 240ft below the valley (Fig 35). Two Davey hydraulic engines were installed in 1880: one (centre left) worked the pumps (two large vertical pipes) and another (behind camera viewpoint) the winding gear. One cage is suspended just below floor level.

early workings, is an idea that can be challenged. For example, the presence of a line of small shafts has traditionally been taken as indicating early mining (Raistrick 1975). However, when extracting ore from shallow deposits, this was the most appropriate technology. Such features represent the presence of an economic ore-body near the surface. Early miners were likely to have found these deposits attractive, but in locations such as Grassington Moor, Yorkshire documentary evidence suggests that shallow mining did not commence until the mid 18th century (Gill 1993). In contrast, in the 17th century, some mines in Swaledale, Yorkshire were working in the Main Limestone at depths of over 200ft (60m) at a time when the use of gunpowder for blasting rock was unusual (Raistrick 1982). This, and other evidence, indicates that the rock-breaking technology of the medieval miner did not preclude deep mining. The main technical obstacle to working at depth in earlier periods was that of mine drainage. However, social factors were just as important. In areas where traditional mining law prescribed the allocation of 'meers' (short lengths along a vein) to different partnerships of miners, extraction by lines of small shafts was almost inevitable. But in the minority of mining areas, such as Bere Alston, Devon, where mining developed under Crown control, deep mines with long adits, centralized water-powered pumping and long surface leat systems to supply the water, developed in the medieval period (Claughton 1994; 1996).

The extensive nature of many underground mining remains demands consideration analogous to research into surface landscapes, and the basic techniques of archaeology — survey, excavation, analysis, experiment, conjecture and reconstruction — can all be applied underground. Mines comprise complex three-dimensional structures within which are individual sites or features (Fig 8). Three-dimensional computer modelling of underground spaces is a valuable tool for interpretation. Surveys of workings have produced valuable evidence of changes in ore-mining methods. Examples are the change from fire-setting to the use of explosives, the development of drainage-adits (soughs) together with mechanical and hydraulic drainage devices (Fig 9), horizontal and vertical haulage systems, provision for ventilation, and methods of ore-selection below ground, minimizing the quantities of material brought to the surface.

It is often suggested that metal mining destroys its own past; and modern mining certainly can totally obliterate earlier evidence. In some areas, notably the Pennine lead-fields, ore-dressing wastes were reprocessed and previously uneconomic ores were smelted as new technologies developed; this has been a feature of mining for (at least) several centuries. However, even where more-recent mining has been extensive, destruction of earlier workings is often far from total. For example,

Figure 10: A small-scale 17th- and 18th-century mining landscape at Bonsal Moor, Derbyshire. The upcast (spoil) around the mine shafts dominates the view.

at Alderley Edge, Cheshire, careful archaeological recording was able to disentangle the remaining profiles of Bronze Age shafts from wholesale post-medieval slitting of the vein along which they had been sunk (Timberlake and Prag 2005).

Mining archaeology is defining site components and attempting to place them in a chronological framework. Documentary records of plant and machinery on mining sites are helping to show when technological changes occurred and, therefore, broadly date the related features. This works well for the 18th and 19th centuries but for earlier mining characterization is more difficult, because there are few detailed records and because 17th-century miners were still using medieval methods (Fig 10). To ensure that the recording of underground sites is carried out to adequate standards, the National Association of Mining History Organisations (NAMHO) has a descriptive specification for underground survey which aims to be equivalent to those of English Heritage for surveys of field monuments and standing buildings (Roe 2002). Its use ensures that reports on underground sites will correspond with local and national Historic Environment Records.

1.3 Recording metallurgical evidence

Both survey and excavation can provide information about metallurgical sites. Some are primary production sites where ores were mined or smelted to produce metal, and a wide range of features and structures may be found. However, it is often only the technological debris that survives, but its collection and study can usually identify the processes being carried out.

Sites

Newer methods of survey and recording, and the use of information technology, allow the collection of information from large-scale landscapes and complex underground sites, which can then be brought together with studies of individual features to produce comprehensive site studies (*eg* Roe 2000). The introduction of digital methods is adding layers of information, changing the interpretation and understanding of landscapes of mining and metallurgy, both above and below ground. The results of such site and landscape surveys require recording as sensitive areas in county Historic Environment Records (HERs) or Sites and Monuments Records (SMRs). This may best be undertaken as specific programmes of HER enhancement (see section 1.6). Such recording of data facilitates the long-term preservation of a range of metallurgical sites and sites of metallurgical interest, over the full range of time-periods, site types, regional traditions, and types of industry. This aim has been partly achieved by the Monuments Protection Programme (MPP) (Fairclough 1996, 3–4 and 15; Stocker 1995), by its successor Strategy for the Historic Industrial Environment Reports (SHIERS) and by Scheduling and Listing a selection of the most significant sites (see section 1.6).

It is especially important that all metallurgically-important sites whose preservation cannot be guaranteed, or which are under active threat of destruction, are recorded. Such records should be published promptly (except in cases where this might itself expose the site to threat), and the documentation appropriately archived. Curatorial archaeologists should be encouraged to make full use of planning procedures to preserve important sites. Additionally, efforts should be made to encourage the adequate publication of developer-funded work rather than confining results to 'grey literature'. While this is of very variable quality, the reports are likely to include important historical and field information. Mechanisms for wider dissemination and synthesis are much-needed, perhaps on the lines developed by Bradley (2006) for prehistory. Excavation should be carried out only as part of the response to regional or national research strategies or when there is a threat through development. In either case adequate resources of both funding and expertise, for work in the field and particularly for post-excavation study, must be made available.

A high priority for preservation and/or intensive site-recording in advance of destruction should be attached to sites whose historical importance rests on their association with key innovations, and which may therefore offer unique opportunities to investigate the processes of innovation archaeologically. Similar considerations apply to sites where specific processes are known to have been used but their archaeological manifestations are not yet well characterized. It is hoped that examples of good practice quoted here will encourage a general improvement in the quality of work carried out.

