ANCIENT MONUMENTS LABORATORY

REPORT

4713

SERIES/No CONTRACTOR

AUTHOR J G McDonnell Sept 1985

TITLE Interim slag report. Wharram Percy,
E. Yorks.
Sites 59,70 and76

H.B.M.C.E FUNDED ARCHAEOMETALLURGY CONTRACT

PRODUCTION ENGINEERING DIVISION

ASTON UNIVERSITY

ASTON TRIANGLE

BIRMINGHAM B47ET

WHARRAM PERCY (E. YORKS)

SITES 59, 70, AND 76.

INTERIM SLAG REPORT

INTRODUCTION

This Interim Report summarises the types of slag present on Sites 59, 70, and 76. It also includes the analyses of samples from the Smithy (Sites 59 and 76). A listing of all the slags and their identification is included as an appendix. A proportion of slag recovered from archaeological sites derives from the 'background noise' of residual slags ie. deriving from earlier contexts or is intrusive into the site and does not represent ironworking activity on the site. In order to identify the deposits of interest the slag distribution, both spatial and temporal, must be examined in relation to the archaeological evidence. The slags examined here derive from three sites and therefore further interpretation will be possible when both archaeological and slag data are correlated.

SLAG CLASSIFICATION

The slags recovered from archaeological sites can be divided into the 'diagnostic' and 'non-diagnostic' slags. The former are those that can be directly associated with the ironworking process. The 'non-diagnostic slags' are those that may derive from any high temperature process, including domestic hearths. These are represented by Fuel Ash Slag, Hearth/Furnace Lining, and Fired Clay. Fuel Ash Slag is a by-product of the high temperature (oxidising) reaction between siliceous material and the residual ash in the fuel. It occurs as a low density, vesicular slag commonly light grey or cream in colour, and often vitrified. It is associated with the ironworking process but is also found in domestic hearths and areas of intense burning. Hearth/Furnace Lining is the vitrified clay lining of the structure as a result of very high (oxidising) temperatures. Vitrification normally occurs in the tuyere region of the furnace or hearth. It is not yet possible to distinguish between hearth and furnace lining. Fired Clay is fired clay that has not reached sufficient temperature to be vitrified, it derives from any fired clay structure, but in the context of slag excludes daub.

The diagnostic slags derive from the ironworking process, which includes smelting and smithing. The ironworking process has been outlined elsewhere (eg. R.F. Tylecote Metallurgy in Archaeology 1963. J.G. McDonnell Tap Slags and Hearth Bottoms in Current Archaeology Vol 8 p.81-83 1983). The characteristic smelting slag is Tap Slag, which has a flowed 'ropey' morphology, but it also occurs as raked slag a more viscous (lower temperature) slag, and as slag cakes which are plano-convex accumulations of slag collected in a pit in front of the furnace. The characteristic smithing slag is the hearth bottom a plano-convex accumulation of slag that developed in the smithing hearth. Smithing slag also occurs in randomly shaped pieces that did not fully develop into hearth bottoms. Cinder normally derives from the smithing process and is slag that contains a higher silica content, and may tend towards fuel ash slag (ie. a very high silica content).

The Wharram Percy slags were classified on the basis of their morphology, and a few selected samples subjected to more detailed analyses. The diagnostic smelting and smithing slags are similar in chemical and mineralogical composition, and can therefore be difficult to distinguish analytically and morphologically.

SITE 59

The classification of the thirty point four kilos of slag recovered from the site is shown in Table I. The majority of the slag derives from the smithing process.

TABLE I Site 59 Slag Classification (Weight in Grammes)

SMITHING SLAG	20156
HEARTH BOTTOMS	2710
CINDER	2706
TAP SLAG (smelting slag)	110
FUEL ASH SLAG	1214
HEARTH LINING	815
FIRED CLAY	2495
ORE	236
TOTAL	30442

The tap slag was a single piece (weight 110 grammes)in 4.6 kilos of residue recovered from Context 14, and is regarded as intrusive. Several small pieces of 'ore' were also recoverd from the site, but are not considered significant. The fired clay occured in small quantities (maximum 315 grammes), in 35 contexts most of which included finds of slag. The majority of the fired clay therefore probably derived from structures associated with ironworking. The hearth lining also occured in small quantities (maximum 315 grammes) and in association with smithing slag and cinder.

