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Archaeometallurgical residues from Tolgarrick Farm, Truro, Cornwall

Dr Tim Young
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Dr T.P. Young

Abstract

Archaeological investigations at Tolgarrick Farm produced evidence relating to two different periods of metal extraction: tin extraction in the Bronze Age and iron extraction in the Iron Age. Both phases of metallurgical activity raise questions about the nature and significance of the site, into which the ores were moved.

The tin ores are gravel grade, probably from tin-bearing gravels (alluvial placers) that lay within the lower valley fills (large deposits are known to have been worked from the Carnon Valley 5km SW of the site, but the valley of the Calenick stream, immediately south of the site is likely to have contained similar deposits). The tin ores are mainly contained in two pit fills, contexts (2092) and (2511). They comprise both natural cassiterite-bearing gravel in a range of grain size from approximately 2mm – 30mm (the sub-2mm fraction of the samples was not available, so it is unknown if there was also a sand-grade component) and crushed ore, mostly with a grain size of 2mm – 5.6mm with a small proportion of coarser material.

The only potential evidence for metallurgical activity on the site in the Bronze Age were some partially vitrified clay blocks that may have been tuyères. The vitrified areas were examined by hand-held portable XRF to test for contamination by metals, but no such contamination was found. If tuyères were employed in a shaft furnace then contamination might be expected, but if employed above the level of the ore in an open hearth, then it is conceivable no contamination might result – so the use of these objects in hearth-based tin smelting cannot be excluded.

Iron Age iron-smelting was represented principally by furnace [2178] (dated to 370-160 and 130-120 cal. BC, on the basis of a single radiocarbon date on probable oak sapwood), which produced an assemblage of approximately 104kg of slag, 80kg of which were lifted as a relatively complete 'furnace bottom', with the remainder mostly detached fragments of the original slag cake, together with 4kg of furnace ceramic. The furnace was probably a domed furnace with a 0.8m diameter furnace chamber and a 0.5m wide arch to the NE. It had been constructed over a pear-shaped cut, 1.15m in length, 0.80m wide and at least 200mm deep. The furnace bottom extended to a maximum of 650mm across the pit from the SW side. The blowing arrangements are unclear, but the symmetry of the furnace bottom suggests either blowing from the SW, or from both the SE and NW sides. The furnace pit had been packed with wood, including both round-wood up to a diameter of 45mm and split wood with a maximum dimension of at least 140mm. This provides a link with the method of working smaller slagpit shaft furnaces, rather than later domed furnaces with flat floors.

This remarkable structure represents the first such domed furnace recognised from the Iron Age of SW England. The presence of the entire furnace bottom slag suite is unusual and important. The 100kg weight for the furnace bottom compares with weights of just 20kg that are more typical (even locally on contemporary sites in the Tregurra Valley). Tentative modelling suggests that the furnace may have produced 65kg of iron per smelt. The technology of such large furnaces shows similarities with examples known in central Europe, as well as SE England.

A further 39kg of iron smelting residues of similar type were recovered from other features.

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Methods

The material described here derives from excavations at Tolgarrick Farm, Truro, Cornwall, conducted by AC Archaeology Ltd. This project was commissioned by Naomi Payne.

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 (apart from the pXRF analysis of potential tuyères). The identifications of materials in this report are therefore necessarily limited and must be regarded as provisional.

The possible tuyère specimens were analysed on a qualitative basis using a Bruker Tracer III-SD portable X-Ray fluorescence spectrometer (instrument belonging to the Department of Archaeology, Cardiff University, and the National Museum Wales). The instrument was operated with the Bruker 'yellow' filter (300µm Al + 25µm Ti), at 40kV and 9.60 µA, with a filament current of 189 µA, for 100s. The instrument was controlled by a PC running Bruker's S1PXRF software.

Results

Description of residues

A total of approximately 163kg of materials were examined. Most of these were from iron smelting with 108kg retrieved from Iron Age furnace [2178] and a further 39kg from a variety of other features. Some 3kg of retents containing a high proportion of cassiterite were recovered from three Bronze Age features. The collection also contained almost 13kg of fired clay, much in the form of perforated blocks that were probably related to the larger collection of fired clay objects described elsewhere (Poole 2016) It should also be noted that the assemblage assessed as fired-clay objects by Poole contained several items (Group 2) that she suggested might be tuyères. These have not been re-described here, but limited analysis is presented.

Cassiterite

Two contexts ((2092) and (2511)) produced significant assemblages of cassiterite-bearing materials (Table 2). A further context (2297) produced a single cassiterite-rich pebble.

The two large assemblages bear pebbles extending up to 63mm maximum dimension and 88g weight (2511) and 26mm and 18g weight ((2092). The larger pebbles in all three cassiterite bearing assemblages were rounded

In both cases, the assemblages contained a proportion of angular, rather than rounded material. Such angularity might reflect the immaturity of the sediment (although the larger clasts are dominantly moderately well-rounded), perhaps with such textural immaturity being more obvious in smaller fragments more strongly influenced by internal foliations. Angularity may also be due to natural breakage of the clasts (or even breakage during recovery). Thus, even in the absence of deliberate crushing, some of the material might be expected to be classifiable as angular under the methodology employed here. The most likely source of much of the breakage, however, is deliberate crushing of the originally more rounded clasts. In an attempt to reduce the number of naturally angular fragments, they have not been recorded as 'angular' if their surfaces show polishing, a separate indicator of textural maturity.