Evidence for metal production

The production evidence for the prehistoric through to the medieval period is inevitably scant, but does exist; most comes to light through excavation. Furnaces and other structures were frequently insubstantial so usually the only indicators of early metal production are residues. Specialist expertise can help to identify what little evidence may survive, so working with an archaeometallurgist will often lead to the retrieval of a more complete sample of the available production evidence (see sections 2.2 and 2.3) than just retaining readily identifiable metallurgical material for post-excavation processing. Collaborative working is crucial for the full understanding of the archaeometallurgical resource, especially that of earlier periods. The very wide type- and date-range of non-powered iron-smelting sites remains incompletely understood and so the survey and excavation of those with the possibility of such production evidence is a priority (see Part 3). Copper, tin and lead production sites for the earlier periods are extremely rare, thus the identification of any such operation would be of importance (see section 3.1). In particular the identification and excavation of Roman and early medieval non-ferrous metal production sites is a priority.

The later medieval period has more substantial production evidence, and smelting and forging sites can be identified from the historical record. Early blast-furnace sites (*c*1490–1560 AD; Figs 12 and 13) are a high priority for study and preservation as are copper-smelting sites of the 16th and 17th centuries, the period of Crown encouragement of copper extraction. The medieval and post-medieval 'blowing house' tin smelter is relatively common in south-west England, although few have been excavated. However, the tin industry is of international importance and therefore justifies a high level of preservation. Later medieval lead smelting is a topic of developing interest, and further research into technical improvements should be encouraged.

The later developments in iron smelting, especially the post-medieval blast-furnace in the period of adoption of mineral fuel, warrant further study, so it is a priority to identify and preserve sites where production evidence

Example: Metal industries in Cornwall

Archaeologists working in Cornwall potentially have the evidence for a metal industry spanning more than two millennia on over 2000 (and probably many more) sites. Some are exceptionally well-documented or survive as upstanding buildings or earthworks (Fig 11); others have been identified only from aerial survey, chance finds, excavation or field survey. Over nearly thirty years, the resources available to professional archaeologists have provided a massive data base with which to work. Emergent research frameworks and contextual information has allowed targeting of attention to mineral processing activities as part of developer-led excavation, where opportunities for more leisurely data-gathering are available, and evidence can be accurately dated and analysed within a secure, wider context. Such excavations have produced a wide range of evidence which is helping to refine a local research agenda. Tin, copper and iron slags have come from a large number of sites; fragments of cassiterite and haematite from prehistoric settlements well away from any known lodes, and stone weights, ore-grinding mortars, smithing hearth bottoms and hammer scale from sometimes unexpected sites. Evidence for secondary iron and, possibly, copper-working has come from Trevelgue Head promontory fort (which may have been exploiting a local iron lode) (Nowakowski forthcoming) and Romano-Cornish iron-working has been identified at Little Quoit Farm near Goss Moor (Lawson-Jones 2003). Secondary metalworking has also been found at Tremough, Reawla (Appleton-Fox 1992) and Trethurgy (Quinnell 2004) Iron Age enclosures and, most interesting of all, a late prehistoric defended enclosure at Killigrew Round seems to have been wholly devoted to metallurgical activities. In a context where secondary gold-working appears to be the norm rather than the exception in late prehistory, professional archaeologists in Cornwall now make provision in their project designs for methodologies designed to detect and analyse such evidence.

Figure 11: The Crowns engine house, Botallack mine, Cornwall, is set at the foot of a cliff on an outcrop of a rich tin and copper lode. This mine was worked from at least the 16th century.

Figure 12: Chingley blast furnace, Kent, under excavation, showing the bellows area in the foreground and the furnace hearth beyond.

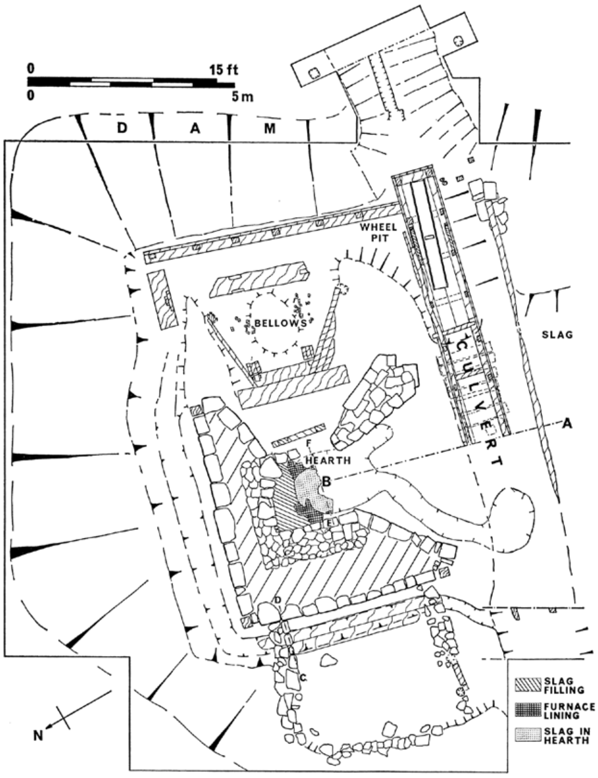

Figure 13: Plan of Chingley blast furnace with bellows area at the top and the wheel pit to the right, discharging into the culverted tail race.

is likely to exist. Similarly, the development of conversion forges (which turn cast iron into 'wrought' iron) is incompletely understood, excavated evidence having come only from two charcoal-fuelled Wealden examples. Archaeological investigation and preservation of 17th- and 18th-century finery-forge sites is badly needed. In addition, scientific research is needed, particularly on forges of the late 18th century that used the 'potting and stamping' process, on early puddling furnaces, and on those with balling furnaces for recycling scrap (King 2003, 58–66) (see section 3.8).

Technological debris

Technological debris comprises a crucial part of the available resource. This falls into five broad groups: raw materials, structural evidence, process evidence such as crucibles and moulds, waste products and the metal itself (which is discussed further in section 1.4). Often it is only the process-residues that survive to contribute to the archaeological record.

Raw materials

The geological identification, size, size-distribution, shape, and mineralogical composition of mining wastes can yield information on the technology of both underground mining and surface processing. On smelting sites ore can occur as raw fragments, as roasted ore pieces and as small roasted ore fines. Charcoal is not necessarily found in abundance on smelting sites, as it was too valuable a material to waste. Samples, especially from features, are potentially important not only for dating but to identify the species used and as an indication of woodland management by coppicing. Coal and coke were not used for smelting until the post-medieval period.