Smithing slag occured in fourty-nine contexts , seven of which contained more than one kilo of slag, (Contexts 10, 14, 19, 20, 21, 47, and 50). It had a typical morphology, having an agglomerated appearance, randomly shaped, and contained a proportion of foreign matter, eg. pebbles, bone etc.. The larger deposists of smithing slag contained embryonic hearth bottoms that were not included in the hearth bottom catalogue. Nine hearth bottoms were recorded, and had mean values of:-

weight	300 grammes
diameter	80 millimeters
depth	29 "

Analysis of a soil sample from context 50 contained flake and spheroidal hammer scale which derive from the smithing process during hammering or welding.

SLAG ANALYSES

Ironworking slags normally comprise of three mineral phases. Firstly iron silicate, normally Fayalite ($2FeO.SiO_2$), secondly free iron oxide, normally Wustite (FeO), although Magnetite (Fe_3O_4) may also be present. The third phase is a glassy phase that contains silica, iron oxide, alumina, and alkali metal oxides. The quantity, texture and chemical composition of the phases can indicate the genesis of the slag, and in particular whether it is a smelting or smithing slag.

Two samples (WP1 and WP2) of smithing slag were randomly chosen from context 50 for detailed analyses. They were sectioned and prepared in the usual manner.

The polished sections were examined under the reflected light microscope to determine the mineral texture and approximate phase composition. The micro-structure of WP1 was silicate laths which in parts became massive, surrounded by a glassy phase which contained crystalites of another phase. There was no free iron oxide present, but there were inclusions of metallic iron. Sample WP2 had a similar microstructure but contained fine dendritites of iron oxide. The low iron oxide content is not untypical of smithing slags, but is unusual. The absence or low percentage of free iron oxide indicates that most of the iron oxide was combined with silica to form silicate. This suggests heavy fluxing (with sand) of the iron during forging.

The approximate phase compositions are shown in Table II,

TABLE II SMITHING SLAG PHASE COMPOSITION (MEAN OF 5 READINGS)

	Silicate %	Iron Oxide %	Glass %
Sample WP1	75	-	25
Sample WP2	65	5	30

Elemental analysis was carried out using the scanning electron microscope with the Link energy dispersive analysis system. Bulk analyses were obtained using a raster scan of an area at magnifications of about 200 times. Spot analyses were obtained for each phase.

The Bulk Analyses of sample WP1 (Bulk 1 and 2, Table III), showed a low iron oxide content particularily in Bulk 1. A calculation to determine the theoretical minerals formed from such a composition resulted in no excess iron oxide, which accords with the metallographic analyses. The analysis of the silicate showed it to be Fayalite ($2FeO.SiO_2$), containing some Calcium silicate. The glass analysis shows a high silica content, this would suggest that the crystalites observed in the optical study to be fayalite or orthoclase (potassium aluminium silicate [$K\ Al\ O_2\ .\ 3SiO_2$). The analyses (Bulk 1 and Glass) show a high phosphorus content that would be untypical in smelting slags.

The analyses of WP2 show a higher iron oxide and lower calcium oxide content (Bulk 1 and 2). The theoretical calculations show an excess of free iron oxide in Bulk 1 which accords with the metallographic study, while Bulk 2 shows an excess of silica. The silicate is Fayalite containing very little calcium. The glass composition is similar to that in WP1. The iron oxide was analysed and the minor oxides total 4.5%. The low iron content (68.4% as Fe) indicates that the oxide is not wustite (FeO) but either Magnetite (Fe_3O_4) or Hematite (Fe_2O_3), and hence either formed under slightly oxidising conditions or was oxidised after formation, during cooling. The fine dendritic structure would suggest the former, which are conditions expected in a smithing hearth.

