

GeoArch

Report 2010/08

Evaluation of archaeometallurgical
residues from sites D1 and D5,
Avon SWW pipeline, Devon.

Dr Tim Young & Thérèse Kearns
March 10th 2011

Evaluation of metallurgical residues from sites D1 and D5, Avon SWW pipeline, Devon.

Dr T.P. Young & T. Kearns

Abstract

Site D1 yielded large quantities of highly fragmented glassy tin slag with a grain size ranging up to about 50mm. It remains unclear whether this material has fragmented during chilling or whether it has been deliberately broken. The material formed a major component of several deposits of waste, in part covering primary features of metallurgical purpose. The slag-bearing deposits were mostly within what appears to have been a small building, with a poorly-preserved wall forming its SW corner. Within this SW angle there were three cut features: one large pit and a gully in the south, both partially stone-lined and a second, smaller pit to the north which contained a mouldstone.

Although detailed interrogation of site records may assist with the interpretation of these features, they are not currently interpretable with any degree of confidence. Pits are not associated with later medieval/post-medieval tin smelting furnaces, so their role is hard to determine by analogy. Various speculative interpretations are discussed.

The nature of the slag assemblage suggests close parallels with that from the slightly older site at Crift Farm, which forms the only significant published analytical investigation of tin slags of the period. To assist with the development of a research strategy for Site D1, the evidence for medieval tin smelting technology is reviewed, the evidence from published slag analyses is reassessed and some proposals made for possible alternative models for the evolution of the technology during the medieval period. Analytical investigations to address these issues are suggested.

Site D5 is briefly addressed as an appendix to the report on the main assemblage.

Contents

Abstract	1
Methods	1
Results	
Description of residues	2
Discussion of the metallurgical features	2
Discussion of the metallurgical features	2
Interpretation	2
Discussion	3
Evaluation of potential	5
Suggested further studies	5
Appendix: Site D5	5
References	6

Methods

All investigated materials were examined visually, using a low-powered binocular microscope where necessary, and were summarily described and recorded to a database. As an evaluation, the materials were not subjected to any form of instrumental analysis. The identifications of materials in this report are therefore necessarily limited and must be regarded as provisional.

The large quantity of slag and its highly fragmented state meant that the usual approach of GeoArch to assessing assemblages (to examine and log every piece) was not a practical proposition. Instead, a methodology was adopted of checking the contents of all bags for any obvious variation, followed by examining material from a small number of bags in more detail.

Careful visual inspection of the residues was accompanied by other approaches, including panning of representative samples to check for the presence of any unreacted ore.

A summary description of the residues is followed in this report by a thorough assessment of the research potential of the material and a review of current understanding of medieval tin smelting.

Results

Description of residues

Large quantities of slag were retrieved from 18 different contexts at site D1. All of the material was highly fragmented and dominated by dark grey slag with a slightly matte surface with moderate density and glassy internal structure. The thickness of the macro samples ranges from 5-50mm. The slags fall into two main categories by overall texture – (a) thin (5mm) flat plates with occasional flow structures on their upper surfaces and (b) larger coarser examples with a more vesicular texture (i.e. frothier appearance).

Micro residues were also examined and seen to predominately consist of minute angular fragments of glassy slag. Some subsamples of fine-grained residues were washed and panned to assess whether the deposits contained any residual ore, but none was found.

No significant differences could be observed between contexts. None of the material preserved complete slag flows; all was fragmented. It is not clear whether the range of size fragments was due to deliberate crushing, or to simple fragmentation of a rapidly cooled vitreous material.

The prior sorting of the assemblages by size meant that simple visual comparison of the size of fragments from different contexts was difficult, but no significant variation was recorded. Assessment of the significance of the fines contained within the samples was also complicated by the prior sorting. Although samples did contain some very fine grained material, it was difficult to differentiate between genuine fines and material produced by abrasion with the bulk samples

These complications notwithstanding, the over-riding impression from these samples was one of homogeneity. Despite assiduous inspection of the residues no significant variation could be found between samples.

The materials closely resemble the description of samples from Crift Farm (Malham *et al.* 2002), with the exception that the present materials mainly apparently contain flowed materials with a tabular morphology, whereas the Crift slags were described as having a more rod-like form. However, both assemblages were reduced to similarly small-sized fragments which made recognition of original flow form very difficult.

