GeoArch

Report 2013/35

Assessment of archaeometallurgical residues from Cardiff Castle mill leat

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23rd December 2013

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Abstract

This report describes a small assemblage of approximately 6.5kg of archaeometallurgical residues and associated materials from archaeological investigations undertaken with the Cardiff Castle mill leat, Bute Park ,Cardiff (Archaeology Wales: mlbp-13/wb).The material mainly derived from waste dumps (c112/172) close to a stake revetment on the western bank of the leat.

The material mainly comprised dense, iron-rich, clinkery slags that can be identified as residues from the working of iron (blacksmithing) in a coal-fuelled hearth. Some of the slags occurred in moderately well-formed slag cakes (smithing hearth cakes), but much occurred as poorly consolidated small prilly lumps. Alongside the dense slags were lower density materials, mostly coal clinkers (and probably gradational with the more iron-rich slags) but also including vitrified materials that may have other precursors, probably either gravel or hearth wall ceramic.

The archaeometallurgical residues are accompanied by fuel-related materials that may be associated, but are not certainly so. These include fresh coal, coal residue (coke) and pieces of coal-coated ironstone, probably concretions from within a coal seam and present as impurities with the fuel.

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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 summary catalogue of examined material is given in Table 1.

This project was commissioned by Amelia Pannett, of Archaeology Wales.

Results

Distribution of materials

The origin of the various residue classes is summarised in Table 2. 93% of the material by weight derives from material dumped along the W side of the leat (c112/c172). The other contexts containing archaeometallurgical residues are closely associated.

Description of materials

The residues are dominantly those typical of coal-fuelled blacksmithing. None of the material showed any evidence for the use of charcoal as fuel.

Iron-rich forms of slag occur both as masses interpretable as smithing hearth cakes (large plano-convex slag masses which form in front of, and below, the tuyère) and as more amorphous, prilly or lobate pieces. The more amorphous material grades into

much lower density clinker bearing much coal shale. Some material contains highly vitrified clasts that do not appear to be derived from coal shale. Although only some of these materials can be assigned to blacksmithing with certainty, all of these classes are compatible with an origin in smithing. Their co-occurrence is circumstantial evidence that all the materials share a common source.

The fuel-related materials include pieces of coal, burnt coal residues (coke) and coal-encrusted ironstone fragments, probably discarded fragments from concretions from within the coal.

Iron working (smithing residues)

Smithing hearth cakes
As is usual for post-medieval coal-fuelled smithing, the examples of slag cakes that can be termed 'smithing hearth cakes' are rather poorly developed and grade into the rather indeterminate material assigned to the following category.

The identified SHCs weighed 108g?, 128g, 152g, 170g, 304g, 360g, and 538g. The SHCs were all dense but showed a prilly internal structure on the distal margin in most cases and a well formed non-wetted contact extending down the proximal lower surface of the bowl. The slags were internally grey and crystalline or dark and glassy. Upper slag surfaces were typically maroon.

The total weight of material referable to SHCs was 2570g, 40% of the assemblage.

Other dense slags
Dense slags also occurred as small prilly or lobate masses without an SHC-like overall morphology and also as small fragments. One interesting slag piece in this category is the 440g clinkery slag mass from c112. This is suggestive of a slag accumulation against a rounded right-angle corner of the hearth, possibly, but not necessarily, the foot of the wall below the tuyère, because the orientation of the piece is uncertain.

A second highly significant, if unfortunately small, piece is the 48g fragment from c115. This shows the margin of a small slag puddle, clearly one that was completely fluid, with a texture of elongate bladed olivine crystals up to 10mm long extending in from both lower and upper surfaces of the lenticular mass.

The indeterminate dense slags totalled 2082g, 32% of the assemblage.

Low density clinkers
The collection included a good quantity (656g, 10% of the assemblage) of low density, typically rather friable clinker. Many of these pieces had a rather wispy, porous texture and contained coal shale clasts in varying degrees of melting and assimilation.

These materials are less iron-rich than the previous two categories and such material may be formed by the burning of coal in non-metallurgical contexts. In this case, however, the amount of clinker is entirely in keeping with the amount of denser slags and there is no reason to suspect they were derived from different sources.

