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Evaluation of archaeometallurgical residues from South Hook LNG Terminal, Dyfed (52787)

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Abstract

The submitted assemblage contained two main groups of residues

Residues from iron-making dominate the collection and are represented by 53.1 kg out of the total of 60.6kg submitted material. Of this material 40.1kg was from Complex 1 and 10.4kg from Complex 4. The material from these two areas was almost identical in character, with approximately 60% by weight smelting slags, 8% smithing slags and 28% slags not attributable to either class with certainty, together with 2-6% furnace lining. A further 2.5kg of iron-making residues occurred in other complexes and as unstratified material. The smelting slags are indicative of use of a small slag-tapping furnace, probably producing a rather small volume of tapped slag per smelt. Smithing slags are apparently dominated by smithing hearth cakes with weights of between 750 and 1440g. These are fairly large, and are probably indicative of bloomsmithing being undertaken. The ore source is not immediately obvious: the tapped flows do not appear to carry unreacted ores, as is sometimes the case. The site has yielded rocks from two potential iron sources: weathered iron-rich concretions probably derived from the drift, but of Carboniferous origin and a block of mottled bog ore.

The second group of residues includes highly vesicular, friable, low density, green lining or fuel-ash dominated slags. These are most abundant within Complex 7, where they were recovered in significant quantities (1.1kg) in association with corn driers, and are therefore interpreted as being of non-metallurgical origin.

The ironmaking assemblage is of great significance because of the lack of evidence for iron smelting of 8-10th century age in Wales, and the paucity of evidence in SW Britain in general. The large nmuber of sites now known from this period in SE Ireland are disitniguished by the use of a an entirely different, non-slag tapping furance type.

Contents

Methods

All pieces in the assemblage were examined, where necessary using a low-powered binocular microscope, and weighed. The full catalogue is presented (listed by bag to allow easy retrieval of particular specimens in Table 1. Summary data structured by complex are presented in Table 2.

Results

Iron-making slags

The dominant class of slag in the assemblage comprised tapped iron-smelting slags. These provided 27.7kg (49%) of the entire assemblage. The tap slags were extremely dense slags forming accumulations of typically rather narrow (10mm) rivulets. No complete tap slag accumulations were recovered, but the shape of the largest surviving fragments suggested that the accumulations were rather small. The largest block weighed 1450g and was probably slightly less than half of the original accumulation.

In no case could tapslag blocks be related back to material from the taparch area, but a block of approximately 650g preserved dense flows from the taparch in connection with slag solidified within the furnace. The morphology of this block suggested tapping took place through a narrow (c.40mm wide) channel. Furnace slags from close to the taparch were mainly charcoal-rich and often showed a slightly lobate upper surface. Several large blocks of massive charcoal-rich slags were probably also furnace slags.

In some cases certain differentiation between blocks of charcoal rich furnace slag and poorly consolidated smithing hearth cakes could not be made. Reasonably certain identification of a few smithing hearth cakes was possible. The possible and certain SHCs are listed below:

C901 possible dense shc, 704g
C1003, certain shc, 1115g
C1004, certain shc, 776g
C1005, possible shc fragment, 264g
C1033, possible shc fragment, 334g
C1037, certain shc, 756g
C1043, possible shc, 1440g

Several of the SHCs seem to have charcoal-rich bodies with little or no crust development. The examples from c1003 and c1004 are rather more conventional in form, although the specimen from c1003 is very broad and shallow.

The slags listed as being of indeterminate origin probably derive largely from smelting furnace slags and from smithing slags. The tapped slags are recognisable in general down to very small pieces, so are probably not strongly represented amongst the indeterminate debris. Much of the indeterminate material is extremely rusty, and an origin is likely in the basal part of the smelting furnace where metallic iron is common, even away from the main bloom. It is also possible that some of the rusty material is slag detached from the bloom during the early stages of bloom cleaning and consolidation.

Low density vesicular slags

The second group of slags comprises low-density, friable, highly vesicular slags with a “frothy” appearance. These slags are typically pale or greenish externally, but the fresh glassy slag may be very dark, almost black, on fresh internal surfaces. Most of the slag specimens are small irregularly rounded blebs, but larger pieces may coalesce to form crudely-developed sheets. Some fragments appear to show the nubs as heated small pebbles. Material that was sufficiently fluid to form smooth-surfaced green glass droplets was recorded from several contexts.

