ASSESSMENT OF IRON SLAG AND RELATED HIGH TEMPERATURE DEBRIS FROM SITES IN LYMINGE, KENT (Site codes: LYM 08, LYM 09, LYM 10 & AFL 10)

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Introduction and methodology

A medium-sized (38kg) assemblage of slag was examined for this report. This represents something approaching three-quarters of the iron slag retrieved over several years during excavation in Lyminge, Kent. The total weight unexamined is not known but it appears that most of the bulk slags from LYM 08 and LYM 09 have been examined. Very little of the slag from LYM 10 was available for examination at this stage and no material from soil samples from any of the sites was presented for examination as sample processing is just starting or is on-going. The absence of hammerscale and other microslags from samples – and the help in pinpointing foci of smithing activity these may have provided – obliges this report to discuss and arrive at conclusions based on bulk slags alone. No detailed descriptions of features were available at assessment so any furnaces, raised smithing hearths, or pits which might have been used to make charcoal or roast ore were not located. Some significant features for slag such as LYM 08 [111] and LYM 09 [1141] could not be found on the site plans as they are at present.

The assemblage was examined by eye and categorised on the basis of morphology and colour. Each slag or other material type in each context was weighed except for smithing hearth bottoms and furnace bottom cakes, which were individually weighed and measured for statistical purposes. During quantification a magnet was run through soil adhering to slags and thus some hammerscale was detected.

All bags of slag quantified by this specialist have the initials LK in pen on them. Important slags and smelting slag worth analysis have had an asterisk put on the bag (and asterisks are shown in the comments column of the slag spreadsheet). Quantification data and details are given in the table below in which weight (wt.) is shown in grams, and length (len.), breadth (br.) and depth (dep.) in millimetres.

Table 1: Quantification table for all material in assemblage : Lyminge, Kent (site codes: various)

cxt	slag identification	wt	len	br	dp	comment	pcs
4	cinder	9				glassy cinder & burnt flint	1
4	cinder	16				fused with fuel ash slag & burnt flint	1
4	cinder	18					
4	fired clay	9					
4	hammerscale	4				a little very broken flake & three spheres	
4	iron	24					
4	iron-rich undiagnostic	12				microslag runs & dribbles	
4	iron-rich undiagnostic	69				very magnetic; could be smelting slag	1
4	iron-rich undiagnostic	76				very magnetic: mostly iron?	
4	iron-rich undiagnostic	76					1
4	smithing hearth bottom	55	51+	50	25	fragment	
4	smithing hearth bottom	75	0	0	35	fragment	

4	smithing hearth bottom	92	55+	55+	25	incomplete	
4	smithing hearth bottom	104	0	0	45	incomplete	
4	smithing hearth bottom	106	80	60	20	tiny example	
4	smithing hearth bottom	119	0	0	35		
4	smithing hearth bottom	119	0	0	30		
4	smithing hearth bottom	145	70	55+	35	incomplete	
4	smithing hearth bottom	165	70	70	55		
4	smithing hearth bottom	226	90	55+	45	incomplete	
4	smithing hearth bottom	266	80	65+	45	incomplete	
4	smithing hearth bottom	332	80+	70+	45	incomplete	
4	smithing hearth bottom	871	130	110	60		
4	stone	4				** ore? To be examined by geologist	1
4	undiagnostic	30				with run surface	1
4	undiagnostic	85					1
4	undiagnostic	119					2
4	undiagnostic	122				very tiny fragments	lots
4	undiagnostic	171				many voids	1
4	undiagnostic	173			45	possible smithing slag	
4	undiagnostic	683					16
4	vitrified hearth lining	2				finely finished surface - mortar?	1
4	vitrified hearth lining	35				small, broken pieces	lots
12	furnace slag	18					
12	slag run	14					
12	stone	29				geological identification required	
20	cinder	20					
20	coprolite	7					1
20	hammerscale	0				none in soil	
20	iron	14					2
20	iron-rich undiagnostic	2					1
20	smithing hearth bottom	82	60	55	25	very tiny example	
20	stone	11					1
20	stone	42				** ore? To be examined by geologist	3
20	undiagnostic	28				with iron pieces incorporated	1
20	undiagnostic	126				cindery and also small cindery runs	lots
20	undiagnostic	394					lots
20	vitrified hearth lining	20				reduced fired - white ash colour	1
20	vitrified hearth lining	119				small, broken pieces	lots
52	cinder	3					
52	iron-rich undiagnostic	8					
52	run slag	61					
52	undiagnostic	114					1
68	ferruginous concretion	183				sample 5	
72	slag run	15					
72	undiagnostic	417				furnace slag/ massive smithing hearth bottom **	
76	highly magnetic stone	3				heat magnetised? Geolog. identif. required	

