Caldarium? An antimony bronze used for medieval and post-medieval cast domestic vessels

David Dungworth and Matthew Nicholas

ABSTRACT: The archaeological evidence for medieval and post-medieval casting of large domestic vessels in England is reviewed. This consists of archaeological features, waste products and the finished artefacts. The distinctive nature of the alloy used (an antimony-rich leaded copper alloy) is discussed. It is argued that this alloy was a waste product from the extraction of silver from fahlerz ores.

Introduction

This paper describes the archaeological evidence for medieval and post-medieval manufacture of copper alloy domestic vessels, primarily three-legged cauldrons. Hemispherical cauldrons made from riveted wrought copper alloy sheets had been made from the Bronze Age until the late Anglo-Saxon period. In the medieval period these were replaced by cast vessels, usually with three feet and two lug handles near the rim (Fig 1, and see Butler and Green 2003; Cherry 1987; Drescher 1968 and 1982–3; Goodall 1981; Lewis 1978 for further details). Posnets and skillets are both smaller versions of cauldrons (they still have three feet) but with a single strip handle. Posnets usually have the same profile shape as cauldrons while skillets have flatter bases and straighter, more vertical sides.

The earliest illustrations of three-legged cauldrons date to the 12th century (*eg* London Museum 1940, fig 68) and the earliest use of the word cauldron is in 1300 (Oxford English Dictionary). Posnets appear in 13th century illustrated manuscripts (*eg* Butler and Green 2003, 174–5) and the earliest use of the word is in 1327 (Oxford English Dictionary). Skillets are perhaps a later version of a posnet: the earliest use of the word is in 1403, and three-legged skillets were produced (in cast iron) into the 20th century (Butler and Green 2003, 17). Three-legged cooking vessels in general appear to go out of fashion in the modern era as cooking 'technology' changed.

Documentary evidence shows that large cast domestic vessels, such as cauldrons, posnets and skillets, were common in most English households during the medieval and early post-medieval periods (*eg* Field 1965). It is likely that in the period in question (12th to 18th centuries) several million vessels were produced.

Manufacturing evidence

The archaeological evidence for the manufacture of large copper alloy domestic vessels consists of workshop features (such as furnaces and casting pits), moulds and casting waste. Importantly, the archaeological evidence for the casting of church bells is almost identical and until recently archaeological evidence for the casting of large copper alloy artefacts was usually labelled 'bell-casting'. As discussed below, the chemical analysis of casting waste can provide the clearest

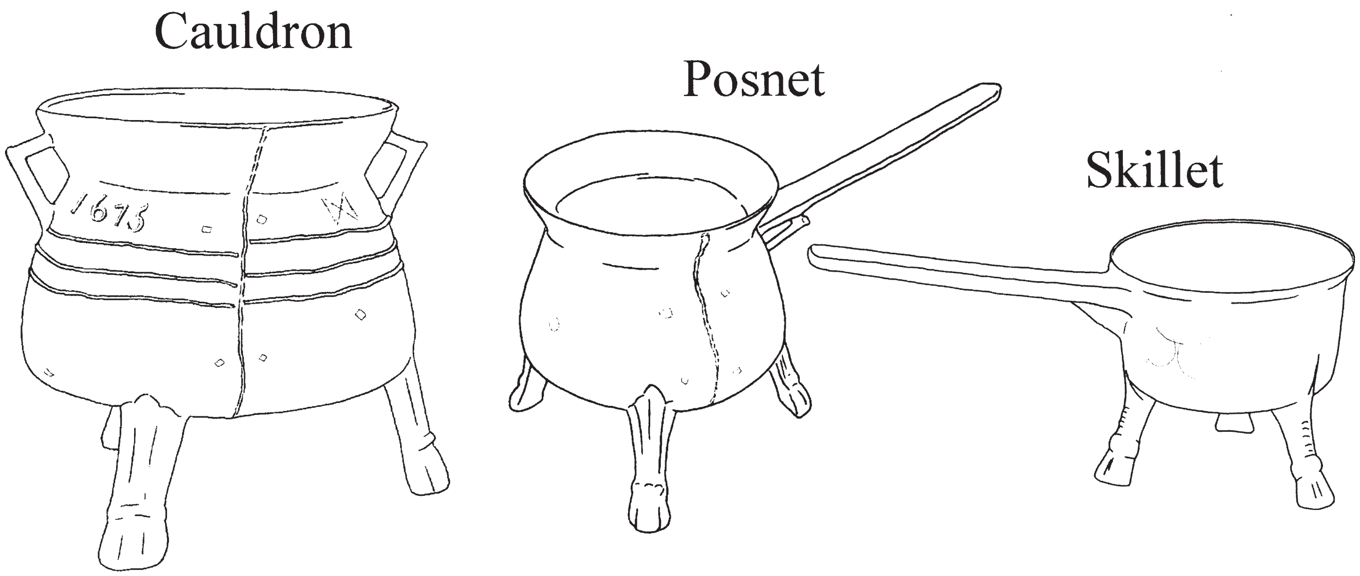

Figure 1: Examples of a cauldron, a posnet and a skillet (after Butler and Green 2003, 35)

archaeological evidence for the types of artefacts manufactured. Nevertheless, while we may wish to distinguish between the casting of bells and domestic vessels, many foundries are known to have produced both (Butler and Green 2003, 30). In addition, the seals of medieval bronze casters often show bells and domestic vessels (*eg* Blair and Blair 1991, fig 48). Many of the artisans who described themselves as bell-founders may have spent most of their time casting domestic vessels.

In some cases the archaeological context provides a clear indication of what was produced, for example, the 'bell-casting' pit (containing 'bell-mould' and casting waste) and the furnace at St Peter's Church, Barton-upon-Humber were situated under the tower (Dungworth and Maclean 2002). The prepared bell-mould would have been placed in the pit, the bell cast and then lifted straight into the tower. The analysis of the casting waste confirmed that bells were cast.

Quarry pits, casting pits and furnaces

Crucibles were unsuitable for the casting of large domestic vessels (and bells) due to the large quantities of metal required. Instead, the metal was melted in a furnace and then allowed to flow under the force of gravity into a prepared mould. This meant that it was usually necessary to excavate pits into which the prepared moulds were placed. Biringuccio (Smith and Gnudi 1990, 288) describes how channels would be constructed between the top of a mould and the tapping hole of the furnace. Casting pits can be up to 1m deep and so are relatively common archaeological survivals. In some foundries (*eg* Blaylock 2000, fig 6) large quarry pits were dug to extract the 'clay' used to make the moulds (see below for further details of moulds). Quarry pits could be re-used as casting pits and were sometimes back-filled with used mould fragments. Furnaces for the melting of copper alloys are rarely preserved; the few late examples (*ie* 16th and 17th centuries) are all rectangular reverberatory furnaces, typically 1m by 2m (*eg* Blaylock 1996, fig 10).

