

Caerwent *Forum-Basilica*: Evaluation of metallurgical residues

Abstract: Evaluation of the metallurgical residues has involved three activities: (1) the detailed investigation of the contents of a single example of one of the phase 4 structures in the nave identified as a “bowl-hearth”, (2) the rapid evaluation of variation in the macroscopic slags from the other phase 4 “bowl-hearths” and (3) an overview of metallurgical residues from other phases/areas to identify any other metallurgical activity forming an intrinsic part of the history of the *forum-basilica*. Not all tasks which were hoped to form part of the assessment have been completed (with chemical examination of the fines, and quantitative evaluation of the fines classes still outstanding), because the assessment has included more SEM petrography of the macroscopic slags than was initially envisaged would be necessary.

(1) The detailed investigation of the “bowl-hearth” context 2861 showed that most residues were associated with a single context of its fill (2835). This fill comprises a dark, silty soil, with abundant small charcoal fragments, which bears abundant (>11 wt%) hammerscale, including both flake (dominant) and spheroidal varieties. The excavators picked most of the macroscopic residues from this matrix, forming a collection of 4.6kg of material, which includes 3.5kg of slag proper, 0.4 kg of hearth lining, 0.6kg concreted smithing pan and 0.06kg coal and associated debris. The slags are dominated by dark, glassy materials with a major component from the hearth lining. There is a lesser proportion of denser, small plano-convex cakes. The assemblage as a whole is indicative of blacksmithing. The smithing pan fragments were discovered to have been generated almost universally through the corrosion of iron objects causing cementation of the fine matrix. The iron objects were mainly small to medium sized nails. The corrosion of the iron seems likely to have occurred within the deposit, rather than there having been deposition of already-cemented pan. Evidence for the use of both coal and charcoal was noted.

(2) A rapid assessment of materials from other examples of the “bowl-hearths” was undertaken. The range of slag types was similar in all the “bowl-hearths”. Some contexts (e.g. 2833) may show a higher proportion of conventional plano-convex smithing cakes than 2835. Context 2833 also contained a minute flake of corroded copper alloy.

(3) Review of residues from other phases/areas revealed several potentially significant activities:

- a) **Phase 1c and Phase 1d** (G3248, G3384). Material dumped on site from elsewhere includes abundant iron smelting residues, including tapped slags and pieces of ore.
- b) **Phase 1c and 3c** (G3348, G3395, G2780). Some materials in the slag collections may be associated with lime-burning.
- c) **Phase 3a** (G4067). Abundant copper alloy slags, moulds and crucibles associated with hearth in nave. Possibly associated materials occur (derived) in phase 3b and 3c contexts (G2780, G1196).
- d) **Phase 5** (G1165, C1172, C1178, C1184). Abundant evidence for non-ferrous metalworking in *Tribunalia* antechamber. Includes working of copper alloy and lead, including use of cooking pots as large crucibles.

The metallurgical activity evidenced by material from the *forum-basilica* was thus more diverse than had been initially envisaged. Pre *forum* iron smelting somewhere in the vicinity is documented by the slags imported as make-up. No metallurgical activity associated with the initial construction has been noted, although working of copper alloys necessitated the construction of a hearth in the nave during the early stages of the reconstruction (Phase 3A). Only small mould/crucible fragments have been identified so far from this context, so it is unlikely that it will be possible to determine exactly what fittings were being made or salvaged. The phase 4 activity in the nave appears to be restricted to blacksmithing. Considerable doubt exists as to whether the “bowl-hearths” are indeed the smithing hearths, or just the dumps of smithing waste. If the dumping of waste was limited to the inside of the *basilica* then the amount of slag involved is relatively small, and multiple hearths would appear unnecessary, unless used synchronously by a team of smiths producing for a specific short-lived purpose. The phase 5 activity seems to be associated with the salvaging of non-ferrous materials from the structure.

Future studies should:

1. define the nature of the pre-*forum* iron smelting activity and its ore source.
2. define the nature of the copper alloy working during the reconstruction, identify the alloy(s) involved, and interpret the technology of the associated hearth.
3. attempt to clarify the nature of the corroded iron fragments associated with the phase 4 smithing.
4. re-examine the excavation evidence for the nature of the supposed bowl-hearths.
5. define the nature of the phase 5 non-ferrous metalworking, identify the alloys involved, determine whether the metals were being melted down for salvage or were being actively worked on site, examine and describe the use of greyware pots as crucibles.

PART 1: RESIDUES FROM WITH THE PHASE 4 METALLURGICAL ACTIVITY IN THE NAVE

1A. The Macroscopic Slag Assemblage from context 2861

1A.1 Material

The fill of “furnace” 2861 was selected by PG for detailed evaluation. The furnace fill comprised three contexts (2835, 2862, and 2863). 2835 was represented in the archive by 27 bags of sediment and 5.24kg of picked macroscopic “slag”, 2862 by 0.14kg macroscopic “slag” and 2863 by 0.06kg “slag”.

2835: The assemblage was dominated by dark slags which were divided into glassy, low density slags (1.880kg) and dense slags (1.620kg, of which the largest specimen was 0.800kg). In addition there was 0.550kg of concreted smithing pan, 0.360kg of hearth lining and lining slags, 0.055kg of coal, coke and associated slagged shaley debris, together with 0.175kg of dust and fines. Total 4.640kg.

2862: This small assemblage comprised single specimens of lining and dark slag (with adhering coked coal), together with two pieces of corroded iron/smithing pan. Total 140g.

2863: This small assemblage comprised three small fragments of dense slag prills, 1 tiny lining fragment, 1 larger piece of lining slag, together with a stray pebble. Total 60g.

Sampling was undertaken mainly from the significant assemblage from context 2835; an additional furnace lining analysis was selected from a specimen from context 2832, since that specimen showed a well-preserved blowhole:

Sample	Context	Material	XRF	ICP	SEM
CWT1	CB92/2835	dense smithing cake	y	y	y
CWT2	CB92/2835	smithing pan		y	y
CWT3	CB92/2835	smithing cake	y	y	y
CWT4	CB92/2835	glassy slag	y	y	y
CWT5	CB92/2835	glassy slag	y	y	y
CWT6	CB92/2835	glassy slag	y	y	y
CWT7	CB92/2835	bluish fuel ash slag	y	y	y
CWT8	CB92/2832	lining from blowhole	y	y	
CWT9	CB92/2835	lining	y	y	

Table 1: Selected samples and techniques employed. XRF = X-ray fluorescence for chemical analysis of major elements (undertaken at the Dept. of Earth Sciences, Open University), ICP = induction-coupled plasma mass spectrometry (ICP-MS; undertaken at the Dept of Earth Sciences, Cardiff University), SEM = backscattered electron petrography and microanalysis by energy-dispersive spectrometry (EDS) (undertaken at the Dept of Earth Sciences, Cardiff University).

1A.2 Slag descriptions

CWT1 (Figure 1: a – j)

CWT1 is a smithing slag cake with a weight of 800g, measuring 100x120mm and 70mm maximum thickness. It is the largest slag block from context 2835, and at 800g provided a major contribution to the dense slags recorded from that context.

The upper part of the slag contains abundant fuel fragments, apparently including both charcoal and coked coal fragments. These fragments are generally <8mm, but some elongate charcoal fragments range up to 20mm in length. The slag matrix to these fragments is rather porous, and stained brown by iron oxides.

The lower section of the slag is mid-grey colour, rather dense, and bearing well rounded vesicles of up to 8mm diameter, although generally much smaller. There is some suggestion of a similar dense grey slag above the fuel rich layer, giving the cake a compound form, and suggesting two separate phases of development.