Distribution of the residues

The metallurgical residues appear to be distributed across the site as spreads of waste material. None of the material could be considered as in-situ and it is quite possible that the slag-bearing contexts were not even primary dumps, but represent reworked waste (particularly perhaps where the slag-rich contexts overlies what appear to be the primary metallurgical features.

Discussion of the metallurgical features

Perhaps the most likely, although very speculative, configuration would be for a furnace to have been positioned to the west of the large pit [1398] (if so, it is not clear whether the furnace lay E of wall (1355), or whether the abnormally wide wall section N of the angle formed a

plinth for an elevated furnace), with the pit potentially functioning as a fore-hearth – or perhaps something akin to Agricola's 'dipping pot'.

The furnace structure itself in later blowing houses is essentially an upstanding structure, so easily lost through truncation. A common plan in the water-powered blowing houses (e.g. Outer Down, Hansford Worth 1927, plan redrawn by Tylecote 1986) was to mount the furnace in the thickness of a supporting wall, allowing separation of the bellows from the area of the float, and possibly, following the account of Agricola (1556), to keep materials from the charging of the furnace from falling into the float. Both Agricola's account and later ones of the blowing houses in SW England specify that the bellows were mounted opposite the tapping hole – and it seems likely that this would have been the arrangement in the 13th/14th centuries too.

Applying such a model to Site D1 is not easy. There appear to be two possibilities for the arrangement if the site is taken at face value and both pits [1395] and [1398] were close to a furnace. Firstly, given the poor preservation of the walls, it is not impossible that the bellows might have lain in the concavity on the west of the wall (west of (1355), if wall (1352) was actually internal to the structure. This would imply perhaps that [1398] may have been in the general area of the fore-hearth. If wall (1352) was an external wall, then the blowing is likely to have been from the south (since the pits [1398] and [1395] lie to E and N of the likely setting) and pit [1395] would have been in the fore-hearth area. The available space between (1355) and the internal angle of the wall is small, but not impossibly so, for bellows of the type likely to have been employed (Tylecote 1986 shows bellows only about 1.2m in length for the water powered Outer Down blowing house). At this period is not impossible that an arrangement similar to that employed in contemporary smiths' hearths would have been employed – with an overhead pivoted bar allowing the person blowing the bellows to stand in front, or to the side of the bellows, rather than to their rear. The presence of a stone-demarcated compartment (1353) in this corner, however, hints at the presence of a storage bin in this area, rather than bellows.

Several contexts in gully [1372] also yielded slag, of the same general character as that from the other deposits. A gully on the northern, upslope, side of the metallurgical building would probably have been designed to keep surface waters clear of the furnace area.

Interpretation

The site interpretation is not easy because of the partial nature of the preservation. The large quantities of slag filling and overlying the cut primary features, suggests that much of the slag recovered is either not in primary dumps, or that it was dumped in this area when the tin smelting was being conducted elsewhere on site.

The cut features, with burnt deposits and the granite mouldstone appear to be associated with tin smelting – but there is just a slight possibility that they relate to some other activity within the tin smelting site. They lack, on the currently presented evidence, any conclusive evidence to identify their precise nature. The stone lined gully [1354] could potentially be associated with the tapping of the furnace (although significant heat alteration might be expected if that were the case), but alternatively might be associated with drainage of the furnace location.

The presence of a mouldstone probably indicates that at least parts of the technique were similar to those documented in later periods, in which the tin would be ladled into a mouldstone after separation of slag in the float (and possibly after drossing in an iron pot). The pits might have various interpretations in such a setting:

- a location for a fire to warm a drossing pot,
- a dipping/tapping pot of the Agricola technique,
- a float,
- a setting for float (float stone?) at an elevated level.
- a pit for receiving the slag scraped sideways off the float

Detailed revision of the morphology of these features may assist with the interpretation.

The slag on the site was highly fragmented and although it is tempting to see this as part of a recycling process to extract tin prills from the slag it is far from certain this was the case. If slags were crushed to extract prills, then the practice, at least in later periods, would be to resmelt, using a slightly different technique, all the reduced slag. Thus, it would be expected that the tin would be removed, leaving a relatively prill-free slag, plus perhaps fine-grained waste from the rushing of the primary slags. At Crift Farm (Malham *et al.* 2002) this appears not to be the case; the slags were all prill-rich and they argued that the dumps of slag at Crift Farm were from primary smelting.

