SAXON IRON SMELTING FURNACES AT HEMYOCK, DEVON

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Summary

An archaeological excavation was undertaken by AC archaeology in 2012 to the south of Culmstock Road, Hemyock. An area of 40m by 15m was stripped of topsoil revealing the remains of slagpit furnaces, pits and gullies which were sealed beneath 0.5m of slag and fuel waste derived from iron smelting activity. Two radiocarbon dates indicate a probable late 8th century date for this activity.

INTRODUCTION (Fig. 1)

An archaeological excavation was carried out by AC archaeology from October to November 2012 on land to the south of Culmstock Road, on the western outskirts of Hemyock, Devon (NGR ST 1325 1335). It was agricultural land, sloping gently down to the north at around 150m aOD, with the underlying solid geology comprising Triassic Mercia Mudstone.

BACKGROUND

Previous archaeological trench evaluation had been undertaken on the site by AC archaeology. The evaluation provided clear evidence for iron smelting, with a significant area of smelting debris present in the north-west corner of the field, where a subsequent accumulation of colluvium at the base of the field appears to have protected it and the underlying features from disturbance by ploughing. The debris included furnace and tap slag, as well as vitrified furnace lining suggesting the presence nearby of furnaces and/or hearths. The date of the ironworking was not established, but was thought to relate to the early medieval period (Stead and Payne 2012). The principal aim of the excavation was to further investigate the features and deposits identified in the trench evaluation and was undertaken in support of a planning application for residential development. The excavation was commissioned following consultation with Devon County Historic Environment Team.

THE EXCAVATION

Introduction

The excavation comprised the machine stripping of the topsoil under close supervision in an area of 40m east-west by 15m north-south totalling approximately 600m (Fig. 2). This stripping exposed a large area of metal working debris which was sampled by two 3 x 3m sample pits with extensions (Fig. 3). The remainder of the metal working debris was then removed from across the site and the features revealed below the debris excavated by hand.

The topsoil (1) consisted of a pale to mid grey brown clay loam topsoil which overlay a subsoil (2) of colluvium consisting of mid yellowish grey silty clay which had collected at the base of the slope and protected the underlying archaeology. The natural subsoil (3) consisted of pale grey yellow to brownish yellow silty clay.

Metalworking debris (Figs 3-4)
The metalworking debris (4) was densest in the north and west of the site and petering out to the south and east. It consisted of a dark grey silt clay containing abundant small to large fragments of ironworking slag, common charcoal and occasional patches of burnt clay to a maximum depth of 0.25m (Fig. 10). This layer was sampled by the excavation of two 3 x 3m areas with trenches extending north and south from each to provide an extended section. The sample areas contained a total of 1,274kg (2,804lb) of slag. Following the sampling the metalworking debris was carefully removed by machine to reveal the metalworking features described below.

Metalworking features (Figs 5-15)
All of the features were identified as cuts into the natural subsoil (3). They were positioned on the southern periphery of the major concentration of metalworking debris (4), and with only a few exceptions, described specifically below, the features were filled by metalworking debris (4). The features are identified as slagpit furnaces with associated pits and gullies.

The slagpit furnace pits
Pit F12 was sub-circular in shape with a length of 0.56m and width of 0.43m and a depth of 0.34m. It had steep sides and a concave base (Fig. 11). A tunnel positioned close to the base of the feature may join with pit F13 although this was not established. Pit F13 was less distinctive due to its association with gully F9. Gully F9 was located towards the east end of the excavation area and was narrow and steep-sided and up to a maximum of 0.48m wide and 0.18m deep and curving to the west from a north to south orientation. It appears to be cut by a pit (F13), although this is on balance, as the relationship was not firmly established.

