# Archaeometallurgical contributions to the Ariconium report

## Chapter 4 The artefacts

The iron working residues are typical of those Roman sites producing iron from the Bristol Channel Orefield, in which the ores are haematite/goethite, and typically of high-grade. Since these compositions are not self-fluxing, the furnaces operate in a slightly different manner to those smelting ores of a lower degree of purity, and generally produce slags of a rather high density. A selection of specimens (Table 1) of materials associated with iron smelting was examined petrographically and chemically in an attempt to provide information on the technology of smelting and on the provenance of the ore being smelted. This analytical investigation was designed to complement the report by Starley (1995) and focussed on the types of slag which fell into Starley's "**tap slag**" and "**dense ironworking slag**" categories. In this study 21 slag samples (total weight 5kg) along with 3 lining samples (0.4 kg) and 2 ore fragments (52g) were obtained from 220kg of material excavated by the Hereford and Worcester County Council Archaeology Service during their 1992 excavations associated with the Welsh Water trenches (HWCM 6097, 12666). A full description of this material is being lodged as a separate document.

The petrography of all slag specimens (except A20) has been examined by back-scattered scanning electron microscopy, together with energy dispersive spectroscopy microanalyses of selected components. Most of the slags have a wustite + fayalite + glass mineralogy, but some tapslags show leucite and the massive blocky slags contain leucite and hercynite.

Chemical analysis of selected specimens has been undertaken by X-ray fluorescence (major elements; Table 2) and ICP-MS (minor and trace elements) of 2 ore samples (1 not from the HWCM archive), 9 slags (tap slags A1,A2, A3, A4, A7; possible tap slags A9, A10; massive "furnace" slags A18, A19) and 1 sample of furnace lining (2 other lining samples were sampled for trace elements only). The analyses of the slags form a fairly homogeneous group. The massive, blocky slags with a blotchy texture, which correspond to Starley's "dense ironworking slag" category, do not show any significant difference in chemical composition from the tap slags, despite their textural and mineralogical differences (presence of hercynite and leucite). Uranium occurs at 2.8-6.3ppm in the slags and in the two ore samples at 1.8 and 2.5ppm; such levels are entirely consistent with a provenance for the ore in the eastern part of the Forest of Dean.

## Chapter 6 The origins of the settlement

The recovery of pre-Roman iron smelting residues is of great significance, for there is little evidence from this region for the technology of smelting in the pre-Roman Iron Age. The single specimen examined in the project (A2: from HWCM 12666 101) is very small, but is entirely consistent in morphology, microstructure and chemical composition with being a small piece of tap slag flow similar to the Roman examples examined (HWCM 6097). This specimen was not amongst the material reported on by Starley (1995). The only other pre-Roman site in the region (and smelting Forest of Dean iron ore) for which we have data is Frocester Court, Gloucestershire (authors' unpublished data), where similarly small specimens suggest slag tapping technology from at least the 3$^{rd}$ century BC.

## Chapter 8 Industry and Trade

***The source of the iron ore and the distribution of smelting***

The two samples of iron ore have been analysed to provide evidence of origin. The broad features of the samples clearly indicate an origin with the Bristol Channel Orefield, but details of their trace element geochemistry provide strong evidence for a source within the eastern side of the Forest of Dean. The ore sources on the eastern side of the Forest of Dean include those closest to Ariconium in the area of the Wigpool Syncline (approximately 4km SSE).

The exploitation of the ores of the Bristol Channel Orefield has been characterised, from pre-Roman times, by the movement of large quantities of ore away from the major sources (the Forest of Dean, Glamorgan) for smelting in other areas. In the Roman period smelting has been documented over a wide area from the edges of the Cotswolds, the Severn Vale from South Gloucestershire to Worcester, across the southern parts of Worcestershire and Herefordshire, and down through Gwent, west of the Wye. Doubt has been cast on the sourcing of all the ore for the widespread smelting in this part of the region from the Forest of Dean (Bick 1990), but the analytical studies support derivation from Dean. Increasing evidence for a similar pattern of activity in Medieval times is supported by finds of Forest of Dean Iron ore on quays around the lower Severn.

Within this context there is an apparent divide between the widely distributed smelting, occurring on rural settings, and which, in some areas at least, formed a component of the Villa economy, and the smelting focussed in "urban" settings more or less close to the ore sources (Worcester, Monmouth, Ariconium…). Very little is known in sufficient detail about these two styles of activity to generate a model to explain them. There is no evidence, so far, of any significant difference in technology between the centralised smelting and that in the rural areas. A likely scenario is that a proportion of ore was shipped to regions with local fuel supplies. It remains uncertain whether the rural smelting (e.g. sites like Frocester Court) took place on a regular basis, or whether they were sporadic activities, perhaps associated with local demand (e.g. building projects). In either case, it also remains uncertain whether the smelting was undertaken by the estates themselves, or whether there were itinerant iron-makers.