Under the SEM the texture can be seen to be very heterogeneous. A very patchy development of wustite dendrites of up to 500µm in length, is followed by leucite and a syntectic development of magnesium-rich fayalite ($\text{Fe}_{88}\text{Fe}_{12}\text{O}_{12}$) and hercynite (Figure 1: a, c, d, e, g). The fayalite is locally elongate, but dominantly sub-

equant and approximately 100µm. The hercynite forms euhedral to anhedral blebs within the fayalite, and up to 50µm. Hercynite compositions show high magnetite substitution at 10-17%, but with low substitution of other components (low Ti, moderate Mg and with V and Cr both below detection: Table 2). At various points, but particularly near the margin of the specimen there are arcuate (sub-spheroidal?) features 200-400µm in diameter, formed of leucite, overgrown with a leucite/wustite syntectic (Figure 1: a, b). This syntectic also occurs and dendritic like growths, also typically occurring in areas without the wustite dendrites. The areas enclosed by these structures are largely free of the wustite dendrites. The ?spheroidal features apparently represent margins of vesicles, and the large quantities of leucite may suggest that these are the results of burning fuel.

Although the leucite structures are unusual, this slag was developed under strongly reducing conditions in a relatively Al-rich fayalitic melt. The patchy distribution of wustite might be associated with the localised assimilation and reduction of workpiece debris, but as would be expected in a slag of this composition, there was no preserved scale observed.

	Fe ²⁺ /Fe ³⁺							divalent						
	Fe ²⁺ /Fe ³⁺	Fe ³⁺	Al	Cr	V	Ti	Fe ²⁺	total	Fe ²⁺	Mn	Mg	Ca	Ni	total
cwt1 h6	0.80	1.98	13.83	<	<	0.10	0.10	16.00	7.73	<	0.27	<	<	8.00
cwt1 h5	0.75	2.73	12.96	<	<	0.15	0.15	16.00	8.00	<	0.00	<	<	8.00
cwt1 h4	0.76	2.45	13.40	<	<	0.07	0.07	16.00	7.48	<	0.52	<	<	8.00
cwt1 h3	0.75	2.49	13.38	<	<	<	<	15.87	7.54	<	0.46	<	<	8.00
cwt1 h2	0.78	2.15	13.72	<	<	0.07	0.07	16.00	7.34	0.04	0.61	<	<	8.00
cwt1 h1	0.77	2.29	13.54	<	<	0.08	0.08	16.00	7.70	<	0.30	<	<	8.00
cwt3 h1	0.83	1.37	14.31	0.04	0.09	0.07	0.07	15.95	6.63	<	1.37	<	<	8.00
cwt3 h2	0.88	1.01	14.57	0.09	0.07	0.05	0.05	15.84	7.25	<	0.75	<	<	8.00
cwt3 h3	0.89	0.86	14.71	<	0.04	0.08	0.08	15.76	6.99	<	0.98	0.03	<	8.00
cwt4 h1	0.88	0.83	14.23	0.21	0.05	0.11	0.11	15.54	5.78	0.04	2.05	0.06	0.08	8.00
cwt4 h2	0.90	0.69	14.71	0.12	0.05	0.08	0.08	15.73	5.92	0.05	1.96	<	0.08	8.00
cwt4 m	0.36	14.55	1.00	<	<	0.08	0.08	15.71	8.00	<	<	<	<	8.00

Table 2: EDS microanalyses of spinels from selected samples. Values show number of ions when Fe^{II}:Fe^{III} ratio is adjusted to bring the divalent sites to a total of 8. < = below detection.

The hercynites from CWT3 and 4 have 6-8% magnetite, whereas those from CWT1 show 10-17% magnetite. The magnetite from CWT4 shows 6% hercynite. TiO₂ substitution is low throughout, but MgO substitution in the hercynites is high, particularly in CWT3 and 4. CWT3 shows enrichment in Cr and V; CWT4 shows very high substitution of Mg, increased substitution of Cr and some substitution of Ni.

CWT2 (Figure 2: a,b)

This specimen is a small fragment of the “smithing pan” recorded in the macroscopic assessment. The material is a pale rusty brown colour and bears a variety of clasts including scale and fuel debris.

When cut, the specimen could be seen to enclose a square-sectioned, entirely corroded iron artefact, probably a nail shank. The matrix surrounding the nail was full of flake-morphology hammerscale, together with quartz sand (dominantly with grains of about 200µm, but ranging up to >1mm, and down to silt grade), set in fine grained or amorphous corrosion product.

CWT3 (Figure 1: k – v)

CWT3 is a small plano-convex slag cake, 80x70mm and 30mm thick. The upper part of it comprises a dark, fine-grained slag with a smooth upper surface; the lower part is paler with abundant inclusions of partially-melted hearth lining. The upper part of the slag contains abundant small fuel fragments, which appear to be dominantly of coked coal.

At a microscopic level the specimen proved to have a microstructure (like CWT1) dominated by a close association of hercynite and fayalite, but (unlike CWT1) not showing development of wustite (Figure 1: k – t).

The hercynite shows only 6-8% magnetite substitution, but has relatively high levels of Mg and V and low levels Ti and Cr (Table 2). Between the major fayalite/hercynite crystals lies a finer-grained groundmass of elongate crystals of fayalite within a silicon + aluminium + calcium + potassium-dominated material (usually presumably glass, but in some areas it appears crystalline (e.g. Figure 1: k) and maybe a plagioclase feldspar), forming a sheaf-like texture (Figure 1: n, r). The late stage fayalite+glass is locally accompanied by tiny blebs of sulphides (Figure 1: n), and blebs of native iron up to 50µm across occur sporadically (Figure 1 r – t).

	Al ₂ O ₃	SiO ₂	FeO	MnO	TiO ₂	MgO	CaO	Na ₂ O	K ₂ O	S	P ₂ O ₅
CWT3 g1	21.43	60.08	1.69	<	0.68	<	3.72	<	12.39	<	<
CWT3 g2	24.97	56.03	2.69	<	0.42	<	9.15	<	6.74	<	<
CWT3 g3	25.56	55.58	1.33	<	0.48	<	9.60	<	7.45	<	<

Table 3: EDS microanalysis of glass phase in CWT3. Values quoted are wt% oxide. < = below detection.

CWT4 (Figure 2: c – j)

This specimen has a mid-grey coloured slag bearing dispersed sediment grains and larger clots of furnace wall and pebbles, in various stages of assimilation. Some slag surfaces show a slightly lobate form, which together with an overall layered structure, suggests that this slag may have formed on the hearth wall.

In the SEM this specimen proved to have a very finely crystalline matrix, dominated by hercynite and calcic plagioclase. The hercynite occurs as needles (1µm x 50µm) perpendicular to remnant quartz grains (Figure 2: l), small scale dendrites up to 20µm long (Figure 2: f), as well as isolated crystals ranging from sub-micron size up to approximately 5µm. After an initial hercynite dominated zone 20-50µm thick over the remnant materials, the plagioclase forms laths or needles up to 150µm in length and 5µm wide (Figure 2:d – g). The remnant quartz grains range up to approximately 200µm. The hercynite compositions show high levels of Mg substitution, and with substitution by Cr, V, Ti and Ni all detectable (Table 2).

