2FH9 LAB(2T)983

Ancient Monuments Lab. Report No 4237

Crucibles and clay moulds from Dunadd, Argyll

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March 1984

Parts of the fort were excavated in the earlier years of this century (Christison 1904-5 and Craw 1929-30) but many unanswerable questions prompted a further two seasons work on the site. These excavations, like the earlier ones, produced large quantities of debris from metalworking industries, both ferrous and non-ferrous, which date to around the 6th-9th centuries AD. It is expected that a study of the finds, particularly the typology of the objects being cast in the clay moulds, will allow a refinement of the broad date-range suggested at present.

The finds relating to metalworking include iron slag (being studied by Gerry McDonnell), clay crucibles, clay moulds and a small quantity of scrap metal. The few metal objects from the site were also analysed. Some preliminary analyses on both moulds and crucibles were carried out by Jim Tate of the National Museum of Antiquities of Scotland.

The Crucibles

The two hundred or so sherds examined are listed in Table 1 together with a summary of information gleaned from each. Where a bag contained more than one sherd they are listed separately unless they obviously joined. The information given is the sherd type (ie body sherd (B), rim (R), lid(L) knob(K), base (Ba) or complete vessel (All)), its wall thickness and whether it had an added extra layer of clay on its inner or outer surface. If a crucible was to be re-used it was sometimes relined while extra outer layers of clay are commonly found on crucibles of Roman and later date, probably added to increase the thermal capacity of the crucible or to protect it from thermal shock. Volumes (where given) are brim-full ones; the crucible would not have been used quite that full. The second section of Table 1 deals with the vessel type (see below) and any dimensions that could be measured.

The final section of Table 1 records the metals detected on the crucibles by energy dispersive x-ray fluorescence analysis (XRF). The results are all for the inner surface of the sherds unless otherwise stated. The elements naturally present in the clay fabric of the crucibles have been omitted from the table. Those crucibles with no entry in the "XRF Results" column were not analysed. The elements of metallurgical interest are gold (Au), silver (Ag), copper (Cu), Zinc (Zn), tin (Sn) and lead (Pb). In general the elements are written in order of decreasing signal strength, ie the element that gave the strongest XRF signal comes first. Where an element is written within brackets it was only just detectable. Where "Au*" appears in the table, gold droplets were visible under the microscope although not always detectable by XRF because of their small size.

Unfortunately, different elements fluoresce more or less strongly so their order in the Table is not necessarily the same as that of the relative abundance of the elements present; in particular tin and silver only fluoresce weakly. Zinc often heads the list not because it was particularly abundant in the metal being melted but because of the way it behaves. It is a very volatile metal so its vapour penetrates into the fabric of the crucible where it gets trapped. It can also become included in the slaggy surface of the crucible where it is chemically bound while the other elements or their alloys are only present as metal droplets physically held by the roughness of the surface and easily dislodged by enthusiastic washing in the finds hut!

