(2087)

Ancient Monuments Laboratory
Report 72/90

EXAMINATION OF THE SLAGS FROM SIDBURY, WORCESTER, WORCESTERSHIRE.

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Summary

Examination of the slags from Sidbury, Worcester showed that iron smelting had been carried out in the second and third centuries AD. Smithing slags and debris were also present, but there was no evidence to indicate that the smelting and smithing processes had been carried out in the area excavated. Examples of slag were analysed, but there was no characteristic composition to indicate the ore type used. There is no known ore source near Worcester, but the evidence from this and other sites show that there was a major iron smelting industry in Worcester during some phases of the Roman settlement of the area.

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Examination of the Slags from Sidbury, Worcester

By Dr Gerry McDonnell

1 Introduction

Excavations at Sidbury, Worcester revealed medieval and Roman occupation. The medieval levels were published by Carver (1980), and current work is now concentrating on the Roman deposits.

The excavations produced large quantities of ironworking slag, which is a characteristic feature of previous excavations in Worcester (eg Carver 1980). The high concentration of iron smelting slag is of particular interest since there are no recognised ore deposits in close proximity to Worcester. It has therefore been implied by Morton and Wingrove (1969) that the ore was transported up the River Severn from the Forest of Dean.

2 Slag Classification

The slags were visually examined and the classification is solely based on morphology. In general they are divided into two broad groups. First are the diagnostic slags which can be attributed to a particular industrial process; these comprise the ironworking slags, i.e. smelting or smithing slags. The second group, the non-diagnostic slags, could have been generated by a number of different processes but show no diagnostic characteristic that can identify the process. In many cases the non-diagnostic residues e.g. hearth or furnace lining, may be ascribed to a particular process through archaeological association. The only strictly non-diagnostic residue recovered from the Sidbury site was hearth or furnace lining, but because much of it occurred in association with the ironworking debris, it probably derived from that process.

The residue classifications are defined below.

2.1 Ferrous Diagnostic Slags and Residues

Smelting Slag (SMLT) - silicate slag generated by the smelting process, i.e. the extraction of the metal from the ore. It does occur in characteristic forms, in particular tap slag, which was the predominant type in the Sidbury material.

Smithing Slag (SSL) - randomly shaped pieces of silicate slag generated by the smithing process.

Hearth Bottom (HB) - a plano-convex accumulation of silicate slag formed in the smithing hearth. The range and mean dimensions of 32 individually recorded hearth bottoms is given in Table 1, (one hearth bottom was distorted and was very deep (110mm), and this value was excluded from the Table).

Table 1 Range and Mean Dimensions of Hearth Bottoms

Dimension		Range	Mean	Standard Deviation
Weight (gms)		95-1204	490	339
Major Diameter	(mm)	80-160	106	26
Minor Diameter	(mm)	60-115	80	17
Depth	(mm)	20-70	43	15

Cinder (CIN) - high silica-content smithing slag, often formed at the reaction zone between the smithing slag and the hearth lining.

2.2 Non-Diagnostic Slags and Residues

Hearth Lining (HL) - the clay lining of an industrial hearth, furnace or kiln that has a vitrified or slag-attacked face.

Cinder (CIN) - high silica-content slag that can either be formed as described above or by high temperature reaction between silica and ferruginous material. It can be ascribed to either the non-diagnostic slags or the diagnostic slags depending on the iron content and its morphology.

Other Material which normally comprises fragments of fuel, ferruginous stones (not "ores") etc.

3 Slag Distribution

The site was excavated in the 1970's and it is certain that only some of the slag was kept, for example excavation records show that the road in Phases 5 and 6 (early to late 3rd century) was metalled with slag, though none of the slag was retained. There is no record of the sampling strategy except that it was different for Phase 6 due to a change in the overall excavation strategy. Since large quantities of slag were retained from a number of features it is probable that only the road material was thrown away.

A total quantity of 145kg of residues were retained. A full listing of residue weights (in grammes) in each context, ordered by phase and context number is given in Appendix 1.

