Ancient Monuments Laboratory
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CRUCIBLES, MOULDS AND TUYERES FROM MUCKING, ESSEX

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Summary

Excavations from 1965 to 1978 of the complex, multi-period landscape at Mucking, Essex produced examples of crucibles, moulds and tuyeres from Late Bronze Age to Anglo-Saxon contexts. The crucibles and moulds provide evidence for the casting of copper alloys on a fairly limited scale. One concentration of 8 crucibles and 7 moulds, associated with an Iron Age round house, is noted. The tuyeres vary in form and include types that are rare and even unknown in other parts of Britain; some were probably associated with iron working.

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Crucibles, moulds and tuyères from Mucking, Essex

David Dungworth & Justine Bayley

Introduction

Mucking, Essex (NGR TQ 673803) is a multi-period site/landscape situated on a gravel terrace at the head of the Thames Estuary. The archaeological significance of Mucking was first realised as a result of aerial photography in 1959 that revealed a palimpsest of features over a large area. The increase in awareness of the existence such sites/landscapes and their destruction resulted in a major excavation project from 1965 to 1978 which ultimately explored over 18 hectares.

A range of excavated features were dated to the Neolithic, the Bronze Age, the Iron Age, the Roman period and the Anglo-Saxon period. One of the principal features of the site and one of the original motivations for the excavation was an enclosure known as the South Rings which has been dated to the late Bronze Age. A similar enclosure (North Rings) was excavated and reported on separately (Bond 1988). These features belong to the Springfield Lyons type of enclosure and are likely to have been significant elements in the late Bronze Age settlement pattern in this region. During the Iron Age a series of enclosures were constructed, some of which may have been contemporary. These usually contained round houses and post built structures. In addition some round house and post built structures were found outside the enclosures. The Iron Age also saw the establishment of small cemeteries containing inhumation and cremation burials. The features dated to the Roman period are principally field boundaries and the main focus of domestic settlement appears to have shifted beyond the limits of the excavation. The Anglo-Saxon period provided ample evidence for domestic settlement (especially the *grubenhäuser*) as well as extensive cemeteries dating from the 5th to the 8th centuries AD.

The results of the excavation are to be published in a series of volumes: the first two providing a plan of all excavated features (Clark 1993) and detailing the Anglo-Saxon settlement (Hamerow 1993) have already been published. Future volumes will describe the prehistoric and Roman occupation and the Anglo-Saxon cemeteries.

This report discusses the finds related to metalworking (excluding the slag that is reported by McDonnell 1993). These comprise crucibles, moulds and tuyères that were used to melt and cast copper alloys (although the tuyères may have been used in iron working) and were recovered from Bronze Age, Iron Age and Anglo-Saxon features. While interim statements on this material have already been published (Bayley 1993; Jones 1975; 1991) this report examines these artefacts in greater depth.

Excavation and Recording Techniques

The large area excavated and the sandy nature of the natural subsoil as well as the fill of many archaeological features made the excavation and recording of contexts somewhat difficult. The excavation strategy followed that used on the continent with archaeological features and the surrounding natural excavated in arbitrary levels. Contexts were not recorded although the depth at which finds were discovered was noted. Features were identified by their site co-ordinates, although some distinctive features (e.g. graves and *grubenhäuser*) were given identifying prefixes and numbered. Some of the metalworking debris has been dated to particular periods based on excavation and post-excavation work while some has been dated according to typological criteria (e.g. triangular Iron Age crucibles). Such phasing is nevertheless relatively broad and a substantial proportion of the debris remains unphased (caused in part by the fact that most of the features were shallow and did not intercut). Some of the metalworking debris described here was recorded during the Mucking Post Excavation project and have FC (fired clay) catalogue numbers. Other numbers have been assigned to the artefacts by different researchers and illustrators. Those examined by Hilary Howard (Howard 1983) are indicated in the HH column in the following tables. Some of the artefacts have been illustrated in previous publications (e.g. Jones 1975, 1991; Clarke 1993) and many of the tuyères have been drawn by Casper Johnson as part of the Mucking Post Excavation project.

The passage of time since the first excavation of the artefacts from Mucking has meant that it has not been possible to locate every artefact relevant to this publication. In some cases descriptions, illustrations and/or lists were all that were available. The status of artefacts (in particular whether or not they could be found) is indicated below.

Methodology

The finds described and discussed here are all ceramics used during metalworking. Each fragment was carefully examined to assess the extent and nature of vitrification as well as the overall shape (and so function) of the original artefact. The crucibles and moulds were extracted (by JB) from several boxes of possible moulds and crucibles that had been separated from the large bulk of fired clay finds by the Mucking Post Excavation team. The selected moulds and crucibles were all analysed qualitatively by energy dispersive X-ray fluorescence to identify if the ceramics had been used in working metal. In addition, where possible, the sort of the metal being worked was determined using EDXRF (methodological issues relating to the use of EDXRF for the analysis of moulds and crucibles is explored at some length). In some cases the EDXRF signals were so weak that no reliable interpretation could be given and the results are not considered diagnostic (a more detailed examination of the use of EDXRF for the determination of the types of alloys melted is given below). All of the crucibles, moulds and tuyères are listed in tables below and a selection of these is described in detail. General themes (distribution, date and function) are discussed in a separate section.

The Examination of Crucible 14 and Adhering Metal

Crucibles and moulds are routinely analysed using EDXRF in order to determine the sorts of metals that may have been melted or cast in them (Bayley 1989; Bayley *et al*. 1991; Wilthew *et al*. 1991). This technique is non-destructive and allows many samples to be analysed quickly. The technique may be used qualitatively to determine which metallic elements have entered the fabric of the crucible or mould.

The survival of a droplet of metal adhering to the inside of Mucking crucible 14 made it possible to study this procedure more closely (for further details on this crucible see the section on crucibles and table 5 below). In particular the opportunity was taken to examine the relationship between the proportions of alloying elements in a copper alloy melted in a particular crucible with the proportions of those elements which then become incorporated into the crucible.

The crucible was analysed using EDXRF (40 kV accelerating voltage, 75 mA current, 2 mm collimator and 100 seconds count time). Figure 1 below shows a typical spectrum taken from Mucking crucible 14. This shows the characteristic peaks for copper, zinc, lead and tin (as well as characteristic peaks for elements from the clay and mineral temper of the crucible itself and scattering peaks). This indicates that it was a copper-based alloy that was melted in the crucible (rather than gold, silver or other non-ferrous metals or alloys). Using the spectrum to estimate the proportions of the different metals in the crucible fabric is not a straight-forward process. In broad terms the height of a peak is proportional to the amount of that element present. However, peak heights for a given amount of different elements vary depending on factors such as density and fluorescent yield, and are further influenced by the presence of other elements. Nevertheless EDXRF analysis of crucible 14 implies the use of a leaded bronze (which would have also contained a small amount of zinc).

A small droplet of metal was found adhering to the inside of crucible 14. A sample of this was removed, mounted and polished to a 1 µ finish. This was examined using optical and electron microscopes and analysed using EDXRF following the same procedure as that for the crucible. Metallographic examination of the droplet showed a dendritic structure, with some lead and copper sulphide inclusions. Figure 2 shows the EDXRF spectrum collected from the polished sample of the metal droplet. This shows an extremely strong peak for copper and weaker peaks for zinc, tin and lead. This spectrum implies that the metal melted in the crucible was an impure copper with lead (~1%), tin (~1%) and zinc (0.2%).

The counts for the principal characteristic peak for each metallic element are given in table 1. From this the crucible to metal ratios for each element were calculated. This shows that the levels of zinc, tin and lead are three to nine times greater in the crucible than the metal while the level of copper has fallen. The degree to which each element has been enriched compared to copper was obtained by dividing the crucible to metal ratio for each element by that for copper. This shows that the enrichment of the alloying elements relative to copper is of 3 orders of magnitude.