For the assemblage from (2092) only a relatively small proportion of the material was potentially crushed (some 13% by weight of the ore), with most of the crushed material being in the 2-5.6mm size fraction. For the material from context (2511) there was some broken material up to a grain size of 30mm, but again, the majority of the potentially crushed material was in the 2-5.6mm size fraction – but here comprising 47% of the overall ore assemblage by weight.

Context (2297) produced a single rough irregular pebble, measuring 40x20x17mm. It was formed mainly of a pale crystalline material, probably quartz, but had a variable texture with fine zones of darker colour. This was a cassiterite-bearing vein fragment, but of a somewhat different texture to those in the main two cassiterite-bearing assemblages.

Possible tuyères

Poole (2016) identified several objects as possible tuyères. These have not been re-examined in detail here, but a series of analyses were taken by handheld

pXRF of representative areas of vitrification and other heat alteration. The spectra from these analyses are illustrated in Figure 1.

In no case was the peak for tin present at above more than trace, background levels. However, there was some variation, with analysis '34 kf e face' showing considerably more tin and arsenic than the other samples, albeit still at very low levels.

In-situ iron-smelting residues

The most significant occurrence of iron-smelting residues was within furnace [2178]. Furnace [2178] (dated to 370-160 and 130-120 cal. BC, on the basis of a single radiocarbon date on probable oak sapwood) produced an assemblage of approximately 109kg of residues, 80kg of which were lifted as a relatively complete 'furnace bottom'. Of the recovered residues that were not attached to this block, approximately 20.6kg were probably originally contiguous sections of the furnace bottom, suggesting that it had an original overall weight of approximately 100kg.

The furnace was constructed over a cut, now 1.15m in length and 0.80m wide, pear-shaped in plan, with the deepest section (approximately 210mm surviving depth) towards the wider end. Although the cut was heavily truncated, the furnace bottom it contained survived to almost 300mm maximum thickness. The furnace bottom was approximately 700mm wide and extended (on its upper surface) 320mm anteriorly, and a maximum of 550mm. The main body of the cake was plano-convex, with a lower bowl filled by apparently flow lobed material, overlain by a layer of rusty slag with abundant fine charcoal. There was a marked lobate lip along the contact between the wall and the top of the lobed slag fill. The upper section of the furnace bottom showed overhanging furnace ceramic to a line approximately 50mm inward of the maximum rearward extent of the lobes. The upper surface of the cake was planar centrally, but to either side it showed a substantial upward extension of dense slag against the lateral walls. These dense slag masses were approximately 100mm thick, this leaving a central gap down to the planar surface of approximately 400mm width.

The rear and lateral faces of the slag bowl (below the lobed lip) show contact with shillet, fragments of which form an indurated coating to this side of the bowl. Anteriorly the base of the furnace bottom, as well as the base of many of the detached fragments, were formed of flow lobed slags, with a very shiny non-wetted surface. A large detached block weighing 5.5kg shows the flow-lobed slag formed a build-up 50mm thick in the base of the pit overlain by at least 110mm of massive, or at least not certainly flow-lobed, slag. The base of the furnace bottom shows a neatly rounded form beneath the lobate lip, but probably vertical sides above the lip.

The frontal face of the slag cake shows the open moulds of large wood fragments, with a maximum observed size of 80mm by 50mm by 35mm. Similar moulds occur in the detached material and presumably continue within the furnace bottom. Detached fragments of the furnace bottom show imprints of wood of at least 140mm in length. In the anterior region the lowest slags show lobate lower surfaces and thus do not show any interaction with the shillet substrate.

The surviving fragments of ceramic hearth lining are strongly foliated, perhaps because of the influence of phyllitic debris. The surviving layer is typically less than 25mm thick. It is preserved over perhaps an arc of 70° clockwise from a direction just off the axis of the cake, but only intermittently on the anticlockwise side. A short distance from the axis on the anticlockwise side a substantial piece of lining is preserved and has a much more oxidised colour than the longer section. This suggests the location of the blowhole, which must have been close to, or slightly anticlockwise of the plane of symmetry of the slag cake (perhaps from 10° anticlockwise of the axis of both slag cake and pit). Thus, it is reasonably certain, from both the bilateral symmetry of the hearth bottom and location of the reddening that the furnace was blown from a single direction (the south west), with the slag flowing anteriorly towards the narrow end of the 'pear'-shaped plan.

Images and drawings of the furnace during excavation show that some of the large detached blocks of slag were originally close to the wall at both sides of the anterior face of the furnace bottom, with no significant slag blocks found across the arc of the pit between them. This would support the suggestion that the narrow end of the 'pear'-shape formed a gap in the curving wall line and was probably either a simple arch, or probably more likely an extension to the furnace.

Context (2180) yielded two small fragments of slag film suggestive of being pieces from a slag film formed on the tip of a tool. Such films are common finds in smithing assemblages, where they form on the tips of the smith's tongs and poker – but in this instance they have a shape suggestive of formation on the tip of a 42mm wide prise bar.

Ex-situ iron-smelting residues

There were some 31.9kg of iron-smelting slag and 7.2kg of furnace ceramic recovered from other features. This collection adds little to the understanding of smelting on the site, for they closely resemble the equivalent in-situ materials – including evidence for very thick furnace bottom slag. One important piece is a fragment of furnace ceramic from context (2288) that may be from the base of the 'bottle-neck' – the junction of the dome and chimney sections of the furnace superstructure.

Other materials

Very small quantities of other materials were recovered, including small amounts of fuel ash slag and one piece of possible clinker. None of these need necessarily be the residue from a metallurgical activity.