	Number of ions on basis of 32 (O)										Mol. %			
	Si	Al	Fe ₃	Mn	Mg	Ti	Ca	Na	K	Z	X	An	Ab	Or
cwt4 p1	8.98	7.04	<	<	<	0.02	3.24	0.31	0.17	16.02	3.76	87%	8%	5%
cwt4 p2	9.25	6.78	<	<	<	<	3.04	0.38	0.21	16.03	3.65	84%	10%	6%

Table 4. EDS microanalyses of plagioclase feldspars from CWT4. Analyses adjusted by removal of iron as fayalite.

A few small isolated examples of hammerscale exist, with thicknesses of less than 60µm.

CWT5 (Figure 2: k – q)

This is a small irregularly rounded slag fragment approximately 30mm in diameter. The surface is dark, and shows a smooth or slightly wrinkled surface, suggestive of some high viscosity flow. One end of the specimen has a particularly dark, shiny surface, with dimples up to 10mm across, suggestive of a fuel-contact surface. The surface has adhering “smithing pan-like” material, containing abundant small charcoal fragments.

The cut surface shows a dark glassy slag, dominantly black, but locally greenish, with vesicles up to 16mm (but usually much smaller) and with blebs and trains of pale sediment grains.

The microstructure of this specimen is dominated by glass through much of the specimen (Figure 2: k), but near iron fragments (Figure 2: l) the groundmass is of finely crystalline, elongate fayalite, typically only 10µm in length, bearing larger fine fayalite laths of up to 1.5mm in length.

The iron fragments are all partially dissolved into the melt, leaving a carious texture, and range up to approximately 1mm across. Most of the cavities within the iron are filled with the same glassy material as occurs outside the fragment, but in one fragment the iron has similar sized porosity filled with iron sulphides (Figure 2: o – q).

		Al	Si	Fe	Mn	Ti	Mg	Ca	Na	K	S	P
cwt5 - g1	between quartz	7.71	26.20	13.89	0.13	0.46	3.74	2.22	<	3.10	0.10	<
cwt5 - g2	dark	7.93	29.03	11.08	<	0.44	2.66	2.08	<	4.57	<	<
cwt5 - g3	bright	6.96	25.22	18.81	<	0.41	3.52	2.75	<	2.38	<	<
cwt5 - g4	glass assoc iron	5.60	23.44	30.26	<	0.30	1.72	3.88	<	2.10	0.38	0.17
cwt5 - g5	small iron void	5.27	23.62	30.24	0.18	0.29	1.12	4.04	<	2.30	0.73	0.76

Table 5. EDS analyses of glass from CWT5. Analyses are quoted as number of ions with O=32 (i.e. calculated as if a feldspar). < = below detection.

CWT6 (Figure 2: r – t)

This sample is a sub-spheroidal slag, approximately 50mm in diameter. The surface appears externally to be very dark, but the cut section shows most of the slag to be very pale. The dark surface layer shows adhering and impressed charcoal fragments and hammerscale. One side of the specimen is formed by a highly vitrified, porous (but with very small vesicles, up to 8mm, but more typically <100µm) material, possibly a discrete pebble, but more likely highly altered furnace wall, 40x20mm in section. Draped around this vitrified lump is a pale, porous, slag with vesicles up to 16mm and commonly 1-2mm in diameter.

The polished block shows a generally finely vesicular texture (vesicles dominantly <1mm) with a very finely crystalline groundmass (Figure 2: r). The surfaces of the vesicles may be finely, and irregularly, coated with tiny (sub-micron) crystals, probably of magnetite (Figure 2: s). These magnetite crystals may also form trains and swirls in the glassy matrix.

One margin shows a contact with a thin layer of fayalitic slag, itself in contact with an adhering layer of concretionary pan (Figure 2: t).

CWT7 (Figure 2: u –x)

This small sample shows a glassy slag of variable colour, but locally bluish, bearing large vesicles, some of which contain rusty charcoal debris.

In the SEM the fuel fragments are surrounded by complex corrosion products. The slag is dominantly glassy, and shows extensive alteration.

1A.3 Chemical analysis

The major element analyses (by XRF, undertaken at the Dept, of Earth Sciences, Open University) are presented in table 3 and some minor elements determined by the same method in table4.

The hearth linings have moderate Si and Al contents, and relatively high Fe, Mg and K. Ca is low.

Two of the slags show influence of material of similar composition to the analysed linings: CWT1 and CWT6. The composition of CWT6 is very close to the lining specimens in general – supporting the macroscopic textural observation that it appears to be dominated by melted lining. CWT1 has a very high iron content, but a crude mass balance (Table 5) suggests this is mixed with a 15-20% contribution from lining and a lesser contribution from fuel. The usual interpretation of the plano-convex cakes like CWT1 is that they are produced by interaction between fragments derived from the workpiece, and lining fluxed from the wall by the fuel. The iron-rich nature of CWT1 suggests that it may have been generated by processes involving a large degree of loss to the workpiece, for instance during a process involving multiple heating of iron to welding temperature, or by a prolonged period in the hearth.

The modelling of the analyses for CWT3, 4, 5 and 7 suggest a much higher involvement of fuel in the generation of these slags. The iron contents of these specimens are low-intermediate (11.1 to 41.4 expressed as wt% Fe₂O₃). The interpretation of these slags is for an origin within the hearth bed (in much the same way as clinker forms in a modern blacksmiths hearth) where fuel is interacting with scale and lining (perhaps from the floor as well as the sides of the hearth). The morphology of CWT3 suggests an origin in a similar location to that for CWT1, but has a much lower input from the workpiece – perhaps reflecting only a

short time of accumulation, or lower temperature working. CWT4 has a low iron content (13.3% expressed as wt% Fe₂O₃), reflecting low iron input from hammerscale, and possibly a rather low degree of assimilation of the scale. CWT5 has a much higher iron content (32.2% expressed as wt% Fe₂O₃), and shows evidence for iron assimilation from relatively large iron fragments.

	LOI	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Total
CWT1	0.19	11.42	4.57	83.30	0.10	0.45	0.58	0.02	0.72	0.21	0.53	102.08
CWT3	0.34	50.83	11.99	25.73	0.21	2.31	3.38	0.42	2.95	0.55	0.75	99.45
CWT4	-0.09	61.38	14.60	13.30	0.19	2.06	3.39	0.56	3.21	0.64	0.78	100.02
CWT5	0.49	45.49	10.01	32.17	0.14	3.52	3.72	0.30	2.49	0.53	0.50	99.36
CWT6	-0.03	68.09	12.87	11.11	0.14	1.61	0.69	0.62	4.19	0.78	0.20	100.26
CWT7	2.72	34.21	8.44	41.44	0.28	1.88	3.93	0.27	2.52	0.44	1.08	97.20
CWT8	0.43	71.11	10.90	9.76	0.18	2.34	0.33	0.43	3.58	0.59	0.15	99.81
CWT9	0.89	68.75	11.87	7.97	0.17	2.37	0.76	0.50	3.95	0.64	0.23	98.11

Table 6: major elemental analysis of selected samples by XRF

	Ba	Cr	Ni	S%
CWT1	290	36	<	0.32
CWT3	1212	68	68	0.18
CWT4	1230	100	136	0.06
CWT5	446	58	64	0.18
CWT6	450	60	40	0.06
CWT7	646	46	44	0.34
CWT8	388	50	38	0.02
CWT9	460	62	48	0.02

Table 7: minor element analysis of selected samples by XRF

	fuel	lining	loss from workpiece	interpretation
CWT1	<5%	20%	80%	Iron-lining reaction
CWT7	5-10%	55%	35%	Iron-lining-fuel reaction
CWT5	<5%	70%	25%	Iron-lining-fuel reaction
CWT3	5-10%	75%	20%	Iron-lining-fuel reaction
CWT4	5-10%	90%	5%	Lining-fuel reaction
CWT6	<1%	>95%	<5%	Lining
CWT8	<1%	>95%	<2%	Lining
CWT9	<1%	>95%	<2%	Lining

Table 8: Crude mass-balance interpretation of slag composition

1B. The Microscopic Residues from Context 2835

A sample of approximately 350g was taken from the stored matrix to c2835. The material was oven dried and then sieved, with collection of samples on 4mm, 2mm, 500µm and 250µm sieves. A part of the coarser fraction passing through the 250µm sieve was also retained (material passing the sieve allowed to settle for 5 minutes and then decanted). The dried size fractions were then weighed and magnetic material removed using a handheld magnet. Isolated particles were hand-picked from the magnetic separates, cleaned ultrasonically and mounted for examination on the SEM.

