Offprint from

Metals and Mines
Studies in Archaeometallurgy
S. La Niece, D. Hook & P. Craddock (eds)

Archetype Books
2007, 46-55

Towards a functional and typological classification of crucibles

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ABSTRACT Two approaches to crucibles classification are outlined. The first is based on technical attributes such as form, fabric and thermal properties. The second is based on functional categories: namely cementation, assaying and metal melting. In both classifications there is considerable variability within each of the defined groups – much of it due to technological and cultural choices. The identification of technical attributes can often be carried out in the field or museum, while identification of function frequently requires more invasive instrumental analysis. Despite their differences in approach, both typologies end up with similar groupings, reflecting a strong relationship between functional requirements and technical attributes of crucibles.

Keywords: crucible, metalworking, ceramic, melting, cementation, assaying.

Introduction

Crucibles are a major and varied group of ceramic vessels. They can be defined as potentially movable reaction vessels in which high-temperature transformations take place, but with no permanent unidirectional airflow; it is the latter condition that separates them from furnaces (Rehren 2003). Crucibles have been used for thousands of years all over the world wherever high-temperature processes were carried out; they are thus truly cross-cultural artefacts. The examples given here all relate to metals, but other materials such as glass (Bayley 2000; Rehren 1997a) or artificial pigments (Heck *et al.* 2003) are also made or worked using crucibles. Common crucible processes are physical changes such as melting but a wide range also involves chemical reactions. It is the uses to which the vessels are put rather than specific material properties or stylistic attributes that define them as crucibles; indeed some crucibles were made as domestic pottery.

Investigation of crucibles provides information in three separate but related areas:

- their stylistic attributes such as shape, size and other design features that reflect their cultural context and date;
- the ceramic fabric, the choice and preparation of which may be culturally determined but also needs to be 'fit for purpose';
- and the technical function of the crucible.

The first two aspects are summarised as technical attributes, while the third one places crucibles in their functional categories.

Crucibles and the processes carried out in them can be very diverse. To increase our understanding of crucibles and to highlight the link between attributes and function, we propose a typology into which individual finds can be placed. In this way past work and experience can readily be applied to new material, bringing order out of the apparent chaos as well as deducing, at least tentatively, specific functions without necessarily having to employ scientific and often invasive analysis.

Archaeologists tend to classify objects first by shape – and then ask how they were used. As archaeological scientists, our view is different. While form has relevance, it is not the best basis for classifying crucibles; our research has shown that function is the prime factor of archaeological importance. The properties of crucibles and crucible materials limit their functionality but within these technical constraints a considerable range of culturally determined design solutions are found. We have developed two models with different starting points, which at first sight may appear contradictory but complement each other – and incidentally end up with similar groupings. These approaches are based on the technical attributes of the crucibles themselves, and on the nature of the processes carried out in them.

Technical attributes

The first approach to classifying crucibles is based on functional requirements which are common to all cultures and periods because they are technically determined. For a crucible to function, it needs a combination of physical and chemical properties that are interrelated and affect vital process characteristics such as thermal shock resistance, melting speed, redox control and ease of manipulation. The variables that can be controlled are fabric, form and how the crucible is heated. These are not independent, however: for instance, even a poor fabric can be used provided the crucible form and the way it is heated are appropriate.

Crucible fabrics

Crucibles must be strong enough to hold the weight of the metal they contain, at high temperatures as well as when cold. In general, the fabric must be sufficiently refractory so it does not soften at high temperatures, which usually means a ceramic high in silica and/or alumina and low in iron, alkalis, and alkali earth elements that act as fluxes. It must also be relatively inert otherwise it will react with metal oxides (especially lead oxide) and alkalis from the fuel ash. The selection of specific clays for crucible fabrics is not seen regularly before the Roman period; until then, the required properties were achieved by adding different tempers or choosing specific shapes.