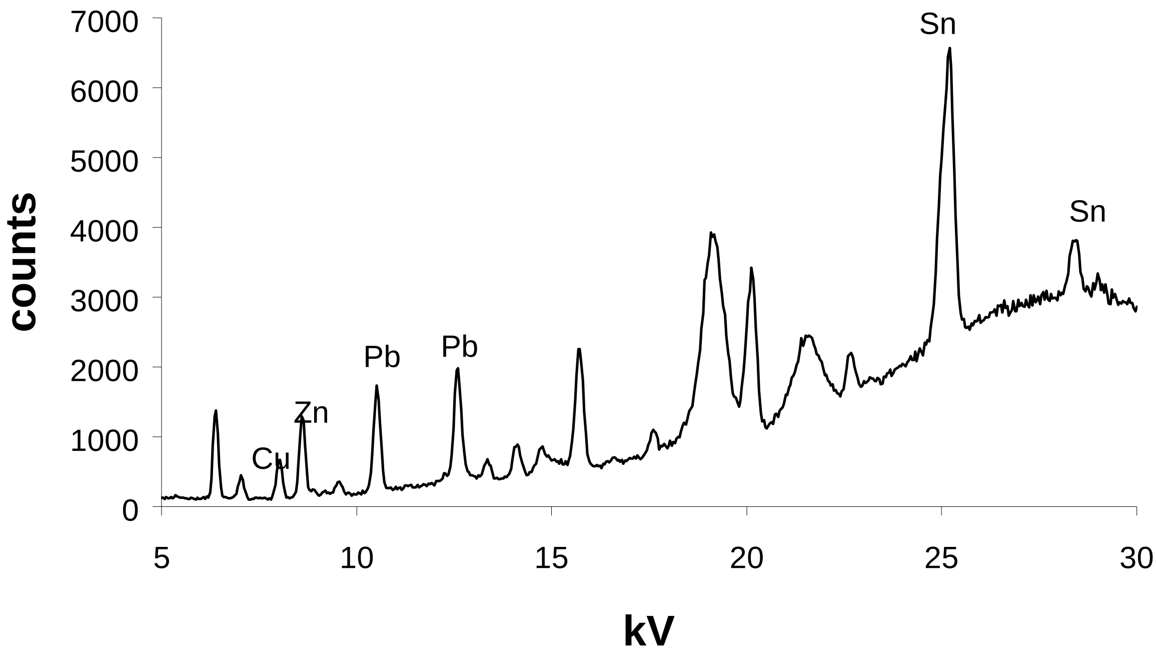

Figure 1. EDXRF Spectrum taken from Mucking crucible 14

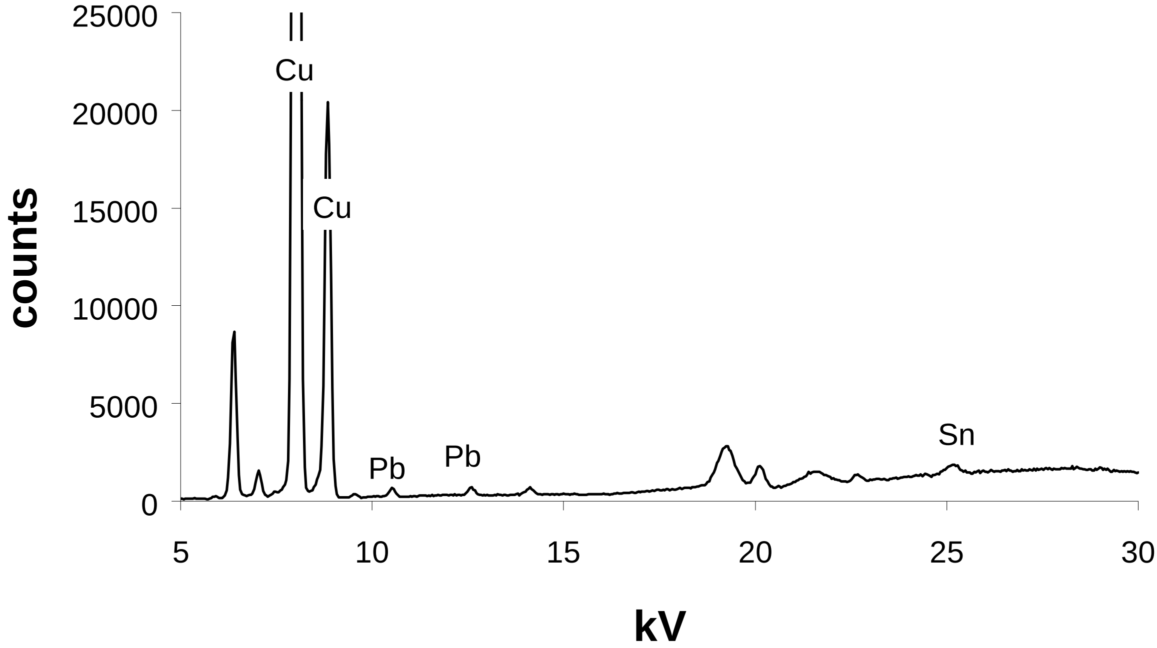

Figure 2. EDXRF Spectrum taken from copper alloy droplet in Mucking crucible 14

The EDXRF analysis of the crucible and its adhering metal has highlighted the problematical nature of this method of analysis. The problems inherent in the technique and material have been discussed before (e.g. Barnes n.d.; Bayley 1989; Bayley *et al*. 1991; Wilthew *et al*. 1991). The next section discusses the thermochemical background to melting and casting copper alloys and goes some way to explain why the proportion of elements in a crucible or mould may be very different to those in the metal melted or cast.

	Crucible	Metal	Crucible/Metal	Enrichment in crucible compared to copper
Copper	5.5	1340	0.0041	[1]
Zinc	11	2.0	5.5	1340
Lead	15	4.5	3.333	812
Tin	42	4.7	8.936	2180

Table 1. Counts per second (background subtracted) for copper, zinc, tin and lead in crucible 14 (crucible and metal)

Crucibles and Moulds: the Thermochemical Background

When a copper alloy is melted in a crucible some of the metal may become oxidised, react with the crucible and become trapped within the crucible or vitrified layers on the surface of the crucible. Additionally, metallic elements (or oxides of these elements) may be volatilised and diffuse into the mould or crucible fabric. The proportions of different metallic elements in the crucible or vitrified layers are unlikely to be identical to those in the molten metal for a number of reasons. The most important factors which affect the ways in which metallic elements are trapped in a crucible are the temperature and redox conditions of the melting regime and the free energies of oxidation and the volatility of the different elements in the molten metal. High temperatures will increase the volatility of metals and so their transfer to the mould or crucible fabric. The more oxidising the conditions within the crucible, the more likely it is that metallic elements will oxidise and react with the crucible fabric and/or vitrified layers.

Reaction	Free energy ($kJ/moleO_2$) at 1100ºC
$4Cu + O_2 \Rightarrow 2Cu_2O$	136
$2Cu + O_2 \Rightarrow 2CuO$	65.3
$2Pb + O_2 \Rightarrow 2PbO$	183
$Sn + O_2 \Rightarrow SnO_2$	293
$Zn + O_2 \Rightarrow 2ZnO$	380

Table 2. Free energies for formation of oxides (from Reed 1971).

The free energies of oxidation vary for different elements and table 2 shows the values for copper, zinc, tin and lead at 1100ºC. The greater the value for the free energy of oxidation the more energy is released when the reaction takes place. The greater the amount of energy released the more likely it is that the reaction will take place. It is possible that particularly exothermic reactions (such as the oxidation of zinc) will lead to the reduction of other oxides (e.g. copper). Some zinc is regularly included in modern copper-based casting alloys for this reason. During melting, some of the zinc in the alloy is lost but this ensures that the copper is not oxidised. The values quoted in Table 2 are for pure elements rather than alloys but clearly demonstrate that all three major alloying elements in archaeological copper alloys are more easily oxidised than copper itself.

The degree to which the different elements in a copper alloy are volatilised during melting can be assessed from the vapour pressure values. Table 3 gives values for vapour pressure for the principal alloying elements in copper alloys. It should be noted that these vapour pressures have been determined for pure elements and values will be somewhat different in complex alloys (data for such alloys is not readily available). Nevertheless it can be seen that zinc, and to a lesser extent lead, are significantly more volatile than copper or tin and will be easily lost during melting.