76	tap/run slag	11						1
76	tap/run slag	118						1
78	tap/run slag	226				thick deposit - depth 45mm		1
82	cinder	12						
82	furnace slag	10						
82	iron-rich undiagnostic	130						lots
82	run slag	2				broken fragment		
82	run slag	17				smelting		
82	stone	12				geological identification required		
82	tap/run slag	323						
82	undiagnostic	41						
82	undiagnostic	54			20	fragment of smithing hearth bottom?		
105	iron-rich undiagnostic	20				TP17		1
112	iron-rich undiagnostic	167						6
112	quern fragments	33						
112	run slag	99				could be broken-up tap slag		4
112	slag run	6						
112	stone	6						
112	tap slag	192						1
112	undiagnostic	34						lots
112	undiagnostic	63						1
112	undiagnostic	151						1
163	undiagnostic	35						2
163	undiagnostic	440			40	fragment of smithing hearth bottom?		
180	smithing hearth bottom	192	75	65	45			
204	iron-rich undiagnostic	6						
204	tap/run slag	191						1
225	tap slag	215				slightly magnetic		
225	undiagnostic	81						1
247	run slag	136			30	furnace slag		1
248	highly magnetic stone	18				heat magnetised? Geolog. ident required		1
331	stone	80				geological identification required		2
513	furnace slag	148						1
513	runs	19				very cindery		3
513	stone	12				geological identification required		
513	undiagnostic	111						
519	iron-rich undiagnostic	33						
519	run slag	595	120	100	40	possibly furnace slag		1
519	smithing hearth bottom	286	90	65	40			
519	undiagnostic	49						
527	run slag	24				iron-rich; possibly smelting		1
527	stone	8				identification required *		
531	iron	2				flat - blade fragment?		
531	iron-rich undiagnostic	6						
531	stone	11						
544	furnace slag	325				run surface		
544	undiagnostic	403			65	furnace slag or part of smithing hearth bottom		1
572	iron-rich undiagnostic	43						2

572	stone	16				2
576	ashy silica run	9				1
576	dense slag	7				
576	furnace slag	96			slightly flowed	1
576	furnace slag	438			small pieces concreted with clay	
576	iron-rich undiagnostic	122				
576	iron-rich undiagnostic	282				10
576	iron-rich undiagnostic	324		45		
576	silica run	24				2
576	smithing hearth bottom	124		35	fragment	
576	smithing hearth bottom	165	80 50	50	frag.; tiny magnetic smithing spheres on top	
576	smithing hearth bottom	268	80 70	35	iron rich	
576	undiagnostic	42			possibly smelting slag	1
576	undiagnostic	111			fragment of smithing hearth bottom?	
576	undiagnostic	166				lots
576	undiagnostic	209				lots
576	vitrified hearth lining	11				
586	furnace slag	583	125 70	50	furnace ** analysis?	1
588	undiagnostic	272				1
608	furnace slag	199				1
620	furnace run	23				
620	iron-rich undiagnostic	38				
620	stone	9				
620	undiagnostic	3				
629	run slag	30			broken tap slag	
629	undiagnostic	96				lots
629	undiagnostic	128				1
629	vitrified hearth lining	25			and cinder	
633	dense slag	45				1
633	iron-rich undiagnostic	49				
633	silica run	15				
633	smithing hearth bottom	422	100 0	60	incomplete	
633	smithing hearth bottom	621	120 100	60		
680	undiagnostic	18			sample 513	1
681	bone	18				
681	stone	81			identification required **	
681	undiagnostic	80				2
725	slag dribbles	3			iron-rich	
725	tap/run slag	54				1
725	undiagnostic	27				
1002	tap/run slag	276		55		1
1037	iron-rich undiagnostic	23				
1037	run slag	8				
1037	smithing hearth bottom	282	110 60+	45		
1037	tap slag	73				1
1037	undiagnostic	30				1
1037	undiagnostic	31				2
1041	iron-rich undiagnostic	189				2