The main temper chosen for crucible fabrics throughout the Bronze Age was organic material, such as straw or chaff. This increased thermal insulation due to the voids left when it burnt out, as did walls several centimetres thick (Fig. 1). This was important in crucibles that were heated from above as the underside of the crucible would then remain relatively cool. In these cases, less refractory clays could be used as the cooler outer zone provided the required strength even if the inside had been melted or fluxed. The transition from heating from above to heating from the side or below is characterised by a change to thinner walls and to mineral temper, mostly quartz or igneous rock fragments, often together with selecting lower iron (white-firing) clays (Fig. 2). The thin walls and mineral temper facilitate heat transfer through the fabric and the temper increases its refractoriness.

A number of specialist fabrics were also used for metalworking including bone ash, which was used to make cupels (see below), graphitic clays, and even pure graphite (Hochuli-Gysel and Picon 1999). Graphite is a highly refractory mineral form of carbon with excellent thermal conductivity; in addition, it acts in a similar way to inclusions of vegetable matter – both help produce reducing conditions within the crucible.

Figure 1 Cross-section through the rim of a Late Bronze Age bronze-melting crucible from Qantir-Piramesses, Egypt. It is made from non-refractory Nile silt and heated from above/inside, resulting in extensive vitrification and bloating of the ceramic. Wall thickness *c.* 20 mm.

Figure 2 Early medieval bronze-melting crucible from Novgorod, Russia. It is made from refractory clay tempered with quartz to improve its thermal performance and has been heated from below/outside. Wall thickness 6–10 mm.

Crucible form

The overall crucible form is determined by the refractoriness of its fabric and hence the way in which it was heated. As noted above, crucibles that were not refractory had shallow open forms and were heated from above. More refractory fabrics allowed heating from below, and the vessel form (and fabric) was modified to increase heat transfer from below while reducing the loss of heat from the upper surface of the melt. This meant the crucible diameter was smaller relative to its height, and the shape became more closed – in extreme cases with only a narrow opening near the top (Fig. 3d). Additional features that may or may not be present affect the ease of use of crucibles of all types. Examples are the provision of knobs or handles (Fig. 3a and d–e), pouring lips or spouts (Figs 3a–b and 4b), which can aid the manipulation of the vessel when pouring molten metal into a mould – though it is notable how few crucibles carry the imprint of the tools that must have been used to manipulate them in the fire.

Most Roman to medieval crucibles have rounded or pointed bases as these have good stability when placed in a heap of red-hot charcoal as well as thermal shock resistance (Figs 3 and 4). Most top-fired crucibles were flat-bottomed vessels as the fire was above them. More sophisticated hearths or furnaces with an iron grate to support the crucibles required flat bases for stability (Fig. 5); thus the crucible form must suit that of the hearth in which it is to be heated.

The control of redox conditions within vessels is also important as oxidation leads to the loss of metal into massive crucible slags, which is usually not desired. Deep rather than shallow forms and luted-on lids (for example Fig. 3a) increase reducing conditions within the crucible and the use of carbon-

Figure 3 Roman and early medieval crucibles from the British Isles, mostly used for melting copper alloys, not to the same scale: (a) reconstruction of lidded type, height *c.* 55mm (Dinas Powys, after Alcock 1963); (b) open form, diameter 65 mm (Doncaster, this example used for melting silver); (c) hand-made thumb pots, diameter 45 mm (York); (d) with handle and rim pinched together, length *c.* 75 mm (Ipswich); (e) handled, used for gold melting, height 25 mm (Dunadd); (f) wheel-thrown, diameter 84 mm (Snodland); (g) wheel-thrown with added outer layer, partly broken away, height *c.* 120 mm (Dorchester).