Moulds

The moulds used to cast large domestic vessels were very similar to those used for the casting of bells. Modern reports usually refer to these moulds as being made of clay (to distinguish them from sand moulds which did not become prevalent in England until the end of the 17th century [Butler and Green 2003, 27–8]). However, the 'clay' is usually a mixture of sand, silt and clay and contemporary accounts of bell and vessel manufacture usually refer to the use of 'loam' (*eg* Biringuccio: Smith and Gnudi 1990, 218). Early accounts also stress that large quantities of organic matter should be added to the 'loam', Biringuccio recommends woollen waste (*eg* wool-cloth clippings) or animal dung. The organic matter would be burnt out as the mould was fired, which would leave the mould sufficiently porous to allow the escape of air as it was filled with metal.

By the end of the 17th century, clay or loam began to be replaced as the favoured moulding material by sand. Sand has the refractoriness needed to withstand the heat of molten copper alloys and the permeability needed to allow the escape of gases from inside the mould; however, used on its own it does not have sufficient strength. Moulding sands usually contain small amounts of clay to help the bond. In addition, so-called greensands also contain small amounts of moisture which helps the mould to bond (Sandham and Willmore 1971, 132–3). It is not necessary to dry the mould before casting as the sand gives the moulding material sufficient porosity to allow the escape of any steam that forms. The removal of the need to allow moulds to dry greatly increased the productivity of foundries. Unfortunately greensand moulds do not survive in the archaeological record as they are relatively fragile and the material would be re-used many times.

The exact procedures employed for casting are still uncertain (for various possible techniques see Blaylock 1996 and 2000; Butler and Green 2003). It is possible that some vessels were cast using the lost-wax process. However, most surviving cauldrons have flash lines on their outer surfaces and this suggests that the cope mould (the mould for the outer surface of the vessel) was split which would not be necessary if the pattern was made of wax. Davies and Ovenden (1990, 126) note the presence of finger marks on the exterior parts of core mould fragments (that is the mould for the inner surface of the vessel) which suggests that the moulding clay was pressed onto a pattern. Such a pattern would, of course, have to be a durable material and formed in two halves so that it could be removed before casting. Biringuccio (Smith and Gnudi 1990, 263–4) describes the use of loam as a modelling material, while later documentary records (*eg* Butler and Green 2003, 123) show that metal patterns were used. The moulds for the handles and the feet were made separately and added; these could have been formed around patterns of wax, wood or bone. The moulds for the feet were sometimes closed (*eg* at Cowick Street, Exeter: Blaylock 2000, 85, figs 15 and 23) and sometimes open (*eg* Whirligig Lane, Taunton: Blaylock 2000, 85). The existence of open feet confirms that cauldrons were cast upside down; the molten metal could have been poured into one of the open feet. Some sites, however, have produced examples of mould ingates (*eg* Anund *et al* 1998, figs 4 and 5; Blaylock 2000, fig 28) and many extant cauldrons (see Drescher 1968, figs 4 and 5; Butler and Green 2003) have the scar of a sprue in the centre of the base.

Used clay mould fragments usually have a reduced-fired (black or grey) inner surface which would have been in contact with the molten metal, while the outer parts of the mould are oxidized fired (orange or red). Fragments of core moulds have convex inner surfaces, while cope moulds have concave inner surfaces. In general cope mould fragments survive better than core mould fragments.

Casting waste

During the casting of copper alloys, small quantities of metal may be spilt. These would usually have been collected and re-used. Nevertheless, small quantities have been found in most foundries. In addition, fragments of metal are occasionally found adhering to the inner surfaces of mould fragments (especially where the casting failed). The melting of copper alloys may also lead to the formation of slags which contain some copper (as well as other metals from the copper alloy).

The chemical analysis of casting waste (and fragments of failed castings) has shown that the alloy used in the manufacture of large domestic vessels is completely different from that used for bells. The analysis of bells and bell-casting waste shows the consistent use of an alloy which typically contains 20–25% tin, a few percent of lead and the balance copper (Table 1; cf Tylecote 1992, table 44). The analysis of domestic vessels and associated casting waste, however, shows the use of a completely different alloy (Table 1).

The analysis of medieval and post-medieval copper alloys has shown that they can be categorized on the basis of their zinc, tin and lead contents (Bayley 1991; Blades 1995). Alloys rich in zinc are brasses, those rich in tin are bronzes, and alloys containing roughly equal proportions of zinc and tin are gunmetals. In most medieval and post-medieval copper alloys, it is rare for either arsenic or antimony to exceed 0.5% (Blades 1995). However, the alloy most frequently used to cast vessels usually contains low levels of tin, virtually no zinc and high levels of lead, but it is the antimony and

Table 1: Average chemical composition (wt%) of medieval and post-medieval bells and bell casting debris from Barton upon Humber, and vessels and vessel casting debris from various sites in Britain.

		Composition (wt%)									
	Number	Cu	Zn	Sn	Pb	Sb	Ni	Fe	As	Ag	S
Bell samples	4	74	<0.1	22.1	3.8	<0.5	<0.1	<0.1	<0.3	<0.3	<0.2
Vessel samples	85	69	0.6	4.8	13.7	4.9	0.4	0.3	1.2	0.1	0.3

Note: Data for bells is from Dungworth and Maclean 2002. Data for vessels is from Blades 1995, Craddock 1985, Dungworth 2002, McDonnell and Dungworth forthcoming and Nicholas 2003. A variety of analytical techniques has been used by the different authors. Note vessel samples with <1% antimony have been omitted.

Figure 2: Map of England and Wales showing the distribution of sites which have produced evidence for the casting of large copper alloy domestic vessels

the arsenic contents that are most distinctive. This alloy may perhaps best be described as a leaded antimony bronze. The significance of this alloy and its origins and other uses are discussed below. A small number of vessels were cast in alloys which contained low levels antimony, usually a leaded bronze, and these but not included here.

A systematic study of documentary evidence for the production of cauldrons is beyond the scope of this paper (see Blair and Blair 1991 for a discussion of some sources). The interpretation of documentary sources is complicated by the fact that a variety of professions are named, *eg* potters, brasiers and founders, but it is not always clear what the names meant in terms of the types of artefacts they produced. There is also uncertainty of the exact meaning of the names given to different alloys, *eg* potmetal, latten, graycober, stelebake, marshalbras, etc, while the word brass was used to mean at least some alloys which would now be called bronze.