1041	smithing hearth bottom	816	110	95	60	orig. slag rested on lots tiny charcoal pieces	
1041	undiagnostic	25				run surface	
1065	smithing hearth bottom	742	120	110	50		
1152	cinder	2					
1152	furnace slag	309				very cindery; some voids from burnt-out fuel	1
1152	iron-rich undiagnostic	159					1
1152	slag run	1					
1152	smithing hearth bottom	196	80	80	35		
1152	smithing hearth bottom	221	95	65+	30	incomplete	
1152	smithing hearth bottom	255	80	55+	40	incomplete	
1152	smithing hearth bottom	259	95	50+	35		
1152	smithing hearth bottom	359	105	90	50		
1152	smithing hearth bottom	550	105	90+	35	incomplete; fine charcoal inclusions	
1152	smithing hearth bottom	742	120	90	80		
1152	smithing hearth bottom	900	120	100	80		
1152	smithing hearth bottom	904	130	120	50		
1152	smithing hearth bottom	1274	130	105	60	wt. includes slag chunk adhering to surface	
1152	smithing hearth bottom	1351	145	110	75	or furnace bottom slag **	
1152	smithing hearth bottom	1374	140	110	50	weight includes extra slag adhering	
1152	smithing hearth bottom	1642	140	115	85		
1152	smithing hearth bottom	2000+	180	120	85	or furnace bottom slag **	
1152	smithing hearth bottom	2000+	130	110	50	weight includes extra slag adhering	
1152	tap/run slag	776					
1152	undiagnostic	4					
1152	undiagnostic	90				lots tiny charcoal inclusions	3
1152	undiagnostic	98					bits
1152	undiagnostic	218					
1152	undiagnostic	401			50	possible fragment smithing hearth bottom	
1152	undiagnostic	424					lots
1152	undiagnostic	675					1
1152	vitrified hearth lining	3					
1186	iron-rich undiagnostic	70					1
1186	vitrified hearth lining	107					1
1455	furnace slag	1673			185	incomplete fragment	1
1491	slag run	9				silica rich	
1491	undiagnostic	350					1
1491	vitrified hearth lining	24					
1596	crucible	52				50mm dia.; slight lip; black inside base	
1596	crucible lid	22				50mm dia.	
1635	vitrified hearth lining	34				vitreous surface	
1642	iron	20				flat fragment	
1642	stone	112				ore? - to be examined *	
1642	undiagnostic	57					

1665 stone	94				ore? - to be identified	4
1665 tap/run slag	60					2
1665 undiagnostic	489				broken fragments	
1667 iron-rich undiagnostic	35					
1710 smithing hearth bottom	2118	185	125	85	or furnace bottom slag **	
1737 silica lump	7				black and glassy *	1
1817 magnetic dribbles	10				black and glassy *	
1817 silica dribbles	28				black and glassy *	
2019 stone	27				geological identification required	
2033 undiagnostic	137					
2093 undiagnostic	1					
2199 fuel ash slag	15					
2199 undiagnostic	11					
2245 undiagnostic	99					

total wt = 37.934kg

Table 2: Significant slag types in assemblage:

slag type	**wt. (g)**	**comment**
dense slag	52	
furnace bottom cake	7392	minimum wt.
furnace slag	3822	
hammerscale	4	
iron-rich undiagnostic	1939	
run slag	972	
slag runs	45	
smithing hearth bottoms	15428	min. wt.; see main quant. table
tap slag	2515	
undiagnostic	8216	
vitrified hearth lining	380	