	Vapour Pressure (mmHg)		
	25ºC	727ºC	1100°C
Zinc	1.2×10^{-14}	89.5	4064*
Lead	5.4×10^{-26}	1.2×10^{-2}	4.91
Copper	1.1×10^{-50}	7.8×10^{-9}	3.5×10^{-4}
Tin	1.6×10^{-44}	5.4×10^{-8}	8.7×10^{-4}

Table 3. Vapour pressure for different metallic elements (after Brandes 1983: Table 8-13).
[this value for zinc has been extrapolated (data is only available up to 727°C)]*

Barnes noted the high volatility of zinc during casting experiments to examine mould residues (Barnes nd). Barnes cast copper alloys containing varying levels of zinc (1, 2, 3, 4 and 5%) into ceramic moulds and these were then analysed using EDXRF; in each case very strong zinc peaks were noted. This phenomenon can also be seen when Iron Age crucibles and moulds have been analysed. For example, zinc was detected in 24 out of 37 moulds and 8 out of 11 crucibles from the Iron Age site at Kelk, East Yorkshire (Bowstead Stallybrass 1999) even though it has not detected in contemporary metalwork from the region (Dungworth 1996). The EDXRF system which has been used for the last decade or so at the English Heritage Centre for Archaeology (previously the Ancient Monuments Laboratory) is able to detect zinc down to approximately 0.1%. This suggests that minute levels of zinc (<0.1%, i.e. undetectable) in an Iron Age tin bronze can give rise to modest levels of zinc (>0.1%) in the crucibles and moulds.

Interpretation of EDXRF data from the analysis of moulds and crucibles

The values for the free energies of oxidation and the vapour pressures indicate that when a copper alloy is melted the alloying elements are more likely to be incorporated into a crucible or mould fabric than the copper. The behaviour of the alloying elements will vary depending on the proportions of them present in the melt, the activity being carried out (melting in a crucible or casting in a mould) and the temperature and redox conditions. It should now be possible to offer some suggestions as to what will happen under specific circumstances.

When melting a copper alloy in a crucible under oxidising conditions the zinc, tin, lead and copper will be progressively oxidised and react with silica and alkalis (often not present in significant amounts) in the crucible fabric to form crucible slags. When such a crucible is analysed using EDXRF the proportions of the four principal elements in copper alloys will be different to those in the original metal: zinc will be most enriched (compared to copper), then tin and then lead.

When melting a copper alloy in a crucible under suitably reducing conditions little or no metal will be oxidised and no crucible slags will be formed. However, the high volatility of zinc and lead will mean that these two elements may be detected in the crucible fabric (zinc will be more enriched than lead).

When casting a copper alloy into closed moulds the conditions within the mould itself are automatically reducing and so little or no oxidation will occur. The high volatility of zinc and lead will mean that these two elements may be detected in the mould fabric (zinc will be more enriched than lead). The extent to which zinc and lead may be detected in a mould fabric probably relates to the length of time the cast metal remains molten (vapour pressure is dependent on temperature and physical state). A mould for a large object will remain hot longer than a small one and so may contain higher levels of zinc and lead.

This suggested framework can now be compared with the EDXRF analyses of Mucking crucibles and moulds (Tables 5 and 6). Table 4 shows the proportions of crucibles and mould in which each element was detected. Copper and zinc are detected in roughly equal proportions in the crucibles and moulds whereas tin and lead are found less frequently in the moulds. Copper is the principal ingredient of these alloys (usually >80%) and so is regularly detected. Zinc is both extremely volatile and easily oxidised and so is also found in most crucibles and moulds. Tin is detected in only a small number of cases (particularly in the moulds) suggesting that reducing conditions were usually maintained. The low incidence of lead (particularly in the moulds) is surprising as this element is much more volatile than tin or copper. The low incidence of lead may be due to the fact that it was not an important addition to the alloys (this may be especially true for Iron Age alloys — see Dungworth 1996: figure 5).

	Crucibles (Σ=19)	Moulds (Σ=33)
Copper	14 (74%)	23 (70%)
Zinc	15 (79%)	25 (76%)
Tin	7 (37%)	4 (12%)
Lead	7 (37%)	7 (21%)

Table 4. Number of crucibles and moulds in which different elements were detected.

The interpretation of EDXRF spectra obtained from moulds and crucibles may be further complicated a range of other problems: alloy composition, re-use of moulds and crucibles, the presence of naturally occurring metallic elements in clays and temper, and corrosion effects. The enrichment or depletion of particular alloy elements in a crucible or mould can only occur if that element is actually present in the original alloy. The absence of a particular element in a mould or crucible may be due to the particular thermochemical conditions or simply because that element was not present in the alloy. Crucibles were re-used (Bayley 1992: 755) and a range of different alloys could be melted in the same crucible. Analysis by EDXRF will not be able to distinguish between repeated use of a crucible to melt a gunmetal and use of a crucible to melt first brass and then bronze. Analysis by EDXRF will not be able to distinguish between metallic elements naturally within a crucible fabric and those that have been introduced by melting or casting, except where the metallic elements are relatively abundant. During long periods of burial metal tends to corrode and some elements may be depleted or enriched at the surface.

Crucibles

Nineteen crucibles or possible crucibles were identified from Mucking. Most of these were highly fragmentary and in some cases could only be identified by the distinctive vitrification seen on some of the more complete examples and the results of EDXRF analysis. As discussed above, the archaeological material from Mucking has been dated by a combination of context and typology. Most of the crucibles could be dated to the Iron Age and only three were dated to

the Anglo-Saxon period. All of the crucibles are listed in table 5 with their provenance, reference numbers and other information. Each crucible was analysed using EDXRF and the characteristic peaks present were noted (e.g. figure 1). The height of each peak is proportional to the amount of that element present but the heights of peaks of different elements are not strictly comparable because of the varying fluorescent yields of the different elements. Thus the order in which the elements that were detected are listed in table 5 has no significance.
The more interesting and complete crucibles are described below in more detail.

Figure 3. Iron Age and Anglo-Saxon crucibles (Scale = 1/1, Numbers refer to catalogue)

1 Iron Age?
Joining fragments comprising a large part of a triangular crucible with a pouring lip at each corner (figure 3). The side is about 50 mm long and the crucible is about 50 mm high. The walls are thickest at the base and thinnest at the rim with thickness of up to 12 mm. The fabric is black with fine quartz and grog inclusions; the outer surface and the rim show some vitrification. The crucible is dated to the Iron Age on the basis of its shape rather than the date of its context.

Catalogue	HH	North	East	FC	Date	EDXRF	Fabric	Inclusions	Vitrification	Feature and location
1		301	-53		IA ?	Zn	Black	Quartz + opaque	Slight	Post pit, ABC Enclosures
2	19	1835	845	2593	IA	Cu, Zn, Sn, Pb	Dark grey	Charcoal + quartz	Yes	Pit, North Enclosure
3	17	1835	845	2594	IA?	Cu, Zn, Sn, Pb	Dark grey	Charcoal + quartz	Yes	Pit, North Enclosure
4		2047	673		IA	Cu, Sn, Pb	Pale grey	Quartz	Very	Ditch terminal, Round house
5	14	2085	680		IA	Cu, Zn, Sn, Pb	Pale grey	Quartz	Very	Vicinity of Round house
6	16	2108	689		IA?	Cu, Zn	Mauve	Quartz	Very	Vicinity of Round house
7	10	2085	680		IA	Cu, Zn	Grey brown	Quartz + opaque	Very	Vicinity of Round house
8		1444	623	2592	IA?	Cu, Sn	Grey	Quartz + charcoal	Very	Pit, RB cemetery III
9	18	2085	680		IA	Cu, Sn	Pale grey	Quartz	Yes	Vicinity of Round house
10	13	2079	650		IA	Cu, Zn, Pb	Grey	Quartz + opaque	No	Vicinity of Round house
11	11	2085	680		IA	Zn	Grey	Quartz + opaque	No	Vicinity of Round house
12	20	2105	672		IA?	Cu, Zn, Sn	Grey	Quartz	Slight	Vicinity of Round house
13		380	100	2603	IA?	Zn	Brown	Quartz	No	Pit RB enclosure III
14		1687	474	2291	AS	Cu, Zn, Sn, Pb	Grey	Quartz	Yes	Grubenhauser 126
15		2265	896	2283	AS	Cu	Dark grey	Quartz	Yes	Grubenhauser 177
16		2260	900	2284	AS	Cu, Zn, Pb	Dark grey	Quartz	Yes	Grubenhauser 177
17		335	25		?	Zn	Light grey	Quartz	Slight	Ditch
18		1378	312		?	Cu, Zn	Light grey	Charcoal + quartz	Slight	Ditch, Round house
19		186.5	206		?	Zn	Light grey	Quartz	Slight	Pit, RB I/South Rings

Table 5. Crucible fragments from Mucking
(HH and FC see page 2; Date: IA=Iron Age; AS=Anglo-Saxon)

2 Iron Age

Rim fragment from a triangular crucible that includes a corner. Not enough survives to reconstruct the full length of a side of the depth of the crucible. The walls are thickest towards the base (up to 8 mm at the lowest surviving point). The fabric is dark grey with varied inclusions: charcoal (up to 1 mm across), moderately fine quartz and a little angular flint. There is some vesicularity, especially towards the surfaces that also show some vitrification. The surface is varied in colour from grey to green, red and cream. Very similar to, and found near to, 3 but not a joining fragment.