Structural materials

Clay was used in the construction of furnaces and once fired it can be important for the identification of sites by geophysics, and for their archaeomagnetic dating (see section 2.2). The processes carried out can sometimes be identified, particularly when slags etc adhere to the clay. Stone, brick and tile were also used in furnace structures. Examples are the distinctive clay tiles found on some Roman sites (Fig 60), and firebricks associated with post-medieval cementation steel furnaces. The high temperature in a furnace can vitrify clay, giving it a glassy surface, but all furnace and hearth structures will show some evidence of some degree of heating.

Crucibles and moulds

Crucibles and moulds are non-recyclable so are probably the best and most recognizable and abundant archaeological indicators of non-ferrous metalworking. Ceramic crucibles used for metal-melting are usually reduced-fired (grey or black) as metals have to be melted under reducing conditions to stop them being oxidized and lost into the crucible slag (Fig 14). As they are used at high temperatures, crucibles become vitrified and small quantities of the metal being melted may be chemically or physically trapped. Visual examination, with the naked eye or under low magnification (x10–x30), can give some idea of the metal being melted. Some vessels identified as crucibles in the course of excavations may

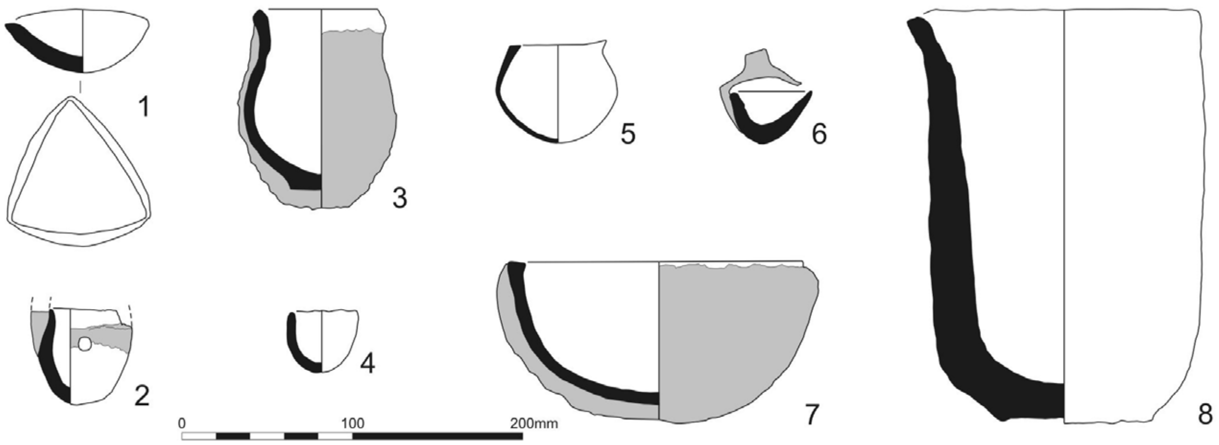

Figure 14: Drawings of common crucible forms dating from Iron Age to the post-medieval periods. 1: Iron Age, 2-3: Roman, 4-6: early medieval, 7: later medieval, 8: post-medieval. The grey tone represents added clay, serving either as lids (2 and 6) or extra outer layers (3 and 7).

actually have been used for processes other than metal melting (Bayley *et al* 2001).

Molten metal was cast, either direct into objects, or into small ingots. The latter could be hammered to produce rods, wire or sheet, which was in turn made into objects. Ingot moulds were usually made of stone, though some are brick or tile with shapes cut into them. Moulds for small objects were usually made of fired clay though stone and metal moulds are known.

Slags

Slags are formed during the smelting and working of metals. Iron slags of various types are the most frequently found, usually dumped in negative features such as pits and ditches. If a large accumulation of slag is found in the base of a furnace, it is possible that the smelt failed and the furnace had been abandoned. Copper-, lead-, tin- and iron-smelting slags can be sparse, due to re-smelting, but can lead to the discovery of furnaces and other related structures (Fig 15). The excavation of slag deposits can provide stratigraphic information, allowing the documentation of technological change when sequences of slags are analysed in the laboratory. The presence of dateable material within a slag-heap, such as diagnostic pottery or charcoal for radiocarbon dating, can allow site chronologies to be related to technological changes and developments (see section 3.3).

Figure 15: Base of excavated Iron Age bloomery furnace at Crawcwellt West, Gwynedd. The red-burnt clay shows the walls were originally ~200mm thick. Scale bar 0.5m.

The amount of slag which can be expected at a primary production (smelting) site varies considerably with the period. With prehistoric examples even a few kilograms can be significant. Deposits at Roman and medieval iron-smelting sites can vary widely, up to thousands of tonnes. Slags are not datable in themselves, but consideration of the types which occur (Figs 16 and 17) and their quantities may give some indication of the period. With prehistoric iron slags there can be difficulty in distinguishing smelting from smithing residues. However, in the Roman period and later, smelting slags are more readily distinguished, with tap-slags from bloomeries and glassy blast-furnace slags being characteristic. Routine examination of slags aids the accurate identification of site function (Fig 18) and can potentially provide the basis for a better understanding of questions raised in Part 3. A combination of visual examination and scientific analysis can also indicate the variability within a slag assemblage, and hence inform decisions about the discard or dispersal of some of the material — often a welcome relief to museum professionals with over-full stores (SMA 1997, 29).

Where there were large quantities of slag, they were often removed from the site. Many early slags contained significant quantities of metal so they were re-smelted as technologies developed. Slag could also be re-used as hardcore in areas lacking good supplies of local stone, and large quantities were used as ballast under railway tracks.

Figure 16: Tap slag, showing its characteristic flow-form surface structure.

Figure 17: Blast-furnace slags are usually glassy in appearance and can range in colour from blue/green through to grey/brown. They were often re-used as hardcore and so can be found in small pieces far away from furnace sites.

Metals

Smelting normally produces ingots of metal, sometimes called pigs, that were cast direct from the furnace. As iron could not be melted in early furnaces, the end-product of smelts was a 'bloom' — effectively a sponge of metallic iron full of slag — which was taken from the furnace and hammered to compact it and squeeze out the slag, producing forgeable bars. Late and post-medieval blast furnaces produced liquid iron that was cast into ingots, like other metals, or direct into large objects such as guns. For more information on metals, see section 1.4, below.

