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Assessment of archaeometallurgical residues from the Nether Wasdale Pipeline, Cumbria

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Abstract

This report covers material from two separate sites investigated within the pipeline scheme: an early medieval site in Field 23 and a medieval site (Site 22).

The early medieval site yielded archaeometallurgical residue assemblages of three types:

- *An assemblage of smelting slags from pit [1114] is indicative of iron smelting in a non-slag tapping bloomery furnace. It is likely that the assemblage was in situ and that [1114] should be interpreted as a furnace rather than a pit or posthole.*
- *Assemblages from eight pits interpreted as postholes, lying to the west of the centre of the site were dominantly of smithing residues, but also contained pieces of roasted iron ore. These are interpreted as representing residues from ancillary activities adjacent to the smelting itself.*
- *Gully [1100], just to the north of the smelting furnace [1115] contained badly weathered slag including residues from smelting and smithing.*

The smithing residues included tentative (not certain) evidence for the use of a ceramic tuyère, suggesting ironworking in a tradition that was to be found in early medieval Ireland, but typically not in Britain.

The great similarity of the assemblages with smithing residues present in the postholes (particularly of Building 2) raises the possibility that the fills may represent relicts of a now-truncated waste layer or dump. If this was the case, then it may be possible that the problematic 14C determinations are due to late medieval postholes being cut through an early medieval forge waste layer – in which case the supposed rectangular buildings 2 and 3 might be late medieval in age.

The later medieval Site 22, was largely avoided by the pipeline scheme, with residues acquired from an excavation in a marginal slag dump. These residues were entirely from iron smelting in a slag-tapping bloomery furnace.

The collection also includes a badly weathered large smithing hearth cake, an unstratified find, probably from close to Site 22, that is a residue from bloomsmithing.

The collections also include some examples of local iron ore collected from close to Site 22.

Despite the poor preservation of material from some contexts, this collection has great potential for further scientific investigation to enhance understanding of early iron production in the area – particularly for the very poorly-known early medieval period.

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Methods

All materials were examined visually with a low-powered binocular microscope where required. As an evaluation, the materials were not subjected to any high-magnification optical inspection, not to any form of instrumental analysis. The identifications of materials in this report are therefore necessarily limited and must be regarded as provisional.

The examined materials are listed in Table 1.

This project was commissioned by Helen Evans of Oxford Archaeology North.

Results

Description of residues

The submitted materials amounted to an overall total of approximately 49kg. Of this total, there were 21.4kg of residues from Field 23, 18.6kg or residues from Site 22 and 8.7kg of samples of a local iron ore. Residues from the two sites are described separately below.

Field 23

Iron smelting residues

Smelting slags occurred in three main morphologies:

- Isolated flow slags
- Flow slags amalgamated into basal sheet
- Flow slags amalgamated into furnace bottom

The assemblage in the probable furnace [1114] included approximately 92og of fine flow slag prills (with average fragment weight of less than 3g), 350g of coarse grained flow slags amalgamating into blocks, 1200g of fine flow slags amalgamated into a thin layer which appeared to line part of the furnace pit, a 60g coarse isolated flow slag prill ad approximately 130g of flow slags amalgamated into furnace bottom-like material. This assemblage is therefore suggestive of a flow slag assemblage from the base of the basal chamber or pit of a non-slag tapping furnace, but largely excluding any 'furnace bottom' (a more consolidated mass of slag that typically directly underlies the bloom).

Within gully [1100] context [1101] contained a large quantity (13.7kg was present in the archived collection) of mainly rather large blocks of highly weathered slag. Many of these were probably fragments of furnace bottom; they comprised a mass of small amalgamated flow slag prills, often with a denser layer near the pit margin and with a smooth, slightly lobate, upper surface preserved in some instances. Some of these features are closely similar to some smithing hearth cakes, so the collection has mostly been listed as 'indeterminate', although most is probably from smelting.

Smithing residues

There were some blocks of weathered slag from (1101) that were more likely to be from smithing than from smelting, including a 1.1kg incomplete block, but the high degree of alteration precludes certain identification.

Smithing hearth cakes were represented in the assemblage from the 'post holes' to the southwest by material (1219), (1227) and (1231), all suggestive of, but not conclusively, small SHCs with weights under 200g.

A 32g slag piece from (1221) was a curved slag mass, with a smooth face on the inside of the curve and finely prilly slags on the outside. The curve was not quite regular, but had an approximate radius of curvature of 40mm. Pieces similar to this have been recorded widely in assemblages from Ireland, where they have been interpreted as pendent slags from the lower face of the tip of a ceramic tuyère (e.g. at Ballykilmore Young 2009, 5).

Indeterminate dense slags

Material classified as 'Indeterminate dense slag' was present in almost all contexts.

As mentioned above, the highly-weathered material from (1101), although probably mainly from smelting, was not strictly determinable.

For the 'posthole' fills, the indeterminate material was typically highly fragmented, either so fragmented as to provide little evince of original morphology or representing prilly and blebby, rough-surfaced, crude flow slags.