Conclusions

The slag from Site 59 was morphologically identified as smithing slag. This conclusion is supported by the chemical and mineral analyses. The type and quantity of slag indicates the presence of a period of intense smithing activity on the site.

TABLE III ANALYSES OF SAMPLE WP1 (WEIGHT % OXIDE)

	BULK 1	BULK 2	SILICATE	GLASS
NaO	0.5	0.1	0.0	0.8
MgO	0.1	0.4	0.5	0.0
Al_2O_3	5.1	2.6	11.0	
SiO_2	34.6	30.2	28.6	40.0
P_2O_5	4.2	0.8	0.0	8.9
S	0.1	0.0	0.0	0.1
K_2O	4.1	1.2	0.0	9.0
CaO	13.5	4.4	6.0	15.5
TiO_2	0.3	0.1	0.3	0.2
V_2O_5	0.0	0.1	0.0	0.0
CrO	0.0	0.9	0.7	0.0
MnO	0.1	0.1	0.1	0.0
FeO	37.8	59.5	60.1	22.7
TOTAl	100.4	100.4	96.5	108.2

TABLE IV ANALYSES OF SAMPLE WP2 (WEIGHT % OXIDE)

	BULK 1	BULK 2	SILICATE	GLASS	IRON OXIDE
NaO	0.0	0.5	0.0	0.5	0.3
MgO	0.1	0.0	0.0	0.0	0.0
Al_2O_3	3.1	3.0	0.5	8.5	1.7
SiO_2	26.5	31.4	29.2	44.6	1.6
P_2O_5	0.9	0.0	0.0	2.1	0.3
S	0.0	0.0	0.0	0.1	0.1
K_2O	3.1	2.8	0.0	9.6	0.1
CaO	2.2	2.2	0.7	8.8	0.0
TiO_2	0.1	0.1	0.0	0.2	0.3
V_2O_5	0.1	0.0	0.1	0.0	0.3
CrO	0.0	0.2	0.0	0.6	0.0
MnO	0.0	0.0	0.2	0.0	0.1
FeO	63.2	59.8	67.6	22.7	87.9
TOTAL	99.3	100.1	98.4	98.1	92.4

SITE 70

Site 70 produced a small quantity of smithing slag (140 grammes) from context 2, and 20 grammes of cinder from context 19. This quantity is not significant and is regarded as the background level expected on a site.

SITE 76

Site 76 produced no smelting slag and only a small quantity of 'ore' (60 grammes). The classification of the 60.5 kilos of smithing residue is shown in Table IV.

TABLE IV SITE 76 SLAG CLASSIFICATION (WEIGHT IN GRAMMES)

Smithing Slag	54035
Hearth Bottoms	2415
Cinder	610
Fuel Ash Slag	621
Hearth Lining	1947
Fired Clay	861

The greater proportion of fuel ash slag, hearth lining and fired clay occured in contexts containing smithing slag, hearth bottoms or cinder, indicating that they probably derived from iron smithing activity.

The majority of the smithing slag and hearth bottoms derived from context 70 (40.53 kilos), with smaller amounts from contexts 19 (2.30 kilos), 24 (4.34 kilos), 28 (1.17 kilos), and 65 (2.88 kilos). All other contexts contained less than one kilo of smithing slag. This distribution indicates significant smithing activity in the area of context 70.

WHARRAM PERCY SITE 59 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	SMELT	FAS	CINDER	HL	ORE
4	85	0	0	5	5	70	25
5	0	0	0	0	45	10	0
6	796	0	0	25	70	251	21
10	1905	0	0	20	635	400	20
12	0	0	0	0	0	15	0
14	2835	880	110	20	476	316	0
15	40	0	0	0	0	130	0
16	435	0	0	6	45	156	0
19	1950	0	0	30	400	200	0
20	1220	450	0	0	0	150	0
21	3375	0	0	0	0	200	0
24	220	0	0	0	0	1	0
25	530	285	0	15	0	160	0
26	45	0	0	0	0	15	0
28	0	0	0	0	20	0	0
29	20	0	0	0	0	0	0
30	0	0	0	0	0	31	0
34	0	0	0	1	0	0	0
39	400	510	0	301	540	140	10
40	195	0	0	0	25	70	0
47	2070	0	0	645	95	481	10
48	0	0	0	50	0	0	0
50	2300	0	0	0	0	0	0
51	240	0	0	0	110	0	150
53	60	0	0	15	30	0	0
54	50	0	0	20	40	0	0