A summary of the smelting and smithing slags by phase is given in Table 2 (cinder, hearth/furnace lining and "other" material has been excluded). Nearly 75% of the smithing slag and over 50% of the smelting slag derived from medieval contexts (Phase 99). Much of this will be residual Roman material but the high proportion of smithing slag in this phase is indicative of smithing activity in the vicinity of the site during the medieval period. Overall, about 47% of the slag was smelting slag (predominantly tap slag), and the largest deposits of phased smelting and smithing slags occurred in Phase 6 (Late 3rd century). Table 2 shows that neither slag type was present in Phases 1 and 2 (1st and early 2nd century). The absence of smelting is not surprising, but some background level of smithing debris would normally be expected. A small but significant amount of smithing slag was recovered from Phase 3, which is indicative of smithing in the vicinity. Also present was a small amount of smelting tap slag.

TABLE 2 Summary of Slag Distribution by Phase of Smithing Slags (SSL + HB) and Smelting Slag (SMLT) (weight in kg).

Phase	Date	SSL + HB	SMLT
1	1st C	-	-
2	early 2nd C	-	-
3	2nd C	5.4	0.5
4	late 2nd C	0.4	0.01
5	early 3rd C	1.1	-
6	late 3rd C	7.7	26.1
7	early 4th C	4.5	5.5
99	Medieval	54.7	36.2
Total		73.8	68.3

The quantity of slag saved from Phases 4 and 5 is considered background level, i.e. the amount that occurs due to deposits of rubbish etc. which incorporate a small slag component, or is residual from earlier activity. Phase 4 contained a large quantity of hearth/furnace lining relative to the weight of slag (see Appendix 1), which possibly indicates that it derived from processes other than ironworking. The slag metalled road was constructed in Phase 5 which would indicate either that the period of smelting activity or a period at which the slag became available for use as metalling occurred in Phase 5 rather than Phase 6.

The contexts in Phase 6 contained the major retained deposits of Roman smithing and smelting slag. The slag is widely distributed across the site and shows no evidence of spatial concentration indicative of the slag spreading onto the site from any specific direction. These features were associated with or open during the lifetime of the road, and therefore the slag probably derives from resurfacing and disturbance of the road as well as deliberate infilling of pits etc.

The material in Phase 7 contexts is considered to be redeposited Phase 6 material.

4 Discussion of Slag Distribution

The earliest evidence of iron smithing and iron smelting occurs in Phase 3. The presence of a small amount of smelting debris in this phase is indicative of iron smelting being carried out in the Worcester area in the 2nd century. The major period of slag deposition occurred in Phase 6, but with earlier use of slag in the Phase 5 road surface. The use of the slag for surfacing and infilling of pits may have occurred contemporaneously with, or later than the smelting activity. Therefore the smelting may have been carried out in the second century and the slag heaps used for hardcore etc in the third century.

There is no evidence in the Romano-British period for later iron smelting or smithing in the close vicinity, the later contexts containing only redeposited material.

5 Analysis of Selected Slag Samples

The fundamental question is whether the ore that was smelted was imported from the Forest of Dean or was from a local source. Analyses of Dean ores by Percy (1864 p206) are given in Table 3, and show that samples A.D. 3 and 5 were not rich enough in iron to be used in early furnaces. Samples A.D. 2 and 4 are suitable for early smelting and contain low levels of gangue oxides.

Table 3 Analyses of Forest of Dean Ores after Percy 1864

Sample No:	A.D.2	A.D.3	A.D.4	A.D.5
Fe_2O_3	90.05	32.76	89.76	48.98
MnO	0.08	trace	0.04	0.16
Al_2O_3	trace	0.05	0.63	0.12
CaO	0.06	0.25	0.49	14.07
MgO	0.20	0.25	0.40	10.21
SiO_2	0.92	63.45	2.14	0.79

A limited programme of chemical analysis of the Sidbury slag was carried out, which will be discussed in detail in the Deansway Report when all the evidence for iron smelting in Worcester will be examined.