Lining
Fragments of hearth/furnace lining were generally rather rare in the collection. The dumped deposit (1101) contained a few tiny pieces, as did furnace fill (1115). Most of the 'posthole' fills contained small quantities, again generally in very small fragments, with the exceptions of an 18g fragment from (1229) and a 28g fragment from (1219). The latter piece is potentially significant for the vitrified and slagged surface of the oxidised-fired clay is both gently curved in one plane and curved through almost 90° in the perpendicular plane – a morphology strongly suggestive of this piece being from the margin of ceramic tuyère.

Lining slag
Fragments of lining slag were a minor component of the assemblage form the 'postholes', with lesser proportions in the dump (1101) and the furnace (1115). In general the lining slag was not particularly informative, but one complex piece from (1219), weighing 210g, included a fragment of ow-density burr-like texture and possessed a small central hole. This block may possibly have been slag from the tip of a ceramic tuyère.

Vitrified sand/gravel
Alongside the vitrified lining and lining slag present in the assemblages from the 'postholes' was pieces of a rather unusual material. This was a dominantly white spiky material resembling a sinter, present as small fragments. In detail the white material can be seen to grade into a green glass, which is the medium binding partially-melted sand and fine gravel.

This extremely unusual material somewhat resembles, albeit in a very much finer scale, the partially melted gravel that has been recorded associated with, or interpreted to have derived from, floor-level smithing hearths on various mainly Roman sites (e.g. (Caergwanaf, author's unpublished data; Caerleon Priory Field and Endowed Schools Field, author's unpublished data and Young & Kearns 2010; Calstock, Young 2014b; Exminster, Young 2014c; Neath, Young 2014a). None of these sites produced, however, sintered sand of this type.

Slag spheroids
Slag spheroid occurred in the 'furnace' fill (1115) where they were of dense slag, essentially forming as a variant of the fine prilly flow slags.

Spheroids were also recovered from five of the 'posthole' fill contexts. These showed a greater variety of composition – ranging from green, glassy lining slags to dense slags. They typically showed a fairly low degree of sphericity and were commonly dimpled, but some of the smaller, denser examples were more close to spherical.

Smithing microresidues
The deposit (1101) produced two examples of slag flats (very thin sheets of slag, with a planar contact surface where it was attached to iron).

Flake hammerscale was recovered from the washings of the macroscopic residues from context (1101) and were present in the 'hammerscale' sample from (1219). This was the only 'hammerscale' sample to contain hammerscale.

Iron ore
Strongly magnetic interpreted as roasted iron ore were recovered from both the 'furnace' (1114), and from five of the 'postholes'. The furnace yielded 187 fragments with a total weight of 76g (average weight 2.5g) and the 'postholes' produced 40 fragments weighing 18g (average 2.2g). The ore fragments were mostly dark coloured, angular, showing a slight crust, possessing shrinkage cracks and some showing the crust with re-entrant profiles between cracked angles – all suggesting significant shrinkage of the cores.

Site 22
Iron smelting residues
Smelting residues dominated the two samples from this site. They were dominantly of tapped slags, which showed a range of density (and so, presumably, composition).

Indeterminate residues
The indeterminate residues from the sample from context (3308) were charcoal-rich slags, of which details were obscured by concretion. Although strictly indeterminate, charcoal-rich slags will form within the furnace of slag-tapping furnaces (and are often referred to as 'furnace slags'). These present example is very likely to be such a furnace slag.

Lining slag
Lining slags and slagged vitrified lining were present in the sample from context (3008).

Iron ore
The sample from context (3008) contained a variety of ore and related materials. Although some of this material was probably accidentally incorporated ore (as in field 23), most of this material appears to be fractured waste from ore preparation. Given that iron ores occurred locally (as sampled in sample <3> ascribed context (3025), distinguishing material that was entirely natural from waste gangue material will rely mainly on somewhat subjective interpretation of the fractures.

Smithing residues
A single unstratified block of highly rusted slag was archived as sample <4>. As this sample number is in sequence with others from Site 22, it is assumed that the slag block was derived from somewhere in that area. This piece appears to be a very large SHC, with some edges missing, and probably originally c240x300mm and 80mm thick. Approximately 70-75% of the SHC is preserved in this block, suggesting a minimum original weight of approximately 4kg. The slag is, however, very iron-rich and rusted, probably indicating the slag originally contained a large quantity

of metallic iron, that has now largely altered (and thus the original weight may have been even greater than the 4kg given above). The 25mm-thick basal crust contains tubular vesicles, but otherwise the internal structure was not visible. The top is flat or slightly lobate in some areas but in others is slightly raised and contains large charcoal clasts.

Distribution of residues

The stratigraphic distribution of the residues is illustrated in Table 2 and in Figure 1. This table divides the productive contexts by geographical area and indicates the total weight of various macroscopic residue classes and a general indication of the abundance of microresidues.