Spatial and chronological distribution

Three-legged copper alloy cooking vessels have been found throughout the British Isles, the Low Countries, north Germany and Scandinavia. Figure 2 shows the distribution of sites in England for which there is archaeological evidence of production (see appendix for further details). Given the biases inherent in archaeological data, it would seem that there is an even distribution of production sites throughout England. Most of the production sites were in urban centres where there would have been sufficient demand for the vessels. In two cases there is evidence for production at castles (Launceston and Prudhoe). Several continental foundries where large domestic vessels were cast have been excavated, *eg* Lübeck, Germany (Gläser 1988), Odense, Denmark (Vellev 1998), and Uppsala, Sweden (Anund *et al* 1992).

The earliest evidence for the production of cauldrons is from the 12th century in Winchester (Collis 1978) and the latest is possibly from the 18th century at Peterborough (Cherry 1978, 98) and possibly Salisbury (Algar 1973). Most production evidence, however, dates to the 14th to 17th centuries (Fig 3).

The composition of leaded antimony bronze

The composition of the alloy used in the manufacture of medieval and post-medieval domestic vessels can be seen from analytical work on samples from extant vessels and debris from production sites. Blades (1995), Craddock (1985), Dungworth (2002), McDonnell and Dungworth (forthcoming) and Nicholas (2003) provide data on 83 samples, including 27 fragments of vessels (many of which are failed castings from production sites) and 56 samples of scrap or casting waste (mostly from production sites). Figure 4 shows the distribution of antimony, tin, arsenic, zinc, nickel, iron, lead and

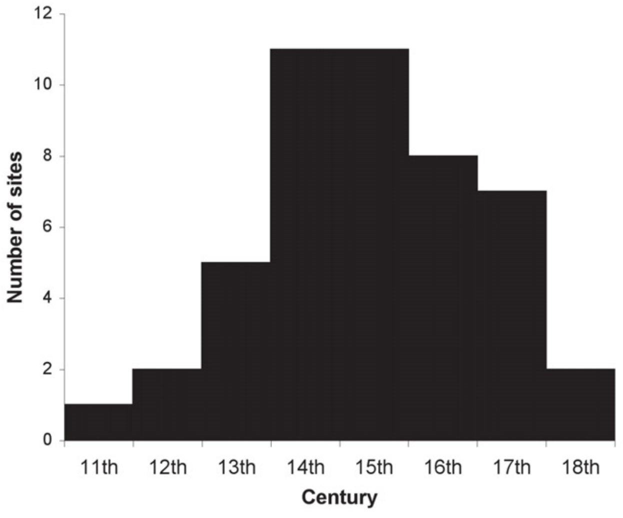

Figure 3: Chronological distribution of English sites which have produced evidence for the casting of large copper alloy domestic vessels

Table 2: Average composition (wt%) of prehistoric antimony bronze and medieval and post-medieval leaded antimony bronze

	Composition (wt%)									
	Number	Cu	Zn	Sn	Pb	Sb	Ni	Fe	As	Ag
Prehistoric	64	90	<0.1	1.4	1.1	2.1	0.3	0.1	1.1	1.3
Medieval and Post-medieval	85	69	0.6	4.8	13.7	4.9	0.4	0.3	1.2	0.1

Note: Data for prehistoric metals from Craddock 1979, Ambert and Barger-Mathieu 1991 and Niederschlag *et al* 2003. Data for medieval and later metals from Blades 1995, Craddock 1985, Dungworth 2002, McDonnell and Dungworth forthcoming and Nicholas 2003. A variety of analytical techniques has been used by the different authors. Note samples with <1% antimony have been omitted.

silver contents for these samples (the average values are given above in Table 1).

After copper, the most abundant element is lead; a small number of samples contain no lead but most contain 5–20% lead. The lead content is rather variable with no apparent favoured concentration. Lead is not soluble in solid copper alloys and so is present as discrete droplets. During casting the lead may tend to segregate towards the bottom of a large casting. Thus, the lead composition of a cauldron may vary depending on the point at which the sample was taken. Antimony and tin are present in roughly equal proportions; most of the samples with relatively high levels of tin come from sites in the south-west of England (Exeter, Taunton and Launceston Castle). Arsenic is present in most of the samples but at levels that are lower than the antimony. Both antimony and arsenic are present at much higher levels than in other contemporary copper alloys (cf Blades 1995). Most of the samples contain less than 1% zinc. The iron, nickel and silver contents are typical of medieval and post-medieval copper alloys. The nickel contents appear to show a bi-modal distribution with one group having low levels of nickel (~0.1%) and one with high levels of nickel (~0.6%). The British cauldrons appear to be broadly of the same composition as German examples (see Drescher 1982–3 for limited analyses of continental vessels).

The physical properties of leaded antimony bronze make this alloy ideally suited for casting large vessels and unsuitable for many other purposes. The high lead content lowers the melting temperature and decreases the viscosity of the molten alloy, which makes the casting of large complex objects easier. The thin walls of some vessels would have been difficult to cast with an alloy with a low lead content. Large quantities of lead in a copper alloy reduce its ductility making it unsuitable for the manufacture of sheet or wire objects.

The chemical analysis of medieval steelyard weights by Brownsword and Pitt (1983) shows that some were made from brass while others were made from leaded alloys, some of which contain high levels of antimony. The alloy was also used in the post-medieval period to produce manillas, penannular rings exported to West