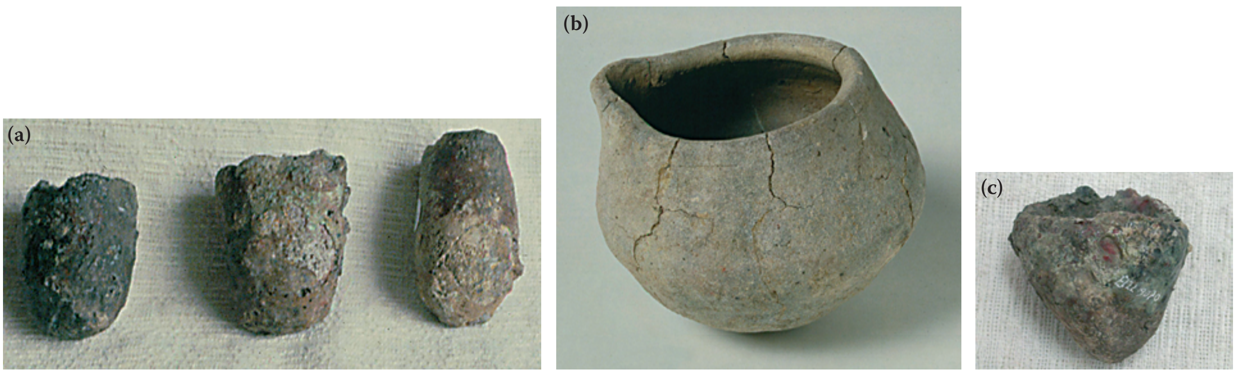

Figure 4 Viking Age (10th century) melting crucibles from (a) Haithabu, Germany (height 35–40 mm); (b) York (diameter *c.* 80 mm); (c) Dublin, Ireland (height 34 mm). Those from Haithabu were used to melt copper or brass; the other types were used for melting both copper alloys and silver.

Figure 5 Flat-bottomed 16th-century crucibles from the Tower of London, probably used for melting copper alloys: (a) coarse refractory fabric, rim diameter 67 mm; (b) finer fabric, rim diameter 108 mm.

rich fabrics also helps to counteract oxidation. Despite this, many crucibles used for metal melting had shallow open forms. Heating was effected by radiation from the fire above, and the red-hot charcoal would have limited the air that reached the metal. In these cases the position of the crucible, relative to the tuyere or blowing hole in the hearth, was critical as the air blast introduced oxygen, making the fuel burn more fiercely and increasing the temperature but also potentially oxidising the metal in the crucible.

For some processes, such as scorification and cupellation, oxidising conditions are essential, and in these cases the vessel form is always a shallow open one (Fig. 6). Conversely, a lid is essential for cementation processes that require reaction of the charge with a vapour phase.

Thermal properties

Crucibles had to allow the temperature of their contents to be raised relatively easily, while also providing thermal insulation to retain the heat and keep the charge or melt at the desired temperature. The early top-fired vessels therefore had a wide opening and were relatively shallow, typically not deeper than hemispherical, and their fabrics were designed to be insulating. The thermal insulation of the ceramic was crucial both to maximise heat retention in the vessel and to guarantee its mechanical integrity at high temperatures, as discussed above. Crucibles heated in this way normally have a distinctive pattern of surface vitrification – mainly on and inside the rim (Figs 1 and 7).

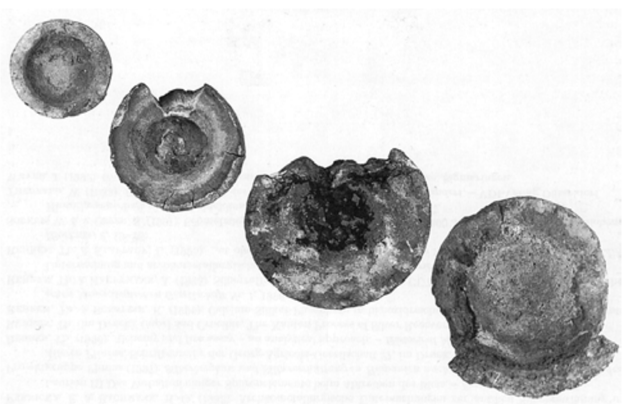

Figure 6 Examples of the four main groups of late 16th-century bone ash cupels from Oberstockstall, Austria. The smallest measure 30–35 mm across, the largest 85–100 mm.