These slags have a morphology and texture typical of slags of a non-metallurgical origin. The two largest concentrations occur in c516 (544g) and c629 (320g), both upper fills of corn driers.

Interpretation

Iron-making slags

The iron-making slags show that both the smelting and bloomsmithing (refining) processes were undertaken on, or close to, the excavated site. Excavation revealed the bases of a pair of small slag-tapping shaft furnaces, and much of the smelting slag may have been associated with these furnaces, although the stratigraphic distribution of slag suggests many of the contexts bearing the slag date from a period after disuse of the furances. Until detailed plans and sections become available during the post-ex process little can be said in detail about the morphology of the furnaces, but they appear to be small. The basal part of the furnaces was excavated into natural bedrock, which accounts for the large quantity of natural stone included with the tapped slag collections and locally incorporated within the slags themselves. The small size of furnaces is also indicated by the nature of the tapslags that show a small size of rivulet (typically strongly convex and approximately 10mm wide) and probably also the small size of the tap slag accumulations. It is not possible to estimate the overall size of the tapslag flows produced during a smelt, but the size of the surviving fragments suggests a figure of around 3-4kg is probably appropriate. This is small in comparison with the slag flows produced from other sites around the Bristol Channel, and corresponds to production of a very modestly-sized bloom. Construction of a mass-balance solution for the furnaces after full analysis of the slags may help to constrain this more closely.

The ore source could not be determined by examination of the slags, although this is commonly possible on other sites with the bases of tap slag flows carrying small particles of unreduced ore. The site produced examples of two types of iron-rich rocks, claystone nodules probably ultimately of Carboniferous origin but derived from the drift and a probable bog iron ore of unknown origin. It would appear rather unlikely the thin drift at this locality would produce enough iron concretions to provide a suitable source, so smelting of bog ore or an imported ore seems more likely. Further analysis of the slags should be able to determine this (Pembrokeshire ore sources are further discussed in Appendix 1).

The smithing hearth cakes are all large. Crew (1996) suggested that SHCs range from 100-2000g, with blacksmithing SHCs typically 200-600g. That all five possible complete SHCs from this site weigh over 700g is strongly suggestive that they are from bloom refining rather than artefact manufacture.

It is very interesting that the two larger collections of slag (complexes 1 and 4) have very similar proportions of slag from the various classes (Table 2) and this presumably reflects a uniformity of taphonomic process. The question of whether this represents a proportionate sample of the residues from the iron production is impossible to answer without some knowledge of the mass-balance of the reaction. At first examination the amount of smithing slag seems very low compared with the smelting slag.

It is possible to provide some rough limits within which the production of iron equivalent to the surviving slags may be constrained. It is known experimentally that approximately one half of the bloom is lost during compaction (Crew 1991, Sauder & Williams 2002), so the weight of iron in the smithing slags is approximately equal to half the original bloom weight. Since a typical smithing slag is approximately 50% iron, then the smithing slags are approximately equivalent to the original weight of original bloom being processed (some iron is of course also lost as microresidues). In this case the weight of smithing slags is between 4.1 and 19.5kg. The weight of smelting slags is between 32 and 47kg. If the ore employed was an oxide ore, then it may be appropriate to compare with the theoretical figures produced by Thomas & Young (1999) who calculated that each unit weight of bloom produced involved production of approximately 1.5 times that weight of slag. That would mean the production of bloom was between 21 and 31kg. Other estimates (based largely on experimental work; Cleere 1976) would suggest that smelting slags weigh three times the weight of the raw bloom produced for leaner ores. That higher ratio would suggest iron production of 11-18kg. The two ranges of estimates of bloom production overlap, with that derived from consideration of the smelting slags being 11-31kg and from the smithing slags 4-20kg. Thus despite the apparent mismatch of the quantities of smithing and smelting slags it is conceivable that the assemblages of slag from complex 1 and 4 are representative of original slag production and the original dump composition represents both parts of the process of iron production. It is to be hoped that further detailed analysis will be able to address the issue of how representative the surviving slag assemblage may be.