3 Iron Age

Rim fragment from a triangular crucible that includes a corner. Not enough survives to reconstruct the full length of a side of the depth of the crucible. The walls are thickest towards the base (up to 7 mm at the lowest surviving point). The fabric is dark grey with varied inclusions: charcoal (up to 1 mm across), moderately fine quartz and a little angular flint. There is some vesicularity, especially towards the surfaces that also show some vitrification. The surface is varied in colour from grey to green, red and cream. Very similar to, and found near to, 2 but not a joining fragment. Dated to the Iron Age on the basis of the shape of the crucible rather than the date of its context.

14 Anglo-Saxon

Several joining sherds from a crucible that could have been circular, oval or half pear shaped with a maximum wall thickness of 4 mm (figure 3). There is an added outer layer that is thickest at the rim and stands proud of it (maximum wall thickness including added outer layer is 9 mm). The outer layer probably extended upwards to make a lid to the crucible. The rim diameter is around 25–30 mm. The fabric is grey with some fine quartz inclusions. The added outer layer is heavily vitrified, vesicular and light grey in colour.
EDXRF analysis of metal on the inside of the crucible suggests it had been used to melt impure copper.

15 Anglo-Saxon
A body fragment from a possible crucible. Maximum wall thickness is 16 mm. Fabric is dark grey with fine quartz inclusions. Vitrification and vesicularity are present on the outer (convex) surface and may represent the remains of an added outer layer. The outer surface is light grey with green patches. Similar to and found near to No 16. It is probably from the same object.

16 Anglo-Saxon
A body fragment from a possible crucible. This is very similar to No 15 and probably from the same object. Maximum wall thickness is 16 mm. Fabric is dark grey with fine quartz inclusions. Vitrification and vesicularity are present on the outer (convex) surface and possibly represent the remains of an added outer layer. The outer surface is light grey.

Moulds

Thirty-six ceramic moulds or possible moulds were identified with varying degrees of confidence. The moulds came from late Bronze Age through to Anglo-Saxon contexts although in many cases the contexts could not be dated. Only one mould fragment (No. 37) came from a Roman context. As no crucible fragments were found in Roman contexts it is likely that this mould fragment is residual. All of the moulds are listed in table 6 with their provenance, reference numbers and other information. Each mould was analysed using EDXRF and the characteristic peaks present were noted. The height of each peak is proportional to the amount of that element present but the heights of peaks of different elements are not strictly comparable because of the varying fluorescent yields of the different elements. Thus the order in which the elements that were detected are listed in table 6 has no significance. The more interesting and complete moulds are described below in more detail.

Most of the moulds were made from fine clays with fine quartz inclusions. Almost all had reduced fired inner surfaces and oxidised fired outer surfaces. In a few cases the inner faces of the moulds survived but these were rarely complete enough to allow the reconstruction of the shape of object being cast. In one or two cases it can be seen that the mould is either a two-piece mould or an investment mould; in most cases, however, the mould fragments are too small to allow their type to be determined. In a few cases the only indication that the moulds were indeed moulds was the detection of metallic elements by EDXRF.

Catalogue	HH	North	East	FC	Type	Date	Found	XRF	Feature and location
20		268	206	2599	mould	LBA	cast only	cast only	Vicinity of South Rings
21		268	206	2600	mould	LBA	cast only	cast only	Vicinity of South Rings
22	7	109	281	2596	mould ?	LBA	yes	Zn	Pit, South Rings
23	8	159	260	2598	mould	LBA	yes	Cu, Zn, Pb	Pit, South Rings
24	9	159	260	2598	mould	LBA	yes	Cu, Zn, Pb	Pit, South Rings
25		120	230	2597	mould?	LBA?	yes	Cu, Zn	South Inner ring
26		2077	651		mould	IA	yes	Cu, Zn	Round house [2075N 675E]
27		2085	680		mould	IA	yes	Cu, Sn, Pb	Round house [2075N 675E]
28		2057	652		mould	IA	yes	Cu, Zn, Sn, Pb	Round house [2075N 675E]
29	23	2085	680		mould	IA	yes	Cu	Round house [2075N 675E]
30	22	2077	651		mould	IA	yes	Cu, Zn, Pb	Round house [2075N 675E]
31		2057	652		mould?	IA	yes	Cu, Zn	Round house [2075N 675E]
32		236.5	167	2595	mould	IA ?	yes	Cu, Pb, Ag, Au,	Pit, RB I/South Rings
33	21	2080	668		mould	IA?	yes	Cu, Zn, Sn, Pb	Round house [2075N 675E]
34		1000	-50		mould	IA?	yes	Cu, Zn, Sn	Enclosure ditch ?
35		940	208		mould	IA?	yes	Cu, Zn	Pit complex, 'Banjo' Belgic area
36		1807	871		mould?	IA?	yes	Cu, Zn	North enclosure
37		125	133		mould ?	RB?	yes	Zn, As	Ditch, cutting South Rings
38		1040	650	2285	mould	AS	yes	Cu, Zn, Pb	Grubenhaus 109
39		1481	695	2287	mould	AS	yes	Cu, Zn	Grubenhaus 119
40		234	387	2286	mould	AS	yes	none	Grubenhaus 30?
41		188	280	1866	mould	AS	yes	Zn, Cu	Grubenhaus 36
42		1491	680		mould?	AS?	yes	Cu ?	Pit, near Grubenhaus 119
43	12	2061	905		mould	AS	yes	Zn, Cu	Grubenhaus 81
44		1493	765	2619	mould?	?	yes	Zn	Pit (isolated)
45		1446	715	2616	mould?	?	yes	Cu, Zn, As	Post hole
46		353	147	2601	mould	?	yes	Zn	Pit ?
47		1497	685		mould?	AS?	yes	Cu, Zn	Pit, near Grubenhauser 119
48		~950	~150		mould	?	yes	Cu, Zn	???
49		220	165		mould?	?	yes	Cu, Zn	???
50		1378	312		mould?	?	yes	Cu, Zn	Ditch ?
51		1493	765	2618	mould?	?	yes	Zn	Pit (isolated)
52		1020	178		mould?	?	yes	Zn	Pit (isolated)
53	24	1055	268	2608	mould?	?	yes	none	Ditch
54		988	296		mould?	?	yes	Cu	Pit (isolated)
55		353	280	2601	mould?	?	yes	Zn, Sn	Pit

Table 6. Mould fragments from Mucking
(Date: LBA=Late Bronze Age; IA=Iron Age; RB=Romano-British; AS=Anglo-Saxon)

23 Late Bronze Age
A fragment from a piece mould for a rod-like object or one with a lip or ridge (figure 4). The fabric is black (reduced) on the inner surfaces and red or buff (oxidised) on the outer surfaces and contains some quartz and opaque mineral inclusions. There is no sign of a finer inner surface to the mould although this may have been eroded after the mould was used. Found with mould No 24 but probably used for casting a different object.

24 Late Bronze Age
A fragment from a piece mould for a curved rod-like object (figure 4). The fabric is black

(reduced) on the inner surfaces and red or buff (oxidised) on the outer surfaces and contains some quartz and opaque mineral inclusions. There is no sign of a finer inner surface to the mould although this may have been eroded after the mould was used. Found with mould No 23 but probably used for casting a different object.

27 Iron Age

Fragment of a mould that is too small to allow the reconstruction of the shape of the object being cast. One flat-topped knob, about 7 mm high stands up from the inner surface and rough patches suggest other similar protuberances have been broken off. The knobs may have produced an openwork effect for a plaque or some such object. The fabric is black (reduced) on inner surfaces and buff to orange (oxidised) on outer surfaces and contains quartz inclusions. The fragment is possibly from a piece mould although this would be most unusual for the Iron Age.