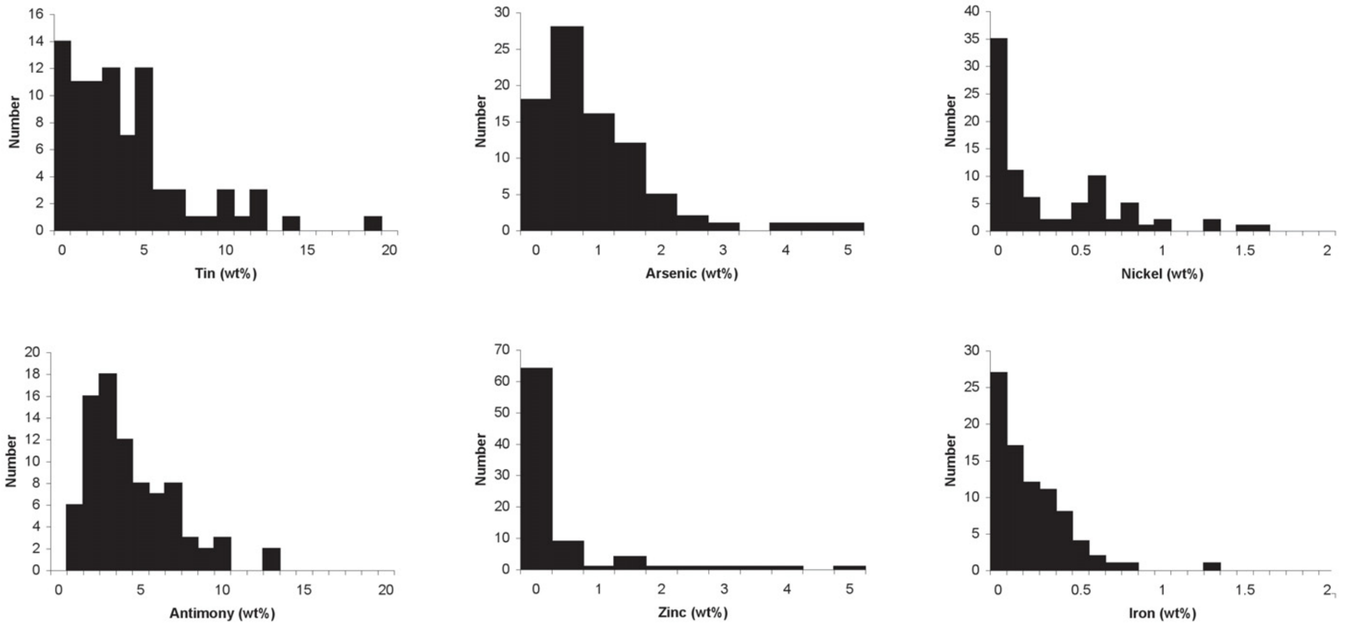

Figure 4: Chemical composition of cauldrons and cauldron casting waste

Africa from the 15th to 19th centuries and used as currency in Nigeria until 1948 (Craddock and Hook 1995; Herbert 1984, 99, 200–5).

Prehistoric antimony bronzes are also known, although rare, in many parts of Europe and the Middle East. Craddock (1979) drew attention to several Late Bronze Age samples from Britain which contained levels of antimony considerably higher than was normal for the period. Similar alloys are known from the Chalcolithic in France (Ambert and Barger-Mathieu 1991) and the Early Bronze Age in central Europe (Niederschlag *et al* 2003). Many of the items from the Nahal Mishmar hoard from Israel were cast using a broadly similar alloy (Northover and Shalev 1993; Tadmor *et al* 1995). However, these prehistoric alloys usually contain low levels of lead but relatively high levels of silver (see Table 2).

The leaded antimony bronze used in the manufacture of medieval and post-medieval vessels contains a wide range of elements and is of rather variable composition. It is unlikely that it was deliberately produced by adding lead, antimony, tin, arsenic, etc to copper; indeed, some of the elements present in the alloy were not known as individual metals until the post-medieval period. It is much more likely that at least some of the elements present in the alloy were introduced by smelting ores which contained those elements.

Antimony bronzes, the smelting of fahlerz ores, and speiss

The presence of antimony and arsenic in both prehistoric alloys and medieval and post-medieval alloys has often been explained as a result of smelting ores which contain these two elements, in particular *fahlerz* ores (Ambert and Barger-Mathieu 1991; Blades 1995; Blair *et al* 1986; Brownsword and Pitt 1981; Craddock 1985; Pike *et al* 1996; Werner 1977). *Fahlerz* is commonly used to refer to the grey-coloured copper sulphosalts tetrahedrite ($Cu_{12}Sb_4S_{13}$) and tennantite ($Cu_{12}As_4S_{13}$) which form a solid solution series with each other (Ixer and Pattrick 2003). A wide range of other metals may also substitute for copper, arsenic and antimony in *fahlerz* ores, *eg* silver, zinc, iron and bismuth. *Fahlerz* ores (Evans 1987) have been found in volcanogenic massive sulphide deposits (*eg* Parys Mountain, N Wales), hydrothermal vein deposits (*eg* Cornwall) or sedimentary deposits (*eg* the *kupferschiefer* Mansfeld, Germany).

Experimental smelting has shown that the impurities present in an ore may be absorbed by the smelted copper (Pollard *et al* 1991; Tylecote *et al* 1977; Zwicker 1980). Unfortunately most of these experiments have been carried out on oxide ores, such as malachite and olivenite, and relatively little on sulphide ores (*eg* Pernicka 1999; Zwicker and Goudarzloo 1979).

The smelting of oxide copper ores is a relatively straightforward process in which the ore is heated in a reducing atmosphere. The smelting of sulphide ores, however, is more complex. The most widely used technique since the 16th century (*eg* Agricola: Hoover and Hoover 1950, 401–7) has been the matte process in which the ore is cleaned and roasted to remove some of the sulphur (partial roasting), and then undergoes a series of reduction and roasting treatments to isolate the copper sulphides, which are subsequently oxidized and then reduced to metallic copper. It is possible to dead-roast sulphide ores to convert all of the sulphides into oxides and then smelt this roasted ore. There has not been sufficient experimental work on different copper sulphide smelting techniques and the effects that these might have on the composition of the smelted copper.

The modern copper extraction industry devotes considerable attention to how impurities such as antimony and arsenic might be removed (*eg* Percy 1861, 370–4; Yazawa 1980; Yazawa and Azakami 1969). Such concerns can also be seen in the 16th century records of copper smelters (Donald 1955, 209–12). Where medieval and post-medieval copper was destined to be used for the manufacture of wrought items (*eg* sheet and wire) or for the manufacture of brass, considerable efforts were made to obtain copper free from impurities.

Werner (1977) noted that leaded antimony bronze became common in the 14th century and related this to the exhaustion of the oxidized zone of copper ores in the Harz mountains of Germany and the increasing use of the deeper sulphide ores. He suggested that leaded antimony bronzes could have been produced by smelting bournonite ($CuPbSbS_3$) or by mixing *speiss* and copper (Werner 1977, 152). *Speiss* is a byproduct of smelting sulphidic ores containing high levels of iron, cobalt, nickel, arsenic and antimony (Bachmann 1982, 29; Craddock 1995, 219–21; Paulin *et al* 1999 and 2000; Werner 1976 and 1977). However, the levels of nickel and cobalt in *speiss* are usually considerably higher than in the leaded antimony bronze (even allowing for the dilution of these elements once copper was added) so it is unlikely that *speiss* was used to manufacture leaded antimony bronze.