The results of the analyses of three samples are given in Table 4. They were obtained using a scanning electron microscope (20kV accelerating voltage) with an attached energy dispersive X-ray analysis system. Five area analyses (B1-B5) using the raster scan mode at a suitable magnification (x250-x700) were obtained as "bulk" analyses for each sample. Variation in composition between areas show the degree of sample heterogeneity. Individual phase analyses were obtained using higher magnifications (>1000) and reduced raster scans. The phases are:

SIL silicate phase
FEOX iron oxide phase
GLAS glassy phase

All results were calculated as oxides, with iron calculated as FeO (wustite).

5.1 Sample SID1362-2

A tap runner, ie a tube of slag that froze as it flowed out of the furnace. It had a surviving length of 80mm, and was sub-circular in cross-section, with a maximum diameter of 25mm narrowing to about 15mm. It was heavily vesicular in cross-section with a large (5mm diameter) hole passing along the length of the runner. The prepared section was vesicular and the mineral texture was massive silicate and a low (10-20%) percentage of globular iron oxide dendrites in a glassy matrix. The area analyses (Table 4) give an overall fayalitic composition which is in accordance with the observed mineral structure. The percentage of other oxides was low, in particular MnO was absent. The phase analyses confirmed the silicate as fayalite containing a significant amount of magnesia (MgO). The iron oxide contained minor quantities of alumina (Al_2O_3) indicative of a spinel, ie magnetite rather than wustite. The glassy phase contained the expected oxides, in particular silica was quite high in accordance with the low amount of iron oxide in the slag.

5.2 Sample SID1362-3

A sample from a piece of tap slag which showed the characteristic flowed ropey morphology. In section the slag was finely vesicular with larger vesicles close to the upper cooling surface. The prepared section showed a typical tap slag mineral texture, silicate laths and fine iron oxide dendrites in a glassy matrix. The analyses (Table 4) are similar to those obtained for Sample SID1362-2, the overall composition being fayalitic. The silicate was fayalite, again with magnesia substitution. The iron oxide contained alumina and titania and the glassy phase was also rich in silica.

5.3 Sample SID1360

The sample was a piece of "dense" tap slag lump about 60x60x50mm. It lacked the ropey morphology, but had smooth flowed surfaces. In section it contained very few vesicles, hence its apparent high density. The prepared section showed massive silicate and globular iron oxide dendrites in a glassy matrix. The area and phase compositions are similar to those obtained from the two previous samples, except that the glass phase contains aluminium, silicon and potassium oxides with only a small amount of iron oxide present.

6 Discussion of Analyses

The results obtained from each sample are very consistent. The variations observed in the mineral texture between samples reflects the cooling conditions of the slags. The analyses show that the ore used contained no manganese which Percy (1864) showed to be the case for the Forest of Dean ores he analysed. However, many ores are manganese free, and therefore these analyses cannot be used to confirm that the Dean ores were used.

The composition of smelting slags derives not only from the ore, but also from slag-furnace lining reactions, and therefore direct slag-ore relationships cannot easily be determined. However, the level of magnesia in the slags is of interest and could be an indication of ore source. These aspects will be fully examined in the Deansway publication.

The low percentage of free iron oxide in the slags shows that the furnace was highly efficient (ie all available iron oxide was reduced to metal). The low percentage of iron oxides enables the slags to run freely.

7 Conclusions

Examination of phase distribution of the Sidbury slags shows that there is some evidence for iron smelting being carried out in the second century, but that the major activity may have occurred in the third century. Smithing slag was present in all phases, but there was no evidence to suggest that smithing was practised on the site. The analyses do not exclude the posibility that Forest of Dean ores were smelted in Worcester.

References

Carver MOH 1980 Early Medieval Worcester. An Archaeological framework. Trans. Worcestershire Archaeol. Soc. 3 Series, Vol 7.

Morton G and Wingrove J 1969 Technical Aspects of the Roman Bloomery Process in Barker P A The origins of Worcester. Trans. Worcestershire Archaeol. Soc. 3 Series, Vol 2.