Other vitrified material
Besides the clinkers with coal shale clasts, there were other vitrified materials for which the clast types were not certain. One, the 64g fragment from c172, appeared to be a fused, green glazed, conglomerate of gravel. It was unclear however, whether the gravel grade clasts were natural gravel, or fragments of hearth wall. The other piece was a larger angular piece weighing 152g, also from c172. This had what appears to be an angular clast, with a smoothly blasted haematised surface, but with attached slag prills on one end. These features suggest a large clast that has arrived in front of the tuyère, though whether the slag film conceals a large fragment of coal dirt, or a piece of failed wall, is unclear.

Fuel-related materials

Ironstone
The collections contained two fragments of ironstone encrusted with coal (212g; 3% of the assemblage). Such ironstone layers are not uncommon in the coals of South Wales, and it is likely that these pieces are rubbish discarded at the point of use of the coal.

Coal
The coal fragments present in the collection are all highly sheared materials. They total 630g, 10% of the assemblage by weight. The pieces are highly striated on lustrous curved fractures, suggesting a high degree of internal deformation to the coal. These surfaces correspond to the 'striated' fracture type of Frodsham & Gayer (1999).

Coke
The collection included a few small fragments of coke (108g; 2% of the assemblage). These materials are the waste from the incomplete combustion of coal, rather than being deliberately-produced coke fuels.

Interpretation

The material is all compatible with being derived from coal-fuelled blacksmithing. The principal residue type is a dense iron-rich clinkery slag, of which approximately 56% is in the form of poorly-developed SHCs, the other 44% as more amorphous lumps.

The reason for this poor development of SHCs is that post-medieval coal fuelled hearths generated slag in a rather different way from those typical of earlier periods. The evolving technology actually involves three separate changes:

1. A change of fuel from charcoal to coal
2. The introduction of the iron tuyère
3. The change in raw material from bloomery iron to wrought iron produced by the indirect process.

The term 'smithing heath cake' is really based on the plano-convex slag cakes so typically formed in hearths with a clay wall (or clay tuyère), burning charcoal as fuel. In this setting the slag is formed from iron or iron oxides lost from the work piece reacting with the molten clay, derived from the areas where the hotzone impinges on the hearth wall (or tuyère face). In contrast, the spread of coal (which has a high ash content) for fuel and the introduction of iron tuyères (which tends to distance the hotzone from the wall) produced a switch in source of the non-iron component of the slag from the hearth wall to the fuel. Earlier medieval hearths appear to have mainly used simple blowhole in the wall of the smithing hearth. The adoption of a tuyère to carry the blast to the fuel allows rather easier access for the smith to the reduced zone of the earth, which lies both in front of and above the

entry of the blast. Iron tuyères appear to have been the norm by the end of the 17th century when Moxon wrote his treatise on smithing (Moxon 1703), whereas silicate-rich smithing slags (suggestive of melting of the clay hearth wall) are typical at least as late as the 14th century. Unfortunately, the intervening period has been little studied.

It is likely, therefore, but not certain, that the forge which produced these residues was blown through an iron tuyère. A slight tendency for SHCs to show a slightly glazed proximal upper surface might be taken as evidence for a limited input form hearth ceramic. A single piece of slag (48g fragment from c115) shows a higher degree of melting with a more silicate-rich composition. This might also be the results of the melting of the hearth ceramic, but might also be due to an increased use of sand flux.

In detail, there are rather few detailed descriptions of coal-fuelled smithing residues with which to compare. In addition, the present assemblage is too small for statistical comparisons with other examples.

The majority of coal-fuelled backsmithing assemblages from the Cardiff area that have been examined in detail have actually been of Roman age (e.g. Caerwent, Young 2006; Trowbridge, Young 2009a and 2009b ; Caerleon, Young & Kearns 2010; Cardiff Castle, Young & Kearns 2011; together with unpublished assemblages from Penmark and, Caerau Hillfort). It appears coal fell out of use for smithing the early medieval period, possibly re-entering use in around the 13th century. There are no detailed descriptions of medieval or later coal-fuelled smithing slags from the Cardiff area.

No systematic study of the wider medieval use of coal in the area has been undertaken, but it was present in large quantities in the upper fills of a mid-13th century ditch, below a dump of early 14th century pottery kiln wasters at Llandaff (Young 2001, p. 7). Evidence for particular medieval coal sources is sporadic and local (Rees 1968), but the overall picture is of a small industry which expanded rapidly in the 16th century. This expansion is reflected both in the levels of coal exports from the South Wales ports (Lewis, 1927) and in the attraction of the non-ferrous metallurgical industries to the region (Williams, 1959). The ready availability of coal in Cardiff from at least the 14th century onwards probably meant it would have become the main fuel for smithing operations.