Corn drier slags

The vesicular slags from the corn driers can be interpreted as probably being produced from a reaction between sediment (possibly clay from the drier or mixed with the fuel) with fuel ash. The high vesicularity reflects the importance of volatile release during slag generation.

Evaluation of potential

The South Hook assemblage is of enormous significance for there are extremely few other iron smelting sites known from this period (8-10th century) in Britain and none to date in this part of the country.

Early medieval iron smelting sites in SW Britain are known at Ramsbury, Wiltshire (8th century; Haslam 1980), Blacklake Wood, Devon (7-8th century) and probably at Cheddar (late 10th-11th century; Rahtz 1979). Slightly further east are Gillingham (Heaton 1992) and Worgret (Hinton 1992) in Dorset. Additional evidence is provided, for instance, by the 3 manors in Gloucestershire and 6 in Somerset that are given as paying revenue in iron in Domesday. This indicates that the archaeologically attested iron production is only a very small part of that actually present.

In contrast, many iron-smelting sites of this period are now being recognised in Ireland (e.g. Young 2003a,b, 2005a,b, 2006a,b.), but these differ in technology, being non-slag tapping slagpit furnaces. One single example of a furnace which might possibly have been slag tapping is now under investigation at Woodstown, Co. Waterford (author’s unpublished work).

Detailed description of the technology employed at South Hook would provide an important datapoint in the sparse knowledge of British smelting of the Early Medieval period and would allow full comparison with other sites in Britain and Ireland.

Detailed analysis of the slags should allow modelling of the furnace mass-balance, following the methodology of Thomas & Young, 1999. This approach would allow evaluation of the iron source, the efficiency of the operation and its likely iron yield.

The slags from the corn driers are a class of slag not closely examined elsewhere. Whilst detailed analysis of these slags is unlikely to generate data leading to enhanced understanding of the South Hook site, improved understanding of slags produced in the driers is likely to produced an enhanced potential for interpreting such slags from other sites. For this reason further analysis of these slags would be recommended.

Appendix 1: Iron Ores of Pembrokeshire

The occurrence of early iron smelting in the Milford Haven area was somewhat unexpected in view of the lack of known occurrences of suitable iron ore in the immediate area.

Iron ore is however known in Pembrokeshire in fairly small quantities from several distinct sources:

1. the Carboniferous Coal Measures.

Iron carbonate nodules from the Coal Measures have been mined extensively in the Saundersfoot area and also have been interpreted to have been the source of ore for the 17th century Canaston Furnace. Similar nodules, but highly weathered are commonly encountered in drift deposits, and might locally be sufficiently abundant to be worked for a bloomery.

2. Iron oxide ores at the top of the Carboniferous Limestone

Iron ores are found locally in small pockets with the Lower Carboniferous Limestones, particularly close to the top of the unit. These have been worked locally in South Pembrokeshire (Lydstep, Penally, Jameston). Similar deposits also seem to occur to the north of the coalfield, with occurrences of ochre noted near Haverfordwest (near Cinnamon Grove Gate, Hamlet of St Thomas, and at Greenhill Ochre Mine, Haroldston St Issells; Claughton 1976). These two localities lie on a strongly faulted zone of the northern margin of the coalfield, which to the east passes close to Minwear, where another small iron ore deposit was worked in the 17th century. This deposit was apparently described by Raspe as bog ore. However, the ochre deposits of Haverfordwest were also manganiferous, so that it is possible the Minwear occurrence is a similar orebody.

3. Bog iron ore

A possible occurrence of bog ore was claimed by Raspe at Minwear (P. Claughton pers. comm. 2006; see above), but this has not received critical moden investigation

4. Other sources

Mineralisation is also known close to the site, for a small lead mine operated at South Hook in the 18th century (Claughton 2003). It is just possible that the lead mineralisation might have been accompanied by unrecorded iron ores.