Pit F14 was circular with a diameter of 0.45m and with steep sides and a concave base to a depth of 0.30m. The fill (77) contained parts of the wall and base of a furnace structure with ironworking slag fused to it. A sample from this fill was submitted for radiocarbon dating and provided a date of AD 695-946. Pit F15 was circular with a diameter of 0.45m and with steep sides and a concave base to a depth of 0.35m. It contained two fills (66, 67). Basal fill (66) was a multi-coloured burnt sandy clay containing fragments of ironworking slag. A sample from this fill was submitted for radiocarbon dating and provided a date of AD 662-864 Fill (66) was below upper fill (67) consisting of dark brown and grey slag and charcoal-rich material.

Pit F17 was circular with a diameter of 0.90m and 0.24m deep with steep sides and a concave base (Fig. 7). Its fill (83) contained fragments of furnace. It was connected to pit F79 by a small tunnel, to gully F18 and to pit F55 by a shallow gully. Pit F79 was probably originally circular, but had been cut by a modern land drain on its north. When complete it would have had a diameter of approximately 1.05m and a depth of 0.50m. It had steep but irregular sides and a concave but uneven base. A formerly circular pit F19 has been truncated to the south by a modern land drain. Approximate dimensions give a diameter of 0.65m and depth of 0.35m. Gully F18 was 2.20m long, 0.35m wide and 0.40m deep. It had fairly steep sides and a concave base. Pit F55 was circular with a diameter of 0.70m and depth of 0.53m with steep sides and a flattish base. It contained two fills (56-7) both were charcoal-rich with fragments of slag. Pit F55 appeared to cut scoop F53 which may be part of the same feature as it was similarly filled (54) with a charcoal-rich deposit containing fragments of slag. It was roughly circular in shape with a maximum diameter of 0.65m and a depth of 0.12m.

Shallow pit or scoop F23 had a diameter of 0.40m and depth of 0.10m. It had gentle sloping sides and a concave base. It was adjacent to pit F24 which was oval in shape with maximum dimensions of 0.62m long by 0.40m wide and 0.30m deep. It contained two fills (44 and 45). Basal fill (45) was charcoal-rich, and was below fill (44) which contained fragments of slag and other metalworking debris.

Pit F26 was circular with a diameter of 0.84m and a depth of 0.48m. It had steep sloping sides and a concave base. It contained four fills (71-4). Fill (71) contained clay furnace lining overlain by fill (72) of dark brown clay silt representing a burning layer on the furnace structure. Fill (73) is a relining of the furnace which has eventually been backfilled by metalworking debris (74). It was the most easterly of a group of three adjacent pits with F69 and F70. Shallow pit or scoop F69 was circular with a diameter of 0.64m and depth of 0.15m with shallow sloping sides and a concave base. Shallow scoop F70 was circular with a diameter of 0.38m and a depth of 0.07m. It had shallow sloping sides and a concave base. It had a single fill (76/4) consisting of backfilled metalworking debris.

Pit F27 was circular with a diameter of 0.75m and depth of 0.40m. It was partly truncated by a modern land drain to the east but had gentle sloping sides at the top becoming steeper as they approached the shallow concave base. It contained four fills (46-9). Basal fill (46) consisted of light green to grey with occasional mid brown patches fine silty clay up to 0.05m thick. This was overlain by the main fill (47) consisting of dark brown to black silty clay with patches of reddish and yellow burnt clay and containing occasional pieces of slag. On top of this was a patch of burnt clay (48) containing a fragment from a clay furnace structure. The remainder of the pit had been backfilled with metalworking debris (4). Pit F28 was adjacent to pit F27, although the relationship had been destroyed by a modern field drain. It was almost circular with a maximum diameter of 0.60m and depth of 0.27m. It contained three fills (32-4). Basal fill (34) was a charcoal-rich clay silt up to 0.08m thick and containing fragments of slag and was overlain by a dump (33) of mottled orange sand and light yellow brown clay silt to a thickness of 0.10m and showing signs of having been heat affected. The upper fill (32) was another charcoal-rich layer of clay silt up to 0.13m thick and containing occasional slag fragments.