1.4 Artefacts

Especially for the early periods, often the only evidence of a particular technology that survives is the end product — the artefact itself (Fig 19). Archaeometallurgy has therefore traditionally reconstructed technologies

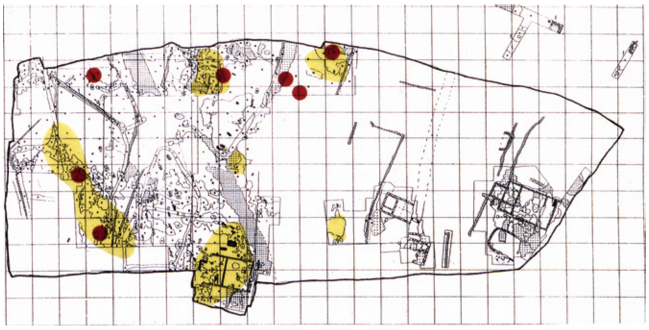

Figure 18: Plan of excavated features at the Roman site at Shepton Mallet, Somerset, where both iron smelting (yellow shading) and smithing (red spots) were taking place. Note the partial spatial separation between the two activities.

from artefacts through laboratory analysis.

Analysis and study

Investigation of artefacts can vary from visual examination, through low-power binocular microscopy and radiography to metallography and full-blown chemical and/or isotopic analysis. There are various techniques available to analyse artefacts and these are discussed in section 2.4. The results of analyses are only as good as the sampling strategy allows them to be (see section 2.3), and with artefacts this can sometimes be as important as the analysis itself. Analysis of metal artefacts and other technological debris can inform on a great many issues:

- Smelting technology: chemical and microscopic analysis can indicate ore type, the efficiency and nature of the smelting process, furnace parameters, whether fluxes were used, etc (Craddock 1995, 135–144).
- Fabrication technology and treatments that modify the properties of the metal: radiography can inform on macro-fabrication and metallography on micro-fabrication. This is especially true for ferrous metals as heat treatments can alter their physical properties, which can be very informative about an artefact's place in the culture that produced it (see section

Figure 19: Hoard of complete and fragmentary precious-metal Iron Age torcs from Snettisham, Norfolk.

2.4). Detailed study of chemical composition can also provide information on workshop and industry organization.

- Material culture: technological choices made when producing artefacts can reveal culturally specific strategies and how these relate to ideas of ethnicity and belonging (see sections 3.3, 3.4 and 3.5).
- Trade and exchange: chemical and isotopic analysis in particular can provide information about artefacts' origins, important in discussing their circulation and exchange (see sections 3.1 and 3.4)
- Economic and fiscal policies: chemical analysis of coinage can aid understanding. For example, two coins of the same size and weight may appear to have the same intrinsic value, but only analysis can tell if the alloy and therefore the value is the same.

Despite all these possibilities, artefactual analysis is still relatively rare and certainly not as routine as other types of archaeological recording and investigation. Photography, drawing and weighing are all standard ways of characterizing artefacts yet composition and fabrication history are deemed relatively unimportant. Indeed, until recently many museums displayed all objects made of a copper-based alloy as 'bronze' regardless of alloy type; yet we now know that alloy type can be an important differentiating criterion (see sections 3.4 and 3.5).

A way forward

Museum collections can be unrepresentative of metalwork in use at any particular time, as they tend to concentrate on the best-quality and most aesthetically-pleasing items. Even some modern acquisition policies can be accused of bias towards artefacts which are of interest to curators, reflect collecting fashions, or which attract visitors and headlines. However, the attempt to preserve all the finds from excavations means that local museums often store excavated archives which contain representative, everyday metalwork. Additionally, under the Portable Antiquities Scheme many museums have Finds Liaison Officers attached to them who can be sources of information and access to recently-discovered metal artefacts (see section 1.6). Museum curators are often keen to have their holdings used for research, as this helps justify the maintenance of the collection as a resource.

Analyses of metal artefacts need to be conducted on a sufficiently large scale to be representative; one or two analyses are not sufficient to characterize manufacturing practices, an artefact type or culture group (Bayley and Butcher 2004) (Fig 20). The statistical examination and investigation of analytical data is also

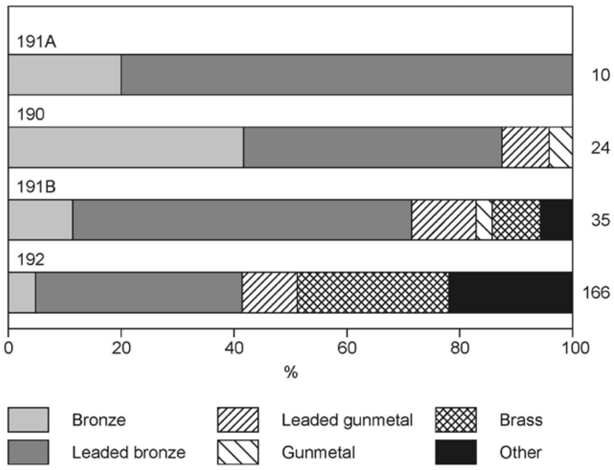

Figure 20: Frequency plot of alloys used to make different types of late-Roman crossbow brooches. The early examples (191A) are mainly leaded bronzes while the latest (192) have only a minority of leaded bronzes but many brasses and other lead-free alloys, many of which were mercury gilded.

now regarded as a necessity. A useful overview of such approaches with a comprehensive bibliography is provided by Baxter and Buck (2000). However, before any analyses are contemplated, there should be an explicit research question to which the results have the potential to contribute, if not to answer.

The counter-argument is that in an ideal world a proportion of metal artefacts from all excavations should be routinely analysed alongside any production refuse. It may be that the analysis of a fibula and a couple of fragments of copper-alloy sheet from a single site are of little inherent interest or value in themselves, but when analyses of metal finds from several sites of a particular type are brought together, patterns and trends can begin to be identified and discussed (*eg* Bayley and Butcher 2004). If this sort of approach is to be adopted, it would be desirable for all developer-funded projects to have funding for analysis of metal-related finds routinely written in.

If a 'future-proof' database of analyses were to be compiled, an acceptable quality bench-mark for analytical data would have to be set up. At present most analyses are directed at answering specific questions, which can be at the expense of providing data of the consistency and quality required for a national archive. It may seem sensible that where an analysis is to be undertaken it is as full as possible, even if a low-level qualitative analysis would answer immediate questions, but in the real world resources are limited so compromises usually have to be made.

The arguments against such a policy are the risk of damage caused by sampling for a quantitative analysis (discussed in section 2.3) and cost. Quantitative analyses are relatively expensive, but some institutions may be able to undertake analyses (Bayley *et al* 2001, 26–7). Commercial analysts are seldom equipped to deal with archaeological material properly, and can provide expensive disasters through ignorance.