The assemblage from Field 23 divides into three components

- An assemblage of smelting slags from pit [1114] is indicative of iron smelting in a non-slag tapping bloomery furnace. It is likely that the assemblage was in situ and that [1114] should be interpreted as a furnace rather than a pit or posthole.
- Assemblages from eight pits interpreted as postholes ([1082], [1084], [1218], [1220], [1226], [1228], [1230] and [1236]), lying to the west of the centre of the site were dominantly of smithing residues, but also contained pieces of roasted iron ore. These are interpreted as representing residues from ancillary activities adjacent to the smelting itself.
- Gully [1100], just to the north of the smelting furnace [1115] contained badly weathered slag including residues from smelting and smithing.

Pit [1114] was 0.39m by 0.40m, approximately circular in plan, with steep sides and approximately 0.20m deep. The available evidence provides no suggestion of an arch leading down into the pit. A simple pit morphology is typical of the known examples of British early medieval slagpit furnaces, and is probably also most common amongst Irish early medieval examples. In the Iron Age of both Britain and Ireland, both examples with simple pits and examples with sunken arches are known.

Interpretation

Field 23

Filed 23 presents the most interesting aspect of this project from metallurgical viewpoint.

The smellting aspect of the operation here is expressed by the residues (1115) from the 'pit' [1114] and (1101) the adjacent gully [1100]. It is unfortunate that the slags from (1101) are so badly preserved, but nonetheless the two collections together allow a good reconstruction of the range of slags generated within the basal section of the furnace.

The available field evidence (which requires further investigation and clarification) suggests that pit [1114] represents the basal pit of a non-slag tapping furnace of the general family of furnace types known as 'slagpit furnaces'. The pit was steep sided, sub-circular and 0.39m x 0.40m and 0.20m deep. These furnaces are typically used by packing the lower part of the furnace and pit with a combustible material (usually either grass/cereals or, more commonly, wood). The smelting itself is fed with a fuel of charcoal and the iron ore through the top of the shaft. Air blast is via one (or more) blowholes in the lower part of the shaft. The rising carbon monoxide from the combustion of the charcoal reacts with and reduces the descending ore. The iron accumulates as a block (the bloom) just below the level of the blowhole, whereas the liquid slag bathes the bloom and descends past it, causing combustion of the material in the basal chamber/pit, creating space for the slag, additional heat and also space for the growing bloom.

Typically, the descending flow slags start to chill as they flow over the pit packing, creating moulds of the organic material. In this example, the flow slags were small, mostly non-amalgamated, and they did not form any identifiable moulds around the packing material.

In many, and possibly all. non-slag tapping furnaces the zone of the furnace immediately below the growing bloom becomes occupied by a slag mass, usually known as a furnace bottom (FB; despite not necessarily forming on the very bottom of the furnace, depending on the depth of the pit/chamber below the blowhole.

Although FBs are usually dense objects, they may include much material that is poorly consolidated, being a friable mass of amalgamated flow prills and much charcoal. Material of this sort may correspond to the highly-altered blocks recovered from (1101).

In general, it would seem that non-slag tapping furnaces producing little slag, would tend to produce the least coherent furnace bottoms. There are few examples of relatively complete assemblages of slag of this type surviving *in situ* within furnaces. Very similar material to that in (1115) has been recovered, however, from sites such as Twinyeo (Devon; probably Iron Age; Young 2013a, 2014d), probably Crawcwellt and Bryn y Castell (Gwynedd; Iron Age; Drew 1987, 1989, 1991, 1998, 2009), Camlin (Co. Tipperary; probably Iron Age; Young 2011b), Ballydavis (Co. Laois; Iron Age; Young 2005), Morrett (Co. Laois; probably early medieval; Young 2005), and Cherryville (Co. Kildare; Iron Age; Young2008).

Most early medieval non-tapping furnaces recorded from southern Britain probably produced rather more slag than these, dominantly Iron Age, examples and according tended to produce quite large FBs (although these vary considerably between sites; Young 2016a).

The non-slag tapping furnace was not the only technology employed in early medieval Britain. Insufficiently-detailed reporting precludes firm determination of the technology employed at many sites, but a recent review (Young 2016a) suggests that slag tapping furnaces were widely employed, particularly in those areas where there had been iron production in the Roman period.

There may have been a further introduction of another slag-tapping technology derived from practice in Merovingian Europe into the southeast of England in the 5th-6th centuries. One of the few examples is at Rook Hall, Little Totham, Essex. The illustrations of this furnace (e.g. Figure 8 at http://adsl06805.freespace.surfree.co.uk/ and the illustrations of the tuyères on the same page; accessed 4/12/15) show evidence for a furnace of very similar style to those of Merovingian age from central Europe. In particular, the use of 'D'-sectioned ceramic tuyères

is a very unusual feature, not known to be paralleled at any other British site. Furnaces with this ventilation (albeit in a very different thick-walled morphology) have been described as the Bellaire type, and are perhaps best known from the site at Boécourt, in the Swiss Jura (Eschenlohr & Serneels 1991).

In Wessex, the non-tapping furnaces appear to have been replaced, perhaps during the late 9th century (Young 2016a), by a different form of slag-tapping furnace, often constructed over a trench and probably introduced from continental Europe. These furnaces are seen, for instance, on sites at Churchills Farm, Hemyock (Young 2016a), and Emersons Green (Young & Young 2013). They were the precursors of the standard furnace of the medieval period.

