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THE ASSESSMENT OF SLAG AND OTHER METALWORKING DEBRIS FROM ARICONIUM (WESTON UNDER PENYARD), HEREFORD AND WORCESTER 1993

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Summary

Salvage recording undertaken along a pipeline trench near the scheduled site of Ariconium, previously known as a major focus of Roman iron smelting, produced over 220kg of ironworking debris and uncovered the base of a furnace. Visual examination of the slag showed the main activity to have been iron smelting, but some smithing, probably only to consolidate the bloom, was also carried out at the site. A small quantity of atypical non-ferrous metalworking debris was analysed by X-ray fluorescence analysis which showed that bronze had been melted.

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The assessment of slag and other metalworking debris from Ariconium (Weston under Penyard), Hereford and Worcester 1993

David Starley

Introduction

In 1993 the Archaeological Service of Hereford and Worcester County Council undertook salvage recording along the line of the Lea and Weston under Penyard sewage transfer pipeline (HWCM 6097&15938)[1]. The work was funded by Welsh Water and the project director was Robin Jackson. The route of the pipeline was directed to avoid significant known archaeological sites. However, monitoring of the pipe trench and easement was undertaken, especially near the Scheduled Ancient Monument of Ariconium, a site which previous excavations has shown to produce large quantities of iron working debris and furnace remains. The easement area was examined before and after topsoil stripping and artefacts were collected from the upper surface and spoilheaps. Where buried remains survived these were investigated with a series of 1m wide trenches:

7 of 5m length (Trenches 2, 3, 4, 5, 7, 8 and 10)
5 of 1m length (Trenches 1, 9, 12, 13 and 14)
Trench 6 was extended to cover an area of 7x5m

Interpretation of the excavated remains was restricted by the narrowness of the trenches. The function of a feature containing clearly stratified bands of charcoal and slag is unclear. One furnace, interpreted as a bowl furnace by the excavator, was located in Trench four. A total of 226kg of slag was collected during the excavation and fieldwalking. Dating from stratified finds, mainly ceramic, suggests all the material to be Roman. All slag from the excavation was saved[2].The reported total weights from the trenches were as follows:

Trench	7	38.1 kg
	5	42.9
	4	78.0
	2	26.65
	3	17.7
	10	6.82

In addition a small quantity of non-ferrous debris was recovered from HWCM 15983 and sieve residues from washed soil samples were retained for examination.

Assessment of the metalworking debris

This involved the visual examination of approximately 40% of the material recovered, concentrating on slag from stratified deposits including the furnace fill (405). The first digit(s) of the Context number indicates the Trench number. The material is classified and quantified in Table 1:

Table 1		Metalworking debris from Ariconium		
HWCM code	con-text	slag interpretation	weight (g)	comments
6097	100	vitrified hearth lining	140	unstratified
6097	200	glassy-blast furnace slag	90	unstratified
6097	200	fired clay	70	unstratified
6097	202	fired clay	260	
6097	202	vitrified hearth lining	560	1 frag. red glaze
6097	202	spheroidal hammerscale, flake hammerscale, fired clay,		from sieve residues
6097	203	dense ironworking slag	280	blocky
6097	203	tap slag	2740	
6097	203	smithing hearth bottom?	2630	unusual, not vitrified on top. Bloom smithing slag?
6097	203	iron-rich cinder	340	
6097	203	undiagnostic ironworking slag	920	
6097	203	Fe object	190	
6097	203	smithing hearth bottom(s)	970	3, very dense
6097	203	cinder	770	
6097	203	spheroidal hammerscale, flake hammerscale, fired clay, tap slag frags		from sieve residues
6097	205	vitrified hearth lining	150	
6097	207	tap slag	40	
6097	207	Fe object	10	
6097	207	cinder	10	
6097	207	undiagnostic ironworking slag	130	parallel twig impressions (15mm dia)
6097	207	fired clay, flake hammerscale, spheroidal hammerscale		from sieve residues
6097	212	vitrified hearth lining	260	
6097	301	undiagnostic ironworking slag	310	
6097	301	vitrified hearth lining	90	
6097	303	flake hammerscale		from sieve residues