Possible slagpit furnace pits

Pit F20 formed a figure of '8' in plan with a maximum length of 1.30m and depth of 0.50m (Fig. 13). There is a possibility that F20 is a pair of inter-cutting pits, but the shared basal fill (63) indicates that both pits would have been open at the same time suggesting that this is a single feature. Fills (62-3 and 64) consisted of charcoal-rich metalworking debris with slag fragments. Upper fill (64) consisted of a mixed yellow and red clay which was suggestive of having been burnt elsewhere and redeposited in the pit. The upper fills were cut by a pair of small pits F22 and F84. Pit F22 had two fills with basal fill (52) comprising pale yellow clean clay, below charcoal-rich metalworking debris (51). Pit F84 contained a single fill (61) consisting of a soft grey silty clay. A small tunnel joined F20 with gully F10. Gully F10 was located towards the west and south of the metalworking debris and may be a replacement for gully F11 which it cuts. It curved from northwest to southeast and was steep-sided and approximately 0.50m wide and 0.34m deep. Gully F11 was 0.44m wide and 0.22m deep with steep sides and a flat-based. It was north-south aligned and faded to the north and was cut and apparently replaced by F10 to the south.

Pit F30 was 0.75m in diameter and very shallow with a maximum depth of 0.08m. It had a single fill (58) of dumped waste which contained fragments of slag and pieces of

charcoal. It may be cut by gully F59, but the relationship was unclear. Gully F59 was aligned northeast-southwest and was 1.5m long, 0.40m wide and 0.22m deep. It had steep sides and a concave base. It is cut by a modern land drain at its northeast end.

Scoop F41 was circular with a maximum diameter of 0.26m and depth of 0.07m with a gentle sloping side and flat base. It had a single fill (38) consisting of a charcoal-rich silty clay with occasional fragments of slag. It was cut by posthole or pit F42 which was circular with a diameter of 0.25m and depth of 0.23m. It had vertical sides and a pointed base. It had a single fill (43) consisting of light brown silty clay.

Isolated features

Gully terminal F16 is probably a fragment of a shallow linear gully. The exposed section was 2m long and 0.32m wide and 0.09m deep. It contained a single fill (36) of dark brown to grey silty clay with common charcoal and occasional slag fragments.

Shallow gully F29 was north-south aligned with a terminus in the north and petering out to the south. It was exposed over a length 2.2m with a maximum width 0.15-0.25m and depth of 0.05m.

THE FINDS

By Naomi Payne

Worked flint

A single prehistoric flint flake (1g) was recovered from buried soil (7). This is an incomplete tertiary flake of mottled light and mid-grey flint. The flint is not diagnostic of a particular period, but is most likely to be of later Neolithic or Early Bronze Age date.

Prehistoric pottery

Two sherds (17g) of prehistoric pottery were recovered during the excavation, one from buried soil (7), and the other from fill 68 of pit F13. The two body sherds are made from a similar fabric and may have formed part of the same vessel, although they do not conjoin. The fabric contains abundant fine mica, sparse sub-rounded iron ore up to 3mm and sparse sub-angular quartz up to 2mm. Both sherds are highly abraded, with oxidised orange-brown external surfaces and reduced dark grey-brown cores and internal surfaces. There are traces of a residue on the internal surface of the sherd from context 68. The sherds are Middle or Late Bronze Age in date.

Medieval pottery

A single sherd of medieval pottery (9g) was recovered from a colluvium layer (2). This is a body sherd from an Upper Greensand-Derived coarse ware cooking jar. This type of pottery was made for a long period of time with little variation in fabric, and as there is nothing diagnostic about this sherd it could date from anywhere between the late 10th century AD to *c.* 1400.