Table 1 - The Crucibles

Bag No	Type	Sherd Thickness (mm)	Extra layers	Vessel type	Vessel interior diameter (cm)	XRF results (inside)
105	B	4				
112/1	L	3-5		C	4	Zn
/2	B	6				
/3	B	5				Zn (Cu Pb ?Ag)
163	K	3		?C (or ?D)		
187	B	2		X		
188	R + K	2		D		Au*
192	R	5	in out	E	4x3.7 high	Zn Cu Sn Pb
193	B	4½-6				Zn
208	K	2		C		
211	Ba	5		?C		Cu Zn Sn Pb
230	B	9				Ag Cu Zn
281	B	2			2	
303	All (vol = 17½cc)	5-6		E	Ext=4.5 x 5.4 x 2.9 high	Cu Sn Pb
308	B	5				Zn (Cu ?Ag)
379	R	3-4				
418	K			C		
425	B	2	out	?A	2	Zn Ag Cu Pb
429	Ba	3-4		?A	Ext=2½	Zn Pb (Cu Sn) outside = Cu Zn Sn
445	L	1-2		C		
459	All (vol = 2cc)			D		outside = Cu Zn Sn Ag (Pb Au) Au*
465	R	4-9		B		
466	R + L	3-5		C		Zn Ag (Cu Pb)
550/1	Ba+R	2		C		Zn Cu Sn Pb
/2	B	2-5				Zn Ag (Au Cu Pb)
600	R	3		A	2 x over 3.4 high	Zn Cu Pb Ag outside=Cu Ag Zn Pb
621/1	Ba+R	8		B	Ext = 8-9	Ag Au Zn Pb (Cu)
/2	?L	5		?C		Nil
/3	B	2½	out	X		Zn
630	K			C		
632	B	2½				Zn Pb Ag Sn Cu
646/1	R	2½	out	A/C	3-4	Pb Zn (Ag Sn Cu)
/2	R	4		X		Au*. Zn Ag Cu (Pb Au)
/3	B	2				Au*
678	B	2		X		Zn Cu (Pb ?Ag)
681	K			C		
697	?R	2½		C		Zn (Cu ?Ag) outside = Zn Ag (Cu)
753	K			?D		
754	R	3-4		X		Zn Pb (Cu ?Ag ?Sn)
756	Ba	2-3		X		Zn Ag Cu (?Pb)
782	Ba	2		X		Ag Zn Cu Au
799	R	4		?C		Au*
816	R	4	out	E(or A?)	3	Cu Sn Zn Pb

Bag No	Type	Sherd Thickness (mm)	Extra layers	Vessel type	Vessel interior diameter (cm)	XRF results (inside)
839/1	R	2-3	out	C		
/2	R	3	out	?C		
842	R	3-4	out	X	2-3	
846	L	4-5		C		
851	L			C		Zn Pb
854	B	5		A	4 x over 4.5 high	Cu Sn Zn Pb
884	R	3-4		E	5	Cu Sn Pb (Zn)
885	K			C		
888	R	4½		A	1.2 x over 3.2 high	Cu Zn Sn Pb
911/1	R	2-3	out	C		Zn Ag Pb (Cu)
/2	B	3-4				Zn Ag Pb (Cu)
/3	L			C		
/4	L			C		
/5	L			C		
932/1	R	3-4	out	?C		
/2	B	2				
944/1	B	2½		X		Cu Zn (Sn)
/2	B	4				An Ag Sn Cu (Pb)
952/1	L	2		C		Zn Pb (Cu)
/2	R?	7				
963	K	4		C		
989	B	4	in			
1004/1	B	3½				Cu Pb Sn Zn Ag
/2	B	4½				Zn (?Ag)
/3	L	4		C		outside = (?Cu Zn)
/4	L			C		
1030/1	K	2½	out	?C		Pb Sn Zn Cu
/2	B	3				Ag Zn Cu Pb
/3	B	2½				Zn Pb (Cu)
/4	B	3				Zn Cu Ag (Sn Pb)
1031	K			C		
1034	K			C		
1135	R			X		
1164/1	?R			C		outside = Zn Cu ?Ag
/2	B			X		Zn Ag (Cu Pb)
/3	B					Zn Ag (Cu Pb)
/4	B					Pb Cu Sn (Zn)
/5	B		in			Zn Ag (Cu Sn)
/6	B					Pb Cu Sn (Zn)
/7	R		out			
1232	R			A	1-2	Zn Pb Cu Sn
1261	All (vol = 4½cc)	3½		E	ext = 3.2 x 1.9 high	Cu Sn Pb
1282	?R	3		?C		Zn Ag (Cu)
1315/2	B	6		?E		Zn Cu (Pb)
/3	R	3-4		?C		Pb Zn Cu Ag
/4	B	4				Zn ?Ag (Cu)
1334	R			D		Zn
1346	B	3			3	Ag Zn Cu (Pb)
1352/1	R	5				Cu Zn (Pb)