Explanation of processes and terms

Activities involving iron can take two forms:

Smelting

This is the manufacture of iron from ore and fuel in a smelting furnace. The products are spongy mass called an unconsolidated bloom consisting of iron with a considerable amount of slag still trapped inside, and slag (waste). The slag produced varies depending on the technology used in different periods: furnace slags (including slag blocks and furnace bottom cakes), run slag, tap slag, dense slag or blast furnace slag.

Furnace bottoms resemble smithing hearth bottoms (see *smithing*, below) but are very much larger and usually weigh many kilos. They were produced in a covered bowl furnace.

Furnace slag is a general term used for slag which can be recognised as smelting slag but is incomplete or has no particular morphology which can identify the furnace type or technological method used.

Tap slag is a dense, low porosity, fayalitic (iron silicate) slag with a 'ropey' flowed structure (a handy analogy for illustration: it usually resembles thick lava flows). It is formed as the liquid slag is allowed to flow out, continuously or intermittently, through a hole in the furnace side into a specially made channel leading to a hollow in the ground. This removal of the slag facilitated retrieval of the bloom after the smelting operation. Furnaces with tap holes replaced bowl furnaces and slag pit furnaces in Britain as their efficiency was recognised early in the Roman period but passed out of use with the advent of the early Anglo-Saxons, re-appearing in England during the Middle Saxon period.

Dense slag is of low porosity like tap slag but lacks the flowed surface; it too represents smelting activity.

Run slag is what its name suggests and was produced by smelting; it can be produced by smelting in slag pit furnaces or tapping furnaces. If tap slag is very fragmentary it can be difficult to identify as such and the term 'run slag' has been used in these instances.

2a) *Primary smithing*
This took place in periods before the late post-medieval development iron casting. It involved the hot working (by a smith using a hammer) of the iron lump on a string hearth (usually near the smelting furnace) to remove excess slag. The slags from this process include smithing hearth bottoms and micro-slags, in particular tiny smithing spheres.

2b) S*econdary smithing*
This involves the hot working (using a hammer) of one or more pieces of iron to create or to repair an object. As well as bulk slags, including the smithing hearth bottom (a plano-convex slag cake which builds up in the hearth base), smithing generates micro-slags. These can be hammerscale flakes from ordinary hot working of a piece of iron (making or repairing an object) and/or tiny spheres from high temperature welding used to join or fuse two pieces of iron.

Table 3: Statistical data for smithing hearth bottoms
40 examples.
Total wt. = 23kgs

	range (g/mm)	aver.	std. dev.
weight	55 - 2000	570	589
length	51 - 185	104	32
breadth	50 - 125	82	25
depth	20 - 85	48	18

Furnace bottoms and smithing hearth bottoms very much resemble each other and it can be difficult to identify a smithing hearth bottom as such if it is very heavy and larger than the average example in size. In cases of uncertainty, laboratory analysis is the only way to determine whether it was produced by smelting or smithing.

Slag described as undiagnostic cannot be assigned to smelting or smithing either because of its morphology or because it has been broken up during deposition, re-

deposition or excavation. Other types of debris in an assemblage may derive from variety of high temperature activities - including domestic fires - and cannot be taken on their own to indicate iron-working was taking place. These include vitrified hearth lining and cinder. If found in association with iron smelting or smithing slag they are almost certainly products of the process.

Key groups
Many contexts produced diagnostic slags useful for interpreting the iron production and ironworking activity on the sites; the following features, however, are the most representative of these. Once again it must be stressed these features are highlighted on the basis of bulk slags only; other features which seem of no importance at this stage may be much more significant when the quantities and distribution of microslags from all contexts are known.