Fired clay

The spread of iron-smelting debris (4) produced a spindle whorl which has been fashioned from a piece of broken pottery. The spindle whorl is circular and very slightly convex with a central hole which has been drilled from both sides. It has an external diameter of 41mm and an internal diameter of 8mm. The fabric is an oxidised light slightly orangey-brown

throughout and contains common very small white inclusions. This has the appearance of South Gaulish samian ware which has entirely lost its slip. Although this object was found in association with Saxon iron-smelting debris, the reworking of pottery sherds into spindle whorls is a more usual feature of the Roman period, Saxon spindle whorls commonly being made from worked bone, antler, or cast in lead. The whorl is, however, in good condition, and it seems unlikely that it is residual. Perhaps it represents the opportunistic reuse of a piece of Roman pottery.

THE SLAGS

By Tim P. Young

Methods

The materials were examined visually (with a low-powered hand lens or microscope when required) and a programme of investigation proposed (Young 2013b). The material was catalogued and this and the detailed archaeometallurgical report is available in the site archive.

The analytical programme recommended by the assessment was an investigation of a suite of residues from the slag dump (context 4), aimed primarily at trying to characterise the technology and the ore resources that were exploited. The scale of such an investigation was limited by external considerations, but a programme of works was developed entailing bulk chemical analysis of appropriate materials, backed-up by petrographic investigation on the scanning electron microscope of a subset of the samples.

The selected samples were slabbed on a diamond saw and subsamples used firstly for preparing a polished block for use on the SEM and secondly for crushing for preparation of a whole-sample chemical analysis. Polished blocks for investigation on the SEM were prepared in the Earth Science Department, The Open University. Electron microscopy was undertaken on the LEO S360 analytical electron microscope in the School of Earth and Ocean Sciences, Cardiff University. Microanalysis was undertaken using the system's Oxford Instruments INCA ENERGY energy-dispersive x-ray analysis system (EDX).

Chemical analysis was undertaken using two techniques. The major elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, and P) were determined by X-Ray Fluorescence using a fused bead on the Wavelength-Dispersive X-Ray Fluorescence (WD-XRF) system in the Department of Geology, Leicester University (this also generated analyses for S, V, Cr, Sr, Zr, Ba, Ni, Cu, Zn, Pb and Hf). Whole-specimen chemical analysis for thirty six minor and trace elements (Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U) were undertaken using a sample in solution on the ThermoElemental X-series Inductively-Coupled Plasma Mass Spectrometer (ICP-MS) in the School of Earth and Ocean Sciences, Cardiff University (this also generates lower quality results for Fe, Mn, Ti, P that are used mainly for QA purposes). The results of the chemical analyses are summarised here.

Locations of EDS analyses are presented as sample-area-analysis (e.g. NTH2 SOI2 #3). The area of the sample in a particular image is referred to as SOIn (SOI = **S**ite **O**f **I**nterest in the terminology of the INCA microanalysis software) and individual analyses (points or areas) are labelled #m. The microanalytical data and images of all SOIs are included in the archive. All EDS analyses were collected with all elements analysed (including oxygen, but not carbon; all samples were carbon-coated). Analytical totals were frequently far from 100%, because the analytical system is designed to provide totals of 100% from spot analyses in the centre of the field. The area analyses required for this project are not standardised in the same way

and will diverge from a total of 100% (either above or below, depending on the location of the area with respect to the centre of the field). In order to make the microanalytical results simply comparable across materials (and also sites), no attempt has been made to adjust for the oxidation state of elements with variable valency. The figures employed in the report have therefore been constructed with elements expressed as oxides in weight% calculated stoichiometrically, except for mineral structure calculations, where the measured oxygen has been used.

Throughout this report standard mineral terminology is applied to both natural and anthropogenic materials – although artificial phases are no longer strictly considered to be minerals.

Results

Distribution of the residues

The majority of the residues were contained within a slag dump (context 4) which had spread over many of the cut features, including furnaces, present on the site. All of the analysed materials were from the dump deposit.