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Context	Sample	Weight	Description
102		30.62	small fragment of tapslag with high-lobed flows
		2.33	low-density highly vesicular lining slag fragment
112		20.76	dense tapped lobe
119		11.06	corrosion around small iron pieces, in c.7 pieces
		8.24	larger piece of probably corrosion (not certain) attached to stone
127		0.16	low-density highly vesicular green lining slag
127		52	broken hollow bleb/flow lobe of dense slag - presumably a tapslag bleb but not classic tapslag
132		1.43	3 low-density highly vesicular lining slag pieces, greenish externally but black internally
137		1.1	melted greenish glass, probably not metallurgical
139		5.47	small dense prill
139		42	small tapslag fragment
		15.7	2 small stone pieces with buff coloured concretion, natural
139		0.58	1 grey-green low-density highly vesicular lining slag piece
168		17.4	small tapslag fragment
188		5.19	disintegrated lump of low-density highly vesicular lining slag
197		14.74	11 pieces of low-density highly vesicular greenish lining slag and vitrified lining material
		11.45	brick like reddish fired clay
197		2.82	green low-density highly vesicular lining slag
		1.1	4 pieces of burnt bone
		7.63	iron rich stone? in 2 pieces
198		124	c.40 pieces of green low-density highly vesicular lining slag in charcoal rich soil
508		1.47	2 rounded lumps of grey low-density highly vesicular ling slag
511		30.3	c.13 pieces of greenish low-density highly vesicular lining slag

Context	Sample	Weight	Description
513		78	small pieces of green low-density highly vesicular lining slag mixed with soil
515		1.63	green low-density highly vesicular lining slag fragment
516		362	pale greenish lining slags - mainly the low-density highly vesicular kind in crude sheets, but also some completely altered pebbles and at least perfect green slag sphere
516		182	63 pieces of pale low-density highly vesicular green lining slag. Some very shiny spheroidal aggregates included here
517		2.02	c.10 pieces of low-density highly vesicular green low density lining slag
517		98	complicated descending flow of tap lobes - possibly from drip area?
543		7.98	small irregular spiky bleb of low-density highly vesicular green lining slag
		226	dense block of slag, irregular in shape but has some small lobes so may be partially flowed furnace slag or very thick tapped flow
623		1.13	3 low-density highly vesicular pale lining slag fragments
629		320	large quantity of very friable lining type slag
737		3.53	greenish low-density highly vesicular lining slag in >6 pieces
901		704	dense bun shaped slag block, possibly part/all of shc?
901	(unstratified)	424	34 pieces of tapslag
		8	slagged lining
		27	2 pieces of claystone ironstone
		128	tapslag fragment
		124	42 small pieces of iron slag indet
		116	4 lumps of rusty slag - not clear if smithing slags or not
962		352	large block of possible bog ore
969		130	4 stones

Context	Sample	Weight	Description
1002		1250	large block of charcoal rich slag with lobate top - probably a furnace slag
		284	vesicular slag with irregular lobate projections - contorted furnace slag?
		228	charcoal rich furnace slag
		112	fractured pebble
		12	6 fragments of flint
		42	fractured flint/chert pebble
		22	fired pebble - possibly ore?
		14	2 flints
		6235	tapped slag -195 pieces
		962	small slag debris
		70	stones
		28	boxstone claystone ironstone fragment
		724	51 pieces of extremely corroded slag and iron - most probably iron rich slags, but at least one appears to be iron fragment - not practical to separate
		494	11 pieces of charcoal rich furnace slag
		346	curved slab of slag with charcoal on one side and smooth on other - probably a crust from with the furnace
		220	30 pieces of lining, some vitrified
1002		722	15 pieces of tapslag, up to 30mm thick, mainly thin flows, some wrinkly, lots of shale clasts on base
		86	4 pieces of lower density vesicular iron slag indet
1002		328	14 pieces of tapslag
		196	11 other pieces of dense slag
		46	6 pieces of fired lining
		22	iron-mottled soil
		10	iron concretion - rusted material?
1003	find416	1115	shc, platy dished top up to 15 thick, below which hangs finely prilly material with a small area of almost thin crust like margin. 140x150x80
		28	small fragment - possibly from lip of the above or a similar cake?
1003		332	three pieces of dense slags, 2 smaller are tapped, large block also has flowed top but seems internally massive at first inspection