Distribution of residues

The stratigraphic distribution of the materials is summarised in Table 3.

Interpretation

Cassiterite

The two contexts ((2092) and (2511)) yielding significant assemblages of cassiterite-bearing materials are suggestive of partly-crushed caches of tin ore. A further context (2297with a single cassiterite-rich pebble is not certainly indicative of deliberate activity.

The cassiterite-bearing pebbles are moderately- to very well-rounded and range up cobble grade. These can be described as texturally mature, and abrasion of pebbles to such well-rounded form would require a high energy environment. The modern hydraulic environment in the rivers of Cornwall would not typically generate such pebbles.

The lower size range is uncertain because of the mode of sampling, but the rounded natural grains certainly range down to 2mm, although the range of 3-5mm diameter appears particularly abundant. The alluvial placer deposits are commonly interpreted as having supplied the majority of the cassiterite for early smelting. Limited examination (Camm & Croot 1994) of fine-grained alluvial placers has suggested they may contain angular cassiterite grains and fractured quartz – suggestive of an origin for the liberated cassiterite in periglacial conditions via head deposit; their most proximal section showed a concentration of tin in the 4 to 8mm size fraction. This would tally with the limited information available for the Tolgarrick caches.

Unfortunately the subsequent degree of disturbance of the gravels accessible to Bronze Age mineral prospectors means that it is not possible at present to trace collections such as the present one to any particular source. Alluvial placer deposits are known to have been worked from the Carnon Valley 5km SW of the site, and similar sediments may have occurred in the valley of the Calenick stream, immediately south of the site.

The largest of the present material is very coarse grained, with the larger pebbles showing particularly high degrees of rounding. This may alternatively (and probably less likely) suggest an origin in palaeo-littoral deposits. Camm & Croot (1994) suggested that such deposits may even be of Tertiary age. A palaeo-littoral origin might place the source rather further afield – perhaps a coastal raised beach, but more likely on high ground in the centre of the peninsula (as in the gravels of Polcrebo, Hill 1906, p. 88-89).

There is no certain evidence for tin smelting on site. However, the circumstantial evidence of close association with burnt deposits and with the possible tuyères is certainly suggestive. There were no finds of tin slag, but in the current lack of understanding of Bronze Age tin production, smelting in a shallow hearth with a low-slag process is not inconceivable.

Iron smelting

Furnace [2178] was represented by a pear-shaped pit. There was a sub-circular furnace chamber of approximately 0.80m diameter, with a gently sloping extension to the pit of approximately 0.50m width to the NE, strongly suggestive of a furnace opening on that side. Such an opening would permit both removal and slag clearance. The furnace did not have its walls preserved, but nonetheless some interpretation may be made of its likely superstructure, with the pear-shaped plan strongly reminiscent of that of Iron Age 'domed' furnaces. A reconstruction of such an Iron Age furnace is given in Figure 2.

Both the diameter of the furnace chamber and the potential width of the opening would be exceptionally large for a typical simple shaft furnace; at Crawcwellt West (300BC – AD50; Crew 1998a, 2009) for instance, the arched non-tapping shaft furnaces had internal diameters of 0.25-0.30m internal diameter, and at Derrinsallagh 4 (Young 2008h) an example was 0.36m diameter at the base of the pit, narrowing to 0.32m diameter at contemporary ground level, with an arch 0.26m wide. Much has been learnt about the functioning of such furnaces through the detailed experimental studies of Crew (1991).

For early (i.e. Iron Age and Roman) furnaces, the only large diameter examples are those with a domed (or bottle-shaped) superstructure, in which the lower section, the furnace chamber, is wider than an upper shaft (or chimney) section. It is also a characteristic of both Iron Age and Roman examples of these in Britain to have a very wide furnace arch.

The best-known examples of this general type in Britain are the very large Roman furnaces at Laxton, Northamptonshire (Crew 1998b). These had furnace chambers up to 1.50m in diameter with arches of 0.80m wide. Similar, but slightly smaller furnaces are now also known from the Weald, with examples at Little Furnace Wood (Young 2011b) and Bexley (work in progress), both of which had internal diameters of 0.7-0.8m and arches of almost a similar width.

Domed furnaces are also becoming increasingly recognised in the Iron Age of the SE of England. Of these, the best known are probably the examples at Sindlesham (Lewis *et al.* 2013) and Wokingham (author's work in progress). The Wokingham examples were flat-floored, pear-shaped in plan, up to 1m wide and 1.25m long, with an arch of up to approximately 0.8m wide. The Sindlesham furnace 505 was even larger, at 1.45m long and 1.35m wide, with an 'arch' 0.90m wide. Both Sindlesham furnace 505 and the earlier of the superimposed furnaces in Wokingham had flat floors below ground level, approximately on a level with an external working hollow – quite unlike the bowl-shaped pit below the furnace and the lack of an external hollow seen at Tolgarrick.

For the Tolgarrick furnace, a diameter of 0.8m is just too great for any meaningful ventilation from a single point in a shaft configuration. It is possible that such a large diameter might function in the same way as a Catalan hearth – with a process of lateral control on reduction, but it is more likely that this example is a domed furnace with multiple blowholes.

The furnace bottom shows raised areas of lining-influenced slag on either side, a central slag mass that only extended 75% of the way across the pit from the rear wall, and a zone of intense slag/wall interaction along the rear wall. Thus it is clear that the rear of the furnace was very hot. Lateral tuyères can leave the back face of the furnace relatively cold and it remains uncertain whether the furnace was blown with multiple tuyères to rear and side, or solely from the rear.