Assemblages from probable primary contexts were also collected, including:

- furnace F17 (approx. 9.5kg of lining plus a *c.* 23kg burr of dense slag formed in the zone of interaction between slag and the hearth or furnace wall just below the tuyère/blowhole with associated lining including the margin of the blowhole),
- fill 48 from furnace F27; a partially *in situ* furnace assemblage, many wall fragments and prilly slags (a 'prill' is a small aggregate of a material, either a spheroidal droplet or a runnel, formed from a melted liquid and either occurring as a discrete particle or as an inclusion within another material),
- Backfill 74 from furnace F26; large wall fragment plus two large prilly furnace bottom pieces and a burr totalling 17.1kg,
- Fill 77 from furnace F14; a 13kg burr and furnace wall lining section.

Chemical composition of the residues

The major element chemistry of the analyses of the slags is iron-rich and moderately aluminous. Contents of magnesium, calcium, sodium and potassium are low. Manganese is present in moderately elevated amounts and phosphorus contents are high.

The trace element composition is largely unremarkable as materials strongly influenced by sedimentary rocks. The residues have a moderately high uranium content (typical of materials incorporating sedimentary phosphates).

Description of the residues: General

The slag recovered from the site was dominated by dense materials. Large burrs (dense slag masses formed in the zone of impingement of hot slag/iron on the wall below the blowhole) were a common feature of the assemblage and included examples recovered *in situ* (F17) as well as in secondary contexts (4). These burrs formed in wide (300mm) zones below a single blowhole. Several samples show the burr in close association with heavily relined wall fragments (indicative of intense wall damage around the blowhole) and the burrs may have developed over the course of many smelts.

The larger burr examples (from furnaces F14 and F17) show a connection down the sloping wall side to lower density, more prilly and charcoal-rich slags in the lower pit. These slags, equivalent to the 'furnace bottoms' of Burlescombe (Reed *et al.* 2006) and Churchills Farm (Young 2013a), were not seen in complete cakes and were not sampled for detailed analysis.

Further dense slags formed distinctive 'puddles' in the base of pits (but only seen in *ex-situ* materials). These puddles formed within or below the pit-packing of split wood (preserved as moulds) by the downflow of slag from higher levels. The puddles typically showed a raised lip of flow-lobed material and the original flow lobes were also preserved as distinct layers visible on the inclined non-wetted wall contact surface.

The microstructure of the studied samples typically showed a paragenesis of primary wustite (an iron II oxide FeO), followed by a slightly phosphoran fayalite (the iron-rich end member of the olivine group, Fe2SiO4. Abbreviated to Fa) plus hercynite (an iron-aluminium member of the spinel group of minerals: FeAl2O), locally with subsequent fayalite plus apatite, and finally a leucite- (frequently a leucite-wustite cotectic) and apatite-bearing interstitial material.

Description of the residues: Details

Sample HCR1 (Chemical analysis only): this very large block (5285g) comprises a complex burr formed by two intersecting smooth convex rear surfaces, with a planar front margin, which forms the upper part of a deep plano-convex bowl side. The upper face has dimpled/whispy texture. It is internally massive, but becomes charcoal-rich on distal base. It is reminiscent of the form of burr on a 23kg piece from furnace F14; dimension: width (chord) *c.* 330mm across with burr extending out 140mm (or 360mm across extending back 180mm depending on which bit of burr is back); maximum crust thickness 60mm; 50mm wide on planar top as seen; 140mm deep.

The chemical composition is significantly more siliceous than the other slags (with a silica content of 21.7 wt% and a silica to alumina ratio of 36).

Sample HCR2: this is a large block (2320g) from the margin of a bowl-shaped basal slag puddle; 130mm deep fragment with edge suggestive of *c.* 400mm diameter; margin. It shows a dense crust up to 30mm thick at the top, but thinning downwards; the side becomes inclined at *c.* 60mm below top, but flattens downwards. Contains moulds of wood fragments of up to 130x40x30mm, many of which are inclined down the side. The upper part of the outside has a regularly lobed, horizontal layered non-wetted texture, becoming simpler and smoother downwards; base of piece becomes more finely prilly and friable.