32 Iron Age?

Incomplete clay ingot mould with U-shaped section. The fabric is fired to a uniform dark grey colour (reduced) except on the base that has a thin orange (oxidised) zone. It would have been used to produce a bar ingot of metal that could then have been smithed to shape or remelted and cast in another mould. Microscopic examination detected some very tiny (about 0.1 mm) metal droplets attached to the surface just below the rim on the inside. Surviving length 65 mm.

EDXRF analysis detected silver and gold together with copper, lead and zinc suggesting precious metal ingots had been made (although it may have been used to produce base metal ingots as well). The firm attachment of the droplets to the ceramic suggests that they are trapped in a thin vitrified surface layer. This is most likely to have occurred if metal had been melted directly in the mould (e.g. by heating filings or scrapings with a blowpipe) rather than if molten metal had been poured in from a crucible. Similar objects have been recorded from an Iron Age site at Thetford (Gregory 1991: 141; Wilthew *et al*. 1991: 142).

33 Iron Age?

Fragment from a mould that was used to produce a fairly complex object as the moulding surfaces curve in two different planes. The fabric is dark grey (reduced) on the inner surfaces and orange to buff (oxidised) on the outer surfaces and contains abundant quartz inclusions. The complex shape of the mould makes it likely that it was an investment mould.

34 Iron Age?

Fragment of a mould too small to allow reconstruction of the shape of the object cast. Two concentric curving impressions can be discerned. The fabric is black (reduced) on the inner surfaces and orange to buff (oxidised) on the outer surfaces and contains quartz inclusions.

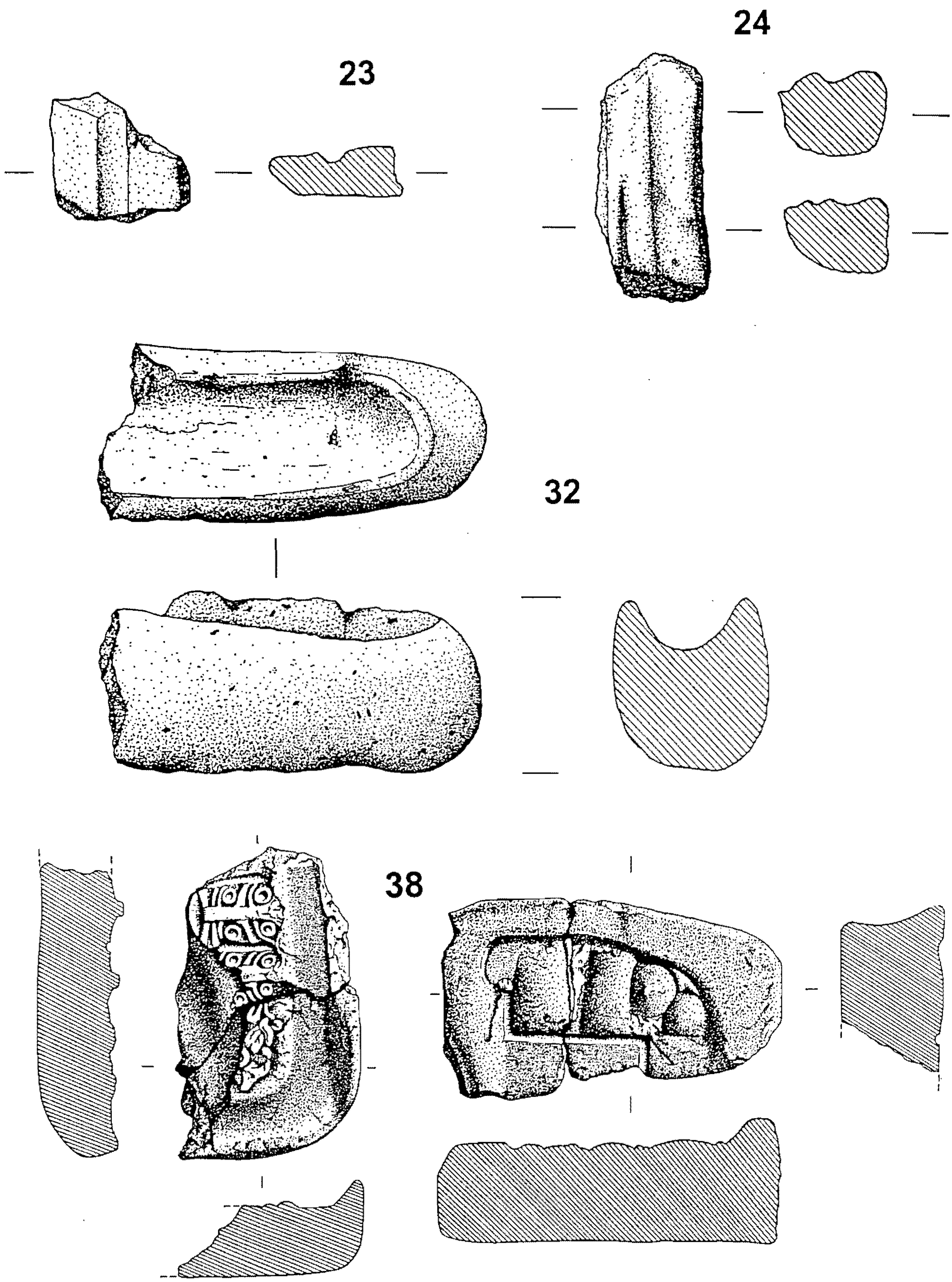

Figure 4. Late Bronze Age and Anglo-Saxon moulds (Scale = 1/1, Numbers refer to catalogue — No. 38 is reproduced from Hamerow 1993: fig 141)

36 Iron Age?

Two fragments of a possible mould with no surviving moulding surfaces. The fabric is black (reduced) to red-orange (oxidised) in colour and contains abundant quartz and opaque mineral inclusions.

38 Anglo-Saxon

Two mating fragments from a piece mould for a square headed brooch (figure 4; Jones 1975; Webster 1993; Hamerow 1993: fig 141.1A–C; Hines 1997: 41–44). Figure 4.38 shows how the clay of the thinner, upper valve has been smoothed down over the more massive, lower one to provide a seal between the two parts. No trace of the luting clay that was normally added to seal these joins survives. Lamm (1991) illustrates a reconstruction of a similar mould. The clay is not very fine though traces of quite intricate detail can be made out on the upper valve (figure 4) and shows that the brooch belongs to Hines group 3 (Hines 1997: 41–44). The mould is oxidised fired to a ginger-brown colour with no sign of the reduced fired zone adjacent to the modelled surfaces which is normally found on moulds that have been used. This fact, when taken together with the lack of luting clay, suggests that the mould may never have been used for casting metal; perhaps it was broken before it could be used.

39 Anglo-Saxon.

Fragment from a mould for a rod-shaped object with a diameter of just under 20 mm. Not enough of the mould survives to determine the type of object or whether the mould was a piece or an investment mould. The fabric is a uniform dark grey with occasional very fine mineral inclusions.

40 Anglo-Saxon.

Fragment from a mould for a rod-shaped object with a diameter of 7 mm. Not enough of the mould survives to determine the type of object although the mould is like to have been a piece rather than an investment mould. The fabric is dark grey to buff with quartz inclusions.

Tuyères

Thirty-seven tuyères or fragments were identified. Tuyères served to protect the bellows and bellows nozzles from the heat of a hearth or furnace (Tylecote 1986: 141–2, fig 87). Most of the tuyères from Mucking consist of plates or blocks of clay with holes for the bellows nozzle. Most of the tuyères are likely to have been used in working iron (possibly smelting and smithing) but some may have been used to melt copper-based alloys. EDXRF analysis showed that a few contained small amounts of non-ferrous metals. In some cases the actual tuyères could not be located and classification is based on archive illustrations.