Table 1		Metalworking debris from Ariconium		
HWCM code	con-text	slag interpretation	weight (g)	comments
6097	306	fired clay, flake hammerscale		from sieve residues, hammerscale very small proportion of magnetic particles
6097	309	vitrified hearth lining	200	
6097	401	vitrified hearth lining	430	
6097	401	fired clay	15	
6097	401	undiagnostic ironworking slag	50	
6097	401	tap slag	60	
6097	402	fired clay, flake hammerscale		from sieve residues, amongst many small frags of slag (=bloom smithing debris?)
6097	405*	flake hammerscale		very small quantity
6097	405*	furnace bottom	4100	
6097	405*	ferruginous concretion	6000	
6097	405*	Fe object	2140	
6097	405*	undiagnostic ironworking slag	1300	
6097	405*	undiagnostic ironworking slag	1400	more glassy
6097	405*	poss. roasted ore	150	?magnetite
6097	405*	dense ironworking slag	23230	much blocky
6097	405*	tap slag	1400	(approx)
6097	504	tap slag	8300	
6097	504	dense ironworking slag	4760	mostly blocky
6097	504	undiagnostic ironworking slag	4040	
6097	504	smithing hearth bottom(s)?	60	(50x30x15mm)
6097	504	cinder	120	
6097	504	vitrified hearth lining	240	
6097	506	tap slag	520	
6097	506	undiagnostic ironworking slag	1810	
6097	506	dense ironworking slag	2000	mostly blocky
6097	506	smithing hearth bottom(s)	490	3
6097	506	poss roasted ore	15	?magnetite
6097	506	ferruginous concretion	110	
6097	506	vitrified hearth lining	180	
6097	506	Fe object	60	
6097	901	vitrified hearth lining	680	
6097	1001	glassy-blast furnace slag	20	
15983	105	Cu alloy dribbles	23	C3-4th
15983	105	vitrified hearth lining	118	
15983	105	crucible frag.	15	
15983	107	vitrified hearth lining	130	green corrosion products
15983	115	tap slag	270	
15983	117	? crucible frags	260	very large
15983	117	tap slag	820	
15983	117	dense ironworking slag	140	

Summary of results

Table 2 Ariconium Slag weight totals

slag type	total weight (g)
tap slag	25660
furnace bottoms	4100
dense ironworking slag	30270
possible. roasted ore	165
glassy/blast furnace slag	110
smithing hearth bottom(s)	4150
hammerscale	not quantified
vitrified hearth/furnace	2930
cinder	900
iron-rich cinder	340
undiagnostic ironworking	9960
ferruginous concretion	6110
fired clay	345
iron objects	2400
total	87440

Visual examination of metalworking debris allowed the material to be categorised on criteria of morphology, density, colour and vesicularity. It should be stressed that many 'classes' of iron working slags form part of a compositional and morphological continuum. Only certain classes of material are strictly diagnostic, and can be unambiguously assigned to a single metalworking process. Others may derive from a restricted range of processes but, when found in association with the diagnostic types may provide support for the identification of these activities. Some forms of debris may originate from a very wide range of high temperature processes and are of no help in identifying crafts or industries. Class names and the criteria on which they are based may vary between specialists. Those currently used by the Ancient Monuments Laboratory are defined below.

Explanation and discussion of classification of iron working debris

On the whole, the slag examined from Ariconium was notable for its lack of vesicularity and its high density. Much of the assemblage showed flow lines and gave a dark grey steak on an unglazed porcelain tile. Although no slag was analysed the composition is undoubtedly close to the low melting point composition iron silicate (fayalite).