Grade	weight	magnetic	grade%*	magnetic%	magnetic % of grade
>4000	24.63	2.38	6.9%	0.7%	9.66%
>2000	25.28	4.15	7.1%	1.2%	16.42%
>500	78.67	16.02	22.1%	4.5%	20.36%
>250	97.13	17.65	27.3%	5.0%	18.17%
<250	62.01	n.d.	36.6%	n.d.	n.d.
lost	68.44				
total	356.16	>40.20	100%	>11.29%	

Table 9: Breakdown by size fraction of a subsample of 356.16g derived from CWT 2835. The proportion of magnetic material has not yet been determined for the <250 fraction.

There were two major classes of scale present:

Flake hammerscale (Figure 3: c, e). This was the dominant material present. The flake scale ranges up to 7mm, but the majority is very small (<500µm) and thin.

Spheroidal hammerscale (Figure 3: a, b, d). The subordinate scale type, with a size ranging up to 3.5mm, but dominantly 1-2mm diameter.

In addition to the scale, the magnetic separates contain a large quantity of magnetic furnace lining material and small fragments of other slags. No quantitative measurements have been made of the distribution of these classes yet, although it is hoped this will be undertaken for the final report.

Whilst flake hammerscale may be produced by slag expulsion (cf. Allen 1986), the most important source of fine scale material, such as this, is by surface oxidation of the workpiece, which can occur at relatively low temperature (Crew 1996, Starley 1995). Spheroidal scale is produced through expulsion of liquid slag during firewelding, including bloomsmithing (Allen 1986, Crew 1996, Starley 1995).

1C. Interpretation of the slags

There is no evidence in the material from context 2861 for non-ferrous metalworking. The slags form a coherent suite indicative of iron smithing activity. The residues from blacksmithing are surprisingly poorly known, and a full interpretation of these materials may best be served by attempting experimental reconstruction of the processes in due course.

The absence of large smithing hearth cakes and flattened slag flakes (hammer flats) indicate that the activity was not bloom-smithing. The dominance of hearth-lining dominated slags and fine flake hammerscale rather suggests a relatively light activity, though some spheroidal scale is present, indicative of attainment of welding temperatures. The presence of significant quantities of nails amongst the iron fragments present in the cemented smithing pan, suggests that nails may have been a significant component of the production.

1D. Interpretation of the deposit

The material from context 2835 represents debris from a blacksmithy. Such material cannot simply represent abandonment of a hearth, but rather represents dumping of hearth cleanings and/or smithy floor sweepings. The significance of context 2861 (the containing "furnace") must be determined on its own properties, not on abandonment fill. The shape of the feature, with an irregularly inward sloping outer area surrounding a shallow central pit, does not correspond to the expected form for a floor-level smithing hearth, and by late Roman times many hearths were more sophisticated waist-level structures. The excavator's section across the feature does not show indication of a discrete clay wall or lining.

One alternative possibility, for instance, might be that the central pit held a large diameter log used as an anvil, and the inward sloping area represents a worn working floor.

1E. Speculative discussion on the scale of production

A very crude, speculative, estimate of the scale of operation can be obtained by trying to estimate the total amount of iron contained in the deposits of context 2835. Very few quantitative data are available on the production of slag and scale during blacksmithing, and their production will vary enormously with the type of

forging being undertaken. Crew (1991) reported an iron loss of 18% during smithing of an iron bar into a simple currency bar, and losses during complex operations would be much higher. If the small soil sample analysed is representative of the overall 27 bags of matrix from context 2835 (currently unweighed, but approximately 150kg), then there should be of the order of 16.5kg of magnetic fines in the bulk collection, which, if all hammerscale made of magnetite, would contain about 11.1kg iron. The 1.6kg of dense slags might be expected to average approximately 55% iron, and the 1.9kg of glassy slags around 20%. This corresponds to approximately 1.3kg of iron in the macroscopic slags, giving an overall total of 5.6kg iron. A crude estimate therefore, based on 20% loss, is that the residues from 2835 are equivalent to the result of working up 70kg of finished iron (itself equivalent to perhaps 3500 of the type of nails, originally perhaps of approximately 20g, found in the residue). Scaling up these figures for the total volume of residues recorded from the nave "bowl-hearths" gives a figure of 250kg iron or 12500 20g nails (this does not take into account any residues deposited elsewhere – and significant amounts of debris may have been deposited into the northern range). These figures have been derived through a series of tenuous and potentially wildly inaccurate calculations, so must be taken only as a very general indicator of the scope of the operation. However, the implication of this crude estimate of production, is that the scale of production may not have been greatly different from the requirement for nails if, for instance, a structure the size of the northern range of rooms was to be re-roofed.

1F. Overview of residues from other Phase 4 contexts

The macroscopic slag collections from all the "bowl-hearths" of the phase 4 metalworking in the nave were examined briefly to establish the degree of variation between the deposits. No significant difference was identified in the range of slag types present in different contexts, even including c2771 (the phase 5 "bowl-hearth").

PART 2: ASSESSMENT OF METALLURGICAL ACTIVITY IN OTHER PHASES/AREAS

2A. Metallurgical residues from the construction of the forum

Context groups G3248 (c3248, 3303, 3326, 3372 & 3298) and G3384 (c3418) provide ample evidence for reuse of debris from iron smelting. The most abundant elements are tapped smelting slags, but ore fragments and pieces of furnace lining also occur.

2B. Copper alloy working during basilica reconstruction

A hearth associated with the initial stages of reconstruction of the basilica (Phase 3A; G4067, c2938) is associated with both crucible and mould fragments. Similar materials occur subsequently in phase 3B (G1196, c2933) and phase 3C (G2780, c2784,2785) contexts, presumably derived from the phase 3A activity.

2C. Copper alloy and lead working in the Tribunalia antechamber in phase 5

Contexts (G1165, c1172, c1178, c1184) in the antechamber, particularly associated with the large pit, have abundant debris from lead and copper alloy working. These include a greyware cooking pot reused as a crucible. There are pieces of hearth lining and part of a tile apparently reused in the hearth. In addition there are pieces of iron working slags similar to those from the phase 4 contexts, in contexts c1175, c2771 and c2769. Some of these may be residual but c2778 (to which 2771 is an ashy fill) is recorded as a phase 5 "bowl-hearth".

PART3: RELATIONSHIP OF EVIDENCE FOR METALLURGICAL ACTIVITY TO THE RESEARCH OBJECTIVES

This assessment demonstrates that there are three phases of metallurgical activity directly related to the evolution of the forum-basilica structure (phases 3A, 4, 5). In addition the construction of the forum employed reuse of iron smelting debris from nearby: Only one of the phases (the phase 4 iron working) relates directly to use of the building.