WHARRAM PERCY SITE 59 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	SMELT	FAS	CINDER	HL	ORE
56	0	0	0	0	0	25	0
57	0	0	0	0	0	20	0
61	0	0	0	0	0	16	0
62	0	0	0	0	0	15	0
63	0	0	0	0	0	20	0
67	0	0	0	0	0	35	0
74	0	0	0	0	0	1	0
75	0	0	0	0	0	30	0
77	0	0	0	0	0	10	0
81	0	0	0	1	0	0	0
84	0	0	0	0	0	20	0
89	0	0	0	0	0	15	0
91	0	0	0	0	0	10	0
94	0	0	0	0	0	20	0
98	0	0	0	0	0	25	0
118	0	115	0	0	0	0	0
126	0	0	0	0	0	6	0
127	410	470	0	10	70	146	0
128	0	0	0	0	0	10	0
149	310	0	0	0	0	30	0
150	515	0	0	35	100	5	0
152	0	0	0	5	0	0	0
159	150	0	0	10	0	55	0
** Total **	20156	2710	110	1214	2706	3310	236

WHARRAM PERCY SITE 70 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	TAP	FAS	CINDER	HL	ORE
2	140	0	0	0	0	0	0
19	0	0	0	0	20	0	0
** Total **	140	0	0	0	20	0	0

WHARRAM PERCY SITE 76 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	FAS	CINDER	HL	ORE
1	90	0	1	0	20	0
5	30	0	25	0	55	0
6	0	0	0	25	10	0
7	30	0	0	10	0	0
8	210	0	35	0	85	0
11	0	525	0	0	0	0
15	0	0	0	30	20	0
16	620	0	45	70	335	40
19	2305	0	0	0	91	0
20	40	0	0	0	50	0
22	50	0	10	70	110	0
23	60	0	0	0	0	0
24	4340	0	50	70	191	0
25	20	0	0	0	15	0
27	30	0	0	0	0	0
28	1170	0	110	95	305	0
30	170	0	15	0	10	0
31	30	0	10	15	30	0
32	20	0	0	20	0	0
37	0	0	0	5	0	0
38	70	0	0	0	0	0
40	0	0	20	0	0	0
41	415	0	0	25	70	0
42	735	0	0	0	30	0
43	25	0	15	0	0	0
44	70	0	5	0	0	0

WHARRAM PERCY SITE 76 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	FAS	CINDER	HL	ORE
52	35	0	10	0	0	0
53	15	0	0	0	0	0
54	65	0	0	0	0	0
55	20	0	0	0	5	0
56	0	0	0	0	0	20
57	40	0	0	0	10	0
58	180	0	0	0	0	0
60	10	0	0	0	0	0
62	5	0	0	0	0	0
64	30	0	0	0	20	0
65	2880	490	0	0	0	0
66	60	0	0	0	0	0
67	190	0	40	75	0	0
70	39130	1400	80	10	1125	0
72	0	0	0	15	30	0
75	55	0	60	35	0	0
76	90	0	20	0	65	0
77	40	0	0	0	0	0
84	0	0	0	10	1	0
88	0	0	20	0	10	0
103	60	0	0	0	0	0
105	0	0	0	0	20	0
119	60	0	0	0	0	0
123	130	0	5	0	20	0
132	90	0	20	0	30	0
139	250	0	20	0	25	0

WHARRAM PERCY SITE 76 SLAG LISTING (WEIGHT IN GRAMMES)

CONTEXT	SMITH	HB	FAS	CINDER	HL	ORE
145	0	0	5	30	5	0
152	70	0	0	0	0	0
165	0	0	0	0	15	0
** Total **	54035	2415	621	610	2808	60

J.G. M

J.G. McDONNELL
SEPT. 1985