Bag No	Type	Sherd Thickness (mm)	Extra layers	Vessel type	Vessel interior diameter (cm)	XRF results (inside)
1352/2	R	3½				Zn Ag Cu Pb
/2	R	2½				Zn (Pb)
1378/1	R	5		C		Cu Sn Pb (Zn)
/2	R	3		?E		Cu Zn Pb Sn
1404	K		out	C		
1431	L + K			C		
1434	K	5	in	D		Zn Ag (Cu)
1506/1	R	5	out	?C		Zn Pb Cu (?Ag)
/2	R	4-5½		A		Zn
/3	B	3				Zn (Cu)
/4	B	4				?Zn
/5	B	4				Zn Ag (Cu)
1514	Ba			B		Pb Zn Cu Ag
1518	Ba	5		?A		Zn Cu Pb Sn Ag
1538/1	K			C		
/2	R		out			Zn
/3	B					Zn Ag Pb
/4	B/Ba					Zn Ag
/5	R	4		X		Zn Sn
/6	R	2		X		Zn Cu Ag Sn Pb
1567	B	3		X		Zn Cu Sn Pb
1576/1	R			A		
/2	B			X		Au*
/3	?L			?D		Zn Ag (Cu Pb)
1602/1		2-6				
/2	B	4				Zn Ag
/3	B	6				Zn Ag
1625	R	4		?E	Ext = 5	Cu Pb Sn (Zn)
1630	R	6	in out	X		(Sn Zn Pb Cu)
1632	R+Ba			B		Au (Zn Cu)
1650/1	B			X		Zn Ag (Pb Cu)
/2	R		in out	X		Zn Ag (Cu Pb)
1665/1	R	3			3	Cu Sn Pb Zn
/2	R	2	out			Zn Cu (Pb)
/3	K					
/4	?L	2-3				Zn
/5	B	4-5				Zn (Ag Cu)
1666	B	4				Zn Cu
1667	B/Ba	8		B	ext = 9	Au Ag Zn (Cu Pb)
1730/1	B/Ba	3				Pb Sn Cu Zn
/2	B	3½				Zn Pb Cu
1731	B					
1748	B	4				Zn
1830/1	K			C		
/2	K + L			C		
/3	K			D		Outside = (Zn Cn)
/4	?					(Zn)
1831	B	3½	out	X		Pb Cu Zn Ag Sn
1847/1	B	4				Zn
/2	B	3				Zn Ag (Cu)
/3	B	3				Ag Zn Cu (Pb)
/4	B	6				Zn
/5	B	5				Cu Zn Sn Ag (Au Pb)
1857	B	6	out			Pb Zn Ag (Cu)

Bag No	Type	Sherd Thickness (mm)	Extra layers	Vessel type	Vessel interior diameter (cm)	XRF results (inside)
1926	?B/Ba	4				Cu Zn Ag Pb (?Sn)
1989	?L					
2024	R	4		?A/C		Zn
2073	B	3				Ag Zn Cu Pb
Outside hut	K			C		

The crucible fragments are parts of a considerable number of vessels of several distinct forms. Theere are three complete crucibles of two forms (Bag nos 303, 459 and 1261), the other types being represented by more fragmentary remains.

The sketches of the various types (see Fig 1) are composite reconstructions, built up from a number of pieces. They illustrate no particular sherds but are representative of each type as a whole.

All the crucibles are hand-made and hence somewhat irregular in shape so small fragments cannot be assigned to particular forms with any degree of confidence. In some cases though the pieces are sufficiently large for an uneven curvature to be noted, suggesting they are not from a vessel of circular cross-section. These sherds are marked 'X' in the vessel type column in Table 1.

All the crucibles (except type B) are relatively thin-walled and would have sat on or in the fire andd have been heated from below. In most cases, especially with the more open crucible forms, the metal being melted would have been covered by a blanket of charcoal to prevent its oxidation. This would have been scraped off just before the molten metal was poured into the moulds.

Type A are cylindrical crucibles, mainly fairly thin walled and with internal diameters under 3cms. There are no complete examples but the fragments suggest that they were connsiderably higher than they were wide. Examples are known from the earlier excavations on the site (Christison 1904-5, no 38; Craw 1929-30, Fig 8,4).

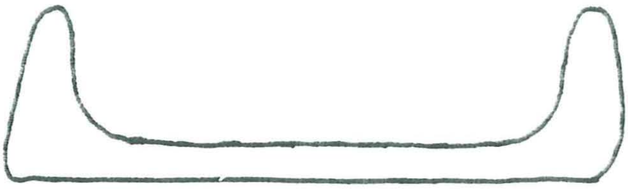
Type B are the various "dog dish" shapes which are discussed in more detail below. They are not in general much vitrified and some have definitely been heated under oxidising conditions, neither of which is consistent with use as a container for molten metal. In this sense they are not crucibles.