Discussion

The simple account of medieval tin smelting, as usually described, is that black tin (cassiterite ore, mainly from stream workings at this period) was taken to a blowing house or other smelting site for smelting. It was placed in a pre-heated furnace (blown by bellows) where temperatures of at least 1150°C were employed. Once the reduced tin became molten, it flowed from the furnace into the fore-hearth (effectively a reservoir where the tin-slag system stabilised and known as a float stone) from where it was ladled into a trough cut into granite called a mould stone and left to cool to form an ingot of white tin. Wood charcoal appears to have been the dominant fuel type used, however peat charcoal was also exploited (Carew 1602).

However, such accounts rely heavily on written accounts of early post-medieval smelting and, in reality, the technology of early tin smelting in SW Britain remains very poorly understood. Despite a moderately good documentary history, the physical remains of the industry have been little investigated. The conventional model for the evolution of tin smelting is that fairly early in the medieval period manually-blown smelting facilities were superseded by the water-powered 'blowing house', the earliest documented example of which in Britain was at Lostwithiel, where in 1332 a 'Blouynghous' was serving Blackmore stannary (Hatcher 1970; Greeves 1991). Documents, particularly leases, of the 15th and 16th century show that use of the term 'blowing house' had spread widely across the SW in this period. Blowing houses are much better known in the post-medieval period, with the earliest comprehensive written descriptions dating to the late 17th century (Earl 1985 cites descriptions from 1664 by Cotton and an anonymous description from 1671). Earl (p. 155) also quotes a sixteenth century account of some details of the furnace, but this provides little of the broader technological context of the detail. One of the earliest descriptions of tin smelting in Europe is given by Agricola (1556) and the techniques appear to have been fairly standardised across Europe by this time. A full, if late,

description of the SW British blowing house was given by Pryce (1778).

The question of what was employed before the blowing house has not been fully resolved. The site of Crift Farm (Cornwall) provides a model for smelting in the early 13th century. This site appears to be a longhouse that was converted for metallurgical use with construction of both an internal smithy and an external extension apparently housing tin smelting. The site lies at moderate altitude, away from a watercourse, and is assumed to have employed a furnace blown manually. Initial studies of slag from this site were conducted by Tylecote (Tylecote *et al.* 1989) and Adriaens (1996). A later, more extensive study of the Crift Farm slag was conducted by Malham *et al.* (2002), who examined the slag using optical microscopy and SEM-EDS. Microscopic analyses showed that the slags were extremely glassy with light and dark banding, the lighter areas being enriched in tin (Aylett 1996, Adriaens 1996) as well as numerous prills of tin trapped in the slag matrix. Results of SEM-EDS analyses showed great variability within single slag samples that was explained by variations in furnace conditions during smelting, as well as by variations in the furnace charge.

Despite the large quantity of slag at Crift Farm (estimated at 5 tonnes), the excavators found no trace of a furnace, which they surmised was likely to have been a hand-blown elevated furnace built of granite blocks.

Crift Farm has not been described as a blowing house. It lacks water power and was not apparently a purpose built structure.

At first sight, the 13th-14th centuries should represent a transition from manual- to water-powered blowing and the evolution of the blowing house. The analyses of Malham *et al.* (2002; discussed further below) would appear to suggest that although the technology varied in terms of power, the metallurgical process remained rather unchanged. It seems likely however that the issues are not quite that simple.

Examination of the historical evidence paints a rather different picture and Greeves (1991) states:

In the 12th century all tin was smelted twice. After the first smelting, which presumably took place near the tinwork itself, a tax of 30d per thousandweight (1200 lb) had to be paid; it was then taken to a market town for a second refining smelt after which it could be sold ... From 1198 an additional tax of one mark per thousandweight had to be paid on tin of the second smelt By 1303 both these taxes had been abolished and replaced by one on the finished metal of 1s 6³/₄d per hundredweight (120 lb). This suggests that at some time during the 13th century there had been an improvement in smelting technique which obviated the need for two smelts, and it may well be that the blowing house, or tin blast furnace, which survived in its basic form until the 19th century, was evolved at this time.