LYM 08, Trench 1
Occupation deposit [82]: tap slag, furnace slag, run slags and undiagnostic slags.
Pit [71] (72): furnace slag fragment or a large smithing hearth bottom, and run slag.
Pit [77] (78): a thick (45mm deep) chunk of tap slag.

LYM 08, Trench 2
Pit [563] (633): two smithing hearth bottoms and some dense slag.
Pit [575] (576): three smithing hearth bottoms (one with hammerscale spheres on its surface) and a fragment of a fourth; some furnace slag - including dense slag - and quantities of undiagnostic slags.

LYM 09
Pit [1151] (1152) contained some of the most interesting and potentially important slags from the site. Identifications are uncertain in some cases because if the specimens are smithing hearth bottoms rather than furnace bottoms, they are larger and heavy than the usual found on sites of the middle Saxon period. Besides the larger slags, the pit produced a fragment of furnace slag which has voids from burnt-out charcoal; it also produced quantities of undiagnostic slags.

AFL 10:
Smithing waste in pit [3], (20) and the layer [4] on top of/disturbed top fill of pit [3].

Discussion of the assemblage
There are two points to make regarding the assemblage. The first is that no foci of smelting or smithing activity – i.e. smelting furnaces or smithies - were located at this stage, although large dumps of slag such as those from pit [1151] in LYM 09 and pit [3] in AFL 10 are probably very near areas of smithing (and, possibly, smelting). The identification of foci for smelting and smithing activity will only be possible when it is possible to examine the quantities and distribution of the microslags from the various sites and when all potential furnaces and features related to smelting can be closely examined. Secondly, most of the slag is fragmentary as if it had been broken up by disturbance and moved across or about on sites.

It is possible that slag accumulated as waste in the industrial area of the settlement and, because other buildings, daily community activities or the necessity to keep access routes open, inhibited it being thrown nearby, it was systematically removed by some authority and deposited elsewhere beyond the settlement. There are mid-Saxon parallels from elsewhere for waste disposal problems and major removal of slag and other waste

from within settlements. At Brandon in Suffolk, an island site, large quantities of waste of all kinds were hauled out to the northern shore to be deposited in heaps (some showing evidence of sorting) (Tester, in prep.). *Lundenwic* also seems to have had a waste disposal problem and - probably because of settlement activities and lack of further space for pits and waste dumping - slag was thrown, not as metalling but as waste, on roads in such a manner that they must no longer have been in use (28-31 James Street & 27 James Street, London WC2, both in prep.), whilst other slag was taken to the north of the settlement to be dumped in old quarry pits (Bowsher, in prep) and in open areas to the west of the settlement.

Pit [3] in AFL 10 contained smithing waste and iron objects but no diagnostic smelting slags, indicating the assemblage came from a forge/smithy (secondary smithing). This unmixed group suggests spatial separation of activities involving iron. It is reasonable to suggest that smelting was probably carried out away from the settlement whereas smithing could – and did - take place within buildings (forges or smithies) depending on how important their work or products were to the daily functioning of the community and the status of the objects they were producing.

Elsewhere on sites LYM 08 and LYM 09 smelting and smithing slags were often mixed together. Pit [1151] (LYM09) stands out as a very interesting group but only analysis will provide secure slag identifications (and some examples are so heavy an accurate weight is still required) and will certainly increase its importance and provide more in-depth interpretation of the site. The [1151] slags are significant for the site: first and foremost they are - at present - the largest examples from all the Lyminge sites and they occur together in one pit; secondly, if some or most are smithing hearth bottoms rather than furnace bottoms, they are larger and very much heavier than the average. This may be the result of intense and prolonged primary smithing of blooms or extended secondary smithing; if smithing hearth bottoms, their size would allow us to estimate the length of each smithing episode.

Thirdly, it is possible that at least two of the large pieces in pit [1151] are furnace bottoms; if the identification of these and others is confirmed, it is evidence either of earlier, pre-tapping iron production or (if contemporary with tapped slags on the site) of different technologies in use at the same time. Because of their weight, the slags in [1151] were probably not moved far from the focus of activity; future in-depth spatial analysis and examination of other features, in conjunction with any microslag evidence, may reveal where smelting/smithing took place. Pit [1141] (LYM 09) contained the only other very heavy smithing hearth bottom and it too will require analysis to securely identify it as such.