No iron ore was recovered from the site, but ore has been recovered from the neighbouring sites at Tremough (Young 2008b) and Tregurra (author's work in progress). At Tremough analysis has demonstrated that the ore was a gossan ore, quite possibly from the adjacent veins later worked by East Wheal Falmouth, which produced substantial quantities of gossan re in the 19th century (Dines 1956). The Tregurra ore is visually similar and may have a similar source (there is no known gossan local to that site). It would appear likely that Tolgarrick may have been employing a similar ore – in which case a source, or sources, in the Threemilestone – Chacewater area (of which Wheal the Falmouth area is the closest), 4km or more W of the site, may have been supplying ore to numerous smelting sites around the area of modern Truro.

Discussion

Cassiterite

The Tolgarrick caches of cassiterite parallel similar finds at both Tremough (Young 2008b) and Tregurra (work in progress). Finds of evidence for tin working in the Bronze Age have been rare, despite the probable large volume of extraction. The subsequent reworking of the tin stream deposits, particularly in medieval and post-medieval times, has left little possibility for evidence to survive within the areas that would have provided the tin ores in the Bronze Age. The existence of this cluster of sites, documenting the industry through the deposition of raw ore on higher ground adjacent to the placer-containing valleys, is thus particularly significant.

Iron smelting

The furnace [2178] provides a very important, unique insight into Middle Iron Age smelting in SW Britain. The single date from the furnace unfortunately covers a wide period of the Iron Age radiocarbon 'plateau', 370-160 and 130-120 cal. BC (SUERC-67876).

Very few sites of the Middle Iron Age are known in the SW: a smelting furnace (Young 2014b, work in progress) in the Tregurra Valley, 3km NE of Tolgarrick is more firmly dated to the 4th century BC (410-290 cal. BC; SUERC-64586) and the smelting at Trevelgue Head (18km N of Tolgarrick Farm) is also of 2nd-4th century BC age (Dungworth 2011). Slags of similar appearance (Young 2008a) to the present material on the Richard Lander School site at Tremough (3km WNW of Tolgarrick Farm) were in contexts apparently of Late Iron Age date.

Somewhat further afield, a site at Twin Yeo Farm, Devon, produced evidence for Middle Iron Age iron smelting (Young 2013, 2014a), with one feature containing Middle Iron Age pottery, and with an associated ring-ditch [1165] dated to 400-350 and 310-200 cal. BC. There are two other sites in the SW that may be indicative of Iron Age iron smelting in non-tapping furnaces: Berry Ball (Young 2009a) and Porthworthy (Young 2011c).

Across southern Britain in general, this period has produced evidence for two contrasting styles of furnace, best represented by smelting sites in the Thames Valley area apparently the dominant iron production area in southern Britain at this period). As well as providing evidence for domed furnaces (see preceding section), the Thames Valley sites show evidence for both narrow shaft furnaces (e.g. at Sindlesham, Lewis *et al*. 2013). Further north, in the East Midlands, the 'sunken shaft furnace' (or Wakerley-type) is more typical of the Middle and Late Iron Age (e.g Jackson. & Ambrose 1978).

The sites in SW England have not yet produced good evidence for furnace form, but Twinyeo and Tregurra are both suggestive of the use of medium-sized shaft furnaces. The Tolgarrick example in contrast, shows morphological features strongly suggestive of it having had a dome-like morphology, as described above.

The large size of the furnace bottoms from earlier Iron Age furnaces has been noted for some time, but the interpretation of the slag has not been possible on most sites in a lack of diagnostic evidence for the furnace type producing such large furnace bottoms. This includes, for instance, the large early furnaces with pits up to 1m across at Hartshill Copse (Young 2005a; tentatively dated to 6th-5th century BC on the basis of ex-situ slag occurring in dated structures to the south by Collard *et al.* 2006), the large furnace bottoms from Brooklands (Hanworth & Tomalin 1977) and the slags from .

A parallel interpretation of the significance of larger earlier Iron Age furnaces in Ireland has also developed over the last decade, with possibly the earliest furnaces at Lagavooren, Co Louth (dated to 520-380 Cal. BC; Young 2011a) represented by four burnt pits, 0.8 to 0.9m in diameter. The furnaces of the period from 400BC to 100BC in Ireland are dominated by examples with moderately large slag-pits, 0.4 to 0.6m in diameter. Numerous examples are now known including Ballydavid (Co. Tipperary; Young 2009c), Ballykeoghan (Co. Kilkenny; Young 2009d), Cherryville (Co. Kildare; Young 2008a), Cloncollig (Co Offaly; Young 2008c), Clonrud (Co. Laois; Young 2008g), Derryvorrigan (Co. Laois; Young 2008e), Leap 1 (Co Laois; Young 2009b), Lismore-Bushfield (Co. Laois; Young 2008f), Morrett D (Co. Laois;Young 2005b), Newrath Site 35 (Co. Kilkenny; Eogan pers. comm.). Two undated examples, but similar in morphology to those listed above, at Adamstown 1 (Co. Waterford; Young 2006) and at Tullyallen (Co. Louth; Young 2003b) produced slag assemblages with intact furnace bottoms, both preserving evidence for a coarse wood pit fill and weighing approximately 19kg and 18kg respectively. These intact furnace bottoms also show clearly that the furnaces were blown from a single blowhole (and therefore employed forced draught; Carlin 2008; Young 2003a). After 100BC furnaces are less well known, but include examples with arches; one well preserved example at Derrinsallagh (Young 2008h) showing at least slightly overhanging sides to the basal chamber.