The examples of non-slag taping technology that are well-attested are largely from the 8th-10th centuries in areas of Wessex and Mercia. The investigated southern British non-tapping furnaces of the 8th-10th centuries may be divided into two traditions – one with very large pits (often greater than 0.8m diameter and sometimes more than 0.5m deep), a straight blowing wall and wood pit-packing, and a second with slightly smaller and shallower pits (greater than 0.45m diameter and usually less than 0.3m deep), apparently rounded blowing walls and a pit packing of grass or cereals. The large wood-packed variety has been recorded at Burlescombe (Reed *et al.* 2006), Culmstock Road, Hemyock (Young 2014e), Millbrook (Tebbutt 1982) and Ramsbury (Haslam, 1980). The smaller cereal-packed variety has been documented at Clearwell Quarry (Pine *et al.* 2009) and Churchills Farm, Hemyock (Young 2016a)

The present example of early medieval iron smelting does not correspond closely with any of the known examples from southern Britain. The northwest of England displays no indication of the persistence of this technology from the Iron Age through the Roman period. There are no known *refugia* of this technology in southern Britain, so an introduction of the technology from outside would seem likely.

The assemblages of residues present in the 'postholes' associated with 'Building 2' of the preliminary report, and the area just to its northwest, are very similar to each other and present a slightly complex composition. They include probable smithing hearth cakes, other macroscopic smithing slags and flake hammerscale on one hand, but fragments of magnetic ore on the other. They do not contain any certain smelting slags. The presence of a slag 'beard', an unusual complex piece of lining slag with included arcuate reaction zone, and the morphology of one of the pieces of vitrified technical ceramic suggest that the smithing technology may have included the use of ceramic tuyères.

The white sintered sands are very unusual materials, without known parallel. It would appear likely that they indicate the impingement of the hot-zone of the hearth onto unconsolidated sand, in the same way that floor-level hearths cut into gravel generated the Roman gravelly-slags as described above.

Ceramic tuyères are not a typical aspect of British ironworking. Rectangular-sectioned block tuyères are known from the British Iron Age (e.g. Young 2016b), 'Y'-shaped tuyères are associated with ironsmelting in the Weald (e.g. Young 2011a), but simple large, rounded ones are almost entirely restricted to the early medieval of Essex (arguably suggesting influence from Merovingian Europe). In contrast, stout round- or 'D'-sectioned tuyères were also introduced (also probably from Merovingian Europe) to Ireland at the start of the early medieval period, and thereafter remained a standard component of smithing technology until (in some areas at least) well into the post-medieval period (Young 2012).

It seems possible, therefore, that the smithing technology employed at Wasdale was within an Irish, rather than British tradition. The evidence from Field 23 thus presents a combination of smelting and smithing that may both suggest technological influences imported from outside the region after the Roman period, with the likely source of that influence being Ireland.

Site 22

The very limited sampling around Site 22 produced a suite of smelting residues that is very typical of those of the medieval period in Britain, but which is only a tiny 'snapshot' of slag associated with the adjacent bloomery.

That the assemblage contains a variety of ore pieces, and that adjacent local ores have been sampled, provides an opportunity for the investigation of the resource exploited.

The rather limited nature of the intervention here, and therefore the rather limited nature of the collection, means that the potential of this section of the assemblage to add to understanding of the technology is limited. Other areas of Britain working high-grade ores in the medieval period include the Forest of Dean and the Mendips; a comparison of the details of the technology would have been useful. It is known that bloomery technology continued to evolve in Cumbria well after the demise of the bloomery iron industry in southern Britain, but the details and roots of the late industry are extremely unclear.

Discussion

The results of the assessment suggest that the ironworking in Field 23 was of unusual technology compared with the better-known sites of the period. In part, this might reflect the lack of well-described northern British assemblages of the period, but is nonetheless striking. The general impression, however, is of an assemblage of possible Irish aspect.

The interpretation of the nature of the deposits (as opposed to the activity) and their date, is somewhat more complex.

The assemblage from pit [1114], and the section of the pit, are suggestive of these residues being *in situ* in the basal pit of a non-slag tapping furnace. The furnace has not itself been directly dated, nor has the ditch segment [1100] containing iron smelting residues. However, ditch [1100] has been interpreted as being of the same phase as ditch [1012] (being separated from it by a possible entrance) which produced a single 8th – 10th century 14C date.

Two of the fills of 'postholes' of Building 2 that yielded examples of the mostly smithing assemblage have also yielded 14C dates: [1231] (7th-8th century) and [1227] (15th-16th century). Across the remainder of the site most of the 14C determinations produced early medieval dates, including four postholes implicated in

'Building 1' that surrounds furnace [1114]. For Building 3, as with Building 2, one result was early medieval (from posthole [1209]), but the other (from posthole [1207]) was medieval (15th – 16th century).