***Technology, mass balance modelling and yield calculations***

Iron-making residues from this study have formed a "test-bed" for a new approach to mass-balance modelling, as a tool for investigating furnace efficiency. The modelling approach has been developed in two publications by Thomas & Young (forthcoming, a and b). The operation of the Ariconium furnaces has been investigated by producing a mass-balance model of the average tap slag, a furnace lining specimen (A13), an ore fragment (A26) and a typical charcoal ash. The modelling suggested that 1kg of raw goethite ore would have generated 0.34kg of iron and 0.54 kg slag from reaction with 0.15kg of furnace lining and 0.02kg of fuel ash. This gives an efficiency of 44% (calculated as weight of iron produced / weight of iron in the ore), which would appear to be fairly typical of Roman bloomeries.

Although the mass balance approach is still the subject of research, and attempts are being made to test the modelling in reconstruction furnaces, the results of the model can be used as a basis for speculation on production figures. The rate of recovery of raw bloom into finished bar iron is not well understood, but in experimental work Crew (1991) obtained average yields of 45% (raw bloom to billet) and 22% (raw bloom to final bar). On this basis 1kg goethite ore might have generated 150g billet or 75g bar iron. If these figures are correct it would suggest a production of 280g billet or 140g bar iron per 1kg slag (which would have been derived from 1.85kg ore).

Tap slag cakes of this period (including those we have seen from Ariconium) usually indicate rather passive accumulation (with no sign for instance of the upturning of slag flows commonly encountered in large Medieval cakes). It is likely, therefore, that they accumulated progressively during a single smelt, with clearance of the tapping pit at the end of the smelt, and that a conversion from tap slag cake weight to bloom weight is possible. However, slags tapped from a bloomery furnace usually develop cracks as they cool rapidly; the slag masses tend to fragment along these cracks on disposal and even relatively large lumps of tap slags may only be partial cakes. Cracked tap slags often become further fragmented during excavation. The most complete cakes give an indication of the weight of slag produced in a smelt, and in the case of some fieldwalking material from Ariconium available to us (maximum fragment weight 5.6kg, in a case where the fragment represents just over half of the complete cake), this appears to have been between 6 and 10 kg, corresponding to raw blooms of 3.8 to 6.3kg, billets of 1.7 to 2.8kg, finished bar of 0.8 to 1.4kg and ore usage of 11 to 19kg. A few (undated, but usually assumed to be Roman) compacted blooms have been recovered from the Forest of Dean area, and have weights between 2 and 2.5 kg (pers. obs.). These are at the small end of the scale of blooms from Britain of Roman age (Tylecote 1986), but are of an appropriate size for smelts producing 6-10kg slag cakes. Elsewhere in Britain compacted blooms of 7-10kg seem more common in Roman contexts.

In contrast to the relatively small cakes from Ariconium, some slag cakes from the Roman smelting site at Chesters Villa, Woolaston (Fulford & Allen 1992), were very much larger; measuring up to 18kg, suggesting raw blooms of 11kg, billets of 5kg, finished bars of 2.5kg and ore charges of 40kg and would suggest the production of compacted blooms within the 7-10kg range. These large flows are associated with furnaces apparently having an internal diameter of close to 40cm, significantly larger than the size Bridgewater (1965) reconstructed from the rather scanty remains in his excavations at Ariconium.

These rather limited data hint at a possible variation in smelting technology, at very least in furnace size, between sites in the area.

## Chapter 9 The nature of the Roman small town

Comparison with Worcester, Monmouth and Cowbridge would be desirable, but we do not have comparative detailed technological data from these sites at present.

## Chapter 10 Areas of future research

The settlement at Ariconium offers great potential for future research into early iron-making. The details of the technology employed in the region prior to the Roman invasion are almost unknown, while considerable uncertainty exists about Roman smelting too. Areas of significance include: structural details of the furnaces, the detailed interpretation of slag types and proportions generated by both primary and secondary processes, details of the fuel (charcoal species and size; source of coal in smithing; control of fuel type choice in smithing), evidence for blowing technology (in smelting and smithing).

Current and future research into the mechanisms of bloomery operation (both theoretical and experimental) will help improve the interpretation of bloomery slag assemblages. Retrieval of "complete" slag assemblages associated with furnaces sufficiently well-preserved to yield detailed information on structural, blowing and tapping arrangements, are an essential part of this research. Such questions will only be answered by excavation targeting the better preserved iron-working sites, with controlled techniques aimed at generating metallurgical data. Ariconium might well be able to make a major contribution to these research goals, as well as being a potential beneficiary of the improved level of interpretation.