Artefacts from the post-medieval period are rarely analysed, although there is a need to do so, to compare with the documentary evidence for industrial development.

1.5 Documentary resources

Recently-produced documents may summarize a variety of information on metalworking in particular areas. Much of this is 'grey literature' which is not fully published, but it will complement and often update the information contained in books and journal articles, as well as that to be found in the variety of documentary sources discussed below.

The historical records of the post-medieval iron and steel industries are used as an example, but archive sources are also available for the working of other metals. Records of many types exist for the lead industry (*eg* Kiernan 1989, Raistrick 1973; 1975), for copper and brass (*eg* Harris 1964, Day 1973, Morton 1985) and for silver extraction. For the latter, the records of the English Crown are a major source; Claughton (2003) has synthesized the documentary evidence for silver production between 1066 and 1500.

Example: 18th/19th-century knife manufacture in Sheffield

Analysis of finds from ARCUS excavations at the Town Wheel cutlery workshop, Sheffield, was undertaken by Rod Mackenzie of Sheffield University. Three blister steel bars provide independent evidence for 18th- and early 19th- century steel-production technology and allowed research into the characteristics of the material. They show the wide range of steels produced at Marshall's Millsands Steelworks, which was only about 100m from the excavated workshop, from lower carbon steels typically used in cheap cutlery to high carbon steels for specific applications.

The two knives were selected for analysis as they dated to the period when Marshall established his steel works at the site. Analysis has shown them to be made of blister steel (see section 3.8). Figure 21 shows at least seven different layers of steel in the blade which originates from the separate bars of blister steel that were forged into a single piece known as shear steel. Cleaner blister steel bars appear to have been selected for the outside and centre of the shear steel as these regions would have formed the exterior and cutting edges of the blade. The use of single-shear steel suggests that this knife would have been of reasonably good quality. In contrast, Figure 22 shows a much higher abundance of inclusions (dark spots) in the metal. Although the blade appears to be a well-finished object it has been 'cobbled together' from separate pieces of steel of varying carbon contents, suggesting that it was made from recycled scrap blades. In the 18th century, steel was a valuable commodity, purchased by weight, and would have been reused rather than discarded. The makers of both objects are identifiable from their stamps. The higher-quality blade was made by an experienced cutler, while the lower-quality one was either made by a less experienced cutler from poorly re-cycled metal, possibly someone only recently apprenticed, or may be an example of lower-quality cutlery.

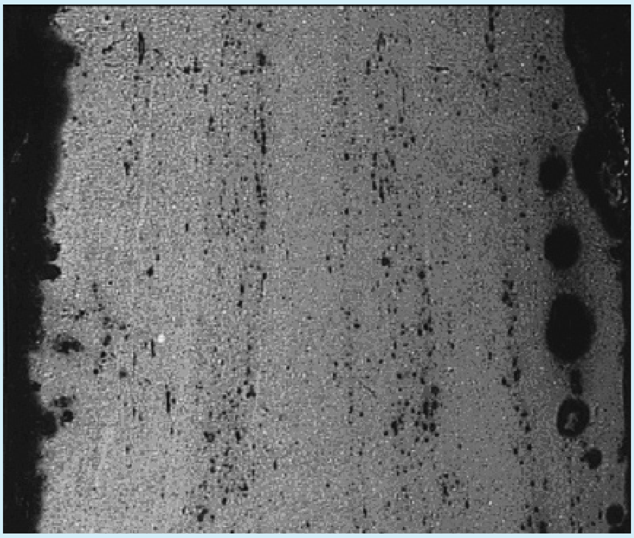

Figure 21: Section through knife blade showing seven layers in the shear steel. Image width ~1mm.

Figure 22: Section through knife blade. The varied texture to the left shows the incorporation of several pieces of scrap metal. Image width ~1.5mm.

Lists of ironworks

Although only giving site-names and outputs, the 18th-century lists of ironworks are a significant source. Those compiled in *c*1716, 1718, 1736 and 1749 were published by Hulme (1928) and evaluated by King (1996) and Evans (1993a). The data for furnaces operating between 1660 and 1980 have been systematically collated by Riden (1992; 1993) and Riden and Owen (1995). Forges have received much less attention and a 1790s list in Birmingham Archives (B&W MII/5/12) appears to be the last survey of them until the later 19th century. Recent research by King (2003) includes a systematic gazetteer of forges which provides an invaluable basis for further work.

Commercial records

Compared with some commercial activities, the surviving records derived from ironmasters are relatively plentiful, but nevertheless far from comprehensive. They are particularly scarce for the period before the middle of the 17th century. However, records of the sales and purchases of one works can provide information on the business of contemporaries. Most surviving records consist of accounts, leases, supply agreements and correspondence, and result from ironmasters or their descendants becoming members of the landed gentry, but a few have remained in the hands of successor firms.

Estate records

Where the internal records of an ironworks do not survive, information about the ownership of the business can be derived from the estate records of its landlord (Fig 23). Obvious sources in this connection are leases. These may not only provide for the letting of a furnace or forge, but often also the provision by the landlord of cordwood (for charcoal) and mining rights for iron ore. In addition to the deeds themselves, details of leases can sometimes be found copied into lease-books, or abstracted in estate surveys, in terriers (lists of land-parcels) written on (or prepared to go with) maps. These records generally do not say much about an ironmaster's business, but do show that the ironworks was in operation and who owned it. Somewhat less useful (but still valuable) are the landlord's own title deeds (including settlements and mortgages), which have a brief description of his property, often naming his tenants.

Other financial records

Land Tax Assessments, which between 1780 and 1832 were lodged with the Clerk of the Peace, are therefore among Quarter Sessions Records in County Record Offices. These survive for many but not all counties. For

Example: Ironworks records up to the mid 18th century

Published ironworks records include those edited by Crossley (1975b), Crossley and Saville (1991), Gross (2001), Riden (1985) and Schafer (1978; 1990). The most important ironworks records in manuscript include:

Backbarrow accounts (Newcastle University Library, misc ms 32; Lancs RO, DDMc 30/1-9; Barrow in Furness RO, z 186–196).

Boycott & Co accounts (National Library of Wales, Cilybebyll 202 413–4 1291–5; PRO, E112/880/Salop 9).

Coalbrookdale and Horsehay Accounts (Shrops RO, 6001/329–35; Ironbridge Gorge Museum Library, CBD59.82.5).