In general, the size of SHCs decreased into the post-medieval period because of the technological changes described above. The range of SHC weights present (102-538g) compares closely with that of other assemblages of a similar age (e.g. the 17th-18th century assemblage from Gorteens, Co. Kilkenny, 52-748g, Dabal & Young 2011; a 15th-17th century assemblage from Ballykilaboy Co. Kilkenny, 50-478g, Young 2010; a 17th-18th? century assemblage from Moyveela, Co. Galway, 44-388g, Young 2009c).

The circumstances for the deposition of the slags into the mill leat are uncertain. The Hearth Tax Assessment for 1670 lists 1 'furnas' in High Street, 1 'furnas' and a house with two forges in East Street Ward, and four houses with forges in West Street (the area between the top of High Street and the bridge over the Taff, including the area now inside Bute Park and adjacent to the site (Parkinson 1994). Clearly this western side of the town centre was the focus of much smithing activity. An origin within the Castle is also, however, possible. The Castle is very likely to have had its own forge for farriery and other work. The County Gaol, housed in the Castle in the 16th century, is also likely to have generated a significant requirement for smithing by comparison with the 18th century accounts in which blacksmiths work is itemised (Mathews 1901).

Evaluation of potential

The assemblage provides a tantalising insight into blacksmithing practice in the early medieval period. The use of coal and the style of residue produced are important contributions to regional understanding. The lack of a clear date or context for the blacksmithing activity, and bearing in mind the small size of the assemblage, means that additional analytical investigations are unlikely significantly to advance understanding of either the site or the technology. Accordingly, although in general the investigation of smithing residues of this period might be held to have a high importance for research, in this instance no further analysis of the metallurgical residues can probably be justified.

In a similar vein, although provenancing work on the products of the early coal industry is an important area requiring further work, pursuing that agenda with the current material is probably not justifiable. Such investigations would be better focused on larger and closely dated assemblages.

Should the metallurgical residues and associated fuel become significantly better-dated during the post-ex process, then their analysis might gain a somewhat higher priority.

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Glossary

Blacksmithing: the working of iron and steel. Often restricted to the secondary smithing – i.e. the smithing of iron to produce or repair artefacts, as opposed to the smithing involved in the production of billets or bar iron from raw iron blooms.

Blast furnace: a furnace for smelting iron from ore in which the iron is produced as a liquid material. The liquid iron absorbs a large quantity of carbon, forming cast iron.

Bleb: a small rounded particle or textural component, often a droplet or prill.

Bloomery: a furnace for smelting iron from ore in which iron is produced as a solid material. The bloomery process was employed mainly prior to the introduction of the later blast furnace from the late 15th century.

Blowhole: A hole through a furnace or hearth wall through which air is blown.

Fuel Ash Slag (FAS): slag formed by the partial melting of hearth wall or substrate under the fluxing influence of the ash (inorganic component) of the fuel. Fuel ashes are often very rich in alkali and alkali earth elements that may lower the melting point of silicates.

Indirect process: the two stage production of wrought iron, through initial smelting in a blast furnace followed by conversion in a conversion forge. By the 1560s, the indirect process arrived in South Wales, with charcoal fired blast furnaces and Walloon finery forges.

Prill: a small aggregate of a material, either a spheroidal droplet or a runnel, formed from a melted liquid and either occurring as a discrete particle or as an inclusion within another material.

Smithing: the activity involved in forming a metal object, including, but not limited to, forging metal and joining metal by welding.

Smithing hearth cake (SHC): the slag cake formed in a smithing hearth by reaction of iron oxides lost from the workpiece with silicate material from hearth ceramic and/or fuel, below and in front of the tuyère/blowhole. They are very variable in form, but are typically plano-convex in shape (although concavo-convex and biconvex forms are common), frequently with a dense lower crust and a less well consolidated upper part. In some cases the top is formed of glassy slag.

Vesicle: a void or pore, usually rounded and formed as a preserved gas bubble in a solidified melt.

Walloon Forge: an early form of conversion forge. It comprises two types of hearth – the finery in which pig iron is decarburised to form a bloom, and a chafery, in which the bloom is reheated and hammered to form wrought iron.