The first question this raises is whether these cuts are indeed postholes. The apparent presence of packing stones in many, together with the apparent rectangular outline of Building 2, would argue that they are. It appears none showed evidence for in-situ burning, such as might be expected if they were smithing hearths.

The similarity of the metallurgical debris present in postholes [1082], [1084], [1218], [1220], [1226], [1228], [1230] and [1236] suggests either that they received input from a single contemporary source, or perhaps that they all received fill from the same earlier source. In the former model, Building 2 might be considered to be a smithy, in the latter, Building 2 might have been constructed over a pre-existing deposit – perhaps a slag dump, that has now been truncated and removed, except where its deposits became incorporated into the postholes. This second alternative would allow the late medieval/early post medieval radiocarbon dates to represent the age of the rectangular buildings, whereas the early medieval dates would represent the age of the slag dump over which they were built.

The present evidence is probably insufficient to resolve this important question, but it should be one of the goals of the post-ex programme.

The presence of what appears to ore, not only in the furnace, but also in the postholes, is very interesting. It suggests, perhaps, that the deposits reworked into the postholes represented not just a slag dump, but materials that accumulated during preparation of materials for smelting. This is important, for it also increases confidence that the smithing and smelting operations on the site were contemporary. The limited evidence for SHCs is currently biased towards smaller examples, that might more typically be associated with blacksmithing than bloomsmithing (the working of raw smelted iron bloom into a usable product).

The evidence for the possible Irish style of ironworking is interesting. The radiocarbon dates suggest that the site predates the development of strong Scandinavian settlement in the area, but do not entirely discount the possibility of Hiberno-Norse influence. Although shrouded in myth, the supposed Irish connection with the founding of St Bee's Priory in the 9th century also hints at connections across the Irish Sea.

Further work

The assemblage presents significant opportunities for improved understanding through additional scientific analysis. The Field 23 assemblage represents a unique opportunity to investigate early medieval iron production, with a variety of smelting slag types and associated iron ore. The refining of the iron may also be addressed through examples of smithing slag, micro-residues and associated materials. These materials should be capable of generating chemical analytical data with which to construct a mass balance model for both phases of the process (using the methods of Thomas & Young 1999a, 1999b and later versions e.g. Young 2016c).

This work should be accompanied by a thorough revision of the associated features in order to improve understanding of the potentially-associated structures, and to determine whether other metallurgical features may have gone un-recognised amongst the group of pits and postholes.

The Site 22 materials (smelting residues and ores) would be worth further investigation both to permit more detailed comparison of these material with their counterparts from other areas of Britain (e.g. Young 2014e, 2015; Young & Poyner 2014) and to compare the nature of the resource exploited in the later middle ages with that exploited in the early medieval period.

A full costed programme of suggested analytical work is attached.

This assemblage is of great significance and the complete collection should be deposited, after the completion of the post-ex investigations, along with the site archive in an appropriate institution.

References

CREW, P. 1987. Bryn y Castell Hillfort – a Late Prehistoric Iron Working settlement in north-west Wales. *In*: SCOTT, B.G. & CLEERE, H. (eds) *The Crafts of the Blacksmith*. 91-100.

CREW, P. 1989. Crawcwellt West excavations 1986-1989. A late prehistoric ironworking settlement. *Archaeology in Wales*, **29**, 11-16.

CREW, P. 1991. The Experimental Production of Prehistoric Bar Iron, *Historical Metallurgy*, **25**, 21-36.

CREW, P. 1998. Excavations at Crawcwellt West, Merioneth, 1990-98: A late prehistoric upland ironworking settlement. *Archaeology in Wales*, **38**, 22-35.

CREW, P. 2009. *Iron working in Merioneth from prehistory to the 18th century*. Darlithiau Coffa Merfyn Williams Memorial Lectures No. 2, Snowdonia National Park/Plas Tan y Bwlch, Maentwrog. 40pp.

ESCHENLOHR, L. & SERNEELS, V. 1991. *Les bas fourneaux mérovingiens de Boécourt, les Boulies (JU, Suisse)*. (Porrentruy; Cahier d'archéologie jurassienne, 3) 144 p.

HASLAM, J. 1980. A middle Saxon iron smelting site at Ramsbury, Wiltshire. *Medieval Archaeology***, 24**, 1-68.

PINE, J., ALLEN, J.R.L. & CHALLINOR, D. 2009. Saxon iron smelting at Clearwell Quarry, St Briavels, Lydney, Gloucestershire. *Archaeology in the Severn Estuary*, **20**, 9-40.

REED, S.J., JULEFF, G. & BAYER, O.J. 2006. Three late Saxon iron-smelting furnaces at Burlescombe, Devon. *Proceedings of the Devon Archaeological Society*, **64**, 71-122.

SHEPHERD, T.J. & GOLDRING, D.C. 1993. Cumbrian hematite deposits north-west England. pp. 419-4445 *In:* PATTRICK, R.A.D. & POLYA, D.A. (eds) *Mineralization in Britain*, Chapman & Hall.