Figure 1 : Crucible types

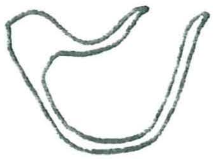
The reconstruction sketches are representative of a general type rather than of specific sherds

Scale approx 1:1

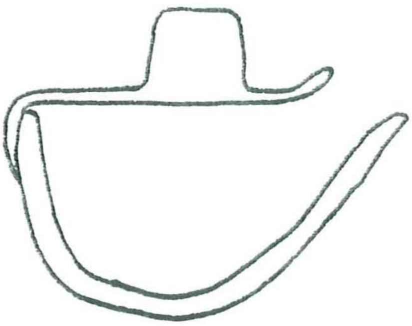
Type A



Type B



Type D



Type C

Type E

Type C are lidded crucibles with half-pear shaped bodies. The lids were made separately from the bodies and had their edges folded over the outside of the crucible and luted on with a smear of extra clay. Rim sherds from this type of crucible can be identified by the unvitrified band near the rim (covered by the lid in use) and the vitrified ridge of luting clay below it. There was an opening at the pointed end of the pear-shape where the lid did not completely seal the vessel but had a rolled back edge (eg bag no 1404). Many, if not all, of the lids had a squarish knob in their centre, presumably to help with the manipulation of the red-hot crucible. It is interesting that many of the lid fragments are not strongly reduced fired, in fact many of them have a distinct reddish tinge suggesting the crucibles sat on rather than in the fire. This is supported by the lack of vitrification noted on both the lids and knobs which can be explained if they never came into direct contact with the fire. For this reason it is suggested that all these knobs were on the lids of the crucibles rather than on their sides where the surface would have become vitrified like the crucible itself. Craw (1929-30, Fig 8,5) illustrates a crucible of this type from the earlier excavations at Dunadd, Alcock (1963, Figs 30-1) has found similar examples at Dinas Powys as has O'Kelly (1962, Fig 21) at Garryduff I.

Type D are small, very thin-walled thumb pots where the rim has been pinched together to give a partly-lidded effect with a knob on the opposite side to the pouring lip. Christison (1904-5, no 37) illustrates a similar find from the old excavations.

Type E is the final well-defined shape. These crucibles have relatively thick walls and are roughly hemispherical. The two complete examples have no pouring spouts.

Many of the fragments with an 'X' in the vessel type column in Table 1 are probably from type C crucibles though there are some rim sherds with no indication of an attached lid. These, as well as some of the other 'X' sherds, may be from triangular crucibles (ie triangular in plan) though there are no complete enough examples to prove their occurance on the site. The type is however relatively common on Dark Ages sites in the highland zone (eg Garranes: O'Riordain 1941-2, Fig 25).

No mention has been made of fabrics as most of the vessels are deeply vitrified which makes any meaningful description nearly impossible. Suffice it to say that they appear reasonably refractory, are highly tempered and, with the exception of type B, are reduced fired.

It can be seen from Table 1 that a variety of metals were being worked on the site. Most metals at this period were not pure but were mixed, either deliberately or accidentally, with other elements. The re-use of metal would tend to reinforce this mixing though scrap would not have been used indiscriminately; even new metal usually contained some impurities. Certainly gold often contains some silver and copper and silver usually contains copper and often other elements too. These additional elements can be looked on as either accidental inclusions or deliberate alloying or debasement. Copper is rarely used in its pure form but is normally alloyed with with either tin (to give bronze) or zinc (to give brass) or both (giving alloys known as gunmetals). Copper alloys, especially those not intented for wrought work, often contain considerable amounts of lead too. By considering these comments on the likely additions to be found in any particular alloy together with the comments on XRF signal strengths the XRF results presented in table 1 can be assessed to identify the metal each crucible once contained. These results for the crucibles of known type are presented in table 2.