Context	Sample	Weight	Description
1003			charcoal stick
		24	tapslag fragment
		158	2 small pieces of dense slag which is finely vesicular with small charcoal - could be shc or furnace bottom
		6	2 indet iron slag fragments
1004		776	105x125x55, medium sized bun like shc with dished top. Details obscured by corrosion, lots of charcoal adhering to base
		5305	87 pieces of tapslag, largest c.700g, thickest c.35mm, mainly fairly narrow flows, base mainly rough some adhering stone fragments
		408	42 small pieces of indet low density vesicular slags
		48	7 pieces of vitrified lining
		680	5 lumps of charcoal rich furnace slags
		514	two pieces including furnace slag like material but with flow lobed top, one is a large block from throat showing flow lobed surface cutting down across finely charcoal rich material and turning towards a tapslag. Length 110, 60 thick on furnace side, 30mm thick towards outside
		126	irregular dense slag fragment
		78	3 stones
		106	7 rusty concretionary lumps which may have contained iron
1005		264	block of furnace base or shc, 40 thick of which 20 appears to be a crust, top vesicular, base dense
		116	26 pieces of broken slag, mainly or entirely from a broken piece of tapslag
1005		64	5 pieces of tapslag
1028		542	95 small pieces of very rusty material, probably mainly slag
		64	5 pieces of rusty material formed around corroded iron
		132	11 pieces of flowed slag, largest certainly tapslag, smaller prills probably so
1033		334	part of an irregular thin crust style cake. Crust to about 5mm, inside charcoal rich or hollow, slightly rusty top, not clear if this is an shc (v odd for Britain) or part of a furnace bottom deposit (more likely?). Mainly c40 thick but with protrusion to 60.
		210	5 pieces of tap sag, single lobe thickness, grey particles on base
		54	5 vesicular slag pieces indet
		20	fired clay with smoothed grey surface
		54	vitrified lining block?
		80	vitrified surface of lining including large stone clast

Context	Sample	Weight	Description
1034		130	3 pieces of tapslag, to 30mm thick, shale rich bases
		14	4 tiny pieces of rusty probably furnace material
1037		756	140x115x75 shc, (bowl 60mm deep), very charcoal rich throughout, smooth top with raised lump, has no real lower crust
		5610	109 pieces of tapslag, largest about 700g
		1090	small iron slag pieces, undifferentiated
		1580	19 pieces of mainly brown fine furnace accumulation, but grading into more normal charcoal rich slag
		210	3 stones
		36	2 pieces of vitrified lining
1037		564	79 pieces of vitrified lining - mostly with orange ceramic but a few pieces are just the slag layer
		236	stone
		88	25 small iron slag pieces indet
		518	15 pieces of tapslag and prill, largest piece 256g, shows base resting on charcoal rich ashy deposit
		182	4 large lumps of amorphous slag, mostly slightly rusty, mostly charcoal bearing, one has some lobes
1037		20.79	tapslag fragment
1038	1039	1450	large block of tapslag - but probably only half cake at most, 160x110x40, narrow lobes, typically 10mm
		424	smaller tapslag block with strongly wrinkled lobes
		772	contorted flow lobed block, not all dense - so may be a tap arch piece, but probably secondarily folded
		1820	42 pieces of tapslag and prills
		146	dense slag piece, rounded cross section with possible flow lobed top - probably a taping channel runner
		498	dense possible furnace floor piece, attaches to the above runner, suggest channel 40 deep by 30 wide
		1115	3 large blocks of dominantly charcoal rich material with some slightly lobed surfaces - furnace slag
		14	3 stones
		1435	c.200 small indet slag pieces
		20	5 pieces of vitrified lining
		2	possible bog ore fragment