The sample mounted for microstructural investigation shows the marginal lobe with a microstructure dominated by elongate fayalite. The fayalite shows a probable length in excess of 10mm.

The primary phase is formed by moderately sparse, delicate dendritic arrays of wustite up to 600µm across. The wustite is closely spatially associated with hercynite (with a composition of 86-88% hercynite and 12-14% magnetite with minor titanium substitution). The hercynite is cotectic (meaning the crystallisation of a liquid to produce two phases at the same time) with the olivine, which is a fayalite (Fa96Fo4 to Fa99Fo1) with 5-6% manganese substitution and less than 1% calcium substitution. The fayalite shows approximately 1% to 4% substitution by phosphorus (i.e. 0.025 to 0.067 atoms per formula unit), meaning that

most can be classifiable as phosphoran fayalite after the criterion (>0.03 APFU phosphorus) of Boesenbery and Hewins (2010). The outer sections of the olivine are commonly intergrown with a calcium phosphate (apatite). The apatite crystals may be entirely contained by the fayalite, but commonly extend as subhedral crystals into the interstitial areas. The interstitial areas are dominated by leucite (typically in a very fine cotectic with wustite) and elongate apatite. Coarser-grained leucite-wustite cotectic mixtures were located around the margins of, and close to, open vesicles (a void or pore, usually rounded and formed as a preserved gas bubble in a solidified melt).

The area EDS microanalyses are tightly clustered, indicating a homogeneous composition to the analysed sample. The cluster is reasonably close to, but slightly less iron-rich than, the bulk composition as determined by XRF.

Sample HCR3 (Chemical analysis only): this block (1010g) is from the margin of a dense basal slag puddle, with characteristic large flow lobes (as in other pieces). As also seen in other samples, there are approximately five horizontal lobe layers on the non-wetted margin. Below this is a more rough but planar surface. The base has a form suggesting the channelised flow of dense slag across the pit floor (it parallels the development of small puddles in Furnace [794] at Churchills Farm, Hemyock; Young 2013a and unpublished observations) following the marginal accumulation of the flow-lobed material. The upper surface has crude elongate hollows, probably suggesting the flows passed beneath round-wood pit-packing. The basal puddles show strong radial elongate fayalite orientation. This has probably formed in a similar way to HCR2, but received less slag input.

Sample HCR4: this is a large (2480g) dense amalgamated flow slag block with an irregular shape. The orientation is difficult to ascertain. It appears to include rod-like mass of downward flows penetrating outside an inclined wood slab, 100x100x50mm or larger; with many large wood moulds including many of curved split round-wood *c.* 30mm diameter. Essentially this is related to the style of development of HCR2, but lies away from the margin of the pit.

The mounted section shows a heterogeneous texture. Much of the sample is wustite-rich, with the wustite forming blebby dendrites, with only a very short range structure visible (a bleb is a small rounded particle or textural component, often a droplet or prill). The wustite is followed by fayalite with hercynite as a frequent cotectic phase (and which typically shows a spatial association with the wustite). The hercynite ranges from 80%-90% end-member hercynite, with 1%-20% magnetite with very low levels of titanium substitution. The olivine is a fayalite (mostly Fa98Fo2) with 4% manganese substitution and less than 1% calcium substitution. The outer parts of the olivine show a cotectic lamellar apatite. Interstitial areas are dominated by a leucite-wustite cotectic. In the infills of former vesicles the wustite may be at reduced levels or entirely absent. The latest of the fills (adjacent to extant porosity) shows development of a graphic texture of fayalite, hercynite and leucite. This late fayalite (Fa99Fo1 to Fa100) shows up to 2% calcium substitution and 3% manganese substitution. The fayalite in the main part of the sample shows apparently up to 2.8% substitution of phosphorus for silicon, such that about half of the microanalyses were classifiable as phosphoran fayalite. The late fayalite was the most phosphoran, with 3% to 3.4% phosphorus substitution, equivalent to 0.06 - 0.07 APFU phosphorus.