1. *pre-forum iron smelting*. This smelting does not form an integral part of the forum-basilica story, but is an important addition to knowledge of the development of the iron industry in SE Wales, and to understanding of the economic development of Caerwent. Chemical and petrographic techniques can be used to provenance the ore samples and to determine much about the “efficiency” of the smelting process.

2. *copper alloy working during reconstruction*. This phase is presumably associated with the fitments for the basilica, and is therefore a significant addition to knowledge of the fabric. What metals were being used? Does this event represent recycling of fitments stripped from the first phase structure, or creation of new ones?

3. *iron working during phase 4*. This is the most important phase of metalworking and is intimately associated with the eventual fate of the structure. The assessment detailed in this report has already clarified many of the issues involved with the interpretation of the activity. Current indications are that this metalworking phase may not resemble that at Silchester as closely as previously thought. The apparent homogeneity of the residues, the lack of non ferrous metalworking, the lack of well-defined smithy structures and the apparent abundance of nails in the residues, may all suggest a short-lived phase of activity providing for a particular (architectural?) need. This is in contrast to Silchester where the basilica is apparently given over to some kind of commercial operation, dealing with iron and pewter. The precise nature of the style of blacksmithing is not determinable within the current understanding of the residues. A co-ordinated programme of experimental work may be able to address this issue.

The biggest outstanding issue is the nature of the features containing the deposits of this phase. The identification of these features as hearths is far from certain. If they are not hearths, then where was the smithing taking place?

4. *copper and lead working during demolition*. The nature of the working of metals during the demolition and salvage phase may shed light on the nature of that phase. Is this activity opportunistic robbing or planned demolition? What were the metals involved and is there any surviving evidence of the nature of the fittings being salvaged? To advance these questions the metallurgical studies will need to be integrated with the study of the metal small-finds from the appropriate contexts – particularly where these involve either metal clippings, or melting losses. The identification of a phase 5 “bowl-hearth” (2778) is interesting – does it represent a continuation of the earlier activity? Is it associated with the other phase 5 metalworking?

In parallel to the research objectives of the Caerwent *forum-basilica* project, there are areas where detailed metallurgical studies will further the broader study of archaeometallurgy. In particular, two areas need flagging as having research potential:

1. The possibility in phases 3, 4 and 5 of being able to identify hearths and to relate them to specific metallurgical processes is important. Only a rather superficial understanding of hearth design in relation to specific purpose currently exists.

2. The large body of residues from phase 4 blacksmithing may provide a resource for the improvement of understanding of this class of residue. This large assemblage provides a real opportunity for Caerwent to aid archaeometallurgy, as well as *vice versa*. This will be particularly true if the study of the assemblage can be paralleled by experimental work.

PART4: SUGGESTIONS FOR FURTHER STUDIES

The following programme is suggested (listed in relation to the four phases described above):

1. *pre-forum iron smelting.*

Evaluation and description of the slags, linings and ores from appropriate contexts.

This to include full chemical analyses of ore sample, lining sample, and representative selection (probably <6, depending on observed variability) of slag samples. Polished samples of slags and ore to be prepared and described, using SEM and optical petrographic techniques.

2. *copper alloy working during reconstruction.*

Evaluation and description of the slags, crucibles and moulds from appropriate contexts.

This to include physical description of moulds and crucibles. Isolation and chemical analysis of residues where possible (<6 samples). Chemical analyses and of slags and linings (<4 samples). Petrographic investigation of slags where appropriate (<4 samples).

Evaluation and interpretation of the associated hearth

Investigate drawings and photographs with the aim of understanding the hearth technology employed

3. *iron working during phase 4.*

Evaluation and description of the iron fragments from appropriate contexts.

This to involve determination of artefact type, and if possible to determine whether imperfect. This may involve systematic X-radiography of concreted smithing pan samples from all contexts associated with this phase of activity. Unfortunately the iron all appears too corroded for useful metallographic investigation

Re-evaluation of the nature of the features containing the residues. Are these hearths? Can any other contemporary features be identified?

Investigate drawings and photographs to understand the hearth technology employed

Extension of existing slag "catalogue" to other "hearths"

Macroscopic classification and description of slags. Additional microscopic or chemical investigation of materials from this phase is not considered necessary.

Focus on hearth 2778 (the phase 5 example) to determine whether it shows any differences, analysing samples (<2) as necessary.

Completion of analysis of "hearth" 2861

Chemical analysis of microscopic residues

Quantitative evaluation of micro-residue types

Magnetic susceptibility studies of fines as an aid to quantification

4. *copper and lead working during demolition.*

Physical and chemical analyses of metallurgical materials

a. metal fragments from the appropriate contexts. Several samples (<3) each of copper alloy and lead. Physical description – are these melted down materials or artefact remnants (this may already be in hand under artefact studies)?

b. selected slag materials, especially those associated with the crucible (<6 samples).

Re-examination of excavation data to try to identify any associated hearth and its technology

This programme would thus entail:

- <30 chemical analyses (XRF + ICP-MS), depending on the details of variability and preservation revealed when the material is extracted from the archive. (£23.50 / sample: < £705)
- Petrographic investigation of <18 residue samples. (£5.90 / sample for preparation: < £106)
- Metallographic examination of <4 metal specimens. (£5.90 / sample for preparation: < £24)
- SEM time (< 3 days) for petrographic work and for investigation of crucible and mould residues.
- X-radiography of concretionary iron pan material (£10)
- Examination of concretionary material by iron artefact specialist
- Re-examination of appropriate parts of drawing and photographic archive
- Macroscopic examination and cataloguing of all Phase 4 slags

This represents up to 9 days work, costing up to £1800 in labour costs and up to £845 in analytical expenses (assuming the new SEM is available, free and capable of the task; otherwise up to an additional £420 for use of the Earth Sciences instrument). These costings are based on the numbers of specimens ideally required to characterise the various activities; in practice the materials may be less variable, or too weathered and fewer specimens may be examined, reducing the work by up to one third.

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Figure 1. smithing hearth cakes

All images backscattered electron photomicrographs

CWT1 a – j

- a. patchy distribution of wustite dendrites (white). In upper right and lower left arcuate leucite rims, overgrown with a leucite-wustite syntectic define areas free of the wustite dendrites. Scale bar 200 μ m.
- b. as (a), but with better-developed leucite rims. Scale bar 200 μ m
- c. low magnification view showing context of (b). Scale bar 1mm.
- d. patchy wustite dendrites (white), associated with large leucite crystals (dark), passing towards upper right into texture with delicate wustite-leucite syntectic dendrites, with both textures dominated by a fayalite (pale grey) –hercynite (mid-grey) syntectic. Scale bar 200 μ m.
- e. Detail from centre top of (d) showing boundary between the two textures. Scale bar 100 μ m.
- f. Low magnification view of wustite-dominated area. Scale bar 500 μ m.
- g. Detail from (f) showing wustite dendrites followed by leucite-wustite syntectic and fayalite-hercynite syntectic. Scale bar 100 μ m.
- h. Low magnification view of fuel remnant surrounded by iron corrosion products. Scale bar 1.00mm.
- i, j. Details of corrosion products around fuel clast. Scale bars 100 μ m.