One area of enormous significance, in which Ariconium might shed considerable light, is the organisation of the industry: how was iron smelting organised within the settlement? How was the fuel industry organised? What evidence is there for the form in which iron left the site? Was ore traded through the settlement? What changes to the industry and its technology occurred through time?

| **Ref.** | **Context** | **Interpret.** | **Material** | **Weight** |
|---|---|---|---|---|
| A1 | HWCM 6097 405 | C4 slag surface/layer | Dense tapslag | 1280g |
| A2 | HWCM 12666 101 | Late IA ditch? fill | Dense tapslag | 32g |
| A3 | HWCM 6097 203 | Post-Roman linear feature | Dense tapslag | 117g |
| A4 | | | Dense tapslag | 74g |
| A5 | | | Leucite-bearing low density tapslag, w. charcoal | 97g |
| A6 | | | Hercynite / leucite-bearing slag tube | 97g |
| A7 | | | Dense tapslag | 59g |
| A8 | | | Dense tapslag | 73g |
| A9 | | | Dense slag tube | 117g |
| A10 | | | Tapslag? Contains much iron | 150g |
| A11 | HWCM TR2 6097 212 | C2-C4 ? ground surface | Lining | |
| A12 | | | Lining | |
| A13 | HWCM TR3 6097 301 | Post-Roman ditch fill | Lining | |
| A14 | HWCM TR3 6097 304 | Roman layer | Dense tapslag | 161g |
| A15 | HWCM TR3 6097 405 | C4 slag surface | Massive slag with hercynite & leucite, blotchy | 980g |
| A16 | | | Bowl shaped vesicular slag, ?smithing slag | 346g |
| A17 | | | Clinkery semi-tube | 57g |
| A18 | HWCM TR3 6097 506 | C3-4 soil layer | Massive slag with hercynite & leucite, blotchy | 249g |
| A19 | | | Hercynite / leucite bearing massive, bowl shape | 294g |
| A20 | | | Dense tapslag | 222g |
| A21 | | | Thin vesicular sheet, ?tapslag | 95g |
| A22 | | | Leucite-bearing, massive, blotchy, ?tapslag | 125g |
| A23 | | | Thin vesicular sheet, ?tapslag with leucite | 66g |
| A24 | | | Massive slag, blotchy | 112g |
| A25 | | | Roasted ore | |
| A26 | | | Partially reduced ore | |

*Table 1: List of examined material*

| | LOI | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |
| ***Ores*** | | | | | | | | | | | |
| A25 roasted | 0.87 | 1.86 | 1.06 | 95.78 | 0.44 | 0.31 | 0.20 | < | 0.11 | 0.05 | 0.20 |
| A26 reduced | -2.27 | 1.37 | 0.33 | 97.57 | 0.04 | 0.29 | 0.12 | < | 0.02 | 0.02 | 0.24 |
| | | | | | | | | | | | |
| ***Slags*** | | | | | | | | | | | |
| A1 tapslag | -5.77 | 26.45 | 5.73 | 61.14 | 0.21 | 1.38 | 2.65 | < | 1.85 | 0.30 | 0.29 |
| A2 tapslag | -6.64 | 19.65 | 4.50 | 70.93 | 0.14 | 0.88 | 1.82 | 0.16 | 1.46 | 0.22 | 0.24 |
| A3 tapslag | -6.89 | 19.20 | 2.82 | 73.64 | 0.21 | 0.66 | 1.42 | 0.55 | 1.09 | 0.19 | 0.22 |
| A4 tapslag | -6.04 | 26.27 | 4.80 | 60.15 | 0.19 | 1.61 | 4.58 | < | 1.71 | 0.21 | 0.38 |
| A7 tapslag | -6.51 | 22.48 | 3.63 | 69.08 | 0.11 | 0.83 | 2.03 | < | 1.26 | 0.21 | 0.37 |
| A9 tube | -6.91 | 8.57 | 2.28 | 82.68 | 0.10 | 0.96 | 2.19 | 2.12 | 0.62 | 0.13 | 0.35 |
| A10 tapslag? | -6.85 | 18.05 | 2.99 | 73.77 | 0.18 | 1.20 | 1.86 | < | 1.32 | 0.17 | 0.46 |
| A18 blocky | -5.54 | 19.60 | 5.14 | 67.22 | 0.13 | 1.43 | 3.40 | 0.79 | 1.72 | 0.29 | 0.28 |
| A19 blocky | -5.60 | 22.57 | 4.99 | 65.78 | 0.12 | 1.10 | 2.81 | 0.45 | 1.52 | 0.24 | 0.43 |
| | | | | | | | | | | | |
| ***Lining*** | | | | | | | | | | | |
| A13 | 0.38 | 70.95 | 11.29 | 6.10 | 0.09 | 0.77 | 0.49 | 0.00 | 2.41 | 0.44 | 0.21 |

*Table 2: Raw wholerock major element analyses by XRF. All iron appears as FeIII.*

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