Domed (or bottle-shaped) furnaces have mostly been associated with the Roman period in SE Britain, including, for instance, sites at Little Furnace Wood (Young 2011b) and Bexhill (work in progress). The largest examples occur in the East Midlands, where those at at Laxton, Northamptonshire, have been compared with examples at Clérimois, Yonne, France (Dunikowski & Cabboi 1995). Increasingly, however, domed furnaces are being recognised from within the Iron Age, as at Sindlesham and Wokingham, as described above. These earlier examples are similar to examples recorded from Germany (although the southern German examples are commonly dug into a bank to provide structural support; e.g. Garner 2011, 2014) and Austria as well as those from, Clérimois, France (Pleiner 2000, 163-172). SE England has also produced a number of medium-sized arched furnaces, for which the superstructure is, as yet, uncertain (Lewis et al. 2013; Young 2012). The Tolgarrick furnace provides strong evidence to extend the known distribution of dome furnaces and also provides an excellent set of residues which will facilitate comparison with other sites.

What has proved somewhat unexpected, is that the domed-furnaces in the SE of England (like the Tolgarrick example), appear to have been operated with an initial pit-packing of split wood, just as in the simpler slag-pit shaft furnaces. Thus, to date, the slag assemblages of the two furnace types have not provide to be able to be differentiated, unless the furnace bottom slag cakes are intact (or largely so). This is also true of the Tolgarrick example, but has not apparently been noted from the French and German examples.

This rather complex dataset may be synthesised by saying that there is evidence that earlier Iron Age furnaces in both Britain and Ireland were large. Arguments presented here would suggest that such large furnaces are likely to have been domed or bottle-shaped. Although there has been a tendency to view domed furnaces as a later Iron Age introduction to Britain, an alternative model, in which domed furnaces were amongst the earliest furnaces employed in Britain an Ireland, might be argued.

The place of such a large furnace within the local economy also requires consideration. As there is no analytical data from Tolgarrick, any consideration of production rests on the use of a mass-balance model derived elsewhere – which means results ae only very tentative. The gossan ore is a high grade ore, so the use of a comparative model from the Forest of Dean (also providing a high grade goethitic ore) may be appropriate (Thomas & Young 1999). In that model 1kg of raw ore would produce 340g iron and 540g of slag. If applied to this furnace, then the 103kg of furnace bottom suggests that 190kg of ore was charged and 65kg of bloom produced. These figures compare well to a recent experiment with a reconstruction Iron Age domed furnace (Figure 2; Romain Bohr pers. comm.) in which 2 runs with a total of 300kg ore and 600kg of charcoal produced 90kg high-carbon iron (60kg of which on the first run alone). This is in stark contrast to Crew's (1981) reconstruction of a Crawcwellt furnace, which produced raw blooms of approximately 2kg. The dynamic of assembling the resources to run a large dome furnace, even occasionally, is quite different from that of running a small furnace on a regular basis. The overall use of the site for smelting is, however, not possible to judge because very little residue survives on site – perhaps because of subsequent agricultural use, slope movement, and a lack of any large contemporary cut features.

There remains the considerable questions of what was the functional difference between the shaft and domed furnaces: whether they have the same extractive efficiency, whether they had the same fuel efficiency and whether they produced the same form of iron. Consideration of these issues is beyond the scope of the current project.

Further work

The slags from the furnace are unique and constitute a very important resource for future research. They should deposited with the site archive in an appropriate receiving institution. Ideally further work should be undertaken to analyse and understand the slag and the use of the furnace – even if this eventually requires funding from outside the development control system.

Similarly, the cassiterite-bearing retents are very important. They too should be retained with the project archive. Although detailed provenancing is not currently possible, it might become so in the future.

Figure Captions

Figure 1: XRF spectra for areas on the possible tuyères. The inset shows the part of the spectrum surrounding the Sn Kα and Kβ peaks, with the data normalised to their average value between 24.0 and 24.5 KeV to facilitate comparison between the different spectra.

Figure 2: reconstruction of an Iron Age domed furnace of similar dimensions to the Tolgarrick furnace [2178]. The reconstruction employs air blown through multiple tuyères from a mechanical blower. The Tolgarrick example would have required multiple sets of bellows. Reconstruction at Neuhäusgen, Luxembourg, April 2016. Photo by kind permission of Romaine Bohr.

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Table 1: summary catalogue of macroscopic materials. All weights in g.

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
1068			1	1	1	orange fired clay
1074			14	14	1	highly bloated grey material, probably a bloated stone fragment
1088			1725	1725	32	large blocks of fired clay, as with (1090) the most characteristic shape is a flat face with an abutting or intersecting apparently ?circular section hole of 80-100mm diameter
1088			2000	2000	10	as above
1088			1815	1815	4	as above
1088			1735	1735	17	as above
1089	49	5.6mm	294	162	3	soft fired clay with organic temper remainder large assemblage of very small pieces of mainly buff coloured soft fired clay
1090	bag1		2350	2350	24	large blocks of grey to buff fired clay, some with large re-entrant curves suggestive of placement onto timber or of channels
1090	bag2		2290	2290	28	large blocks of fired clay, some approaching 100mm thick
1105			238	238	8	buff/grey locally pink fine fired clay, some pieces apparently pressed onto large round sections
1107	53	5.6mm	4	2	5	vesicular pale fuel ash slag, very friable
1107			28	28	6	soft buff fired clay with possible organic temper
2000	area ext tr		28	28	3	silty fired clay with sparse organics, shows orange-grey gradation near surface