Liquation and caldarium, leaded antimony bronze as a by-product of silver extraction

Liquation was used to extract silver from copper alloys. Biringuccio (Smith and Gnudi 1990, 156–8), Agricola (Hoover and Hoover 1950, 491–544) and Ercker (Sisco and Smith 1951, 224–53) provide detailed descriptions of the liquation process as it was practised in the 16th century. Smelted copper was melted and mixed with lead. This lead-copper alloy was then cast into large ingots (liquation cakes), in which the copper and lead would exist as separate phases (copper and lead are virtually immiscible at room temperature). Silver has a greater affinity for lead than copper and so in the liquation cakes the silver would be concentrated in the lead 'phase'. The liquation cakes were then heated to a temperature above the melting point of lead but below that of copper. The lead melted and ran out of the furnace and so was separated from the copper (Fig 5). The extraction of the silver from the lead would then be relatively simple using cupellation.

Agricola also describes a variety of by-products of liquation, *eg* 'tops', 'bottoms', 'exhausted liquation cakes' (*panes fathiscentes*), 'dried cakes' (*panes torrefacti*), 'liquation thorns' (*spinae*) and 'ash-coloured copper' (*aes cinereum*). Agricola's account can be a little hard to follow as he tends to use the same term to refer to what appear to be different materials and by-products. Nevertheless, his description suggests that while some liquation by-products could be refined into pure copper ('red copper'), some could be used to make 'yellow copper' and *caldarium* (Hoover and Hoover 1950, 510–12, 541–2). Hoover and Hoover (1950, 511 note 16) confess to some uncertainty over the exact nature of 'yellow copper' and *caldarium* copper (*geel* and *lebeter kupfer* in the German translation) but conclude that they are coarse coppers. They also quote from Agricola's *De Natura Fossilium* (*ibid*):

> 'Other copper is prepared in the smelters where silver is separated from copper, which is called yellow copper (*luteum*), and is *regulere*. In the same place a dark yellow copper is made which is called *caldarium*, taking its name among the Germans from a caldron.'

The term *caldarium* can also be found in some earlier sources. The 8th century *Mappae Clavicula* contains several references to *caldarium* but the accounts are difficult to reconcile. In chapter 74 there is a description of brass making which specifies that the type of copper to be used should be 'ductile copper of the kind which is called *caldarium*', which implies the use of a pure copper, while in chapter 79 *caldarium* is an alloy of copper containing 20% lead (Smith and Hawthorne 1974, 38). Pliny also uses the term *caldarium* (Book 34, Ch 20: Rackham 1952, 197). He distinguishes between two types of copper produced at mines, *caldarium* which can be melted but is brittle, while *regulare* is ductile. He also states that *caldarium* can be converted into *regulare* by fire-refining to remove the impurities.

A — Furnace in which the operation of liquation is being performed. B—Furnace in which it is not being performed. C—Receiving-pit. D—Moulds. E—Cakes. F—Liquation thorns.

Figure 5: Agricola's illustration of a liquation hearth

Therefore, it can be concluded that various types of copper could be produced as byproducts of the liquation process and that one of these was referred to as 'cauldron copper'. It can be deduced that 'cauldron copper' would contain low levels of silver but high levels of lead remaining from the liquation process. The high levels of antimony (and arsenic) in medieval and post-medieval cauldrons probably reflects the use of particular silver-rich ores (argentiferous tetrahedrite). Early Bronze Age antimony bronzes, *ie* those which had not been liquated, often show a correlation between silver and antimony contents; this is not seen in medieval and later leaded antimony bronze.

Sisco and Smith (1951, 224) suggest that the liquation process was invented in the 15th century. However, Theophilus, writing in the 12th century, provides a rather garbled account of copper smelting (of which he probably had little direct experience) possibly refers to liquation: 'when the stone begins to soften, lead flows out through certain small cavities and copper is left behind' (Hawthorne and Smith 1979, 140). The use of a leaded antimony bronze containing low levels of silver for the casting of cauldrons and other artefacts shows that the liquation process was in use in Europe by at least the 13th century.

Examples of 'liquation cakes' or other debris from the liquation process are extremely rare. An oval ingot from Mulli at Ihala Riasio, Finland (Suhonen 1998), 550 x 370 x 70mm, which contained 14% lead and 0.36% antimony may be an 'exhausted liquation cake'.

Where did leaded antimony bronze come from?

The distribution of medieval and post-medieval cauldrons is largely restricted to the British Isles, the Low Countries, north Germany and Scandinavia (Drescher 1968). Argentiferous *fahlerz* ores can be found in several different locations within this region: in Britain they are known in Cornwall, Devon and Wales (Ixer and Patrick 2003), in Germany in the Harz Mountains, near Mansfeld and in the Erzgebirge (Werner 1976 and 1977), and in Sweden at the Falun mine (Tylecote 1992, 109–10). There was also copper production in other parts of Europe which may have supplied 'cauldron metal', *eg* the Zips in Hungary, the Tyrol in Austria and Italy and Tuscany in Italy. Each of these areas is known to have produced copper and/or silver during this period.

Despite the imperfect state of knowledge of copper production in medieval Europe (see Kellenbenz 1977 for the post-medieval period), several researchers have attempted to assign provenance or chronological significance to the composition of medieval copper alloys. Werner (1977) states that leaded antimony bronzes only began to appear in the 14th century, and notes that the nickel content of copper alloys also begins to increase at this time. Werner explained these changes by referring to the mining history of the Harz Mountains and the supposed exhaustion of the oxidized copper ores near to the surface in the 14th century and the increasing use of reduced, sulphidic ores. This explanation has been followed by others who have interpreted the composition of leaded antimony bronzes as evidence that the metal was mined and smelted in the Harz Mountains (*eg* Blades 1995; Doonan 1997). This seems to be a rather narrow interpretation which ignores contemporary copper production from other sites in the region (*ie* Mansfeld and the Erzgebirge). The same changes in chemical composition have been interpreted by Pollard and Heron (1996, 218) in terms of the decline of Falun mine in Sweden and the rise of the Hungarian mines. Given the lack of detailed archaeological and historical information about copper production in Europe for this period it is difficult to choose a single source; it is possible that several different areas produced 'cauldron metal'.

The origin of the word cauldron

The Oxford English Dictionary suggests that the word cauldron derives ultimately from the Latin word for hot-bath (*caldarium*). The examination of the evidence for the production of medieval and post-medieval cauldrons reviewed here, however, suggests a slightly different derivation. The term *caldarium* is used by Pliny in the 1st century AD to refer to a form of impure copper which was suitable only for casting. In the 8th century, the *Mappae Clavicula* refers at one point to caldarium as a heavily leaded copper alloy. Agricola uses the term *caldarium* in the 16th century to refer to a type of impure copper 'taking its name among the Germans from a caldron' (Hoover and Hoover 1950, 511). It is possible, therefore that *caldarium* was used from Roman times through to the later Middle Ages to refer to some types of raw or impure copper which were used to cast (among other things) large domestic cooking vessels and that word cauldron derives from this usage. The association is unlikely to have originated before the 12th century, as up to this time cauldrons were manufactured from riveted sheet metal (*ie* malleable pure copper).