The most abundant "diagnostic" waste material was **tap slag**. These fragments show a characteristic "ropy" flowed morphology on their upper surface and very low vesicularity at their fracture surfaces. These provide unambiguous evidence of the smelting (*i.e.* primary extraction from the ore) of iron and are typical waste products of the tapped bloomery furnace, in use during the Roman period, from which the molten slag was run out from the furnace. Some of the fragments from Ariconium were of considerable size, thicknesses of over 10cm being noted. Other fragments were of regular cylindrical form, often with two or more parallel cylinders attached and having a rough "sand cast" surface. These appear to be runs of slag which have solidified inside the tap hole. One example of a **furnace bottom** was identified. This also originates from a smelting furnace and may derive either from material that has not been fully run out from a tapped furnace, or possibly from a furnace type in which the slag is not tapped.

The greatest category of material was **dense ironworking slag.** This had a homogenous dense structure but not the distinctive morphology of tap slag or furnace bottoms. Much of this material was of a shattered blocky form and as such may be the broken up fragments of furnace bottoms or the thick plates of tap slag. In either case it can be assumed that at least the bulk of this material derives from iron smelting. Supportive evidence of smelting was provided by the limited quantities of **probable roasted ores.** Although no analyses of these were carried out they appeared (after roasting) to be largely hematite (red streak)/magnetite (attracted to bar magnet) of sufficiently high grade to be a viable source of iron, given the furnace technology of the period.

Evidence for smithing, *i.e.* hot working of iron, is limited. Normally it is recognised in two main forms; bulk slags and micro slags. Of the bulk slags produced during smithing only the **smithing hearth bottoms** are unlikely to be confused with the waste products of smelting and are therefore considered to be diagnostic of smithing. These hearth bottoms are normally recognisable by a number of characteristic features: their plano-convex form, having a rough convex base and a smoother, vitrified upper surface which is flat, or even slightly hollowed as a result of the downwards pressure of the air blast from the tuyère. Compositionally, smithing hearth bottoms are also predominantly fayalitic and form as a result of high temperature reactions between the iron, iron-scale and silica from either the clay furnace lining or sand used as a flux by the smith.

From the 87kg sample of slag examined, only eight possible smithing hearth bottoms were identified and these were generally small and poorly formed. One exceptional lump weighed 2740g whilst the remainder averaged only 200g. The structure of the large piece was much more vesicular, with a rough upper surface and it is possible that it is a misclassified furnace bottom, although it was unlike the other example. If it is a smithing hearth bottom, its size must indicate a very substantial hearth, perhaps as might be expected for the primary consolidation of blooms after removal from the furnace.

In addition to bulk slags, iron smithing also produces micro slags of two types. **Flake hammerscale** consists of fish-scale like fragments of the oxide/silicate skin of the iron dislodged during working. **Spheroidal hammerscale** results from the solidification of small droplets of liquid slag expelled during working, particularly when two components are being fire welded together or when a slag-rich bloom of iron is first worked into a billet or bar. Hammerscale is considered important in interpreting a site not only because it is highly diagnostic of smithing but, because it is often allowed to build up in the immediate vicinity of the smithing hearth and anvil, it may give a more precise location of the activity than the bulk slags which may be transported elsewhere for disposal[3].

Examination of the Ariconium sieve samples was carried out using a bar magnet. Most of these samples contained much material that was attracted to a magnet, most of this appeared to be fired clay and possibly roasted ore particles. Hammerscale was present in many of the sieve residues but the quantities were small. Much of the hammerscale was of the spheroidal rather than flake type (despite the tendency of the former to contain air bubbles and hence float away from the residue). Thus it would appear that the smithing probably only extended to the consolidation of the bloom immediately after its removal from the furnace. The large quantities of small pieces of shattered slag, caught on the coarser sieves may also derive from bloom smithing.

Four categories of debris not normally considered diagnostic are vitrified hearth lining, cinder, iron rich cinder and undiagnostic ironworking slag. However, given the restricted evidence for iron smithing on the site it is probable that most of the debris in these four categories derives from iron smelting. Material listed as **vitrified hearth/furnace lining** forms during either iron smelting, iron smithing or non-ferrous metal working as a result of a high temperature reaction between the clay lining of the hearth/furnace and the alkali fuel ashes or fayalitic slag. The material may show a compositional gradient from unmodified clay on one surface to an irregular cindery material on the other. An associated material, classed as **cinder,** comprises only the lighter portion of this, a porous, hard and brittle slag formed as a result of high temperature reactions between the alkali fuel ashes and either fragments of clay which had spalled away from the hearth/furnace lining or another source of silica, such as the sand used as a flux during smithing. **Iron-rich cinder** is a similar material but contains a significant iron content, making it denser. More dense still are those slags classed as **undiagnostic ironworking slags**. The compositions of these fragments are predominantly fayalitic, but their morphology is irregular and similar materials may be produced by smelting and smithing operations.