Catalogue	North	East	FC		Type	Date	Located	XRF
56	2047	673		Tuyere	A	IA	no	
57	954	172	2564	Tuyere	A	IA?	yes	
58	2078	637		Tuyere	A	IA?	no	
59	2105	672		Tuyere	A	IA?	no	
60	-228	342		Tuyere	A	RB?	yes	
61	178	145	2558	Tuyere	A	RB?	yes	Cu
62	192	92.3	3664	Tuyere	A	RB?	yes	
63	378	716		Tuyere	A	AS	yes	
64	1122	826	3665	Tuyere	A	AS	yes	
65	1899	970	2557	Tuyere	A	AS	yes	
66	1900	970		Tuyere	A	AS	yes	Cu, Zn
67	1903	968	2556	Tuyere	A	AS	yes	Zn
68	1903	968		Tuyere	A	AS	yes	Zn
69	1904	973		Tuyere	A	AS	no	
70	1906	1000	2627	Tuyere	A	AS?	yes	
71	930	230	2563	Tuyere	A	?	yes	
72	1047	633		Tuyere	A	?	no	
73	1048	632		Tuyere	A	?	no	
74	1053	625		Tuyere	A	?	no	
75	1808	972		Tuyere	A	?	yes	
76	754	325.6		Tuyere	B	?	no	
77	695	386	2560	Tuyere	C	?	yes	
78	1000	-50		Tuyere	C	IA?	yes	
79	1374	304	2572	Tuyere	C	IA?	yes	
80	1418	310	2573	Tuyere	C	IA?	yes	
81	2105	672		Tuyere	C	IA?	no	
82	644	154		Tuyere	C?	?	yes	
83	2099	647		Tuyere	C?	IA?	yes	
84	2104	667		Tuyere	C?	IA?	yes	
85	360	130		Tuyere	C?	RB ?	yes	
86	1056	190	2570	Tuyere	C/D	?	yes	
87	850	167	2632	Tuyere	C/D	IA?	yes	
88	1090	0		Tuyere	D	AS	yes	
89	904	219		Tuyere	D	IA?	yes	
90	1900	970		Tuyere	D?	AS	yes	
91	906	219		Tuyere	D?	IA?	yes	
92	940	208		Hearth lining ?		?	yes	
93	1024	455		Hearth lining ?		?	yes	
94	1100	800		Hearth lining ?		AS	yes	
95	2106	676		Hearth lining ?		IA?	yes ?	Cu, Sn

Table 7. Tuyère fragments from Mucking
(Type: A=Plate; B=Triangular; C=Block; D=Disc-and-lump;
Date: IA=Iron Age; RB=Romano-British; AS=Anglo-Saxon)

The **plate** tuyères are the most common and consist of a sub-rectangular or circular plate of clay, typically 80–120 mm across and 10–20 mm thick (figure 5). One of the surfaces is usually heavily vitrified and on occasion these show signs of extreme softening and even

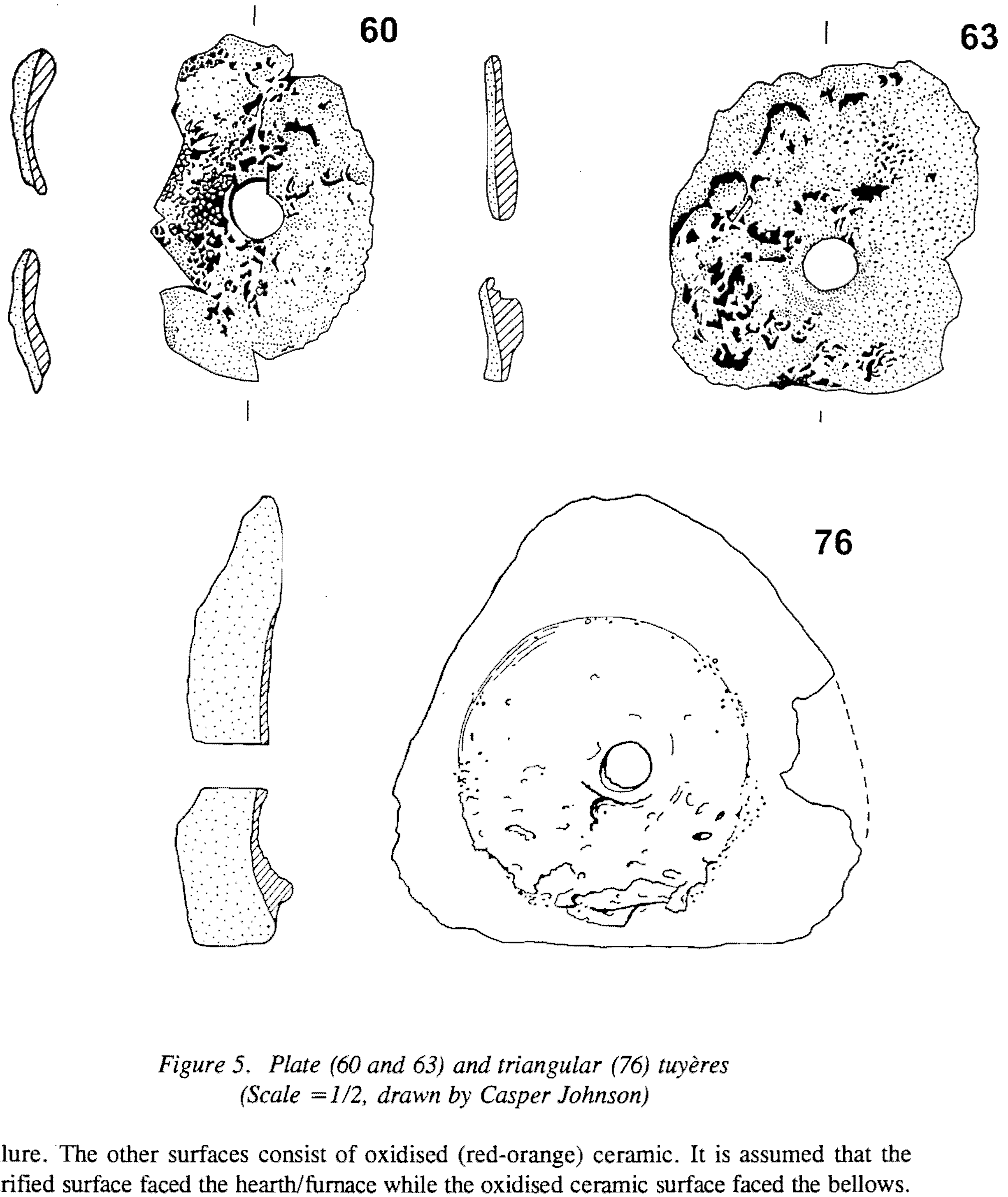

Figure 5. Plate (60 and 63) and triangular (76) tuyères
(Scale =1/2, drawn by Casper Johnson)

failure. The other surfaces consist of oxidised (red-orange) ceramic. It is assumed that the vitrified surface faced the hearth/furnace while the oxidised ceramic surface faced the bellows. The original thickness may have been considerably greater as these pieces of hearth furniture were probably not deliberately fired prior to use and the poorly fired outer surfaces have been lost. In addition the vitrification of the inner surfaces may have resulted in the loss of some of the original ceramic. The perforations in the tuyères are circular and have an average vitrification of the clay. In some cases the way in which the vitrified clay around the perforation has slumped suggests that the bellows nozzle was directed downwards at an angle rather than being horizontal. Plate tuyères at Mucking were found in Iron Age through to Anglo-Saxon contexts and (assuming that all the later ones are not residual) do not appear to be associated with any particular period. Some of the tuyères were found in the vicinity of the Iron Age round house [2075N 675E] and may be associated with the bronze casting there. However, none of those from this area contained detectable levels of non-ferrous metals. In addition there were no observable differences between these tuyères and those of the same type found elsewhere at Mucking.

A single **triangular** tuyère was found during excavations at Mucking. The tuyère itself could not be located although an illustration was found in the archive (reproduced in figure 5). The illustration shows a relatively large tuyère which is triangular although the corners are rounded. The tuyère is approximately 150 mm high, 30 mm thick at its base and narrows towards the top. A perforation 16 mm in diameter is situated 60 mm above the base. One face of the tuyère has a zone of vitrification 100 mm in diameter around the perforation. This side would have been placed to face the hearth or furnace. The fact that the vitrification is restricted to part of the face suggests that the tuyère was placed against the outside of an opening in the hearth or furnace and luted into place rather than built as part of the structure. The tuyère is reminiscent of loom weights but can easily be distinguished by the small size of the perforation, the narrowing towards the top and the zone of vitrification (cf Brinch Madsen 1981: 96–7).