CWT3 k – v

- k. Detail of typical microstructure showing skeletal elongate fayalite crystals (pale) closely associated with equant, zoned, hercynite (mid grey). Late stage phases include minor fayalite and elongate crystals of low backscatter coefficient (dark grey), which may be plagioclase feldspar. Scale bar 20 μ m.
- l. Wider area view encompassing (a) showing variable form of the fayalite. Scale bar 100 μ m.
- m. Vesicle filled with corrosion products, and associated with crack filled by similar materials. Vesicle is surrounded by rim of hercynite crystals. Late stage crystallisation includes fayalite (possibly plus plagioclase feldspar) in sheaf-like structures. Scale bar 100 μ m.
- n. Detail of hercynite-fayalite syntectic followed by fine grained sheaf structure, bearing blebs of iron. In this case the darker phase is probably a glass, and in this area has weathered badly. Scale bar 50 μ m.
- o. Wide area view of texture similar to that of (l), but of slightly coarser grain-size. Scale bar 500 μ m.
- p. Complex alteration surrounding remnants of fuel fragments (compare Figure 2 u-x). Scale bar 500 μ m.
- q. Detail from centre top of (p) showing elongate leucite (dark) associated with margin of fuel residue. Note bleb of iron (white). Scale bar 100 μ m.
- r. Area in which the difference in the two generations of fayalite is very strongly marked. Early fayalite is large, carious and has hercynite marginally, Note association of fayalite cluster with two spheroidal bodies, which may have been iron blebs. Scale bar 200 μ m.
- s, t. Possible altered iron blebs shown in (r). Scale bars 50 μ m.
- u. Fuel remnant with marginal iron oxides (bright). Scale bar 1.00mm.
- v. Area with complex relationships between fayalite and hercynite. Hercynite morphologies include dendrites (left of centre). Scale bar 100 μ m.

Figure 2. smithing pan and glassy slags.

All images backscattered electron photomicrographs

CWT2 a – b

- a. Typical texture showing admixture of quartz grains (dark grey) and scale (white) in fine, iron-rich matrix. Scale bar 1.00mm
- b. Detail showing termination of individual flake hammerscale fragment. Scale bar 200 μ m.

CWT4 c – j

- c. Wide area view showing finely crystalline matrix bearing partially melted quartz grains in clusters, probable coal residue (lower right) and scale (bright) top left. Scale bar 1.00mm.
- d – f. Increasingly higher magnification showing zoned crystallization of hercynite (locally as dendrites) and calcic plagioclase Scale bars 200, 100 and 20 μ m respectively.
- g. Crust on vesicle (left of centre) formed by hercynite. Groundmass hercynite (bright), plagioclase (dark) and glass (intermediate). Cracked quartz grain lower left. Scale bar 100 μ m.
- h – i. Area with similar phases to (g). but with initial hercynite having an acicular habit. Scale bars 100 and 50 μ m respectively.
- j. Partially assimilated scale. Scale bar 100 μ m.

CWT5 k – q

- k. Partially melted quartz grains, surrounded by glass. Small fayalite crystals appearing bright lie close to surface of quartz. The analyses g1-g3 of Table 5 were from this area; dark and bright refer to the compositional zoning of the glass towards the upper left. Scale bar 100 μ m.
- l. Area of sample bearing partially assimilated iron blebs in a finely crystalline matrix. Matrix comprises fayalite in glass. Scale bar 1.00mm.
- m – n. detail of iron blebs. Scale bars 200 μ m.
- o – q. detail of iron bleb, showing porosity filled with glass (analysis g5 of Table 5), but locally also by iron sulphide (brighter pore in (q)). Note that this iron bleb is on the margin of the cluster and is in contact with glass (upper left of (o) and (p)) of closely similar composition (g4 of Table 5) to the glass in the internal pores of the bleb. Scale bars 500, 200 and 20 μ m respectively.

CWT6 r – t

- r. Wide area view of texture showing extreme vesicularity. Scale bar 1.00mm.
- s. Detail of texture showing vesicles with partial crusts formed by spinel, but in this case (as opposed to CWT4, Figure 2g) the spinel appears to be magnetite rather than hercynite (but is too small for microanalysis). Bright grains are remnant ilmenite and ?rutile/
- t. Thin layer of fayalitic (bright = fayalite, intermediate = glass) slag adhering to the margin of the slag block. Note some concreted pan adheres to this in turn too (lower centre). Scale bar 500 μ m.

CWT7 u – x

- u – x. Complex iron oxide concretions around fuel remnants (charcoal), surrounded by vesicular glass. Scale bars 1.00mm.

Figure 3: hammerscale

All images secondary electron photomicrographs

Spheroidal scale a, b, d

a – b. spheroidal scale from >500 μm fraction

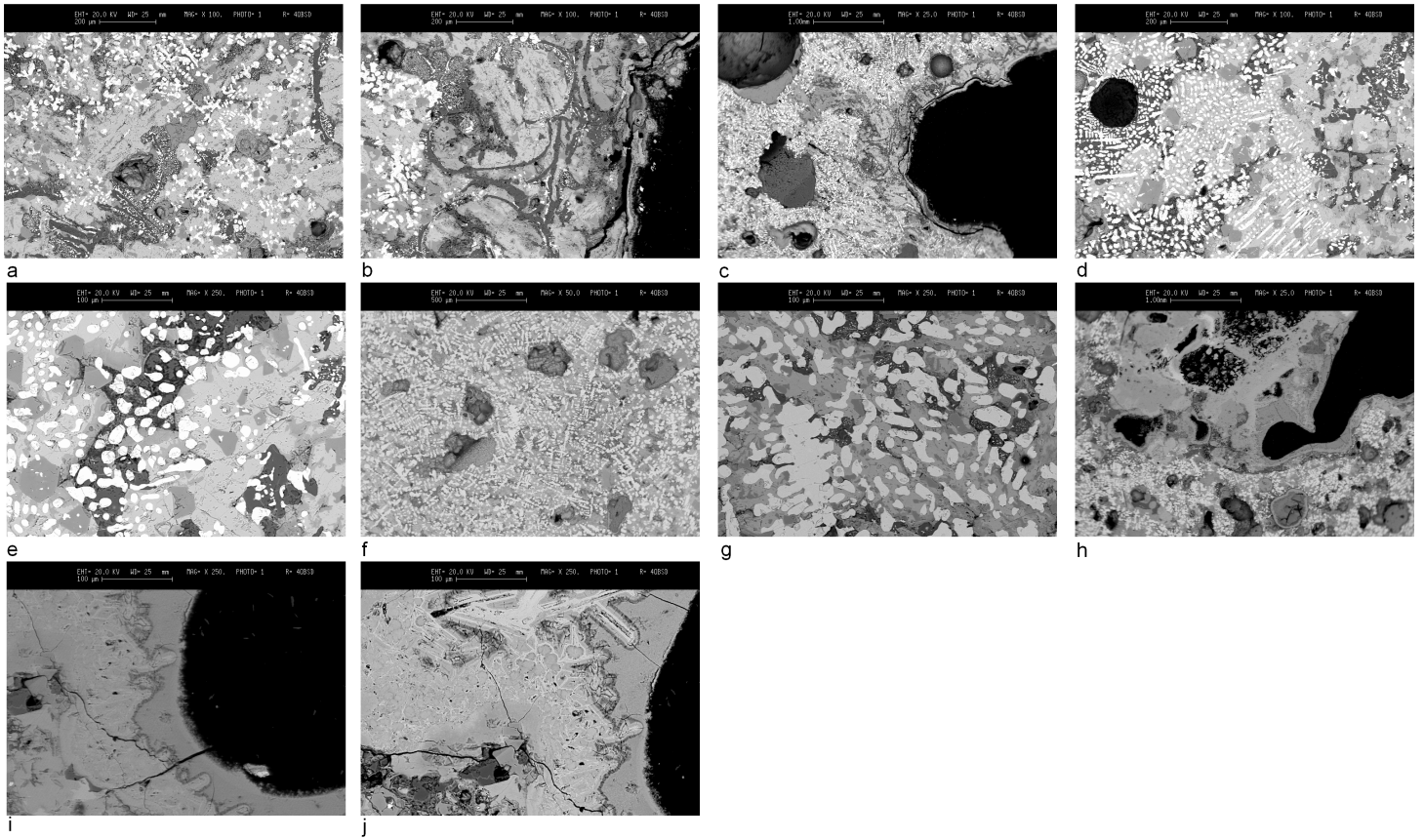
d. spheroidal scale from >2000 μm fraction