Percy J Metallurgy Volume 2 Part 1 204-223 London 1864

TABLE 4 Area (Bulk) and Phase Analyses (Calculated as Oxides)

n.d - not detected

Sample 1362-2 Tap Runner

	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Co	Ni	Cu	Total
B1	1.3	1.2	6.3	29.6	1.0	0.1	2.6	3.6	0.2	0.1	0.1	56.2	n.d	n.d	0.1	102.4
B2	0.7	1.3	4.3	23.1	0.2	0.2	1.7	2.1	0.1	0.1	n.d	69.2	n.d	n.d	0.1	103.1
B3	1.1	1.8	4.6	29.0	0.6	0.1	1.8	2.3	n.d	n.d	n.d	62.9	0.1	n.d	n.d	104.3
B4	1.0	1.4	6.4	28.1	0.4	n.d	2.6	3.1	0.2	n.d	n.d	63.1	0.2	0.1	0.1	106.7
B5	0.7	2.3	3.6	23.9	0.4	n.d	1.3	1.8	0.1	0.2	n.d	69.7	n.d	n.d	n.d	104.0
SIL	0.2	4.8	0.2	33.8	0.5	n.d	0.1	0.8	0.1	0.1	n.d	65.7	n.d	n.d	n.d	106.3
FEOX	0.2	n.d	1.0	0.6	n.d	0.1	n.d	n.d	0.3	n.d	n.d	99.2	0.2	n.d	n.d	101.6
GLAS	1.5	0.3	13.4	42.3	1.5	0.3	8.3	10.2	0.1	n.d	n.d	28.5	n.d	n.d	n.d	106.4

Sample 1362-3 Tap Slag

	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Co	Ni	Cu	
B1	1.2	1.8	4.6	24.3	0.3	n.d	1.4	2.3	0.2	0.1	n.d	69.3	n.d	n.d	n.d	105.5
B2	0.6	1.5	4.5	24.7	0.5	0.2	1.7	2.3	0.3	0.1	0.1	69.1	n.d	n.d	0.1	105.7
B3	1.1	2.0	3.6	24.6	0.1	0.1	1.3	2.2	0.1	n.d	0.1	68.8	0.3	n.d	0.3	104.6
B4	0.4	1.6	4.9	24.3	0.2	n.d	1.7	2.1	0.2	0.1	n.d	67.5	n.d	n.d	n.d	103.0
B5	0.7	1.9	5.3	25.5	0.4	0.2	1.9	2.8	0.2	n.d	0.2	65.3	n.d	n.d	n.d	104.4
SIL	n.d	2.8	0.1	32.4	0.2	n.d	n.d	0.9	n.d	n.d	0.1	64.7	n.d	n.d	n.d	101.2
FEOX	0.3	0.3	1.0	0.6	n.d	n.d	0.1	0.1	0.5	n.d	n.d	95.8	n.d	n.d	n.d	98.7
GLAS	2.2	0.5	18.0	42.0	1.5	0.4	8.7	10.5	0.3	0.1	n.d	22.6	0.1	0.1	0.1	107.1

Sample 1360 'Dense' Tap Slag

	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Co	Ni	Cu	
B1	0.5	0.9	6.3	26.6	0.6	0.1	1.8	2.7	0.2	n.d	0.1	57.8	n.d	n.d	n.d	97.6
B2	0.5	1.3	4.1	26.3	0.3	0.1	1.2	1.7	0.1	n.d	0.4	60.5	n.d	n.d	0.1	96.6
B3	0.6	1.1	5.4	26.9	0.6	0.1	1.7	2.1	0.2	n.d	0.3	56.7	n.d	n.d	n.d	95.7
B4	0.7	0.7	6.1	31.0	0.3	n.d	1.0	1.2	0.4	0.1	0.1	53.9	n.d	n.d	0.2	95.7
B5	0.5	0.9	5.5	26.3	0.5	0.1	1.4	2.3	0.2	n.d	0.1	59.8	n.d	n.d	n.d	97.6
SIL	0.5	1.0	0.1	32.3	0.1	n.d	0.1	1.3	n.d	0.1	0.5	68.0	n.d	n.d	0.3	104.3
FEOX	n.d	0.2	0.7	0.6	n.d	n.d	n.d	0.1	0.9	n.d	n.d	94.8	n.d	n.d	n.d	97.3
GLAS	0.1	n.d	20.4	52.6	n.d	n.d	19.0	0.1	0.5	n.d	0.1	3.8	n.d	n.d	0.2	96.8