Table 2: Metals found in Crucible types A-E

XRF suggests crucible contained:

Crucible type	Bronze	Bronze or Gunmetal	"Cu"	Silver	Silver and/ or gold	Gold
A	854	429 888 1232 1518		425 600		
B				1514	621/1 1667	1632
C	1378/1	211 550/1 1030/1	952/1 1004/3	466 697 911/1 1169/1 1282 1315/3 1506/1		799
D			1830/3	1434 1576/3	188 459	
E	303 384 1261 1625	192 816 1378/2	1315/2			

NOTES 1) Uncertainty of assignment of crucible sherds to types has been ignored here.

2) "Cu" - a copper-containing metal; XRF results are non-specific.

It can be seen from this table that not all crucible types were used equally for all metals. Type A was used mainly for copper alloys though a minority had contained silver. Type B was exclusively associated with precious metals as was type D. (The entries in the "Cu" column in Table 2 should best be ignored; copper can be found in association with all the other metals so on its own it is not sufficiently specific to be useful). Type C was mainly used for silver though copper alloys (and gold) were also detected. Finally Type E was used solely for copper alloys. It is interesting to speculate whether all the metal melting crucibles (Types A, C, D & E) were in use at the same time or whether crucible typology is a chronological indicator.

Both types A and E were used for copper alloys but, apparently, ones with rather different compositions. Half of the type E crucibles contained almost no zinc while only 1 out of 5 type A crucibles had residues of similar composition. It would seem the copper alloys melted in the type E crucibles contained (on average) less zinc than those melted in the Type A crucibles, though the shape of the latter would perhaps contain the zinc vapour more effectively. If we knew the types of alloys used at different periods we could perhaps date the crucibles or conversely the site stratigraphy may suggest at least relative dates and hence given us some idea of the sort of results to expect from a programme of metal analyses. Some of the "bronze or gunmetal" or "Cu" crucibles may have been used to melt brass but the ubiquity of zinc makes this difficult to identify positively.

In many ways crucible types A and E look interchangeable from a functional point of view as both were used for both the zinc-richer copper alloys and silver, though the proportion of silver-containing crucibles is far higher for type C. Type D, understandably, were for precious metals where only small quantities were melted.

The type B crucibles are not strictly crucibles in that they were never full of molten metal but they definitely had some metallurgical use as demonstrated by the metal traces were found on them. They were never placed in a fire but may well have been heated from above by a blow-pipe. They could have held objects being hard soldered or have been used to collect metal filings or trimmings which would then have been melted together to form manageably large pieces of metal. A strongly reducing atmosphere is not as important with precious metals as it is with base metals so their partly oxidised fired appearance is not completely out of keeping with the use suggested. Apparently similar vessels have been found at Mote of Mark (Curle 1913-14).

The clay moulds

Most of the moulds are made from a very fine, fairly hard clay which fires to a variety of colours ranging from brown to grey and nearly black. The most strongly reduced fired areas are normally on the surfaces that would have been in contact with the metal cast in the mould. Some of the moulds (eg SF 222) are made of a rather coarser, redder fabric and one piece (SF 112) appeared to be half and half of each fabric.

All the moulds appear to have been two-part piece moulds. In the cases where all or the majority of a valve survives this is obvious, but many of the smaller pieces are of diagnostic shapes too and can confidently be identified as parts of piece moulds. The few fragments recognised which were not from piece moulds are discussed below. From examination of the mould fragments their method of manufacture and used can be deduced.

First a lump of clay was laid down on a flat surface and roughly flattened, leaving a slightly convex upper surface. A model or copy of the object to be cast was then pressed into the clay slab together with formers for the runners and in-gate (these parts could all be combined in a model). Most of the moulds showed only single runners but in a few cases (eg SF 171, SF 288) two runners radiate from a single in-gate. The clay slab also had depressions made in it so the upper half of the mould would have corresponding protrusions to ensure correct positioning of the valves when they were reassembled. Three types of keying marks were noticed; stab marks made with a ?stick (eg SF 196), cuts (eg SF 299) and rounded depressions made with finger tips (eg SF 72). These marks are mainly round the edge of the moulds but there are some in the centre of penannular brooches (eg SF 525).