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2045			526	522	1	very dense block of slag, up to 65mm thick, prilly/lobate base, has base-parallel round-wood piece with cracking, 25mm in diameter and 85mm long
2063			2560	2560	4	FB material with large wood fragments, some with wedge shaped section, descending prills to discontinuous lower surface and rough top
2063			5270	5270	1	110mm thick FB, flow slag on one edge, very large base-parallel wood fragments, base locally with shiny lobes, but mainly rough with shillet inclusions
2078			8			
				8	1	small irregular slag lump
2092	47	5.6mm	402	granules and cobbles		cassiterite-bearing residue
2092	47	2mm	156	fines		cassiterite-bearing residue
2109			14	14	1	buff/grey fired clay with angular grit temper
2178			300			
				42	5	fired ceramic, buff-grey, some very well laminated with straw/grass inclusions
				254	6	dense vesicular slags, one with large charcoal mould, wall slags?
2178			20	18	1	angular fragment of massive slag
2178			1095	1040	1	large block of rather rubbly appearing, massive slag protruding forward into good flow lobes
				55	2	rather scrappy indurated lining material
2178			78	78	1	360mm diameter?? Oxidised fired ceramic with grey sandy surface, not deeply vitrified (texture as concavo-convex impressed piece)
2178	slags from edge (N+D+E)		202	78	4	dense slightly vesicular slags
				22	1	very glassy highly vesicular slag - from wall contact?
				102	1	charcoal rich furnace slag

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2178	loose slag under piece A		574	574	10	flow slags with large horizontal flow lobes and contacts with large wood fragments
2178	under pieces D-I		34	34	5	grey to buff fine fired clay
2178	piece a		5560	5560	1	part of FB front edge, 160mm tick, very dense slag, lower 50mm of so is 'cowpat' in hollow, then massive build up. Flow lobed material extends forward of massive material and also appears to descend over it. Basal surface rich in shillet, but also shows ribbed and ridged flows and some chilled lobes
2178	piece b		22	22	1	small flow slag fragment
2178	piece B		616	616	1	angular block of dense slag, a few ceramic inclusions and prills on base, suggests wall slag/dense FB
2178	piece D		508	504	1	very dense block of slightly vesicular slag,
2178	piece E		276	272	2	fragments of dense slag with crude tubular vesicles in contact with pale grey indurated wall material
2178	piece G		96	94	1	pyramidal block of grey indurated lining, veined with, and attached to, black glassy slag, lining appears to have been fissured
2178	Piece I		314	314	1	dense wedge-shaped slag sheet attached to very pale wall on one large face. Slag haematised and reddened, shows smooth top surface at 60 degrees to wall, suggesting wall is overhanging, other large face is a fracture. Pale wall curves around onto far face of wedge
2178	piece K		306	306	1	good flow slag mass around poorly defined voids
2179			2555	86	3	pale grey lining with very strong foliation
				422	1	dense slag with large charcoal moulds with contact against pale grey lining,
				646	1	block of sloping margin of pit side with prilly contact at 45 degrees to vertical, top of block shows lobate surface
				1345	10	variable density fragments of FB, mostly rough without large moulds, but does have small shillet fragments
				42	1	highly indurated and slagged lining with strong foliation

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2179			168	92	8	flow slag prills
				58	5	grey vesicular slags
				14	4	pale grey fired clay
2179			1745	998	10	very dense flow slags with large lobes, shows flow over exceptionally large wood piece larger than 140x40x30mm
				144	8	reduced fired ceramic, much in extremely well-foliated sheets, suggestive of smeared lining
				582	19	rough massive slags, variable vesicular to very dense, probably mostly slag from near wall/burr
2179			806	784	88	fired clay, buff and orange, none with vitrified surface.
				20	2	scraps of iron slag, one rough, indeterminate, the other probably a lining slag
2179			1150	760	71	soft grey orange variegated fired clay
				390	3	soft pinking fired clay with slightly vitrified surface, gravelly with fired clay inclusions, internal curvature is very large diameter
2180			2240	40	2	slag moulds of tool tip - probably prise bar tip 40mm wide, >12mm deep and possibly >24mm deep depending on reconstruction of two fragments.
				278	4	pale reduced-fired foliated wall variously intruded by slag, indurated and slagged
				740	4	dense massive rough slags, some with a few lobes
				698	2	flow slag blocks with large wood moulds
2180	piece k		1110	1110	1	wedge section dense slag block with very large wood moulds – round-wood to c45mm and other small pieces
2180	piece f		3430	3430	1	base of wall block, very dense slag attached in upper part to pale grey indurated wall, passing down into prill-based material. 80-90mm in front of wall passes forward into very black glass material (could this be an iron poor material close to bloom. Suggests FB greater than 140mm thick
2180			1290	1290	1	block of very dense FB material, no charcoal moulds, flow lobes towards base and probably a gravelly contact