Appendix 1 Worcester Sidbury, Slag Listing by Phase and Context Number (weight in grammes)

CONTEXT = Context Number
SMITH = Weight of Smithing Slag Lumps
HB = " " Hearthh Bottoms
SMLT = " " Smelting Slag
CINDER = " " Cinder
HL = " " Hearth or Furnace Lining
OTHER = " " Other Material

CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1609	77					
1613						16
1614						8
1615	250					
1616			8	830	30	
1617	730				69	
1627	1876			107		
1629	1780	390		156		
1631				18		
1635			540			
1636						5
1670	11					
1675	63					
1691				68		
1708	212					
1710				11		
1726				9		
Total in Phase 3	4999	390	548	1199	99	29

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CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1483	429		13	18	86	
1491					128	
1606				88		
Total in Phase						
4	429		13	106	214	

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1392					28	
1395					17	
1405					41	
1472				41		
1499		1071				
Total in Phase						
5		1071		41	86	

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1029	36		2661		83	7
1057			1212			
1099					23	
1102	33					
1283	36					
1287	238		224		20	
1288	1068		1604			
1306			17			
1307	477		1000			
1310			441			
1314	990		693		22	
1316					3	
1318	236		880			

CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1322	139		225			
1323	112				88	
1324	76					
1329	547					
1330			98			
1331			1724			
1332			1733		28	
1333			1720			
1335	24					
1340			1205			
1346	252		478			
1350			247			
1351			258		15	
1353	325					
1357			103			
1358	135		1222			
1360	1680		3800			
1361	36					
1362	1261		4400		40	
1365			143			
1432						3
Total in Phase						
6	7701		26088		322	10

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CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1002	1040	1114	2070			260
1071	616		231			
1077			415			
1206	247		118			
1210			589			
1258	32		425	10		
1259	373	528	261		22	
1269				5		
1312			206			
1313	437		1157			
1363	133					
1390					60	
Total in Phase 7	2878	1642	5472	15	82	260

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1001	517		1303			
1007			11			
1008			388			
1009	61					
1011	323					
1014	687	215	815	46	108	
1019	171		247			
1020			481			
1021	1003		28			
1022	198		345			
1023			50			
1024			38			
1026			103	50		
1027	15					
1032			365			
1035	507		190			
1044			769			

CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1046			48			
1048			155			
1050	49					
1052			100			
1062			57			
1063				155		
1064			323			
1069	325					
1073	187					
1076	646		80			
1078			62			
1079			54			
1081	45					
1082	18					
1083	318		5200			
1084			275			
1086			29			
1087			1524			
1090				7		
1091	146					
1093	647		4200		27	
1094	1029		69			
1096	48					
1110	643		185			
1116	41					
1122	635					
1123						83
1126			15			
1128	5					
1129			1265			
1130	297		134			
1131			444			
1136				5		
1137	136					
1138	41					
1141	314				43	
1144			576			

CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1145			708			
1155				5		
1156				44		
1159	92					
1161	754	265	65			
1165	40		91			
1166	1004	645	169			
1172			120			
1174	223		1062			
1175	53		20			
1181	359					
1187	73	259				
1193	20	389	75			
1194	2350	143	2300			
1195	74					
1198	873	176	414		20	
1202	2580	2853	1065		97	
1204			123			
1205				5		
1208	2580	217				
1212	70		146			
1214	68					
1216	86					
1217			118			
1218	408		695			
1219	1065		325		125	
1220	1157		1482			
1223			554			
1224		115				
1225	278	324				
1226		558				
1227	503		158			
1229			916			
1230	59					
1231	128					
1235	5					
1236	696					

CONTEXT	SMITH	HB	SMLT	CINDER	HL	OTHER
1237			59			
1241	8520	4391	1603	45	6	
1242	57					
1243	1412		41			
1244	643					
1246			646			
1256			644			
1257	1526				10	
1260	888		260	98		
1264	3480	2042				
1266	13					
1274			335			
1275	472		1115			
1277	442		603			
1284	10				18	
1304			289			
1342			39			
Total in Phase 99	42113	12592	36168	460	454	83

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Total on Site	58120	15695	68289	1821	1257	382

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