For vessels heated from below, the ratio of surface area to volume was particularly important as the heat needed to drive transformations within the volume was gained from the outer or lower surface of the crucible. The volume of a body increases as the cube of its dimensions, while its surface area only increases as the square of its size. Furthermore, heat transfer into the crucible increases with increasing temperature difference between the inside and the outside. These constraints mean that most crucibles heated from below are relatively small in size, are made from more refractory fabrics, tend to be relatively taller, and have narrow rather than wide

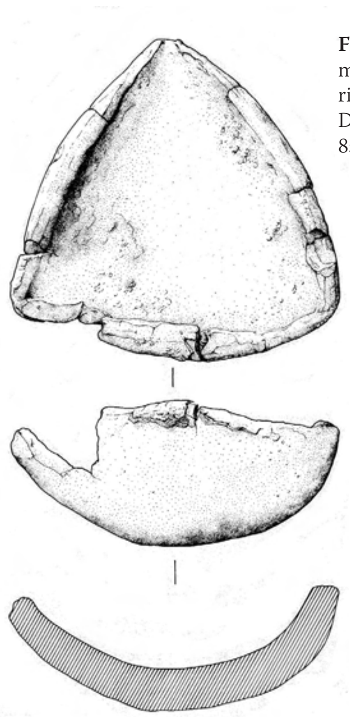

Figure 7 Iron Age bronze-melting crucible with vitrified rim from Gussage All Saints, Dorset. Maximum width 85 mm (after Wainwright 1979).

mouths – to reduce heat loss through the surface and prevent oxidation of the charge. In these cases the vitrification is on the outside, mainly on the base (Fig. 3d–g).

In the context of early crucibles, refractoriness is a relative term, so defining a ceramic as refractory is best done by comparison with domestic pottery from the same area and period. The technical ceramic used for a crucible should only be called 'refractory' if it is more heat-resistant than the local domestic wares, either because of the added temper or through choice of particular clays. Some crucible processes require more highly refractory ceramics than others.

Many thin-walled, externally heated crucibles have an added outer layer of less refractory clay which is often deeply vitrified (Figs 3g and 8). This sacrificial layer had several functions. It provided an insulating layer of highly viscous material, distributing the heat more evenly and reducing thermal shock. This insulating effect may appear to contradict the requirement that externally heated crucibles are thermally conducting, but the glassy nature of the added layer means it is relatively conducting, so on balance their overall effect is positive. The added layer would also seal any cracks in the crucible proper during use thereby reducing the likelihood of breakage and metal loss. It protected the crucible from being fluxed by the fuel ash in the fire, so helping maintain its structural integrity and strength, and it increased the crucible's thermal capacity, helping to keep the melt liquid for longer during casting.

The discussion above has shown how many features can be seen either as constraining the crucible design or resulting from the technical choices made. No one attribute can therefore be considered in isolation; indeed particular combinations of features are characteristic of specific uses. Although most of the examples are metal-melting crucibles, the same technical attributes are also relevant for other crucible processes, which leads to the second model.

Functional categories

The second model starts from the premise that crucibles are reaction vessels whose contents undergo a variety of chemical and/or physical changes. Three main groups of processes are considered: cementation, assaying and melting. It is the nature of these processes that fundamentally determines the vessel form and the ceramic fabric, and is used to classify the crucibles (Rehren 2003). Cultural traditions then modulate the crucible design within the technically determined classes.

Cementation

This general term is applied to a group of processes where chemically active vapour phases produce chemical transformations. They all produce metal of a specific composition, in some cases the process is effectively alloying, in others refining. Cementation processes are usually reactions of solids with a vapour phase, which require carefully controlled temperatures and atmospheres so the vapour phase stays in contact with the other ingredients. The crucibles must thus be essentially closed vessels, though unless the fabric is sufficiently porous a small opening is essential to relieve any build-up of pressure. The processes involved are typically endothermic, requiring a constant supply of heat. In order to maximise the ratio of surface area (= heat input) to volume (= heat use), these vessels are usually relatively small and/or tubular rather than