Some light is shed on this group by slag recovered at a Middle Saxon iron smelting site near Bonemills Farm, Wittering, Cambridgeshire. Here, a larger and heavier than average smithing hearth bottom was recovered from pit [1013] (Wall 2011, 97). The Bonemills example weighed 3 kg and had a diameter of 230mm x 140mm and a depth of 80mm - which makes the dimensions of the Lyminge [1151] example appear small. Because the correct weight for the large Lyminge examples is not known, no comparison with the Bonemills weight can be made. The Bonemills report discusses the problems of interpretation that can arise when very large smithing hearth bottoms are found on Middle Saxon smelting sites.

Slag within areas (LYM 08 and LYM 09) where buildings stood was generally found in pits or in building/structure post holes. One could argue the latter reveals the buildings

were standing while the waste was being strewn across the site and the slag made its way into the holes when posts were removed or rotted away. Layer [82], described as an occupation surface had smelting and smithing slag within which may be disturbed material from layer [163] described as a 'metalled surface'.

Significance of assemblage
The assemblage is significant because we now have secure slag evidence for smelting and smithing at Lyminge in the Middle Saxon period when an extant contemporary document mentions an ironworks was to be set up at the site; how long that ironworks lasted is not known, but the slag evidence may provide an answer. The area was probably chosen not only because of an iron ore source but because it had enough forest in the vicinity to produce the enormous quantities of charcoal required for smelting iron; it has been estimated that it requires 100 kg of charcoal to produce 1 kg of iron (Rackham 2006).

The smelting technology probably involved a furnace with a slag tapping hole in one side - a more advanced and efficient technology than others previously used in the Iron Age Germanic homelands and the early Anglo-Saxon period. At this stage nothing can be said about furnace types, however; this must await examination of all the other slag and examination of descriptions of the pits and features recorded on site.

The slag from pit [1151] (LYM09) reveals that prolonged smithing (possibly of blooms but perhaps of other iron objects) took place in the vicinity. The assemblage from pit [3] (AFL 10) shows that not only slag was dumped as waste; iron objects were plentiful enough to be thrown away rather than recycled.

Importance – locally, regionally, nationally
The assemblage is of national and regional importance, particularly in relation to Middle Saxon industrial activity on monastic sites. It will be of further interest if the reason why this relatively prosperous sixth and seventh century settlement was chosen as the site of an ironworks can be revealed. An equally important research question is how long the ironworks functioned, what layout it had and what it was producing.

Recommendations for further work
It is recommended that, before publication, all remaining unexamined bulk slags and the residues from soil samples are examined and quantified by a slag specialist. When the total amount of material still to be examined is known, time required and costings can be estimated.

Some stones found amongst the assemblage require geological identification to decide whether or not they are ores.

The large smithing hearth bottoms/furnace slags from LYM 09 pits [1141] and [1151] could be analysed now or at a later date to securely identify them; the analysis may also reveal what type of iron ore was being smelted at Lyminge; other information from analysis may prove useful for interpretation. Other slags (marked with asterisks in the table) could wait until all slag has been examined in case other candidates for analysis present themselves.

X-radiography of all iron objects should help to identify unfinished objects, which will have very visible hammerscale adhering to the surfaces. Metalworking tools such as

hammers, tongs, swages, for example, are all evidence for ironworking but may equally have been products of the Lyminge ironworks.

Details of all features with slag - and any that appear to have experienced burning or have burning or evidence of scorching - should be examined in an attempt to map the spatial layout of the ironworks: what is sought are (for example) charcoal burning pits (pits used to turn wood into charcoal); ore roasting pits (preparation of ore to enhance the final iron yield); smelting furnaces; smithies (secondary smithies will be buildings: forges) and smithing hearths.

Bibliographical references

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