The remaining tuyères are formed from large pieces of clay. The first type consists of a **block** generally thinner towards the top and with rounded corners. The second type is formed in two pieces: a disc of clay is partially supported by a separate lump of clay (**disc and lump**). These two types of tuyères were often difficult to distinguish when only small fragments survived.

The **block** tuyères (figure 6) are known from Iron Age sites in Britain (Spratling 1979: 129) and Europe (Jacobi 1974: 246, 255, 347–8, pl. 99). Block tuyères are well known in the Scandinavian world in the early medieval period. These are made from clay (from Helgö, Brinch Madsen 1981: 97–8, see also Coppergate, York, Bayley 1992: 789) or stone (Thålin-Bergman 1979: figures 2 and 5, and some of the stone ones are even decorated, e.g. Roesdahl 1982: 108, Pl. 21). None of the blocks from Mucking are complete and it is difficult to reconstruct their overall dimensions. Assuming that the hole for the bellows is located centrally on the largest fragment (No. 78) then the block tuyère would be 130 mm wide, 150 mm high and 70 mm thick.

There are no direct parallels for the **disc-and-lump** tuyère (figure 6) from Mucking. The perforated disc seems to have been formed and dried (both parts were fired by the heat of the hearth or furnace), and then offered up to the outside of the hearth or furnace structure and wedged into position with the supporting lump. The fabric for the disc-and-lump tuyères are generally more sandy than the other types.

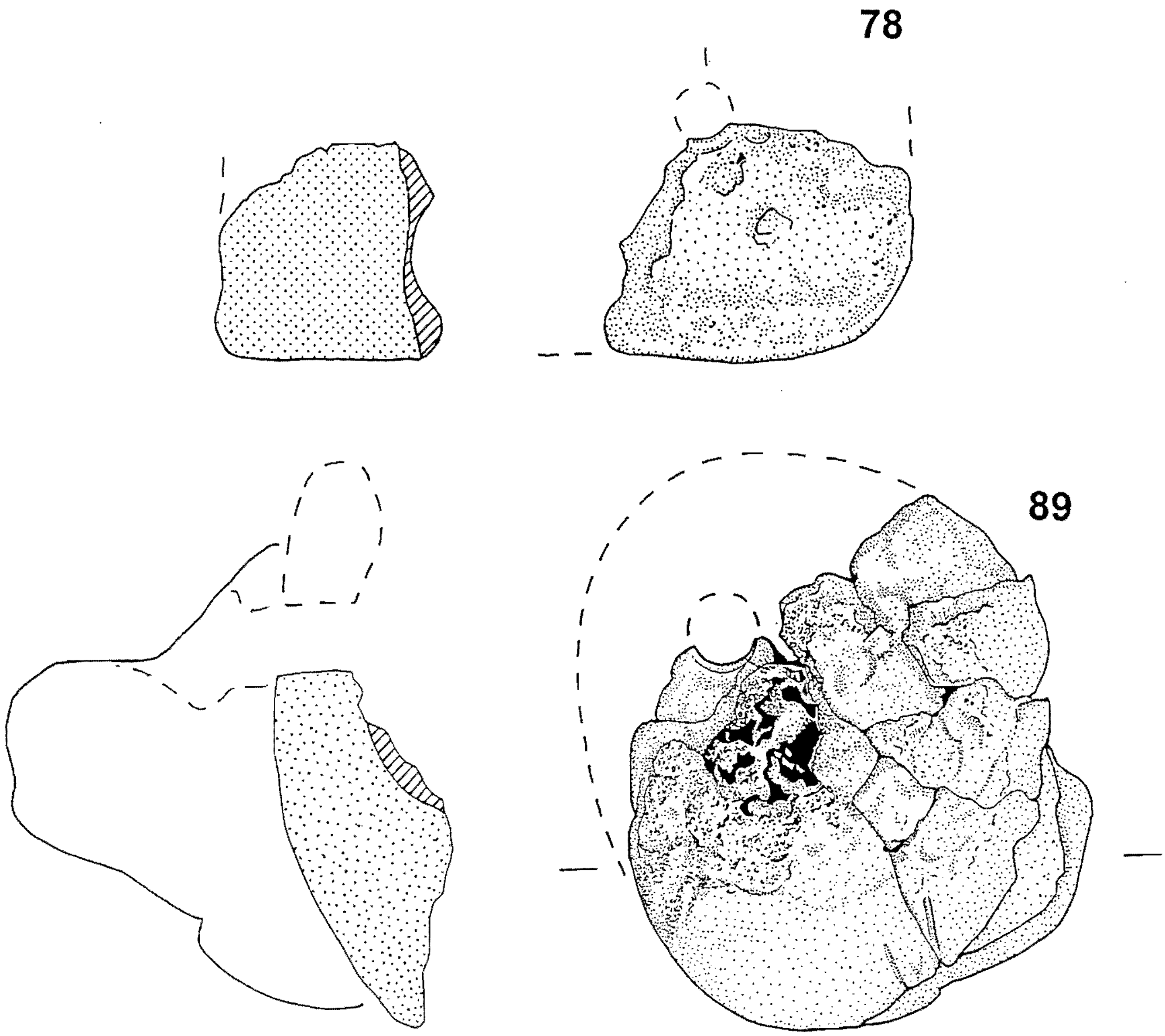

Figure 6. Block (78) and Disc-and-lump (89) tuyères
(Scale =1/2, *drawn by Casper Johnson)*

The high degree of vitrification seen on all of the material examined indicates that they were used for high temperature processes. The provision of a hole allowed the introduction of air and confirms that these objects are tuyères. It has not been possible to find any clear associations between tuyère form and date or find spot. This leaves open the question of precisely what function the tuyères served. They could have been used for smelting or smithing and for working copper or iron. There is abundant evidence for iron smelting, iron smithing and copper alloy casting at Mucking and each would have required the use of tuyères. Jacobi (1974: 255) identifies the block tuyères from Manching as related to the working of copper alloys (rather than iron). Very few of the tuyères from Mucking (and none of the block type) have detectable levels of non-ferrous metals associated with them. In addition the find spots of the tuyères and the crucibles and moulds rarely coincide.

Discussion

This report has described and catalogued 19 crucibles, 36 moulds and 35 tuyères from Mucking. The total area excavated amounted to 18 hectares and the contexts ranged in date from the Late Bronze Age to the Anglo-Saxon period. This material indicates that non-ferrous metalworking did not play a significant role in the economy of the site as a whole.