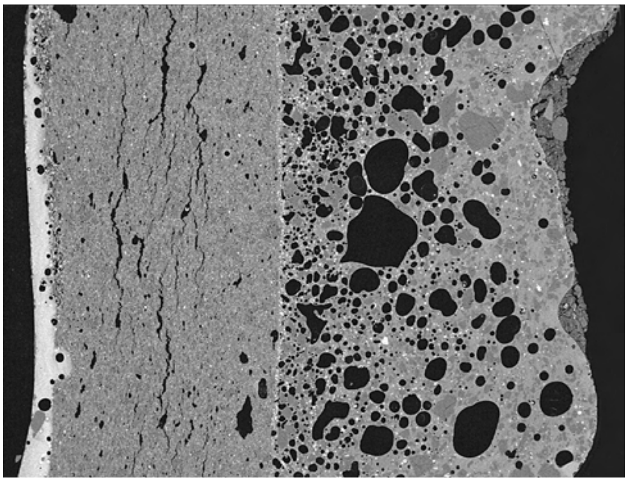

Figure 8 Backscattered electron image of a cross-section through a late Roman bronze-melting crucible from Xanten (Colonia Ulpia Trajana), Germany. It is made from refractory clay and has a thin lead-rich slag layer on the inner surface (left). The outer surface is covered in a layer of less refractory clay which is heavily vitrified and bloated (right). Image width *c.* 20 mm.

Figure 9 Roman domestic lidded pot from London used as a parting vessel. Lid diameter 150 mm.

spherical in shape; in the case of parting, the relatively low temperatures used mean the vessel shape is not important. The processes used as examples here are parting gold from silver, brass-making and crucible steel-making.

The parting vessels from Sardis, dating to the 6th century BC, are probably the earliest true cementation vessels. In these, finely dispersed native argentiferous gold was embedded in a salt-rich matrix and heated to a sufficient temperature to facilitate the reaction of chloride from the salt with the silver in the gold to form volatile silver chloride, leaving behind the now porous, but pure, gold particles (Ramage and Craddock 2000). In Britain, examples of parting vessels are known from the mid-1st century AD onwards (Bayley 1991, 2001) but all come from small-scale urban contexts and seem to have been used to purify precious metal that was being recycled. The process continued in use into the medieval period (for example Bayley 1992a: 751–4) but was eventually superseded by a wet process using nitric acid in the later Middle Ages/Renaissance (Bayley 1996).

The rarity of parting vessels in the archaeological record is partly due to lack of recognition. Even domestic pots could be used (Ramage and Craddock 2000; Marsden 1975: 100; Fig. 9) as a highly refractory fabric was not required because the process took place at relatively low temperatures; the vitrified deposits that are typical of many crucible processes are often absent. The key diagnostic feature is a bleached appearance to the inside of the vessels, often combined with a pink or purple colour due to the presence of specular hematite, a by-product of the reaction with salt (Bayley 1991; Fig. 9). Many vessels were probably crushed to extract the silver they contained by smelting, which is a further reason for the scarcity of archaeological finds.

Brass-making on a considerable scale developed in the Roman world in the 1st century BC. The lidded crucibles contained finely divided copper mixed with crushed calamine ore ($ZnCO_3$) and charcoal and were heated at around 900 °C, below the melting point of the copper; once again a large surface area of solid metal was essential so the zinc vapour could diffuse in. These crucibles were usually small in size (for example Bayley 1984; Rehren 1999a) as this was beneficial for the energy balance of the process. Increased production used larger numbers of vessels, rather than increasing the size of the individual vessels (Rehren 1999a) though there are exceptions (Picon *et al.* 1995). After a hiatus of several hundred years, brass-making in central Europe started again in the medieval period, initially in open vessels (Rehren *et al.* 1993). Improvements in ceramic technology and furnace designs, together with a better understanding of the metallurgy involved, led to a gradual increase in crucible sizes and the re-emergence of lidded vessels (Martinon-Torres and Rehren 2002; Rehren 1999b). The temperature regime changed, too, from the Roman solid-state process; once the cementation reaction had finished the temperature was raised to melt and homogenise the charge within the same vessel.