TEBBUTT, C.F.1982, A Middle-Saxon ironsmelting site at Millbrook, Ashdown Forest, Sussex, *Sussex Archaeological Collections*, **120**, 19–36.

THOMAS G.R. & YOUNG, T.P. 1999a. Bloomery furnace mass balance and efficiency. *In:* POLLARD, A.M. (ed) *Geoarchaeology: exploration, environments, resources*, Geological Society of London, Special Publication, 165, 155-164.

THOMAS, G.R. & YOUNG, T.P. 1999b. A graphical method to determine furnace efficiency and lining contribution to Romano-British bloomery iron-making slags (Bristol Channel Orefield, UK). *In:* YOUNG, S.M.M., BUDD, P.D., IXER, R.A. and POLLARD, A.M. (eds). *Metals in Antiquity*, British Archaeological Reports International Series, **792**, 223-226. Archaeopress, Oxford.

YOUNG, A. & YOUNG, D.E.Y, 2013. The Bristol and Bath Science Park (Spark), Emersons Green, South Gloucestershire. Archaeological Excavation (Excavation Area 1) and Recording Project 2010. Unpublished Report, Avon Archaeological Unit.

YOUNG, T.P. 2005. Evaluation of archaeometallurgical residues from the Heath-Mayfield N7 development (03E0151, 03E0966, 03E0461, 03E0603, 03E0633, 03E0679, 03E0602, 03E0635). *GeoArch Report 2005/12*. 28pp.

YOUNG, T.P. 2008. Archaeometallurgical residues from Cherryville Site 12, Kildare Bypass. 01E0955 *GeoArch Report 2007/24*. 33pp.

YOUNG, T.P. 2009. Archaeometallurgical residues from Ballykilmore, Co. Westmeath, E2798, *GeoArch Report 2009/16*, 81 pp.

YOUNG, T.P., 2011a. Archaeometallurgical residues from Little Furnace Wood, Mayfield, East Sussex. *GeoArch Report 2011/21*. 75 pp.

YOUNG, T.P., 2011b. Archaeometallurgical residues from the N7 Castletown to Nenagh scheme, Camlin 3 (E3580), Co. Tipperary. GeoArch Report 2011/23. 62 pp.

YOUNG, T.P. 2011c. Some preliminary observations on hammerscale and its implications for understanding welding. *Historical Metallurgy,* **45,** 1, 26-41.

YOUNG, T.P. 2012. Appendix 3 -. Exploiting the bog -: iron production and metalworking, pp. A3.1 – A3.60 *In:* P. Stevens & J. Channing, *Settlement and Community in the Fir Tulach Kingdom*. National Roads Authority and Westmeath County Council.

YOUNG, T.P. 2013a. Assessment of archaeometallurgical residues from Twinyeo Farm, Devon. *GeoArch Report 2013-31.* 14pp.

YOUNG, T.P. 2013b. Proposal for analysis of archaeometallurgical residues from Culmstock Road, Hemyock. *GeoArch Report 2013-33*. 7pp.

YOUNG, T.P. 2014a. Archaeometallurgical residues from Dwr-y-Felin School,Neath (GGAT 677 & 716). *GeoArch Report 2013-27.* 53pp.

YOUNG, T.P. 2014b. The archaeometallurgical residues, pp. 86-92 *in*: C. Smart, *A Roman Miltary Complex and Medieval Settlement on Church Hill, Calstock, Cornwall: Survey and Excavation 2007-2010*, BAR British Series 603.

YOUNG, T.P. 2014c. Assessment of archaeometallurgical residues from Milbury Farm, Exminster, Devon (ACD478). *GeoArch Report 2014-09*. 16pp.

YOUNG, T.P. 2014d. Archaeometallurgical residues from Twinyeo Farm, Devon (ACD170/ACD504). *GeoArch Report 2014-10*. 52pp.

YOUNG, T.P. 2014e. Archaeometallurgical residues from Culmstock Road, Hemyock, Devon (ACD591). *GeoArch Report 2014-11*. 43pp.

YOUNG, T.P. 2014f. Report on Archaeometallurgical residues from Torr Quarry, Leighton, Wanstrow, Somerset. *GeoArch Report 2014-12*. 63pp.

YOUNG, T.P. 2015. Archaeometallurgical residues from Site 42N (Cinder Hill), Cutacre, Salford. *GeoArch Report 2014-34*. 36pp.

YOUNG, T.P. 2016a. Archaeometallurgical residues from Churchills Farm, Hemyock, Devon. GeoArch Report 2015/31 108pp.

YOUNG, T.P. 2016b. Metallurgy. pp. 26-30 *in:* T. Havard, T. Darvill & M. Alexander, A Bronze Age Round Barrow Cemetery, Pit Alignments, Iron Age Burials, Iron Age Copper Working, and Later Activity at Four Crosses, Llandysilio, Powys, *Archaeological Journal*, **174**, 1-67.

YOUNG, T.P. 2016c. Ironworking residues from Tregurra, Truro, Cornwall, *GeoArch Report 2016/38*. 125pp.