Flake scale c,e

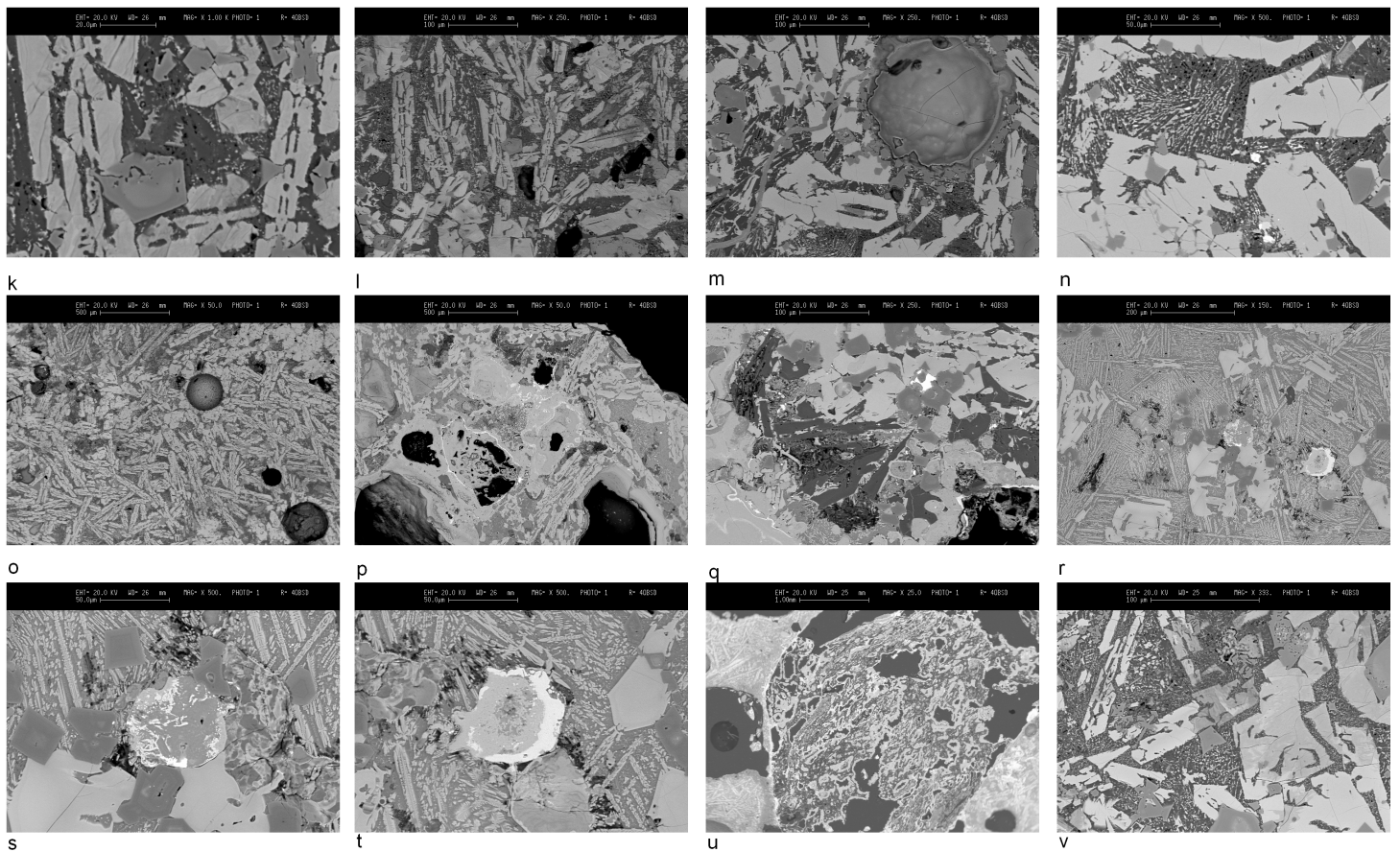
c. flake scale from >500 μm fraction

e. flake scale from >2000 μm fraction

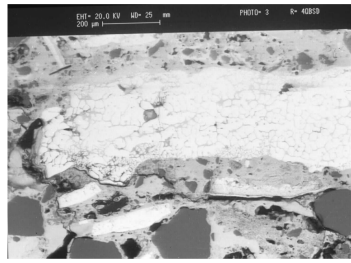
Figure 1: smithing cakes
CWT1



CWT3



CWT2

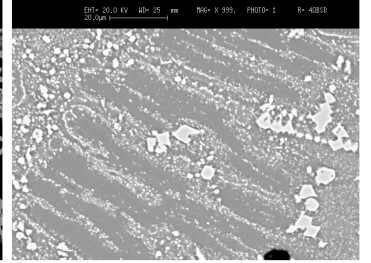
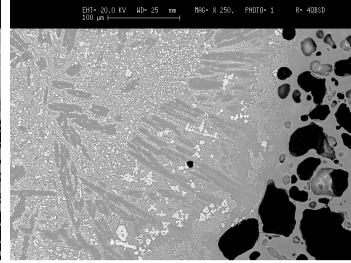
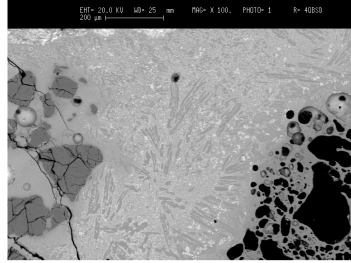
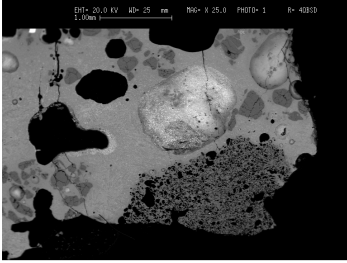


a

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Figure 2: smithing pan and glassy slags

CWT4

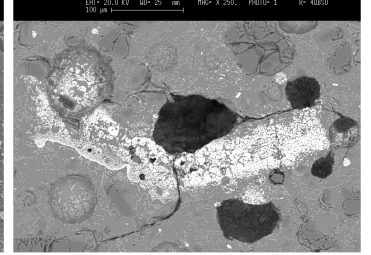
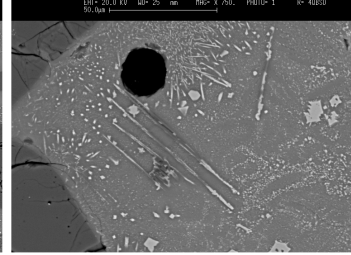
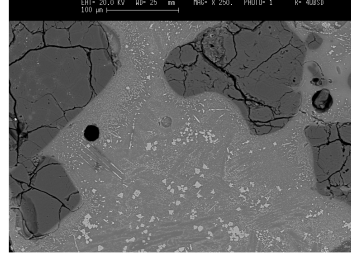
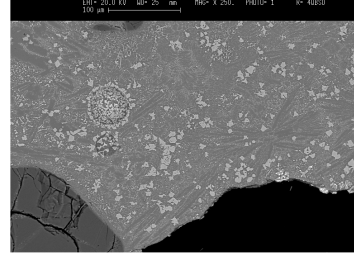