Diagnostic features of many of these brass-making crucibles are their poorly refractory fabrics, particularly during the Roman period, and the high levels of zinc detectable in all of them; frequently, the clay used for the cementation vessels is less refractory than that used for brass-melting crucibles in the same workshop (Martinon-Torres and Rehren 2002). The highly coloured vitreous deposits that are typical of metal-melting crucibles are usually absent from these cementation vessels.

Pre-industrial crucible steel-making was concentrated in central and south Asia; in both regions, large-scale production sites are known with very large numbers of crucible fragments. Rehren and Papachristou (2003) provide a compilation of the available archaeological and technological data. The thermal requirements for cementation crucibles for steel-making are very different from those for parting or brass-making. Steel melts at about 1400–1550 °C, temperatures outside the typical thermal stability range of archaeological ceramics. The two steel-making areas had contrasting ways to achieve the required thermal stability of the crucibles. The central Asian ones are relatively big with a volume of up to one litre, made from a very dense, almost white-firing fabric with a deliberately produced opening in the lid (Fig. 10, left and centre). Those from south India and Sri Lanka are highly porous, small or medium in size, tightly closed and black (Fig. 10, right).

The ceramic material used in central Asia is based on rich kaolinitic clay, with typically less than 5% oxides other than alumina and silica. The crucibles were test-fired in the 1960s and found to be stable up to 1650 °C (Abdurazakov and Bezborodov 1966), well above the required temperature. This allowed the production of large, thin-walled crucibles, based on the availability of this highly refractory clay.

The clays available in the south of the Indian subcontinent contain high levels of iron oxide and are less rich in alumina than those from central Asia. There is evidence that specific clays were being selected for these crucibles but their iron oxide content was too high to make them sufficiently refractory despite their reasonably high alumina content. To compensate, large amounts of rice husk were added to the clay which on firing reduced the iron oxide to iron metal, finely dispersed in the ceramic matrix and no longer acting as a flux (Freestone and Tite 1986). In addition, the rice husk contributed large quantities of free silica which further increased the refractoriness of the clay. The ceramic became suitable for crucible steel production, but only just, and only for relatively small vessels.

Overall, there emerges a clear relationship between the functionality of a cementation crucible and the technical attributes required. Key among these is the closed shape necessary to maintain the particular gaseous atmosphere inside the vessels. The fabric, on the other hand, only matters for the hotter cementation processes, in particular for steel-making; at the lower temperature end, normal domestic pottery could do the job. It must be stressed though that not every closed crucible is from a cementation process. A number of closed melting and casting crucibles are also known, primarily as a protective measure to prevent oxidation of the contents (for example Bachmann 1976).

Assaying

Fire assay, the practice of testing unknown substances by subjecting samples of them to a series of chemical or metallurgical operations carried out in small crucibles, probably developed

Figure 10 Typical steel-making crucibles from 11th-century Akhsiket, Uzbekistan (left and centre) and 19th-century Sri Lanka (right); both are lidded. The Uzbek crucibles are made from white-firing dense kaolinitic clay tempered with quartz sand, are *c.* 300 mm tall and *c.* 80 mm wide internally, and have a small opening in the lid. The Sri Lankan crucibles are about 200–250 mm total length and *c.* 30 mm wide internally. Their ceramic is black and porous due to a high amount of rice husk temper, and their lids are pierced with a few hair-fine vents.

during the Middle Ages in the context of mining and coin production (Rehren 1997b). By the 16th century, fire assay was standardised across Europe, with almost identical remains known from Norway to Portugal to central Europe and into Turkey. The main groups of assaying vessels are scorifiers, which are flat dishes for oxidising operations, crucibles, often triangular at the top and circular near the bottom, and bone-ash cupels for the final determination of the gold and silver content of a sample, concentrated in lead bullion.

One of the key objectives of assaying, as spelled out by Georgius Agricola (Hoover and Hoover 1950), is to emulate on a small scale the metallurgical operations typically done in smelting furnaces. The emphasis, therefore, is again on chemical transformations rather than simple melting. The ceramic materials used for fire assay vessels had to meet specific demands for both thermal and chemical refractoriness; the latter required withstanding attack by liquid metal oxides and aggressive fluxes at high temperatures. In addition, the vessels had to be suitable for quantitative processes, so there was virtually no loss of material during the operations.