In other words, Greeves implies that an early two-stage process was replaced by the later blowing house, which then survived in use for many centuries; either the metallurgical process was changed by the change of power, or that parallel changes in technology and power took place in this period. There are, however, other interpretations that can be placed on this account.

If two smelts were required, then the reason would most likely be either that the product of the first smelt was rich in iron (giving rise to so-called 'hard head', an iron-tin intermetallic) or that there was insufficient metal-slag separation. If a smelting furnace is operated under very reducing conditions to produce a slag with a low tin content, quantities of iron are also produced, which take with them somewhere in the region of nine times their own weight of tin – commonly referred to as refining dross. On the other hand, if the furnace is operated under less reducing conditions, the resulting slag can contain up to 15-20% tin which must be subsequently retrieved (Smith 1996). It is possible that it was this balance that was changed by the 12th-13th century tin smelters. This issue with poor slag-metal separation was addressed in the post medieval period through use of the float/fore hearth. Medieval practice is not known.

Another facet of early tin smelting in the blowing houses which is difficult to reconcile is the resmelting of the slag. To quote Earl (1985):

The emphasis on the stamping, concentration and return of the 'head' collected from the slag resulting from the first melting make it probable that at many sites any glassy slags that are found will be the reject from the final, second treatment- the first melting slag refuse reporting as fine fragments in the tails from the concentrating operations

It is certainly not clear at the present time, whether such a remelting would have been part of the medieval practice of tin smelting. The introduction of stamps is probably relatively late in the medieval period and whether crushing by hand was undertaken in preceding periods is unknown.

At Crift Farm, Malham *et al.* argued that the high tin prill content indicated against the slags being the waste from resmelting and that the large quantity of similarly sized slag fragments (with no large accumulations of crushed fines) also suggested that reprocessing was not being undertaken. Malham *et al.* also investigated representative blowing house slags – and not only found similar slag compositions, but also similar densities of tin prills. Quite bizarrely these authors made no real comment on this observation. The implication of these observations, which was not drawn by Malham and co-workers is surely that not only are the slags from the various sites they described the product of a similar reaction, but also that they have had the same treatment – if the slags from Crift Farm are from primary smelting, then so must be the samples from the various blowing houses that they examined (*contra* Earl's assertion quoted above). The only significant difference, albeit one not investigated by the authors, was that the blowing house slags had much higher iron contents – but it is quite likely that this may be due to the origin of the blowing house slags mainly from sites in Devon, where the iron content of the black tin is typically higher than it is for sites in Cornwall (like Crift Farm). The analyses by Tylecote (Tylecote *et al.* 1989) provide further examples of the composition of blowing house slags, although most of his 'medieval' examples are actually post-medieval.

This scientific data appears in stark contradiction to Earl's interpretation of the historical evidence. Indeed, there is, an almost complete disagreement between the archaeological evidence from the medieval and earliest post-medieval periods and the interpretation of the historical record. On one hand it has been argued that the blowing house technological package includes stamping and reprocessing

of slags, water power and the use of a floatstone (fore-hearth) to facilitate segregation of the liquid tin, and yet on the other hand the slags from a 13th century manually-blown site proved indistinguishable from those from 17th-18th century water-powered blowing houses.

Various scenarios could be invoked to explain this paradox. It is conceivable that the blowing house practices were not as uniform as commentators have suggested, and the blowing house sites sampled by Malham *et al.* were somehow archaic. Perhaps Crift Farm is not a good model to hold in apposition to the blowing house – and was effectively a blowing house in all but power source.

If, as suggested above, the shift from two smelts to one was something to do with reduction in the impurities in the single smelted tin, then a discussion of the impurities in the tin prills within the slags analysed by Malham *et al.* becomes important. In fact the tin at both Crift Farm and from the post-medieval blowing house sites was very pure, with that from Crift Farm showing iron at levels close to the detection limit of the equipment, but with no impurities above detection levels in the blowing house slags. This suggests that in both sets of samples the smelting technology was efficient in its separation of iron.