Context	Sample	Weight	Description
1042		82	4 lumps of ferruginous as on fired clay base - could be with cleaning later
		38	dense iron slag indet, has very large vesicles so may be a tapslag
		148	block of dense slag composed of a complicated mass of prills and lobes
1043		792	mixed ferruginous material in ashy matrix- may be determinable after washing, but matrix interesting in own right!
1043	1039	2020	slab of stone with small attached area of fine furnace accumulation - probably c.100g
		1440	object like a charcoal rich shc, 150x110x75,
		962	127 pieces of similar furnace accumulation, rusty fine charcoal rich, some containing slag blebs, others fragments of stone
		260	block of charcoal rich slag with rusty contact surface, medium sized charcoal
		42	15 pieces of fired or vitrified lining
		470	7 pieces of dense tapslag
		144	30 small or indet pieces of slag
			charcoal stick
		18	2 stones
1044		248	curious block with smooth flown lip above (?) zone of contact with hard substrate. Possibly the lip of a large shc, but could just be tap arch material. Dense dark vesicular slag
1048		28	11 tiny slag pieces including at least two apparently fragments of tapslag
1049		56	5 brown lumps of material (ash?) cemented by "rust"
1054	(=1003?)	34	7 fragments of slag cooled between charcoal moulds
		2.49	fired clay
		42	4 stones
1056		28	tapslag lobe
		54	3 lumps of amorphous iron slag
1083		13.91	5 pieces of non- slag material, 1 stone with attached charcoal, 2 pieces of broken iron-rich stone, 1 small pebble, 1 iron-rich lump of concretionary? Origin
1098		66	3 pieces of tapslag plus debris
1609		2.33	2 pieces of greenish low-density highly vesicular lining slag

Context	Sample	Weight	Description
1853		528	iron cemented ashy soil with abundant charcoal and a few lobes of both very and horizontal prilly material. Presumably some sort of furnace bottom accumulation?
1853	1071	8.79	prill in 3 pieces
		2.07	ferruginous ash?
1886	furnace 1071	644	234 stones
		734	86 pieces of indet grey slag - mainly vesicular fragments
		146	53 pieces of fired lining
		1700	91 small pieces of tapslag- mainly from small flows and prills
1887	1081	338	c150 small indet slag pieces
	fuel ash	76	31 small local stones
	and slag	528	37 pieces of slagged lining, variably reduced or oxidised fired
	run-off see	958	43 pieces of broken grey vesicular slags of medium density
	section 1780	278	9 blocks of dark lining slag, variable density (not the pale low-density highly vesicular type)
		500	5 pieces of thin tapped flow, rubbly bases with attached stone, top unusually flat - might just be flowed bit almost looks like base of obstruction. Max about 25 thick
		376	6 pieces from more normal, but probably small tapped flows
		100	stone
1889	slag from	150	small block from 35mm thick tapslag flow

Table 1. Slag catalogue by bag, ordered by context number

	Complex 0	1	2	4	6	7	8	7&8 cleaning	11	13	unstrat	total	
Tapslag	66	20484	180	6149	98		121	42			552	***27692***	*49%*
Furnace slag		4038			226							***4264***	*8%*
Indet. iron slag		11279	264	2940				5.47			944	***15432***	*27%*
Smithing slag		3359		756								***4115***	*7%*
Lining & lining slag		956.5		600		11.5					8	***1576***	*3%*
Low density green slag				2.33	12.8	1115	12.6	0.58				***1144***	*2%*
Natural stone		3770		459.9		7.63	8.24	15.7		130		***4391***	*8%*
Iron and corrosion		180					11.1					***191***	*0%*
Possible ore		52							352		27	***431***	*1%*
Other		1344				1.1	1.1					***1346***	*2%*
												60582	
Smelting slag total	66	24522	180	6149	324	0	121	42	0	0	552	***31956***	
Smithing slag total	0	3359	0	756	0	0	0	0	0	0	0	***4115***	
Indet. iron slag total	0	11279	264	2940	0	0	0	5	0	0	944	***15432***	
Lining & lining slag total	0	957	0	600	0	12	0	0	0	0	8	***1576***	
Iron slag total	66	40117	444	10445	324	12	121	47	0	0	1504	***53079***	
Low density green slag	0	0	0	2	13	1115	13	1	0	0	0	***1144***	
smelting/total iron slag	1	0.61	0.41	0.59	1	0	1	0.88			0.37	***0.60***	
Indet./total iron slag	0	0.28	0.59	0.28	0	0	0	0.12			0.63	***0.29***	
smithing/total iron slag	0	0.08	0	0.07	0	0	0	0			0	***0.08***	
lining/total iron slag	0	0.02	0	0.06	0	1	0	0			0.01	***0.03***	

Table 2. Summary of slag classes by complex

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