The area EDS analyses are distributed along an array directed away from the FeO pole on the SiO_2-Al_2O_3-FeO ternary diagram and lying close to the fayalite-hercynite eutectic (see

archive report for details). This indicates a rather wide difference in the degree of evolution of the slag, suggesting either a varying composition of the slag supply or, perhaps more likely, a process of fractional crystallisation within the descending slag. In such a fractionation process, the influence of gravity separates the first-formed wustite dendrites from the still-flowing more fayalitic liquid. The iron content (expressed as wt% FeO) varies from 55.5% to 73.7%.

Sample HCR5: this is a fragment (762g) of exceptionally dense, tapslag-like flows with broad, dark, flow lobes up to 60mm across. The lobes have very long internal crystals and fine vesicularity. The basal lobes are very dark, with a metallic sheen. Wood impressions are present, but slightly coarsely-formed because of the large non-wetted lobe size.

The mounted section shows lobes with a very fine microstructure. The chilled margins of lobes show no distinct crust. The primary phase is wustite, which forms dendrites of varying sizes, but mostly rather fine. The subsequent olivine shows a cotectic with hercynite (which shows a spatial relationship with the wustite). The hercynite shows a range of composition centred on approximately 80% end-member hercynite, 20% magnetite. The hercynite commonly forms a cotectic on the margin of the fayalite crystals. The sample differs from the others from the site in not only having a chilled fine crystalline microstructure, but also in showing dominantly glassy interstices. Some of these show some crystallisation, including fine leucite crystals and unidentified fine dendrites.

The area EDS microanalyses are tightly clustered, indicating a homogeneous composition to the analysed sample. The cluster is reasonably close to, but slightly less iron-rich than, the bulk composition as determined by XRF.

Sample HCR6 (Chemical analysis only): this is a planar slab (348g) of oxidised and vitrified lining with a well-formed buried vitrified surface. The overall size of the piece was 120x90x38mm. The earlier vitrified face is buried up to 25mm below the later.

Sample HCR7 (Chemical analysis only): this piece was reduced-fired lining (296g) with some partial refacing. The rear of the piece shows a slight reddish colour towards one margin, presumably in the direction passing up towards the blowhole. The unaltered clay to the rear shows a significant degree of organic temper.

Sample HCR8 (Chemical analysis only): this is a 166g block of a low-density, yellow/brown goethitic or limonitic pelletal iron ore. It has voids coated in a yellow hydrated iron oxide.

Sample HCR9 (Chemical analysis only): this roasted fragment of ore weighed 326g. It has thin dark goethitic skins around patches of red, ruddle-like, clay with the remnants of oxidised pellets.

Interpretation

The small number of analyses of residues makes calculating a mass balance for the smelting process both difficult and imprecise. In particular, inspection of the bulk compositions shows that several of the slag samples are more iron-rich than are the samples of iron ore. This clearly indicates that the analysed ores cannot be typical of the furnace feed. One approach that can illuminate this problem is to consider solely the silica and alumina. Although the two iron ore samples are too impure to be representative of the exploited resource, they do share

a low silica:alumina wt% ratio (approximately 1.68). The two lining samples also have fairly similar ratios – 9.8 and 8.7. This difference means that the contributions of ore and lining can be modelled for the slag samples (Table 1). To convert that into a raw smelting mixture, the actual contents of silica and alumina in the two components are required. These are known, approximately, for the lining (they total 90.5wt% after normalisation of the oxides with iron quoted as FeO). For the ore, the total of silica and alumina in the richer (82.8 wt% FeO) sample is 13.6wt% (when re-calculated on a similar basis). The actual ore employed must have been considerably richer in order for the iron-rich slag compositions to have been possible. Calculating the mixture and yield based on this composition (Table 2) requires a very high contribution from the furnace lining (15-20% for the flow slags, but 55% for the burr) and only a tiny yield (5-13%) for the flow slags and insufficient iron for any yield (i.e. a negative yield) for the burr and flow-lobed basal flow. Increasing the iron content of the model ore to 92wt% (as FeO) and reducing the (silica + alumina) to 6%, allows calculation of the smelting mixture as 7-10% lining for the basal flow slags, 17% for the flow lobed basal flow and 36% for the burr. The yield values are 26-36% for the flow slags, 19% for the flow-lobed flow, but still a negative value for the burr.