Conclusion

Cast copper alloy domestic cooking vessels such as three-footed cauldrons, posnets and skillets were produced in northern Europe (areas bordering the southern parts of the North Sea and the Baltic) from the 12th to the 18th century. There is some archaeological evidence for production in almost every major town in England. The alloy that was used is almost always a highly leaded copper alloy which contains higher levels of antimony and arsenic compared with other contemporary copper alloy artefacts. It is unlikely that antimony was deliberately added; instead the antimony came from the use of copper ores rich in antimony (*eg fahlerz*). The smelting of such copper ores could produce

Appendix: Sites in England with archaeological evidence for the production of cast domestic vessels

Site	Date (century AD)	Evidence	References
Bayham Abbey, Sussex	med	casting waste; qualitative analysis	Wilthew 1983a
Bristol, Avon	13	furnace and moulds	Jones 1983
Chester (Hunter's Walk), Cheshire	13-14	mould, possibly for a mortar	McDonnell 1987
Chester (Crook Street),Cheshire	'med or post-med'	moulds	Wilthew 1983b
Chichester, Sussex	14	moulds	Down 1978, 166-8
Colchester, Essex	17	300kg of mould and casting waste; quantitative analysis	Dungworth 2001
Exeter, Devon	16-17	casting pits, furnace, 109kg of mould (550kg discarded) and casting waste; quantitative analyses of casting waste	Blaylock 1996; Blaylock 2000; Dungworth 2002
Hereford, Hereford & Worcs	14-15	mould	Shoesmith 1982, 101; 1985, fig 64
Launceston Castle, Cornwall	15-17	7.5kg of mould and casting waste; quantitative analysis	McDonnell and Dungworth forthcoming
Lincoln, Lincs.	med and post-med	casting waste; quantitative analysis	Blades 1995
London	13-16	moulds and casting waste; qualitative analysis	Dennis 1998; Howe 2002
Northampton, Northants	mid 14-15	casting waste; qualitative analyses	Bayley 1986
Norwich (Castle Mall), Norfolk	14-15	moulds and casting waste; qualitative analysis	Bayley 1993; Mortimer 1996a
Norwich (Greyfriars), Norfolk	15-16	casting pit, moulds and casting waste; qualitative analysis	Doonan 1997
Nottingham, Notts	?15	moulds	MacCormick 1996
Peterborough, Cambs	17-18	moulds and casting waste	Cherry 1978, 98
Prudhoe Castle, Northumberland	'med or post-med'	moulds	Wilthew 1986
Romsey, Hants	17	casting pits, furnace, moulds and casting waste	Shortt 1949; Budd 1987; Ponsford 1994, 172-5
Salisbury, Wilts	14-18	furnace, casting pit and moulds	Algar 1973; Webster and Cherry 1973, 187
Southwick, Northants	11-13	casting pit with mould and casting debris	Johnston *et al* 1996; Bayley pers comm
Taunton, Somerset	16-17	52kg of mould; quantitative analysis of casting debris	Nicholas 2003
Winchester (Tower Street), Hants	12	casting pit and mould	Collis 1978, 195-6, fig 80, fig 81.18
Winchester (Trafalgar Street), Hants	14	8000 mould fragments	Davies and Ovenden 1990
Worcester, Hereford & Worcs	14-15	furnaces and casting pits, 195kg of mould fragments retained (c4000kg discarded); quantitative analysis of vessels and casting debris	Blades 1995; Taylor 1996
York (Bedern), N Yorks	13-early 16	furnaces, casting pits, 200kg of mould fragments; qualitative (and some quantitative) analysis of casting debris	Mortimer 1996b; Ranson 1977; Richards 1993
York (Walmgate), N Yorks	mid 14-late 16	25kg of mould fragments	Macnab 2003

a copper which also contained substantial amounts of silver. Agricola describes how silver could be extracted from copper by liquating with lead and describes how some of the byproducts could be processed to produce *caldarium* 'cauldron metal'. The existence of this alloy (a leaded antimony bronze with low levels of silver) shows that the liquation process was known by at least the 13th century. Cauldrons were produced in the 12th century; but there are no published analyses of such early cauldrons or contemporary production debris.

The introduction of the three-legged cauldron and the use of 'cauldron' metal coincides with a widespread increase in the minting and use of silver coins in Europe (Spufford 1988). While some of this silver was probably obtained from lead ores, it is likely that some was obtained from copper ores. Indeed the large quantities of 'cauldron' metal that were in circulation imply that large quantities of silver were extracted from copper ores. Estimating the amount of 'cauldron metal' in circulation can be little more than a guess but does indicate substantial production. If each household in England (say 2 million) had a cauldron, which weighed around 20kg, and that the cauldron lasted for up to 100 years, then the annual production of 'cauldron metal' for England would be around 400 tonnes per year.

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References

Algar D J 1973, 'Wiltshire archaeological register for 1972, medieval, Salisbury', *Wiltshire Archaeological Magazine* 68, 137.

Ambert P and Barger-Mathieu H 1991, 'Les mines préhistoriques de Cabières (Hérault)', in J-P Mohen and C Éluère (eds), *Découverte du métal* (Paris), 259–77.

Anund J, Bergquist U, Bäck M and Pettersson K 1992, 'A medieval cauldron foundry—craftsmanship and craftsmen in Pantern, Uppsala', in L Ersgård, M Holmstråm and K Lamm (eds), *Rescue and research. Reflections of society in Sweden 700–1700 AD* (Stockholm), 221–51.

Bachmann H-G 1982, *The identification of slags from archaeological sites* (London).

Bayley J 1986, *Copper alloy waste from the Green, Northampton* (London: Ancient Monuments Laboratory Report 6/1986).

Bayley J 1991, 'Alloy nomenclature', in G Egan and F Pritchard *Medieval finds from excavations in London: 3. Dress accessories* (London), 13–17.

Bayley J 1993, *Assessment of metalworking debris from the Castle Mall excavations, Norwich, Norfolk* (London: Ancient Monuments Laboratory Report 111/1993).

Blades N 1995, Copper alloys from English sites 499–1600 AD, An analytical study using ICP-AES. Unpublished PhD Thesis, University of London.

Blair C and Blair J 1991, 'Copper alloys', in J Blair and N Ramsey (eds), *English medieval industries* (London), 81–106.