YOUNG, T.P. & KEARNS, T. 2010. Evaluation of metallurgical residues from Caerleon Junior School (CA/JS/07). *GeoArch Report 2010/17*, 7pp.

YOUNG, T.P. & POYNER, D. 2014. Two medieval bloomery sites in Shropshire: the adoption of water-power for iron smelting. *Historical Metallurgy*, **46**, 78-97.

Table 1: summary catalogue. Assm = assemblage, FHS = flake hammerscale, SHS = spheroidal hammerscale, SHC = smithing hearth cake. All weights in gram.

Context	Sample	Bag label	Sample weight	Item weight	Item no.	Item notes
field 23						
1083	hs			<1	assm	spikey white fused sand, slag, fired clay
1085	<1011>		112	102	1	piece of dense slag with charcoal, complex shape, with some dimpled surfaces
				10	1	rock fragment - natural
1101	<1021>	1 of 5	460	78	28	small flow slag
				360		indeterminate weathered slag fragments
				8	6	vitrified lining
				1	<1	slag flat
1101	<1021>	2 of 5	7160	126	1	down flow with smooth, non-wetted, rear face and slightly prilly, blebby front face
				2720	30	charcoal-rich FB type slags with no original margins, some pieces show rare stone clasts
				672	16	charcoal-rich FB type slags with a least one surfaces showing slightly lobate or prilly slags
				846	1	denser block of FB-type slag with apparent contact surface on two surfaces- so possible foot of wall piece?
				1120	1	large block, probably slightly incomplete showing dimpled surfaces above and below, like large SHC, (110)x160x55mm
				20	1	small fragment of charcoal-rich slag with slightly lobate reddened surface - potentially from proximal upper surface
				900	1	concavo-convex block, 130x170x55mm, could be from furnace base or SHC
				378	3	dimpled nubs of slag, all slightly complex, non-diagnostic
1101	<1021>	3 of 5	1170	10	1	lining slag
				162	71	small flow slag
				952	c. 500	indeterminate weathered slag fragments
				2	<2	lining
				1	<1	slag flat
				4	2	stones
1101	<1021>		8155	892	1	top of FB/large SHC
				848	1	base of charcoal rich mass
				1240	1	charcoal rich mass showing internal flow lobes towards one side
				380	1	possible bowl margin of charcoal rich slag with flow lobes near margin
				148	1	possible small SHC, base prilly into grey clay, top almost granular, 70x65x30mm
				518	1	planar reduced wall in contact with somewhat prilly charcoal rich mass
				700	1	dense highly altered slag mass - essentially charcoal and rust; could even be bloom fragment
				530	1	dense fb like mass of amalgamated tiny prills and charcoal
				1735	12	pieces of highly weathered concretionary material - probably originally slag
				104	4	pebbles
				278	1	pit wall fragment; internally amalgamated tiny flow slags; small area of smooth maroon lobed top; microdimpled sides
				782	washings	magnetic fraction of washings contains flake hammerscale

Context	Sample	Bag label	Sample weight	Item weight	Item no.	Item notes
1115	<1020>		1680	904	348	fine flow slag
				187	76	probable ore
				134	9	lumps with amalgamated flow slag
				62	1	fragmented large single flow slag lobe
				90	4	rather SHC-like slag, but unclear of origin
				<1	1	oxidised fired ceramic
				2	6	flow slag spheroids
				70	32	lining slag (includes a small amount of lining)
				207	170	slag debris
1115	<1020>		1540	822	1	semi-circular slag mass, probably a furnace bowl side mass of amalgamated mall flow prills; up to 45mm thick, base may have rested on ash, all charcoal very small, one possible fern leaf
				246	1	fairly classic amalgamated flow prills, largest charcoal clast c. 40mm across
				400	10	amalgamated flow lags in more sheet-like form; occasional clasts of furnace clay,
				46	3	concretions
				26	1	massive grey vesicular slag with ceramic contact rich magnetic residues do not contain any hammerscale
1115	hs		14	14	assm	small flow slag prill fragments, plus 1 lining spheroid 6mm and 1 dense spheroid 2mm
1115	hs		22	22	assm	mainly flow slag fragments, 1 vesicular slag chip, 1 small ore fragment, 2 dense spheroids
1115	hs		2	2	assm	charcoal, concretion, bloated ceramic, some denser material probably both slag and ore
1219	<1056>		250	210	1	very complex mass of lining slag, includes some almost burr-like curved all piece (but in buff fabric, not strongly oxidised); central area has hole and it is just conceivable this is a slag mass from the tip of a ceramic tuyère.
				36	1	small amalgamation of blebs of dense slag, non-diagnostic
1219	<1056>		1075	72	15	vitrified lining and related bloated ceramic
				28	16	sintery white glassy material, greenish glass (turning white), often slightly spiky
				2	7	lining slag spheroids
				132	45	lining slag in blebs and sheets
				71	326	dense slags, mostly blebs and prills, but some fragments of larger slag masses
				28	1	curved piece of vitrified oxidised-fired ceramic, resembles marginal section of tuyère
				172	1	complex mass of slag with included stone piece, possibly a deformed SHC
				38	1	charcoal rich slag fragment
				74	5	slag with concretionary material coating - pale and soft, slag below is concealed
				112	221	slag debris
				8	5	possible ore
				<1	3	charcoal
1219	hs		1	<1	assm	some FHS, charcoal and single large spheroid (6mm)
1221	<1057>		116	26	20	dense smooth slag, including one mini flow slag block
				2	1	possible ore
				32	1	curved, beard like slag, 40mm radius of curvature to inner smooth size, finely prilly on the outer side
				<1	2	low density spheroids, c. 4mm diameter
				10	20	irregular rusty brown slag fragments