These functional requirements are reflected in the technical attributes of the three main assaying vessel types. The scorifiers are shallow, open and often rather thick but not particularly refractory; they are designed for general oxidising processes where some reaction between the slag that forms and the ceramic is acceptable. The triangular crucibles are more typically used for reducing operations or those involving particular atmospheres; hence, they are deep, often closed with a lid or cover, and of highly refractory ceramic material (Martinon-Torres 2005). Their walls are thin to promote heat transfer and their rim shape facilitates decanting the contents. The most characteristic assaying vessels are known as cupels; they are small, shallow dishes used to separate noble metals from a surplus of lead metal which is oxidised to lead oxide, while the noble metals remain metallic. For this process they have to be open, to promote oxidation, and have a highly absorbent fabric, to soak up the liquid lead oxide while retaining the liquid metal at the surface (Fig. 6). Silica-rich materials are not suitable for this as the silica reacts with the lead oxide to form a viscous melt which will stop further absorption. Throughout the Bronze Age and into the Roman period, people used open hearths lined with calcareous materials such as clay marls, crushed shells and/or bone ash for this process (Bayley and Eckstein 2006). From late- and post-medieval times cupels were made of finely ground bone ash. The advantage of this material was that it absorbed the lead oxide through capillary action without chemically reacting with it (Rehren and Klappauf 1995).

In summary, assaying vessels have very particular shapes (wide, shallow dishes for scorifiers and cupels, with no pouring lip) and materials, for instance bone ash cupels, or triangular crucibles of either Hessian or graphitic ware (Martinon-Torres and Rehren 2005). Of the assaying vessels, only the triangular crucibles could also be used for either cementation or melting. The technical attributes of scorifiers and cupels are totally determined by their function; they are highly specific in their use, and their shape and fabric are thus diagnostic of assaying.

Melting

Melting is the third and most common functionally defined process. The key requirements of metal-melting crucibles are to hold the charge, to contain the heat, and to maintain a neutral to reducing atmosphere. They are the most widely found types of crucibles, with examples known from the inception of metallurgy in the Late Neolithic up to the present day. Melting is essentially a physical transformation, though sometimes metals are alloyed while being melted, for example tin can be added to molten copper to make bronze. Once molten, the metal is usually poured into a mould.

These functional aspects – heating the charge to fusion and then casting it – determine the necessary technical attributes. The need for casting often leads to the presence of a spout and sometimes a handle (Figs 3 and 4). It also requires the vessels to be small and strong enough that they can be moved and tilted with the liquid metal inside. Therefore, crucible volumes rarely exceed one litre or about 10 kg of metal prior to the industrial revolution (Bayley 1992b). The need for heating is met in two fundamentally different ways: either from above through direct contact of the heat source with the charge, or indirectly by heating the crucible from underneath until its contents become molten. The former leads to open vessels with thick insulating fabrics, the latter to more closed shapes with thin, thermally conductive fabrics. The different technical attributes required to meet these demands, and their developments over time, have already been discussed in more detail above.

Discussion

Studying crucibles provides both technical and cultural information, about the crucibles themselves, their function, and the intentions, skills and activities of the workmen using them. The technical attributes and traces of use provide mostly technical information. Understanding the functional constraints on the one hand, and the particular design solutions such as the quality of the fabrics relative to the local domestic or contemporary technical wares on the other, gives a wealth of culturally relevant information. Based on this wider picture, one can discuss independent development of technical solutions (Rehren 1999b) or adaptation to particular environmental situations (Rehren and Papachristou 2003).

European metal-melting crucibles can be used as an example that draws together the common themes from the two different approaches outlined above. It demonstrates the relevance of technical attributes to the subdivision of this functionally defined class of crucibles. Table 1 summarises a crucible classification based on technical attributes or design features. Note that these technically determined groups have a chronological significance; often there is increasing technical sophistication with time. The attributes in the left-hand column are those commonly found in early crucibles; in British and European contexts these are prehistoric ones – dating to the Bronze and Iron Ages. The centre column shows the features that then develop, the italics indicating changes that are found on Roman and earlier medieval crucibles across Europe. The right-hand column shows further changes, again italicised, which are typical of later medieval and post-medieval crucibles in the same region.