The top half of the mould was made by applying a second lump of clay over the top of the model and smoothing it to fit the lower valve. This gives the upper value a characteristic concavo-convex section. These upper valves tend to have deeper impressions of the objects to be cast than the lower valves do.

The two halves of the mould were then taken apart, the model removed and the parts reassembled and lightly luted together with a smear of the same clay (eg SF 445). The whole was then dried, fired and molten metal poured in with the mould held vertically (ie in-gate at the top). The two valves could then be cracked apart, the casting removed and the mould reassembled for re-use.

The impressions in the moulds carry very fine detail (eg SF 525, the diagonal slashing on the bands across the terminals of the penannular) so the castings were apparently not intended to have much work done to them, except presumably have the inevitable casting flash removed. It is questionable whether the degree of detail noted on the moulds would survive sufficiently well for multiple castings to be made from a single mould. It may be that piece moulds were made to allow the removal of the model without damage so it could be re-used while the moulds themselves were considered as disposable. This would suggest several moulds taken from the same model should be present but no exact pairs were noted in the assemblage examined.

Clay piece moulds of this general type appears to have been widely used in the early medieval period. A very extensive collection of fragments has been found at Helgö in Sweden, and Lamm (1980, figs 3 and 4) ilustrates reconstructions of some of them. The objects being cast different from those made at Dunadd but the principle is identical; Lamm's Fig 3a showing several pins being cast together, radiating from one in-gate can be parallelled by SF 222 and SF 261. In the British Isles similar moulds have been found at Barrow-on-Humber (Bayley 1983) York (MacGregor 1978, Fig 24,8), Mucking (Jones 1980, Fig 1), Lincoln (Bayley 1982), Lagore (Hencken 1950, Fig 60), Garranes (O'Riordain 1941-2, Fig 16), Traprain Law (Curle and Cree 1915-16) and Mote of Mark (Curle 1913-14).

In addition to the piece moulds discussed above there were two fragments, probably parts of open ingot moulds (SF 1013 and Bag 1537). The bar ingots produced in these moulds would have been the raw material for a wrought metal-working industry. This was apparently only a minor facet of the non-ferrous metalworking on the site.

Attempts were made to identify the metals being cast in the moulds by analysing their surfaces by XRF. It was not expected that positive results would be obtained as the moulds had been washed and many had also had silicon rubber casts taken from them. The signals detected were very weak and there were no significant differences between the inside and outside of the same fragment indicating the metals detected were a uniform 'background' and were not related to the use of the moulds.

The metal and other analyses

The few metal finds from the excavations were analysed qualitatively by XRF. The results are given in Table 3, below. It can be seen that a variety of copper alloys were in use at the site which supports the results for the deposits on the crucibles which also suggest a range of alloys rather that one specific, favoured composition.

Table 3: Metal analyses

SF No	Object	Alloy
116	Needle	Bronze
51	Ring-headed pin: ring	Brass
	pin	Gunmetal (with some lead)
123	Lump	Low tin bronze
?	Repousse foil	Bronze (with a little lead)
15	Pin (? for penannular)	Bronze (with some lead) also containing a minor amount of silver.
141	Scrap	Copper
148	Dribble	Bronze/gunmetal

The other samples analysed were a wide range of materials; they are described and the XRF results presented individually:-

SF No	XRF results	Interpretation/description
546	Only arsenic detected	Orpiment - a naturally occuring mineral.
49		Droplet of iron-rich fuel ash slag (not deliberate glass)
340	Major elements: Fe, Mn, Ca (Si, Na, K not detectable)	Part of a glass cane for making beads. The pink colour is due to the present of manganese.

SF No	XRF results	Interpretation/description
432	Major: Pb, Cu Minor: Fe, Zn, Sb Trace: Mn (Si, Na, K not detectable)	Red glass inset. The colour is mainly due to the presence of copper.
352	Only iron detected	Red flecks probably haematite
Bag No		
728	Calcium detected	White material. Needs further (XRD) analysis for identification.
1195		Concretion - ? rock chips cemented together.
1362	Only iron detected	Yellow and liverish red lump - colour probably due to iron oxides.
1368	Iron and titanium detected	Pink material. Needs further (XRD) analysis for identification.

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