Context	Sample	Bag label	Sample weight	Item weight	Item no.	Item notes
				24	10	lining slag in greenish smooth pills and blebs
				12	13	whiteish sintered ceramic material, green glass in lens, but rough and white in had specimen
1221	hs			<1	assm	charcoal
1227	<1060>		910	42	49	stone/ceramic sintered by white/green glass
				98	39	conventional blebby lining slag with dark - green glass
				4	17	spheroids variably dense - glass, 2-10mm
				18	6	probable ore fragments
				56	8	concretion
				238	57	dense slags, mostly prilly and blebby
				46	1	plate like dense slag - almost a tiny SHC, but probably a basal puddle
				<1	5	possible lining ceramic
				197	205	dull rough mainly rusty slag debris
	small bag		186	150	1	60x90x40mm apparently small SHC, transverse; complex, bilobed prilly dimpled base and charcoal rich top
				36	1	small piece of slightly prilly slag around charcoal moulds - potentially part of a similar SHC
1229	<1061>		660	4	2	dark-coloured probable roasted ore particles with shrinkage cracking (magnetic)
				208	60	dense slag, mostly in small blebs and prills
				3	21	spheroids varying from green glass to dense slag - 2-8mm in diameter
				94	91	lining slag fragments
				20	12	vitrified lining
				6	14	oxidised fired ceramic
				20	3	concretions
				14	5	rusty pale FAS
				204	320	small rough rusty scraps of slag
1229	small bag 1		62	44	2	concretions with iron, also with fired clay and straw
				18	1	vitrified lining with deep green glaze
1229	small bag 2		1	<1	1	small fragment of post-med blue and white 'china'
1231	<1062>		176	42	26	dense slags, mainly in the form of very fine blebs and prills
				16	13	lining slag, mainly prills and blebs
				<1	1	lining slag spheroid
				6	8	vitrified lining debris
				30	1	large rounded nub of slightly lobate lining slag
				8	4	probable ore fragments, magnetic
				30	3	concretions
				42	66	small irregular slag scraps
1231	small bag 1		48	48	1	approximately quarter circle fragment of ashy, charcoal rich slag; nature uncertain, possibly, but not certainly, (part of?) incipient SHC
1231	hs			<1	assm	charcoal and charcoal -rich concretion

Context	Sample	Bag label	Sample weight	Item weight	Item no.	Item notes
1237	hs			<2	assm	FAS debris
Site 22						
3007	<5>	2 of 3	8490	4180	46	dense tapslag
				3565	59	low density tapslag and related material
				300	4	pebbles
				294	1	rusty concretionary mass
				88		dust and debris
3008	<6>	2 of 3	6841	6425	276	tap slag (weight includes a little dust and debris)
				68	5	natural quartz-rich vein material - gangue from ore - possibly natural
				144	22	lining and lining slag
				44	8	ore and reject fragments with fresh fractures
				64	11	other natural stone
				96	16	rusty slag- mainly charcoal-rich slag with heavy secondary oxide overgrowth
3025	<3>			6956	1	large block of breccia with iron oxides
				1655	4	smaller blocks of iron stained rocks
u/s	<4>			3925	1	Bowl-shaped slag with some edges missing, probably originally c240x300mm, 80mm thick, very iron-rich and rusted, tubular vesicles in basal 25mm crust; top low and lobate in some areas but others raised slightly with large charcoal clasts, probably 70-75%

Table 2: summary of residues, by type and context. SHC = smithing hearth cake, FHS – flake hammerscale, SHS = spheroidal hammerscale. Numbers = wts in grams, numbers in brackets = coal weights determined by separate investigation of coal. Tr = trace , y = present, yy=common.

fiill	cut	tapslag	smelting flow slag	probable smelting slag	indeterminate dense slag	SHC	other smithing slag	lining slag	vitrified lining	vitrified sand	slag spheroids	roast ore	ore	FHS	concretion
1101	[1100]		240		13735	1268		10	10					y	
1115	[1114]		1406	1222	297			70	1		2	187			46
1083	[1082]				y				y	y					
1085	[1084]				112										
1219	[1218]				257	172		342	100	28	2	8		y	74
1221	[1220]				36		32	36			1	2			
1227	[1226]				481	186		98	1	42	4				56
1229	[1228]				426			91	44		3	4			64
1231	[1230]				84	48		30	6		1	8			30
1237	[1236]				2										
3007		7745													294
3008		6425		96				144					112		
3025													8611		
u/s						3925									

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