Undiagnostic **ferruginous concretion** forms as a result of the redeposition of iron hydroxides, similar to the natural phenomenon of iron panning, although the process is likely to be enhanced by the nature of the surrounding archaeological deposits, particularly iron-rich waste. **Glassy slag** was identified in two contexts. Although bloomery furnaces can (and occasionally did) produce light-weight glassy slags, which could be confused with blast furnace slag, the two fragments examined are probably intrusive piece of post medieval blast furnace slag.

The small quantity of **fired clay** may derive from some form of metallurgical hearth/forge, but could equally come from a domestic hearth or other pyrotechnic process. The **iron "objects"** may be fragments of smelted metal not incorporated into the bloom.

Non-ferrous debris

A small quantity of non-ferrous debris (546g) was examined and surfaces showing traces of metal corrosion products were investigated by qualitative X-ray fluorescence (XRF) analysis.

Table 3. XRF analyses of non-ferrous debris from Ariconium

HWCM code	Context No.	Object	Elements present	Comments
15983	105	?Crucible rim	**Fe Cu** Zn **Sn Pb**	
15983	105	Cu alloy dribble 1 (6g)	Fe **Cu** Sn Pb	
15983	105	Cu alloy dribble 2 (17g)	Fe **Cu** Sn Pb	
15983	107	vitrified hearth lining large frag	(Fe) (Cu) **Sn** Pb	first analysis
15983	107	vitrified hearth lining large frag.	**Fe** Cu **Sn** Pb	second analysis
15983	107	vitrified hearth lining small frag.	**Fe Cu** (Zn) **Sn** Pb	
15983	117	?crucible base fragment	**Fe Cu** Zn **Sn Pb**	
15983	117	?crucible rim fragment	**Fe Cu** Zn **Sn Pb**	

Codes: **XXX** elements strongly detected*
XXX elements moderately detected*
(XXX) elements weakly detected*

* Based on peak height of fluorescence spectrum. This is not necessarily proportional to the elemental concentration in the original alloy, or to the composition of the surviving compounds, for reasons explained below;

Fe = iron, present within soil or ceramic fabric.
Cu = copper, from alloy being melted, the unusually low levels in the Ariconium material probably result from post depositional leaching.
Zn = zinc, from alloy being melted (tends to volatilise and pass into the ceramic easily and is therefore retained in detectable quantities, even when present only as traces in metal being melted).
Sn = tin, was surprising strongly detected in all the Ariconium crucible fragments and linings. This probably results from enrichment caused by the post-depositional, preferential leaching of the copper from the original bronze.
Pb = lead, presence on crucible fragments tends to be exaggerated due to the metal's strong tendency to fluoresce.

The density of the two pieces of debris from Context 105 showed that they contained a large proportion of metal, although at least in the case of the larger fragment, slag-like material was also attached. These were classed as **Cu-alloy dribbles** and may well be waste products of non-ferrous casting. However, it is possible that they result from the accidental melting of bronze in an intense conflagration. Analysis showed them both to be of tin bronze containing a minor proportion of lead. The other debris all exhibited thick deposits of metallic residues, mostly with a green colour indicating copper. Analysis also detected surprisingly strong concentrations of tin and lead with respect to copper, possibly because much of the copper, from the bronze being worked, had been leached away.