Could, for instance, an evolution in the use of the fore-hearth (float) be a more significant reason for the loss of the taxable second smelting? Agricola (1556), describing central European practice, states that slag and tin were tapped into the fore-hearth, which was bordered on one side by a raised wall with charcoal powder ready for covering the molten tin and on the other by a sloping lip over which the slags may flow or be scraped. The tin in the fore-hearth was tapped into the "tapping-pot" or "dipping-pot" from which was ladled onto copper moulds for casting. Other possible techniques and complexities were described by Pryce (1778) in his detailed description of the use of a reverberatory furnace, which employed a similar float to the earlier blowing houses. He describes the furnace tapping into a large float, from which the melt would be ladled up and poured back, to encourage separation of slag and metal. He also describes how much of the slag (with some tin) would remain in the furnace at the end of the main smelt. At this point the temperature in the furnace would be raised to encourage the slag to flow – giving a second flow of metal and eventually merely leaving 'hard-head' inside the furnace. Other accounts tell of the use of wet charcoal immersed into the melt to encourage separation of 'scoria'. It seems quite possible that the evolution of these techniques may have been the 13th century revolution leading to the end of the double smelt.

If this is the case, then it would permit Crift Farm to be considered, in terms of everything perhaps but blowing power, to be considered a blowing house. Current evidence suggests that the D1 site is closely comparable with Crift Farm – and so it sits squarely at the centre of this debate. It is probably, on current evidence, just slightly later than Crift Farm in date. Whether the structure was purpose-built for tin smelting is not known. It was not water-powered – so on current definitions would not be termed a blowing house. The slag assemblage, on the basis of this evaluation, is very similar to that from Crift Farm. However, compared with Crift Farm, Site D1 has much better field evidence which should be interpretable in terms of the physical smelting facilities.

Evaluation of potential

Site D1 offers an exciting insight into tin smelting technology of the 13th-14th centuries, a crucial period in its development according to conventional descriptions of its evolution.

Although D1 has been described as a 'blowing house', it is not entirely clear that this is what it should be called – if the definition of blowing house is taken to include the complete water-powered package. However, Earl quoted a description by Cotton of 1664 (Earl 1985, p. 154) and suggested (p. 155) that the "wall-bellows" referred to might have been manually blown. If it is possible that some later 'blowing houses' might not be water-powered then how complete were the other elements of the package? If some post-medieval structures which might be called blowing houses were not using water power – then how do you define the term and, perhaps more importantly, how can you document the origin of this style of smelting?

It seems quite likely that the switch from manual to water-driven blowing, may not have been a simple isochronous transition, but, like the uptake of water power for bloomery iron smelting, have taken hold progressively over the period 1400-1600.

The situation of Site D1 in an elevated position resembles that of Crift Farm – an apparently slightly older manually-blown site of the early 13th century. Crift Farm lacks any great detail on the arrangements within the supposed tin-smelting annex; Site D1 shows a much greater level of information from features (pits, gullies, mouldstone...) and seems potentially able to answer at least some of the technical questions left unanswered by Crift Farm.

The key questions that need to be asked of the residue assemblage and of the metallurgical features are:

1. what was the nature of the blowing?
2. what was the nature of the furnace? Was it a stone-built shaft furnace or something else?
3. what was the nature of the 'tapping area' of the furnace? Was it a well-developed 'float' as in later blowing houses, or something else?
4. what do the slags tell us about efficiency of tin extraction? Do the slags contain tin as a component of the slag? Do they contain tin prills? Do they have a significant iron content? Do they contain 'hard-head' (material dominated by the FeSn intermetallic).
5. what is the origin of the slags? Are they simple smelting slags, or the product of reprocessing the first generation slag?
6. why are the slags present as small fragments? Do the glassy slags naturally fragment to this size (as was presumably implicitly proposed for Crift Farm), or have they been broken? If broken, was this to facilitate identification of material suitable for recycling? Is there any evidence the fine material was to be recycled?

Since Crift Farm, very little work has been undertaken on tin smelting slags in the UK. The assemblage from D1 therefore presents a good opportunity to further our understanding of this important industry.

Suggested further studies

Analytical investigations of the tin slags should be undertaken to provide data on both slag and prill compositions. Such work would rely on the examination of polished blocks on the analytical SEM. The analytical work should encompass a sufficient number of specimens (perhaps 20) to describe the variation within the material as well as typical compositions (the variation was determined to be rather large at Crift Farm).

The analyses should address the variation of slag composition between dense and vesicular varieties, with a view to the determination of whether the slags include materials from within the furnace as well as scraped from the float (or otherwise tapped), and whether any of the slags arose from a drossing, lading or other induced separation.