Blair C, Blair J and Brownsword R 1986, 'An Oxford Brasiers' dispute of the 1390s, evidence for brass-making in medieval England', *Antiquaries Journal* 66, 82–90.

Blaylock S R 1996, 'Bell and cauldron founding in Exeter', *Historical Metallurgy* 30, 72–82.

Blaylock S R 2000, 'Excavations of an early post-medieval bronze foundry at Cowick Street', *Proceedings of the Devon Archaeological Society* 58, 1–92.

Brownsword R and Pitt E H H 1981, 'Medieval 'bell-metal' mortars—a misnomer', *Metallurgist and Materials Technologist* 13, 184–5.

Brownsword R and Pitt E H H 1983, 'A technical study of some medieval steelyard weights', *Proceedings of the Dorset Natural History and Archaeological Society* 105, 83–8.

Budd P 1987, *The examination of metallurgical debris and other technological material from Romsey, Hampshire* (London: Ancient Monuments Laboratory Report 122/1987).

Butler R and Green C 2003, *English bronze cooking vessels and their founders 1350–1830* (Honiton).

Cherry J 1978, 'Post Medieval Britain in 1977', *Post Medieval Archaeology* 11, 87–100.

Cherry, J 1987, 'Cauldrons and skillets, metal and pottery in cooking', in B Vyner and S Wrathmell (eds), *Studies in medieval and later pottery in Wales presented to J M Lewis* (Cardiff), 145–60.

Collis J 1978, *Winchester excavations. Volume II. Excavations in the suburbs and western parts of the town* (Winchester).

Craddock P T 1979, 'Deliberate alloying in the Atlantic Bronze Age', in M Ryan (ed), *The origins of metallurgy in Atlantic Europe* (Dublin), 369–85.

Craddock P T 1985, 'Medieval copper alloy production and West African bronze analyses — Part 1', *Archaeometry* 27, 17–41.

Craddock P T 1995, *Early metal mining and production* (Edinburgh).

Craddock P T and Hook D R 1995, 'Copper to Africa, evidence for the international trade in metal with Africa', in D R M Gaimster and D R Hook (eds), *Trade and discovery, The scientific study of artefacts from post-medieval Europe and beyond* (London), 181–93.

Davies R M and Ovenden P J 1990, 'Copper-alloy casting moulds from Trafalgar Street', in M Biddle (ed), *Object and economy in medieval Winchester. Winchester Studies, 7.2, Vol 1* (Oxford), 124–8.

Dennis M 1998, *Copper alloy casting debris from the Baltic exchange, City of London* (London: Ancient Monuments Laboratory Report 69/1998).

Donald M B 1955, *Elizabethan copper. The history of the Company of Mines Royal 1568–1605* (London).

Doonan R 1997, *Metallurgical debris from Norwich Greyfriars* (London: Ancient Monuments Laboratory Report 114/1997).

Down A 1978, *Chichester excavations 3* (Chichester).

Drescher H 1968, 'Mittelalterliche Dreibeintˆpfe aus bronze', *Rotterdam Papers* 1, 23–33.

Drescher H 1982–83, 'Zu den Bronzenen Grapen des 12/16 Jahrhunderts aus Nordwestdeutschland', in R Pohl-Weber (ed), *Aus dem Alltag der mittelalterlichen Stadt* (Bremen), 157–74.

Dungworth D 2001, *Seventeenth century copper alloy working from Head Street, Colchester, Essex* (London: Centre for Archaeology Report 53/2001).

Dungworth D 2002, *Sixteenth and seventeenth century bronze casting Cowick Street, Exeter, Devon* (London: Centre for Archaeology Report 19/2002).

Dungworth D and Maclean P 2002, *Analysis of bell-casting debris from St Peter's Church, Barton-upon-Humber, Lincolnshire* (London: Centre for Archaeology Report 104/2002).

Evans A M 1987, *An Introduction to ore geology*, 2nd edn (Oxford).

Field R K 1965, 'Worcestershire peasant buildings, household goods and farming equipment in the later Middle Ages', *Medieval Archaeology* 9, 105–45.

Gläser M 1988, 'Die mitellalterliche Bronzegeißerei auf dem Grunstück Briete Straße 26', *Lübecker Schriften zur Archäologie und Kulturgeschichte* 17, 134–6.

Goodall A R 1981, 'The medieval bronzesmith and his products', in D W Crossley (ed), M*edieval industry* (London: CBA research report 40), 63–71.

Hawthorne J G and C S Smith 1979, *Theophilus On Divers Arts* (New York).

Herbert E W 1984, *Red gold of Africa* (Madison).

Hoover H C and Hoover L H 1950, *Georgius Agricola. De re metallica* (New York).

Howe E 2002, *Roman defences and medieval industry. Excavations at Baltic House, City of London* (London).

Ixer R A and Pattrick R A D 2003, 'Copper-arsenic ores and Bronze Age mining and metallurgy with special reference to the British Isles', in P T Craddock and J Lang (eds), *Aspects of early mining and extractive metallurgy* (London), 9–20.

Johnston A G, Bellamy B and Foster P J 2001, 'Excavations at Southwick, Northamptonshire, 1996', *Northamptonshire Archaeology* 29, 129–60.

Jones R H 1983, 'Excavations at 68–72 Redcliff Street, 1982', *Bristol and Avon Archaeology* 2, 37–9.

Kellenbenz H (ed) 1977, *Schwerpunkte der Kupferproduktion und des Kupferhandels in Europa 1500–1650* (Cologne).

Lewis J M 1978, *Medieval pottery and metal-ware in Wales* (Cardiff).

London Museum 1940, *Medieval catalogue* (London).

MacCormick A. 1996, 'Metalworking in medieval Nottingham 1100–1641', *Historical Metallurgy* 30, 103–10.

Macnab N 2003, *Anglo-Scandinavian, medieval and post-medieval urban occupation at 41–49 Walmgate, York, UK*. The Archaeology of York Web Series No 1 (http//

www.yorkarchaeology.co.uk/wgate/main/index.htm).

McDonnell J G 1987, *Mould fragments from Hunter's Walk, Chester, Cheshire* (London: Ancient Monuments Laboratory Report 213/1987).

McDonnell J G and Dungworth D forthcoming, 'Metal working evidence from Launceston Castle, Cornwall', in A Saunders, *Launceston Castle, Excavations 1961–1982* .

Mortimer C 1996a, *Analysis of non-ferrous metalworking waste from Castle Mall, Norwich, Norfolk* (London: Ancient Monuments Laboratory Report 75/1996).