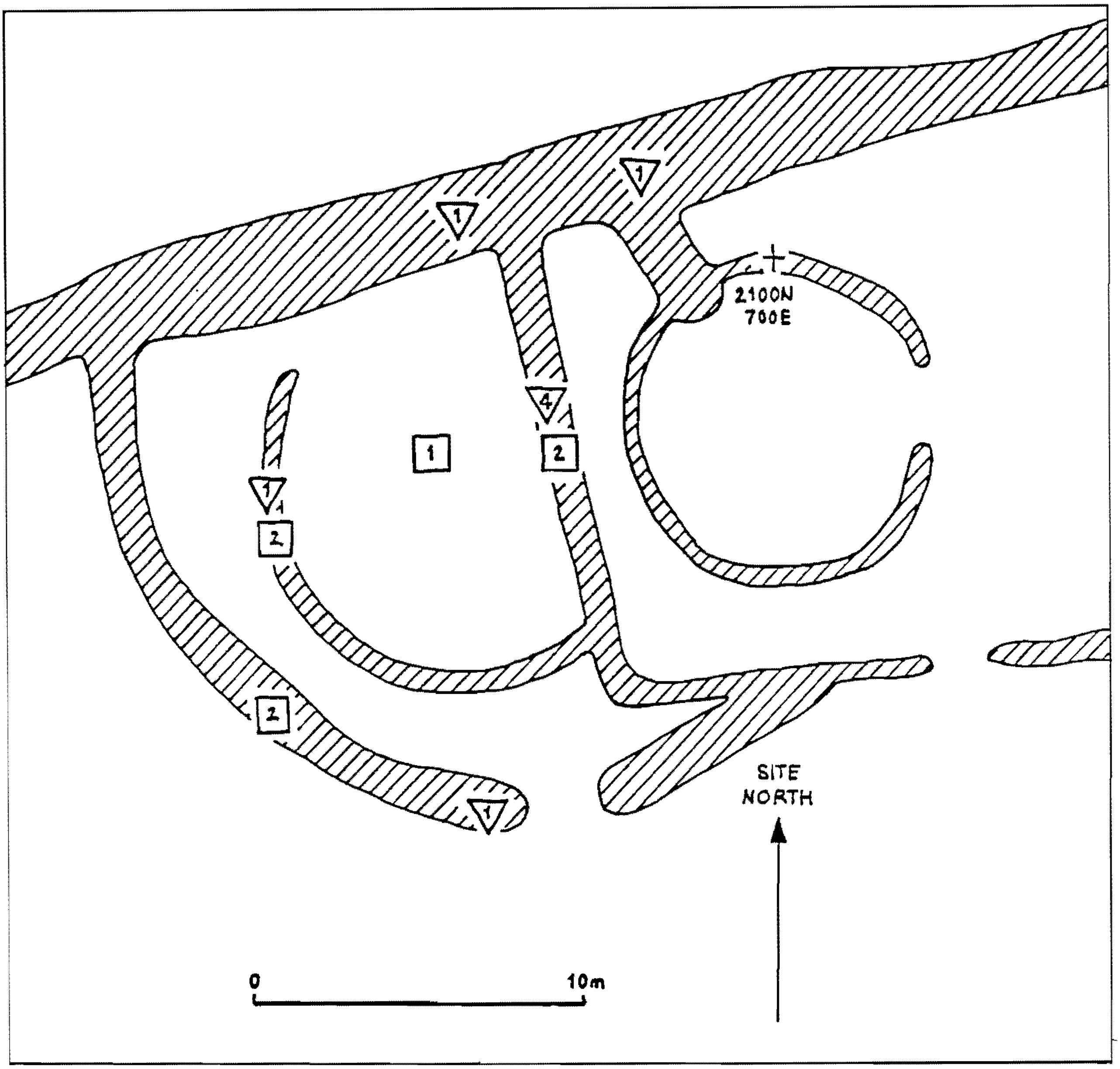

Figure 7. Distribution of Iron Age crucibles and moulds
(Triangles = crucibles, squares = moulds, numbers = number of fragments)
(Plan based on Mucking site plans 20 and 22, Clarke 1993)

working was a significant activity in the Late Bronze Age at the South Rings, Mucking but this evidence has not been preserved.

The **Iron Age** evidence consists of 13 crucibles, 11 moulds and 13 tuyères, of which 9 crucibles, 7 moulds and 6 tuyères come from the immediate vicinity of a round house (figure 7) centred on 2080N 670E (approximately 50 m to the north of the North Enclosure). The concentration of moulds and crucibles from this area suggests that there was at the least one period of fairly intensive copper alloy casting in this area. The tuyères may not be associated with the copper casting, however, as they are also associated with ironworking slag (McDonnell (1993: 32, table 3). The other crucibles and moulds are scattered widely across the site. The other tuyères are also scattered although three come from the area around 900N 200E and may be associated with some of the ironworking slag concentrations there (McDonnell 1993: 32, table 3).

The **Roman** evidence consists of a single mould (possibly residual?) and 4 tuyères. The tuyères are found close to some of the concentrations of slags identified by McDonnell (1993: 32, table 3) and probably relate to the ironworking carried at Mucking at this time.

The **Anglo-Saxon** evidence consists of 3 crucibles, 7 moulds and 10 tuyères. This material is scattered across the site and does not suggest any particular focus for metalworking activities.

References

Barnes, I. nd. The analysis and recreation of bronze and brass mould residues. *The Laboratories of the National Museum of Antiquities of Scotland* Volume 2: 40–44.

Bayley, J. 1989. Non-metallic evidence for metalworking. In Y. Maniatis (ed) *Archaeometry. Proceedings of the 25th International Symposium*. Amsterdam: Elsevier, 291–303.

Bayley, J. 1992. *Non-Ferrous Metalworking from Coppergate*. The Archaeology of York Fasicule 17/7. London: Council for British Archaeology.

Bayley, J. 1993. Non-ferrous metalworking finds. In A. Clark 1993. *Excavations at Mucking. Volume 1: the site atlas*. English Heritage Archaeological Report 20. London: English Heritage, 34.

Bayley, J., Freestone, I., Jenner, A. & Vince, A. 1991. Metallurgy. In A. Vince (ed) *Aspects of Saxon and Norman London 2: Finds and environmental evidence*. LAMAS Special paper 12, 389–405.

Bond, D. 1988. *Excavation at the North Ring, Mucking, Essex: a late Bronze Age enclosure*. East Anglian Archaeology Report No 43. Chelmsford: Essex County Council.

Bowstead-Stallybrass, H. 1999. *Crucibles, moulds and slag from Whitewall Farm, Kelk, East Yorkshire*. Ancient Monuments Laboratory Report.

Brandes, E.A. 1983. *Smithells Metals Reference Book*. London: Butterworths.

Brinch Madsen, H. 1981. Tuyeres. In A. Lundström & H. Clarke (eds) *Excavations at Helgö VII. Glass — Iron — Clay*. Stockholm: Kungliga Vitterhets, 95–105.

Buckley, D.G. & Hedges, J.D. *The Bronze Age and Saxon Settlements at Springfield Lyons, Essex: An interim report*. Chelmsford: Essex County Council.

Clark, A. 1993. *Excavations at Mucking. Volume 1: the site atlas*. English Heritage Archaeological Report 20. London: English Heritage.
Dungworth, D.B. 1996. The production of copper alloys in Iron Age Britain. *Proceedings of the Prehistoric Society* 62: 399–421.
Gregory, T. 1991. *Excavations in Thetford, 1980–1982, Fison Way*. East Anglian Archaeology Report 53. Gressenhall: Norfolk Field Archaeology Division.
Hamerow, H. 1993. *Excavations at Mucking. Volume 2: the Anglo-Saxon settlement*. English Heritage Archaeological Report 21. London: English Heritage.
Hines, J. 1997. *A New Corpus of Anglo-Saxon Great Squared-Headed Brooches*. London: The Society of Antiquaries.
Howard, H. 1983. The bronze casting industry in later prehistoric southern Britain: a study based on refractory ceramics. Unpublished PhD thesis, University of Southampton.
Jacobi, G. 1974. *Werkzeug und Gerät aus dem Oppidum von Manching*. Wiesbaden: Franz Steiner.
Jones, M.U. 1975. A clay piece-mould of the Migration Period from Mucking, Essex. *Antiquaries Journal* 55: 407–8.
Jones, M.U. 1991. Metallurgical finds from a multi-period settlement at Mucking, Essex. In W.A. Oddy (ed) *Aspects of Early Metallurgy*. British Museum Occasional Paper 17. London: British Museum, 117–120.
Lamm, K. 1991. Early medieval metalworking on Helgö in central Sweden. In W.A. Oddy (ed) *Aspects of Early Metallurgy*. British Museum Occasional Paper 17. London: British Museum, 97–116.
McDonnell, J.G. 1993. The slags and metallurgical residues. In A. Clark 1993. *Excavations at Mucking. Volume 1: the site atlas*. English Heritage Archaeological Report 20. London: English Heritage, 31–3.
Reed, T. 1971. *Free Energy of Formation of Binary Compounds*. Cambridge, MA: MIT Press.
Roesdahl, E. 1982. *Viking Age Denmark*. London: British Museum Press.
Spratling, M.G. 1979. The debris of metal working. In G.J. Wainwright *Gussage All Saints. An Iron Age settlement in Dorset*. London: HMSO, 125–149.
Thålin-Bergman, L. 1979. Blacksmithing in prehistoric Sweden. In H. Clarke (ed) *Iron and Man in Prehistoric Sweden*. Stockholm: Jernkontoret, 99–133.
Webster, L. 1993. The brooch mould (GH 109, Fig 141.1A–C). In Hamerow, H. *Excavations at Mucking. Volume 2: the Anglo-Saxon settlement*. English Heritage Archaeological Report 21. London: English Heritage, 62–3.
Wilthew, P. & Bayley, J. with Linton, R. 1991. Analysis of the metal-working debris. In T. Gregory *Excavations in Thetford, 1980–1982, Fison Way*. East Anglian Archaeology Report 53. Gressenhall: Norfolk Field Archaeology Division, 141–3.