Cookson letterbook (Tyne & Wear Archives 1512/5571).

Richard Ford's letterbook (Shrops RO, 6001.3190).

The Foley collection (Herefs RO, E12).

Forest of Dean administrative records (PRO, various classes including E178; SP 18/130/146ff' SP18/156B; E178/6080; LR6).

Knight ironworks accounts (Worcs RO, 899:31 BA 10470; Herefs RO, T74).

William Lewis's The Chemical and Mineral History of Iron (Cardiff Library ms 3.250).

Letterbook of Robert Morgan of Carmarthen (National Library of Wales, Griffith E Owen 162).

Staveley Ironworks Records, which also cover ironworks at Sheffield (Sheffield Archives, SIR).

The Spencer-Stanhope Collections (Sheffield Archives and Bradford Archives, SpSt).

Tredegar Park collection (National Library of Wales, Tredegar Park 76; Tredegar mss & documents 136).

Diary and letterbook of John Watts 1715 (Sheffield Archives MD 3483).

Weale mss (Science Museum Library ms 371/1–4).

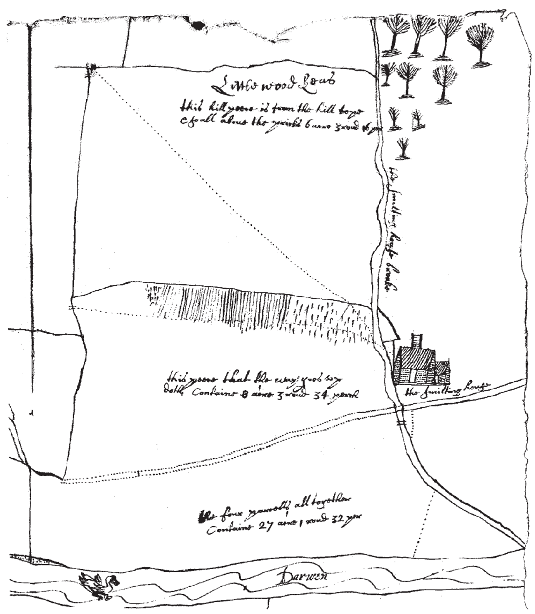

Figure 23: Sketch, probably from the mid-17th century, showing Little Rowsley lead-smelting mill on the Smelting House Brook that flowed west into the River Derwent, Derbyshire (bottom), and the woodland (top) that provided fuel for the smelter (Chatsworth Map H304/43).

some areas there are further copies of the assessments, which have been deposited in Record Offices by Land Tax Commissioners. For parts of Sussex these go back to the 1690s. The amount of tax payable did not vary after 1780, and only rarely changed before that. This enables the ownership and occupation of each property to be followed from year to year. Rating records (in parish deposits) may be used in a similar way if they survive.

Litigation

Much valuable information can be obtained from the records of litigation in the equity courts, preserved in the National Archives (formerly the Public Record Office). These are the Courts of Chancery and Exchequer, and, before the Civil War, the Courts of Requests and Star Chamber. The listing of many of these records is still far from satisfactory. Most classes were originally only listed by the plaintiff's name although in some cases there is a calendar that specifies the subject matter of the claim. If so, a place-name index may have been prepared from this, but there are hardly any subject indices. Work is in progress to enable the National Archives lists, calendars and other finding aids to be searched on-line. Until this work is completed, discovering relevant documents is likely to remain difficult unless the names of individuals are known from other sources. Disputes were of many kinds, but perhaps most valuable are those between the partners in an ironworks. These often list all the works owned by the firm, and may have accounts attached to pleadings. However, many actions were concerned with less-significant matters, such as whether a contract for the sale of goods had been fulfilled, or whether a loan had been repaid. The statements (depositions) of witnesses can be valuable, even in apparently trivial cases, often providing statements of the circumstances of the dispute, some with topographical asides. In some cases documents lodged with the court as evidence were never collected. These are known as Chancery Masters Exhibits, an example being the early-19th-century ledgers of the Ebbw Vale ironworks (PRO, C 114/124–127).

Sources for technology

There are a number of key sources for industrial processes, including metallurgy, which date from the medieval and post-medieval periods. Types and origins of iron and steel are discussed in a 9th-century Arab treatise (Hoyland and Gilmour 2006) while the 12th-century tract by Theophilus (Hawthorne and Smith 1979) is a valuable early source, as are the 16th-century books by Biringuccio (Smith and Gnudi 1943) and Agricola (Hoover and Hoover 1950; Fig 24) which have later equivalents, notably Diderot's *Encyclopedie* (Gillispie

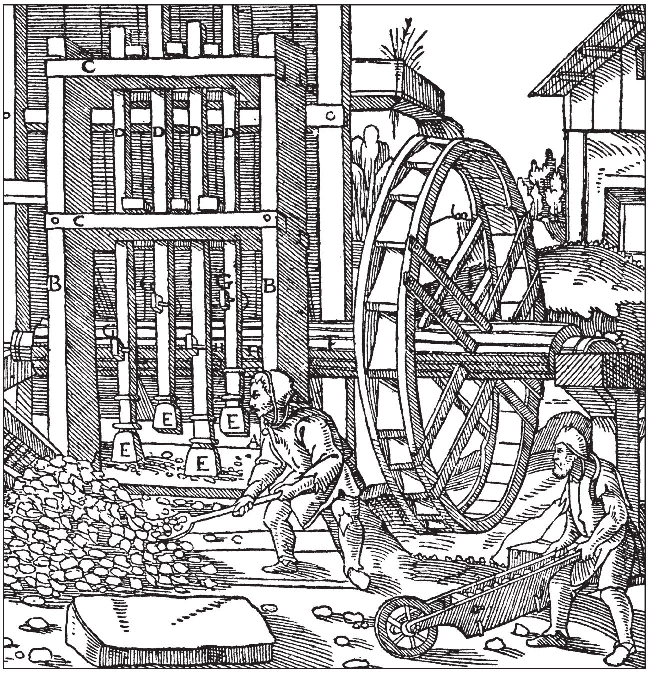

Figure 24: Water-powered stamp mill crushing ore in Germany in the 16th century from Agricola's De Re Metallica. *After Hoover and Hoover 1950.*