Mortimer C 1996b, *Re-examination of material from high-temperature processes from the Bedern foundry site, York* (London: Ancient Monuments Laboratory Report 74/1996).

Nicholas M 2003, *Post-medieval copper alloy casting debris from Whirligig Lane, Taunton, Somerset* (London: Centre for Archaeology Report 34/2003).

Niederschlag E, Pernicka E, Seifert T and Bartelheim M 2003, 'The determination of lead isotope ratios by multiple collector ICP-MS, a case study of Early Bronze Age artefacts and their possible relation with ore deposits of the Erzgebirge', *Archaeometry* 45, 61–100.

Northover P and Shalev S 1993, 'The metallurgy of the Nahal Mishmar hoard reconsidered', *Archaeometry* 35, 35–47.

Paulin A, Spaic S, Heath D J and Tramuz-Orel N 1999, 'Speiss from the late Bronze Age', *Erzmetall* 52, 615–22.

Paulin A, Spaic S, Heath D J and Tramuz-Orel N 2000, 'Analysis of late Bronze Age speiss', *Bulletin of the Metals Museum* 32, 29–41.

Pernicka E 1999, 'Trace element fingerprinting of ancient copper, a guide to technology or provenance', in S M M Young, A M Pollard, P Budd and R A Ixer (eds), *Metals in Antiquity* (Oxford), 163–71.

Percy J 1861, *Metallurgy, Vol 1: Fuel, fire-clays, coper, zinc, brass* (London).

Pike A W G, Cowell M R and Curteis J E 1996, 'The use of antimony bronze in the Koban culture', *Historical Metallurgy* 30, 11–16.

Pollard A M and Heron C 1996, *Archaeological Chemistry* (London).

Pollard A M, Thomas R G and Williams P A 1991, 'Some experiments concerning the smelting of arsenical copper', in P Budd, B Chapman, C Jackson, R Janaway and B Ottaway (eds), *Archaeological Sciences 1989* (Oxford), 169–74.

Ponsford M 1994, 'Post Medieval Britain in 1993', *Post Medieval Archaeology* 28, 119–83.

Rackham H 1952, *Pliny Natural History* (London).

Ranson D M 1977, An analysis of medieval moulds and casting debris from the Bedern, York. Unpublished MA dissertation, University of Bradfrod.

Richards J D 1993, *The Bedern foundry* (London: The Archaeology of York, Fascicule 10/3).

Sandham R and Willmore F R 1971, *Metalwork*, 2nd edn (London).

Shoesmith R 1982, *Hereford City excavations. Volume 2. Excavations on and close to the defences* (London: CBA Res Rep 46).

Shoesmith R 1985, *Hereford City excavations. Volume 3. The finds* (London: CBA Res Rep 56).

Shortt H de S 1949, 'Bronze-founder's moulds from Romsey', *Proceedings of the Hampshire Field Club* 17, 72–6.

Sisco A G and Smith C S 1951, *Lazarus Ercker. Treatise on ores and assaying* (Chicago).

Smith C S and Gnudi M T 1990, *The Pirotechnia of Vannoccio Biringuccio* (New York).

Smith C S and Hawthorne J G 1974, 'Mappae Clavicula. A little key to the world of medieval techniques', *Transactions of the American Philosophical Society* 64, 3–128.

Spufford P 1988, *Money and its use in medieval Europe* (Cambridge).

Suhonen M 1998, 'A lead-bronze ingot from Mulli at Ihala in Raisio', *Fennoscandia* 15, 71–5.

Tadmor M, Kedem D, Begemann F, Hauptmann D, Pernicka E and Schmidt-Strecker S 1995, 'The Nahal Mishmar hoard from the Judean desert, technology, composition and provenance', *Atiqot* 27, 95–148.

Taylor G 1996, 'Medieval bronzefounding at Deansway, Worcester', *Historical Metallurgy* 30, 111–15.

Tylecote R F, 1992 *A History of Metallurgy,* 2nd edn (London).

Tylecote R F, Ghaznavi H A and Boydell P J 1977, 'Partitioning of trace elements between the ores, fluxes, slags and metal during the smelting of copper', *Journal of Archaeological Science* 4, 305–33.

Vellev J 1998, 'Eine mittelalterliche Bronzegießerwerkstatt in Odense—und etwas über Glocken und Grapen des Mittelalters', *Festschrift für Hans Drescher zu seinem 75. Geburtstag* (Neumünster), 195–224.

Werner O 1976, 'Westafrikanische Manilla', *Erzmetall* 29, 447–53.

Werner O 1977, 'Analysen mittelalterlicher Bronzen und Messinge I', *Archäologie und Naturwissenschaften* 1, 144–220.

Webster L E and Cherry J 1973, 'Medieval Britain in 1972', *Medieval Archaeology* 17, 138–88.

Wilthew P 1983a, *Examination of technological samples from Bayham Abbey, Sussex* (London: Ancients Monument Laboratory Report 4048).

Wilthew P 1983b, *Examination of mould fragments from Crook Street, Chester* (London: Ancients Monument Laboratory Report 4029).

Wilthew P 1986, *Examination of mould from Prudhoe Castle, Northumberland* (London: Ancients Monument Laboratory Report 4818).

Yazawa A 1980, 'Distribution of various elements between copper, matte and slag', *Erzmetall* 33, 377–82.

Yazawa A and Azakami T 1969, 'Thermodynamics of removing impurities during copper smelting', *Canadian Metallurgical Quarterly* 8, 257–61.

Zwicker, U 1980, 'Investigations on the extractive metallurgy of Cu/Sb/As ore and excavated smelting products from Norsun-Tepe (Keban) on the upper Euphrates (3500–2800BC)', in W A Oddy (ed), *Aspects of early metallurgy* (London), 13–26.

Zwicker, U and Goudarzloo F 1979, 'Investigation on the distribution of metallic elements in copper slag, copper matte and copper and comparison with samples from prehistoric smelting places', in I Schollar (ed), *Proceedings of the 18th international symposium on archaeometry and archaeological prospection* (Bonn), 360–75.

The authors

David Dungworth obtained his PhD (*Iron Age and Roman Copper Alloys from Northern Britain*) from the University of Durham in 1995 and joined English Heritage in 1999.

Address: English Heritage, Centre for Archaeology, Fort Cumberland, Portsmouth PO4 9LD.
e-mail: david.dungworth@english-heritage.org.uk

Matthew Nicholas has recently obtained a degree in Archaeological Science at the University of Bradford. As part of his sandwich degree course he worked during 2002-3 for the English Heritage Centre for Archaeology.

Address: Department of Archaeological Sciences, University of Bradford, Bradford BD7 1DP.
e-mail: matt@nicholas.nu