Within each of these three groups there are culturally determined variants. Figure 3 shows some of the considerable variability in form and fabric that is found within Roman and early medieval crucibles from Britain. They all share the

Table 1 Technical attributes of crucibles.

small size	small size	*larger size*
shallow form	*deep form ± lid*	deep form
ceramic not refractory	*refractory ceramic*	refractory ceramic
thick walls	*thin walls*	thin walls
heated from above	*heated from below*	heated from below
round/pointed base	round/pointed base	*flat base*

→ Time

attributes in the central column of Table 1 and, although some of the variability is due to the range of processes carried out in them, most is culturally determined – so like many other archaeological finds, they can be used to identify the date and cultural affinities of their users. Understanding process requirements allows us to identify which attributes are technically required and which are culturally determined, through 'technological styles', available raw materials, and economic frameworks of workshop associations and governance.

Examining the examples in Figure 3 further we can identify some of the variables that would not have significantly affected their function and can therefore only be attributed to cultural choices. Most of the Roman crucibles are wheel-thrown (Fig. 3f–g) (although some simple hand-made forms continue in use). This reflects the widespread use of the wheel for making domestic pottery; indeed some of the crucibles are of forms also common in domestic assemblages. The post-Roman period is the first time that lids and handles are found regularly on metal-melting crucibles in the British Isles (Fig. 3a–c). They are known in the Roman period, but mainly for specific applications such as brass-making crucibles or parting vessels, i.e. on cementation vessels where they are functionally required (for example Bayley 1984: figs 1 and 2; 1992a: fig. 320).

In the Viking world a range of crucible types is also found. The tall, thin thimble-shaped crucibles (Fig. 4a) are typical of the Scandinavian homelands but are only occasionally found, presumably as imports, in other lands conquered by the Vikings. At this period the dominant crucible types in northern England, and to a limited extent in the south, were made from Stamford Ware, a fine-grained and highly refractory fabric used to make a range of bi-conical and bag-shaped forms (Bayley 1992a: fig. 322; Fig. 4b). In Viking Dublin a few crucibles of both these types are found, but the majority are hand-made crucibles with a pointed base and a D-shaped or triangular rim (Fig. 4c). These are similar to pre-Viking crucibles from sites such as Garranes (Ó Ríordáin 1942: fig. 25). All these forms are found in a range of sizes (for example Bayley 1992a: fig. 322).

Figures 3 and 4 show that within the one functional group there are many forms. All are culturally determined design solutions – but function comes before form.

Conclusions

Starting from two different approaches, we have shown that similar groupings arise from both. We have come a long way towards a classification system for crucibles. It should however be noted that there are grey areas, so in some places no hard and fast divisions can be made. We have shown that to be useful, any crucible typology must be technically based but can focus primarily either on technical attributes or on functional classes. The identification of technical attributes can often be carried out in the field or museum, while identification of function often requires more invasive instrumental analysis. It is important in this context to realise that technical and functional typologies are simply two facets of the same complex relationship between cultural and technological traditions, practical requirements, individual know-how, economic conditions and available materials. The technical attributes directly reflect the functional requirements; hence, these are not independent systems but closely linked projections of the same multidimensional entity. Therefore, both approaches lead to similar groupings because specific technical attributes are necessary if the crucible is used for a particular process, and individual processes demand specific attributes of the crucibles used. Generally, cultural affinity shows itself in variations in properties that do not affect functionality – such as shape, or in the choice of a particular design solution.

Acknowledgements

We would like to thank all the excavators who have allowed us to study their crucibles and other metalworking finds. Figures 3b–3g, 4b, 5a, 5b and 9 are all © English Heritage. Figures 1, 2, 4a, 4c, 6, 8 and 10 are © the authors.

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