Although it would seem most likely that the material derives from some process involving the melting of bronze, these few fragments were not easily categorised. The heating pattern of some fragments is very similar to that which might be expected from the distinctive Iron Age/early Roman triangular crucibles, *ie* most intense vitrification on the rims and inside surfaces. However, the construction of these fragments is massive, and it is possible that the fabric is a portion of the hearth itself, which has become highly contaminated with metal waste. The fragments from Context 107 certainly appear to be part of the lining of a non-ferrous alloy melting furnace, possibly part of a clay patch which formed a plate tuyère (air blowing hole).

Conclusions

The diagnostic components of the slag and debris from the pipe trench excavation at Ariconium were largely restricted to iron smelting, *i.e.* the primary production of iron from its ore. The morphology of the slag appears to consistent with the use of tapped (shaft) furnaces. This conflicts with the excavator's original interpretation of the single furnace in Trench 4 as a bowl furnace (*i.e.* untapped). It would be wise to reconsider the evidence for this, particularly whether the excavated "bowl" was in fact the tapping pit of a shaft furnace similar to those excavated by Bridgewater[4]. Some probable ores were also associated with the assemblage but as these appear to have been partly processed, the original nature of the ore could not be determined visually. No products of the smelt were recovered but a few "Fe objects" may be detached parts of blooms.

Relatively few bulk slags characteristic of iron smithing were identified, although further evidence, in the form of hammerscale in flotation tank sieve residues was identified. It is thought that only the primary consolidation/working of the bloom was carried out at this location. However, limited quantities of non-ferrous debris, suggested that some production of non-ferrous artefacts was taking place in the vicinity.

The importance of the excavated iron working debris clearly lies beyond the limited scope of the pipeline salvage excavation. Although this investigation produced relatively large quantities of slag (220kg) these are undoubtedly only a tiny fraction of the total quantity of debris that has been reported across the site of Ariconium, the quantities of which are likely to already have been depleted by the re-use of slag for hardcore and as a source of iron for post-medieval blast furnaces.

Potential for further work

One function of the slag identification was to provide finds staff at the Hereford and Worcester Unit with guidance on the visual identification of such materials. Examination of the remaining material (after washing) would be seen as the first priority and this can be undertaken by staff at the unit. This would allow the distribution of the different iron and non-ferrous metals activities to be located along the line of the pipe trench.

If further non-ferrous debris be located it should be examined by a specialist and XRF analysis undertaken. X-radiography of the "iron objects" associated with the furnace (Context 405) should be undertaken to determine whether these could be bloom fragments.

The presence of a wide range of raw materials and products: ores, slags and possibly iron bloom fragments, associated with the remains of a furnace, suggests that scientific (physico-chemical) analysis would be justified. This would allow the type and purity of the ore to be determined, any characteristic compositional traits to be identified and to look at the likely yield (quantity and quality) of the smelting process used. Hence, it would provide a much clearer understanding of the iron smelting operation.

As mentioned above, the pipeline survey provided a rare insight into iron production in a region which, despite assumptions of large scale of Roman iron production, has provided little dependable evidence of this activity[5]. Whilst valuable in its own right, the work also highlights the need to reassess previous excavations at Ariconium, including work by Jack[6] and Bridgewater[7] and Garrod and Bridgewater[8] which has been published to very variable standards. Together these sites should enable a better estimate of the scale, date, technology and organisation of the major Roman iron production industry based on the settlement of Ariconium.

Time requirements for physico-chemical analysis (at the AM Lab)

A range of slag types and ores should be sampled, examined by optical microscopy and the phases present analysed by scanning electron microscope (SEM) based energy dispersive X-ray analysis (EDXA). Ideally, (SEM) based wavelength dispersive (WLD) analysis would also be undertaken on some metallic iron fragments and EDXA on slag inclusions within them.

Preparation, optical microscopy, recording, microanalysis of 5 samples including production of report with black and white plates 10 days

If further non-ferrous debris is recovered, basic alloy type identification could be undertaken at 25 samples/day

Storage of slag

Most iron working slag, being predominantly fayalitic, is not prone to deterioration and requires no special storage treatment. Debris which appears to contain fragments of iron should be stored like iron artefacts in a low humidity environment. All slag from this assemblage should be saved.

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