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2181			316	316	7	very dense flow slag, mostly with relatively large lobes and indications of flowage around large fuel moulds
2182			296	296	1	very dense and rusty birds-foot type flow slag, locally with rather prilly base
2182	22	5.6mm	2900	484	27	good flow slag in isolated or amalgamated prills
				remainder	assm	rough slag, fuel moulds and slag films
2182	22	5.6mm	152	152	assm	assemblage of oxidised fired ceramic with some showing lightly vitrified surface
2183			178	178	4	slightly gritted fine red clay with pale laminae, very smooth surface overlain by slag with some underling vitrification. 3 small pieces probably broadly similar
2183			180	106	11	rough vesicular slag fragments
				74	2	dense flow slags
2183			106	102	2	very rough slags, perhaps physically damaged fuel moulds?, slightly brecciated during extraction?
				4	1	small concretion, probably on iron fragment
2183			668		22	variably slagged and vitrified oxidised fired lining. Some pieces show good evidence for relining. Ceramic is very mixed ,with pale gravel and red lumps suggesting some recycling of old furnace material
2183			66	66	2	vitrified slaggy chaotic wall material
				<1	1	flow slag droplet
2183	21	5.6mm	534	9	46	flow slag prills
				<1	3	stone
				<1	1	oxidised vitrified lining
				10	11	slag films
				472	335	rough slag debris

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2183	21	5.6mm	58	58	18	mostly buff/orange soft-fired clay fragments, largest has a grey sandy concave surface (and looks more like pottery); the concavity is too abrupt to be the real curvature of the furnace
2194			14	14	1	clinkery maroon vesicular slag with abundant white lithic inclusions
2245			166	166	10	grey/salmon fired clay with abundant fine shillet. Some pieces may be fired natural even?
2245			92	92	8	mainly rather sandy fired clay, the largest piece with a planar surface. One of the smaller pieces is reduced, others all oxidised.
2288			1015	1015	42	slagged and vitrified oxidised furnace ceramic. Ceramic fine to moderately gravelly, variable, no particular features observed
2288			838	838	16	fired clay, mostly slightly gravely, 8 pieces extremely gravelly, 1 very hard fired piece could possibly be from the base of a 'bottleneck', possibly narrowing to 200mm diameter (an important piece of very hard fired fabric) 2 pieces soft fine grey clay, no temper except a few shillet fragments
2297	35	5.6mm	42	42	1	40x20x17mm, rough irregular pebble, very dense, formed of pale crystalline material, probably quartz, variable texture with fine zones of darker colour. A cassiterite-bearing vein fragment.
2303			1425	944	4	flow slag blocks/FB blocks , one shows base and large wood moulds, others are more scrappy - despite being large, all may be bit worn
				326	1	unusual piece - plano-convex lump of rough slag with very fine charcoal - similar to sinter, and then the perfectly flat top is overlain by a lobe of flowed slag
				144	3	vitrified and intruded slagged wall of oxidised fired slag. Ceramic is slightly gravelly
2340			1020	654	4	dense FB material with some flow lobes
				286	7	indurated and slagged pale grey furnace wall, slagged surface very irregular
				74	1	small cube of dense slag with maroon surface attached to oxidised fired wall

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2340			4655	4380	1	large section of indurated furnace wall -probably below blowhole and above FB, 160mm tall, reddened ceramic in upper 75mm, lower part curves round towards bowl, upper front shows slag layer 40mm in front of main wall, this section supports spalled wall fragments at top; the curvature is of radius 180mm, but this is probably enhanced because of erosion below blowhole; indurated wall 50mm thick
				260	1	flow slag block with charcoal
2340			2375	1695	1	110mm thick surviving slab of FB, prilly base then multiple >150mm and 40mm wide/diameter base-parallel wood fragments. Lower part shows flow lobe development marginally
				668	1	FB with lots of c50mm equant wood/charcoal fragments
2342			12	12	2	fine grey fired clay
2448			2145	2145	2	two large FB blocks with wood up to 40x40x120mm
2448			1850	1850	11	large FB blocks with extremely large wood fragment
2509	45		<1	<1	7	fuel ash slag
2511	46	2mm	1526	bulk		cassiterite-bearing residue
2511	46	250micron	34	bulk		cassiterite-bearing residue
2511	46	5.6mm	966	bulk		cassiterite-bearing residue
2594			3170	3170	1	block of very dense massive FB material, hint of flow lobes near base, but otherwise indurate contact with slate - which was possibly in situ or at least structured, not as seen in other pieces
2635			40	40	3	open porous slags with large equant olivine, burr/body slags?
2635			3715	3715	1	FB with up to 160mm long wood pieces, base parallel, 130mm thick possibly as much as 150mm, passing to flow lobes at front

Context	Sample	Fraction	Bag wt.	Item wt.	No.	Notes
2635			3245	3245	1	large piece of FB, shillet on base, very large wood moulds, including twig possibly suitable for 14C
2683			926	926	1	large piece of FB with large flat wood sheet mould and flow lobes near shillet-rich base
2683			2075	170	1	lobate flow slag, shows fractured large wood mould at proximal end
				1900	4	very dense FB fragments with extremely large wood, split and round, some with 14C potential
2702			1660	1660	1	mould-rich FB material including split wood >130x80x20mm, multiple pieces of very large wood.
3000			56	56	8	buff pink fired clay with a few gravel inclusions
4000			88	74	1	rounded nub of grey iron slag
				12	1	black glassy slag, possibly a tin slag, but low density
4001			68	68	1	broken fragment of vesicular slag crust, possibly SHC, worn

Table 2: weights of samples containing cassiterite, subdivided by particle morphology.

(2511)

	rounded		angular		shillet	total
fraction	weight	% of total ore in sample	weight	% of total ore in sample	weight	
>16	319g	14%	56g	2%		375
>5.6	374g	16%	114g	5%		488
>2 (*)	34g5	15%	1114g	47%	57g	1516
>250micron	32g	1%		0%		33
total	1070g		1284g		57g	2411

(2092)

	rounded		angular		shillet	
fraction	weight	% of total ore in sample	weight	% of total ore in sample	weight	
>16	0g	0%	0g	0%		
>5.6	379g	72%	16g	3%		395
>2	77g	15%	52g	10%	21g	150
total	456		68		21g	545

Table 3: summary table of residues by context and material.