Since the slag assemblages from the site have been determined by the evaluation to be very similar, further analytical work could be focused, for coherency, onto material from a single context, comparing slag pieces of differing grain size, texture and morphology (within the very limited range of texture and morphology actually present)

It is essential that investigation of the slag is taken forward in parallel with a detailed review of the field evidence relating to the various features and structures associated with the slag. Integration of this with the slag analyses may help to further the identification of the purpose of the features.

Appendix: Site D5

Material from site D5 derives from two contexts within what was described as a bowl furnace. Evaluation of this material suggests that it may possibly not be a tin-smelting bowl furnace, as suggested, although material from a recut does resemble tin slag. The material includes some that is apparently natural. The assemblage requires a full investigation under the analytical phase of the project to confirm its precise nature and, as discussed under Site D1, burnt pits on tin-making sites might have any of a multiplicity of origins (rather than being a bowl furnace *sensu stricto*).

Examination of the residues should be accompanied by a reassessment of the archive for this feature, including the context records and photographs, as well as review of potential archaeometallurgical information arising out of any environmental samples taken from contexts apparently lacking slag.

Samples of the possible tin slags should be examined on the SEM following the methodology outlined above for Site D1 and with a similar purpose. It is likely that the analysis between 4 and 6 pieces might be required to establish the nature and variability of the material, depending on the outcome of the detailed revision of the slags.

References

- Adriaens, A. 1996. Elemental Composition and Microstructure of Early Bronze Age and Medieval Tin Slags. *Mikrochimica Acta* 124, 89-98.
- Agricola, G. 1556. *De Re Metallica*. Trans. Hoover H.C. and Hoover, H.L (1950), Dover Publications: New York.
- Aylett, J. 1996. Medieval Tin Smelting and the Characterisation of Tin Slag from Crift Farm, Cornwall, unpublished BSc dissertation: University of Bradford.
- Buckley, A. & Earl B. 1990. Preliminary Report on the Tin and Iron Working Site at Crift Farm. *Journal of the Trevithick Society* 17, 66-77.
- Carew, R. 1602. *Survey of Cornwall*.
- Earl, B. 1985. Melting Tin in the West of England: A Study of an Old Art, *Historical Metallurgy* 19/2, 153-161.
- Gerrard, S. (2000), *The Early British Tin Industry*, Stroud: Tempus Publishing
- Hansford Worth, R. 1927. A blowing house in the parish of Chagford. *Transactions of the Devonshire Association*, 59, 343-345.
- Lewis, G.R. 1908. *The Stannaries – a study of the English Tin Miner*. Archibald Constable & Co. and the Black Book of the Exchequer, No. 10.
- Malham, A., Aylett, J., Higgs, E., & McDonnell, J.G. 2002. Tin Smelting slags from Crift Farm, Cornwall, and the effect of changing technology on slag composition. *Historical Metallurgy*, 36, 84-94.
- William Pryce (1778). *Mineralogia Cornubiensis: A Treatise on Minerals, Mines, and Mining*. London, Printed and sold for the author by J. Phillips
- Rapp, G. 1977. Trace elements as a guide to the geographical source of tin ore; smelting experiments. In: A.P. Franklin, J.S. Olin & T.A. Wertime, *The Search for Ancient Tin*, Smithsonian Institute, Washington DC.
- Smith, R. 1996. An Analysis of the Processes for Smelting Tin. *The Bulletin of the Peak District Mines Historical Society*. 13 / Historical Metallurgy Society Special Publication *The Archaeology of Mining and Metallurgy in South-West Britain*.
- Tylecote, R.F. 1986. *The Prehistory of Metallurgy in the British Isles*. The Institute of Metals
- Tylecote, R.F., Photos, E. & Earl, B. 1989. The compositions of Tin Slags from the South west of England. *World Archaeology* 20, 432-445.

GeoArch



geoarchaeological, archaeometallurgical & geophysical investigations

Unit 6,
Western Industrial Estate,
Caerphilly,
CF83 1BQ.

<i>Office:</i>	029 20881431
<i>Mobile:</i>	07802 413704
<i>Fax:</i>	08700 547366
<i>E-Mail:</i>	Tim.Young@GeoArch.co.uk
<i>Web:</i>	www.GeoArch.co.uk