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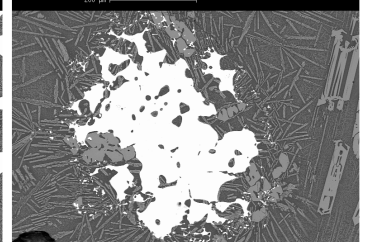
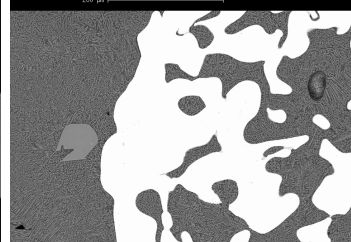
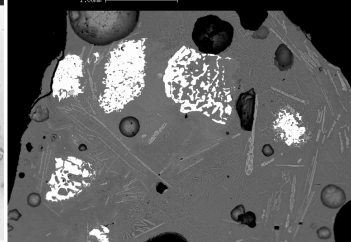
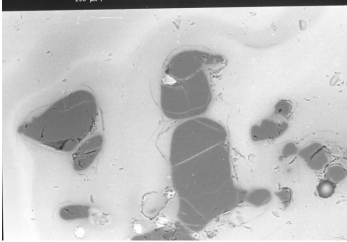
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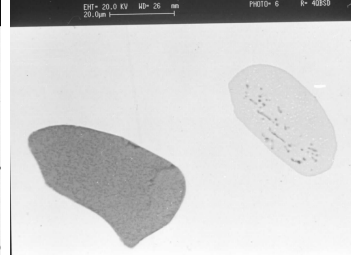
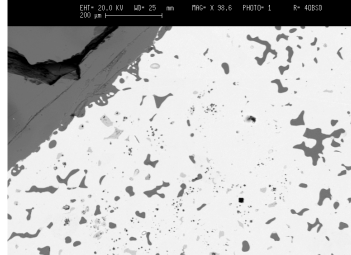
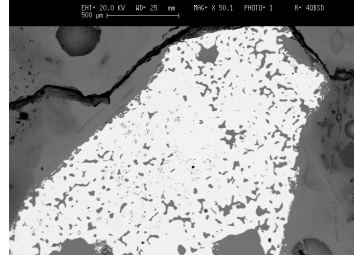


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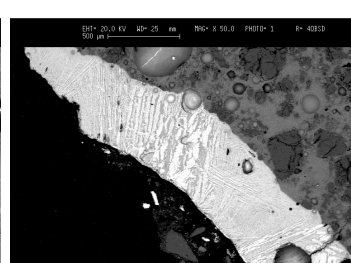
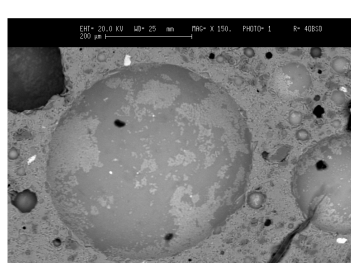
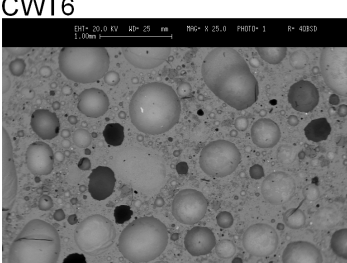
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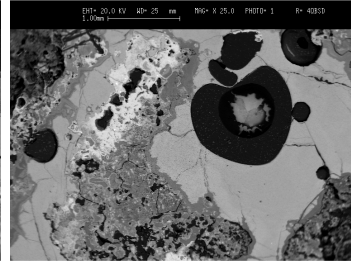
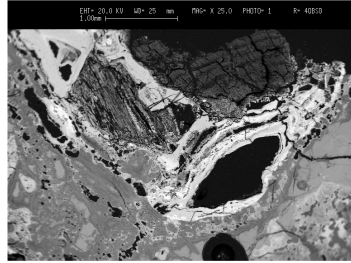
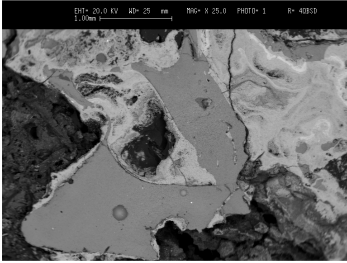


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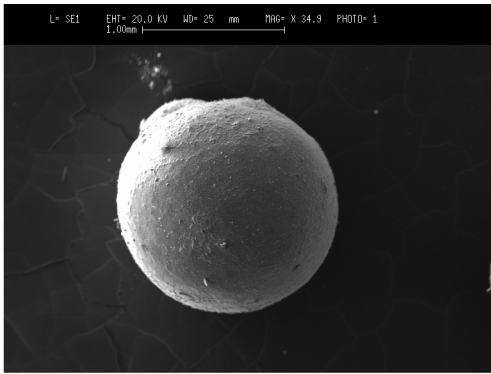


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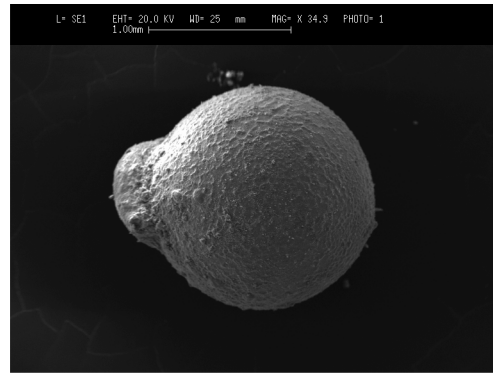
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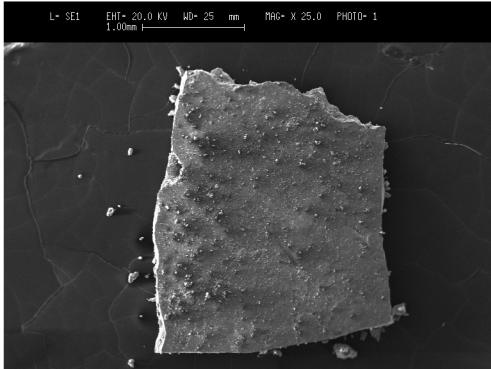
Figure 3: hammerscale



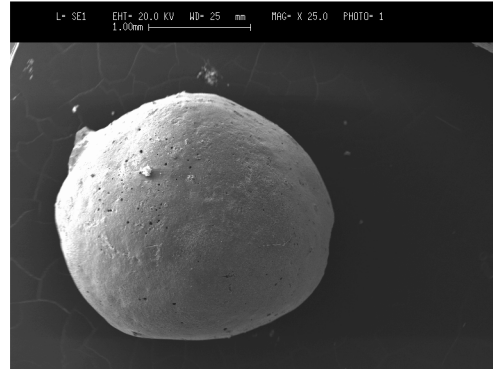
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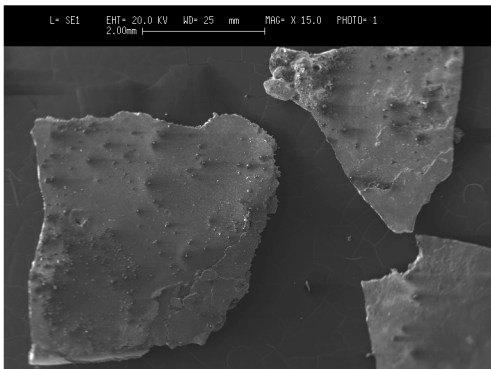
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