Context		fired clay	furnace lining	iron slag	FAS/bloated ceramic	tin ore	tool mould	iron conc	micro	clinker	
1068		1									1
1074					14						14
1088		7275									7275
1089		294									294
1090		4640									4640
1105		238									238
1107		28			4						32
2000		28									28
2045				522							522
2063				7830							7830
2078				8							8
2092						558					558
2109		14									14
2179			2220	4163							6383
2180			617	95202			40				95859
2181				316							316
2182			152	3196							3348
2183			971	754				4	19		1748
	furnace total		*3960*	*103631*			*40*	*4*	*19*		*107654*
2194										14	14
2245			258								258
2288			1853								1853
2303			144	1270							1414
2340			4941	3351							8292
2342			12								12
2448				3995							3995
2509					<1						
2511						2526					2526
2594				3170							3170
2635				7000							7000
2683				2996							2996
2702				1660							1660
3000		56									56
4000				74						12	86
4001				68							68
Total excluding furnace [2178]		12574	7208	31944	18	3084	40	4	19	26	54854

Figure 1

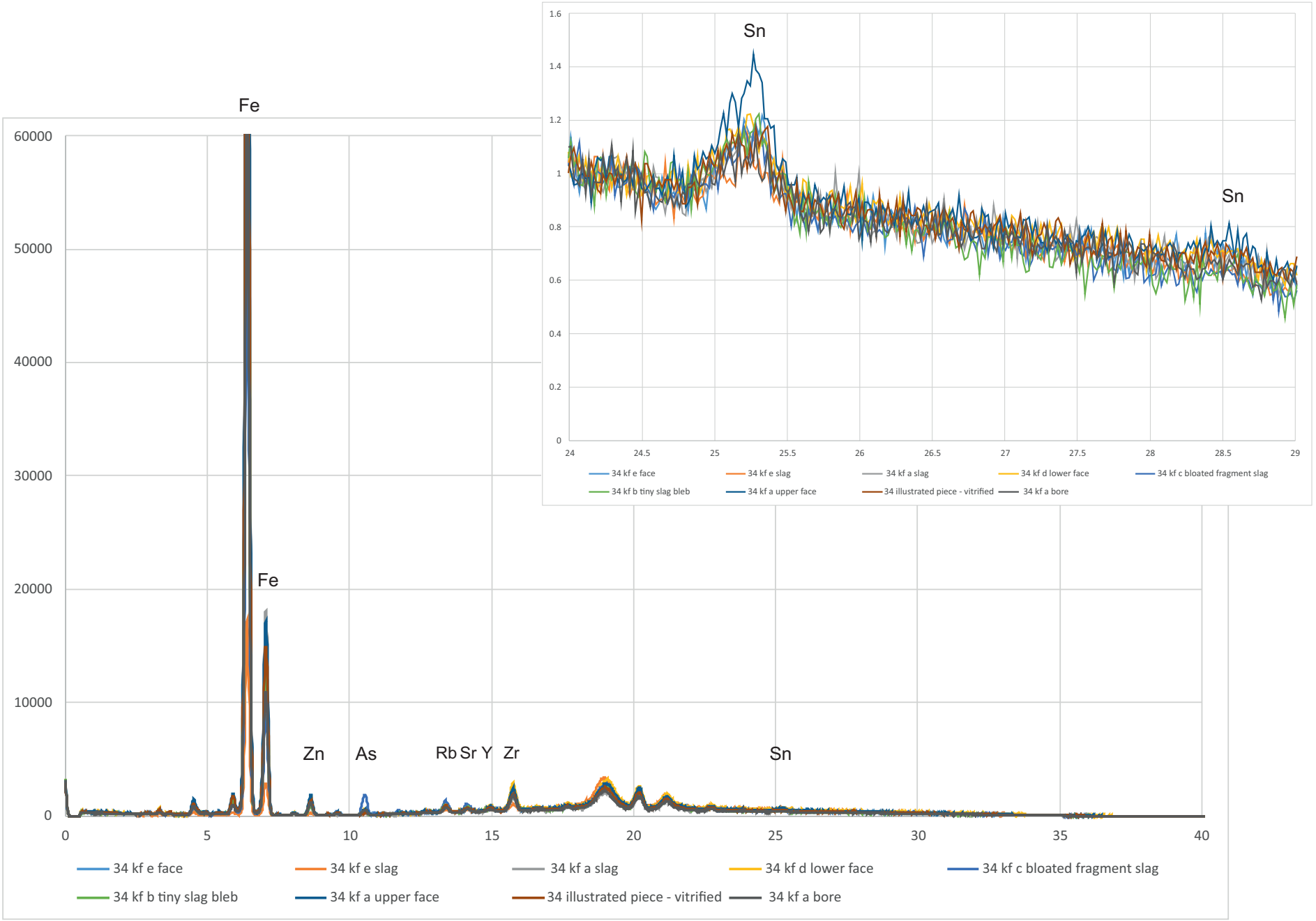
Fe
Fe
Zn
As
Rb Sr Y
Zr
Sn
Sn
34 kf e face
34 kf e slag
34 kf a slag
34 kf d lower face
34 kf c bloated fragment slag
34 kf b tiny slag bleb
34 kf a upper face
34 illustrated piece - vitrified
34 kf a bore

Figure 2

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geoarchaeological, archaeometallurgical & geophysical investigations

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

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