1959) for the 18th century, Rees' *Cyclopedia* (Cossons 1972) and various editions of Ure's *Dictionary* (*eg* Ure 1843) for the 19th century. However, at the practical level, knowledge of processes was generally transmitted from generation to generation by the apprenticeship system, under which a master agreed with the parent of a young man to teach him his trade. This was largely done by demonstration, rather than by the pupil reading a description. Hence contemporary descriptions of metallurgical or other processes are rare. Some new processes were patented, and by the middle of the 18th century the grant of a patent was followed by the enrolment of a specification. These are valuable as far as they go, but do not indicate whether the process was viable, either in technological or economic terms. The economics of a process can be deduced from ironworks accounts, but that does not indicate how it was carried out. For that it is often necessary to rely on what visitors described. Their observations are widely scattered in diaries and journals. Some visitors had little understanding of the processes and their descriptions are less valuable. However, of particular value are the journals of Swedish travellers, who (coming from a country whose main export was iron) were particularly interested in the processes. A recently published example is *Angerstein's Diary* (Berg and Berg 2001; Fig 26). The same applies to certain French visitors, who came late in the 18th century expressly for industrial espionage. The translation and publication of their diaries would add significantly to our knowledge.

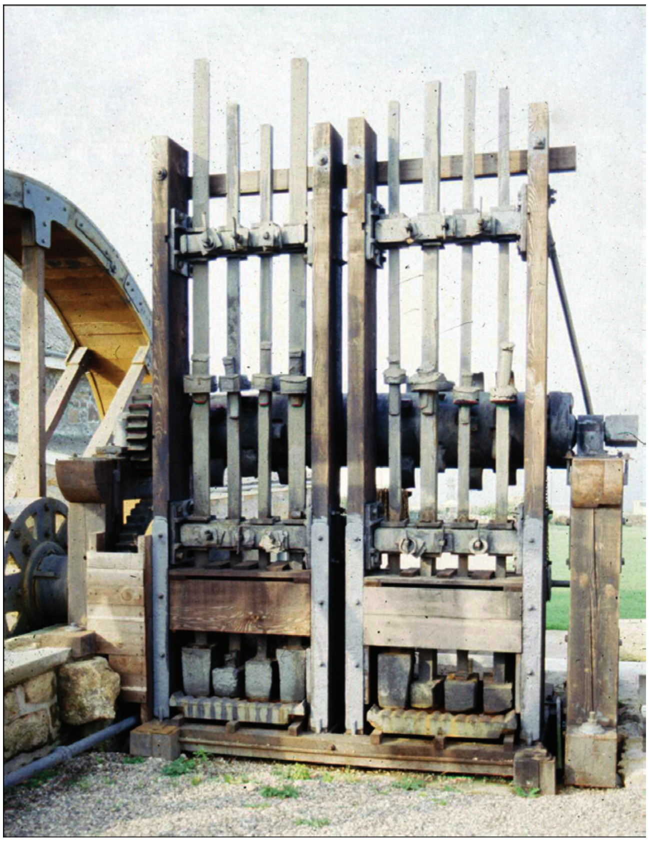

Figure 25: 20th-century ore stamps from Zennor, Cornwall. Compare with Figure 24 and note how little has changed in 400 years.

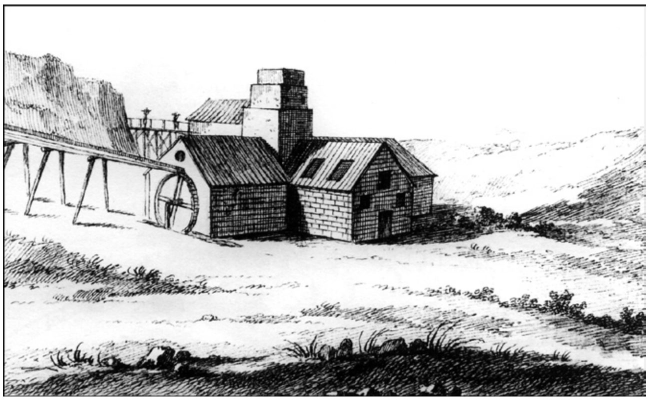

Figure 26: Sketch of Maryport blast furnace, Cumbria, from Angerstein's diary. After Berg and Berg 2001.

1.6 Managing the resource

Statutory protection of sites

The Monuments Protection Programme was set up by English Heritage in 1986 to review and evaluate England's archaeological resource. Although some metallurgical sites and buildings had been Scheduled or Listed, it was acknowledged that their representation was inadequate. Industrial monuments were therefore used to test the methodology, and the outcome was the production of a series of documents. These reports were not formally published but copies were deposited with the NMRC at Swindon and in relevant HERs (see below); it is now planned to make the information in them available on the English Heritage website (www.english-heritage.org.uk). For each industry there was a Step 1 report which included a breakdown of the component features of the industry, including a glossary of terms and the likely date-ranges of each component. These were based mainly on published studies with limited reference to field archaeology. This, however, fitted with the project aim of establishing what is there (Stocker 1995), but was not always able to say what it meant. Later, Step 3 reports were compiled which presented lists of sites that were regarded as representative of the different features and developmental stages of the industries; these were graded according to their importance and desirability for statutory protection.

Although for some industries specific recommendations for statutory protection were made, not all of these have so far been followed through. The outcome of the current Heritage Protection Review (www.english-heritage.org.uk/server/show/nav.8380) will be a faster, more open and unified system that should ensure increased protection for these English sites; it is to be hoped that similar systematic protection will be introduced in Wales and Scotland.

Historic Environment Records

An integrated heritage database, the Historic Environment Record (HER), covering archaeological sites and monuments is maintained by most local authorities in Britain and comprises a sites and monuments record (SMR) and a historic buildings record (HBR). These are publicly available resources that are supposed to be the repository for the archaeological resource within a region. Most HERs have been built-up since computerisation in the 1980s, but older records still have a substantial paper component. In most cases, new information usually comes into the SMR through the planning process. Some HERs such as those in the Lake District and Norfolk, which has a strong tradition of good relations with metal detectorists, now record individual finds. Data also comes from the Portable Antiquities Scheme (see below). The role of individuals seems to be particularly important in the recording of archaeometallurgical sites on HERs; an example is the work of Michael Davies-Shiel who, over some 30 years, has been largely responsible for around 250 iron-working sites being recorded on the Lake District HER (Fig 27). Some HERs are perceived as primarily a tool in the planning process and not specifically an archaeological resource, any archaeological benefit being a

Figure 27: Two linear slag tips at Crowdundle Beck, Cumbria; the left-hand one is being eroded by the beck. This bloomery site was identified by Davies-Shiel and probably dates to the 17th century.

spin-off. Such attitudes can lead to an incomplete and biased record for archaeology as a whole, and especially for archaeometallurgy which is often poorly understood by the archaeologists themselves.