Table 1: summary catalogue of archaeometallurgical residues and associated materials from Cardiff Castle mill leat

Context	Bag	Weight	Number	Notes
111	slag	170	1	dense SHC, 60mm x 75mm x 40mm, transverse, top lobate, dimpled, obscured by accretion but may be convex, base dense neat prilly
		150	1	fragment of maroon slag sheet c. 20mm thick, top dimpled and smooth, base accreted but microdimpled, some fuel clasts
111	coke	22	1	coal
112	slag	128	1	75mm x 70mm x 40mm, triangular-shaped porous prilly SHC or SHC-like mass
		148	1	irregular dense slag piece with prilly base, possibly not an entire SHC - unclear if embayed margin is a break or an irregular vertical face
		78	3	clinkery slag pieces
		<	1	coke
		6	1	charcoal
112	coke	28	3	coke
112	slag	440	1	clinkery slag mass, an unusual shape, with well-formed curved margin, curving through roughly 90 degrees parallel to long axis, overall 110mm x 110mm x 75mm; original orientation unclear - could have formed in a right angled vertical or horizontal corner of hearth, curved surface does not appear to be an SHC base, one side of curve is non wetted prills, other side is less clear
		4	1	flap-like lobe of pale porcellanous slag with maroon surface
		56	1	low density clinker fragment
115	slag/coke	8	1	rusty ironstone fragment
115	slag	48	1	lenticular sectioned piece of dense slag with maroon lobate top, with variable but locally 'blown' appearance, slightly maroon dense smoothish base, internally bladed crystals from top and base up to 10mm long
		22	1	fragment of vesicular clinkery slag with dimpled base
115	coke	26	1	coke

Context	Bag	Weight	Number	Notes
172	slag 1 of 2	360	1	70mm x 95mm x 60mm, transverse thin, slightly dished, maroon-topped SHC, with either a down-wall flow or an earlier SHC inclined at around 30 degrees below
		304	1	75mm x 80mm x 50mm irregular clinkery SHC, prilly basal curved surface down one side, slightly dimpled top
		538	1	140mm x 75mm x 75mm, rounded ball of slag, probably a somewhat deformed SHC with elongate flow lobe protruding on one side
		270	1	75mm x 75mm x 50mm, probably slightly incomplete SHC, top maroon and formed of whispy clinker, curved dimpled sheet forms proximal base, possibly incomplete distally and to one side
		266	10	fragments of low density clinker - clasts include some shale clasts, some bloated indeterminate material and some glazed pieces probably not originally shale
		152	1	smooth-blown block with prills on one side - perhaps a lithic clast smeared with maroon slag, rather than SHC
		960	28	miscellaneous mainly dense clinker fragments
		60	1	dense maroon slag, outer margin curved - dense sub-tuyère piece possibly
		180	1	irregular rounded mass, possibly an irregular SHC, shows hints of more glazed top one end, rest of surface more maroon
		116	1	rounded lump of rather porous slag
		152	1	possible SHC, rounded smooth lobate for a top, dense rusty base, one end fractured across large shale clast
172	slag 2 of 2	212	1	piece rather reminiscent of 360g piece above, has curving lower sheet and an upper mass with a smoothly-blown vertical face and irregular top, curving prilly contact face
		204	1	probably fired ironstone mass from within coal
		108	1	open irregular prilly mass - possibly incipient SHC
		308	4	irregular dense clinkery slag masses
		230	9	irregular low-density clinker masses - many slightly silvery in appearance with vitrified clasts
		64	1	fused glazed mass of gravel or ceramic fragments, greenish glaze on surface
172	coke	608	13	coal, mainly with multiple highly polished/slickensided fractures
		54	4	coke

Table 2: Summary of archaeometallurgical residues and associated materials by type and context. Weights in grams.

Context	Notes	SHCs	Other dense slags	Low density clinkers	Other vitrified material	Ironstone	Coal	Coke	Total	
111	generalised silt deposit	170	150				22		*342*	5%
112	dumps on W side of leat	276	440	138				28	*882*	14%
115	localised deposit near post		48	22		8		26	*104*	2%
172	deposit in trial trench 16 (=112)	2124	1444	496	216	204	608	54	*5146*	79%
	Total	*2570*	*2082*	*656*	*216*	*212*	*630*	*108*	***6474***	
		40%	32%	10%	3%	3%	10%	2%		

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