A positive example is the Lake District National Parks Authority which, in collaboration with the National Trust, has recently undertaken a programme of HER enhancement with particular reference to iron-working sites. The results are quite outstanding and have led to the geophysical survey of over 35 bloomery sites dating from the 13th to the 16th centuries (Hodgson pers comm). There is a general need to expand the scope and quality of HERs, and to raise their profile as research resources. Further progress is needed on converting paper-based systems to a digital format.

The development of digital resources for archaeology is expanding greatly. Alongside local HERs there are now national resources, many of them hosted by, or accessible via, the Archaeology Data Service (ADS; ads.ahds.ac.uk). It preserves digital data in the long term and makes available digital resources such as those listed on HEIRNET (Historic Environment Information Resources Network) or included in the ADS catalogue, ArchSearch. It also gives access to data from projects such as OASIS (Online AccesS to the Index of archaeological investigationS), which provides an online index to archaeological grey literature produced as a result of large-scale developer funded fieldwork. The Scottish Royal Commission's website (www.rcahms.gov.uk/search.html) gives access to their digital archives, including CANMORE and Pastmap, which contain information on archaeological sites and monuments. Similar information for England is accessible through Pastscape (www.pastscape.org), while CARN (The Core Archaeological Recods iNdex) provides an index to information held by archaeological organizations in Wales (carn.rcahmw.org.uk/).

The Portable Antiquities Scheme

The Portable Antiquities Scheme (PAS) was set up in 1997 to record archaeological finds made by members of the public. Finds Liaison Officers (FLOs) cover England and Wales, supported by centrally-based specialists. The scheme, funded by the Heritage Lottery Fund through the Department of Culture, Media and Sport, has led to the reporting of thousands of objects every year, most of which would otherwise have remained unrecorded (Fig 28). A recent annual report makes the point that there are believed to be about 10–15,000 metal-detector users operating in England and Wales and they may find as many as 400,000 archaeological (metal) objects in a year. The PAS is committed to feeding the data it gathers to local HERs, which should in time provide databases for research.

Before the advent of the PAS, some classes of object were almost unknown, due to either a lack of recording facilities or a lack of knowledge as to what they were, or both. One example is the small copper or bronze bars and blanks used during the 3rd and 4th centuries AD to produce unofficial coinage in Roman Britain. Their increasing numbers have made metallurgical analysis on a significant scale possible, which has begun to answer questions about the methods of production of these coins and their alloy composition (see section 2.6). With recording taking place across the whole of England and Wales (www.finds.org.uk) and the recent extension of the Treasure laws to include prehistoric base metal hoards, new opportunities for archaeometallurgical research have opened up.

Figure 28: Metal-detectorists collected this later 3rd century copper-alloy waste from the manufacture of Romano-British coinage, and reported it through the Portable Antiquities Scheme.

Curation of archives

The archaeometallurgical archive normally forms part of a much larger archaeological archive and has two main components: the material and the documentary archives. These are derived from the site record (the materials and records collected during fieldwork) and the research archive resulting from analysis and study. It is, of course, important to maintain this body of material intact, though museums' storage constraints may make some selection inevitable (SMA 1997; Perrin 2002, 9–10; Brown 2007). Surplus material can usefully be placed in teaching or reference collections, such as the Hawley Collection of tools at Sheffield (www.shef.ac.uk/hawley), or can be offered to the National Slag Collection at Ironbridge (www.ironbridge.org.uk/about_us/ironbridge_archaeology/research). This collection can be consulted free of charge, by prior appointment, although deposition of items with the collection may be subject to a small fee to cover storage materials and administration costs. The development of a searchable database of metallurgical samples and related analytical data is under way.

There are basic minimum requirements for creation, transfer and accessioning of archives to recipient museums (Owen 1995), which apply equally to metallurgical material. In some cases, county archive services and archaeological contracting units have drawn up recommendations for standards of deposition and archiving, following the recommendations of the Museums and Galleries Commission (MGC 1992). The material archive may contain ore, fuel, furnace remains, metallic products and waste materials as well as prepared samples removed from them. The fragility and storage requirements of the materials will vary so packaging and handling must be appropriate.

Minimum standards for storage include adequate protective packaging and suitable environmental conditions for both the material archive and the documentary archive; specific requirements for long-term storage have been set out (Walker 1990; MGC 1992). It is common practice to keep samples, such as prepared specimens of metal from artefacts, with the material archive (Davis and Starley 2002; Fig 29). Other types of samples may include polished and mounted pieces of slag or other waste products, thin sections of ceramics for petrological analysis, samples of corrosion products or process residues, and samples for scientific dating. The documentary archive may include paper records, plans and drawings, photographic negatives and prints, as well as electronic media. Methods of documentary archiving are likely to develop towards electronic systems. The active curation and access arrangements for these will require further consideration (Richards and Robinson 2001).

Figure 29: Cabinet containing polished metallurgical samples made between 1863 and 1865 by Henry Clifton Sorby, the pioneer Sheffield metallographer. Now in the collections of the South Yorkshire Industrial History Society.

Current threats

The archaeometallurgical resource faces the same threats as the rest of archaeology: coastal erosion, climate change, and development pressures such as road and house building. In addition, there are extra pressures: those due to continuing exploitation of mineral resources which remove superficial layers, together with evidence for earlier mining, to gain access to deeper deposits; and those caused by the current drive to redevelop brown-field sites and clean up contaminated land. These latter activities have proportionally more effect on archaeometallurgy as many brown-field sites were previously occupied by heavy (metallurgical) industries, and much of the contamination is the result of wastes from those industries — so remediation effectively removes or destroys the archaeology we want to investigate (Payne 2004; see also section 2.3).

To these external threats we sadly have to add the cavalier ways in which past excavators and museums dealt with metallurgical debris. The situation is now better, thanks to increasing awareness in the archaeological community and the provision of guidelines such as those concerning archaeological archives (*eg* Owen 1995; SMA 1997). However, until the archaeological community learns to appreciate the contribution that metallurgical finds can make, they will continue to be vulnerable to second-class treatment, especially when projects are under-resourced.