	SiO_2	Al_2O_3	% lining
slags			
HCR1	87.28%	12.72%	89.37%
HCR2	80.26%	19.74%	63.86%
HCR3	77.28%	22.72%	53.06%
HCR4	77.35%	22.65%	53.30%
HCR5	83.34%	16.66%	75.07%
lining			
HCR6	90.74%	9.26%	
HCR7	89.67%	10.33%	
average lining	90.21%	9.79%	
ore			
HCR8	62.48%	37.52%	
HCR9	62.87%	37.13%	
average ore	62.67%	37.33%	

Table 1: Weight% silica and alumina normalised to 100% for each analysed sample, with calculated lining contribution to the mixture for the slags

Clearly, these figures lack any great degree of robustness and so must be treated with a high degree of caution. There has been a suggestion from similar analyses on other sites (e.g. Cherryville, Young 2008) that slagpit furnace slags are extremely heterogeneous, with basal flows perhaps typically having a high input of ore, but a low degree of iron extraction compared with the more prilly slags lying immediately below the bloom. That may mean that the low estimates of yield in this instance are not indicative of an overall low yield from the furnace – merely that the analyses in this project do not reflect the isolated prilly slags or prilly slag masses from closer to the bloom. None-the-less, the overall modelling does

tentatively suggest that the smelting may have had a relatively low yield (extractive efficiency, *sensu* Thomas and Young 1999a, b).

Model 1

% iron oxide in lining	4
% iron oxide in ore	82.8
% silica + alumina in ore	13.6
% silica + alumina in lining	90.5

	wt % lining	iron oxide in mixture	actual iron oxide in slag	difference	extraction
HCR1	55.82%	38.81	69.22	-30.41	-44%
HCR2	20.98%	66.26	62.73	3.53	6%
HCR3	14.52%	71.36	68.19	3.17	5%
HCR4	14.64%	71.26	62.88	8.38	13%
HCR5	31.15%	58.25	64.82	-6.57	-10%

Model 2

% iron oxide in lining	4
% iron in ore	92
% silica + alumina in ore	6
% silica + alumina in lining	90.5

	wt % lining	iron oxide in mixture	actual iron oxide in slag	difference	extraction
HCR1	35.79%	60.50	69.22	-8.72	-13%
HCR2	10.49%	82.77	62.73	20.04	32%
HCR3	6.97%	85.86	68.19	17.67	26%
HCR4	7.03%	85.81	62.88	22.93	36%
HCR5	16.64%	77.36	64.82	12.54	19%

Table 2: Calculated lining and ore contributions and associated extraction, to model slag compositions

The high level of lining contribution to the slags, particularly to the formation of large burrs (a slag facies not developed to a significant extent at either Burlescombe or Churchills Farm) may be associated with the profile of the slagpits, which show inwardly-inclined sides (i.e. forming a bowl-like profile), which are in contrast to the steeper pit margins on the comparative sites. This would lead to greater impingement of the hot-zone around the blowhole and of the area around the bloom onto the hearth ceramic and pit wall.

The negative yield modelled for the sample of burr (HCR1), together with the strong influence of the lining on its composition, may suggest that it developed, at least in part, because of reaction with iron (presumably that in the proximal end of the bloom) with the wall. It is not impossible, solely from consideration of the chemical composition, that the burr was developed partly during re-use of the hearth for reheating and forging the bloom; the mass balance shows some resemblance to that from bloomsmithing residues elsewhere. There was, however, no independent evidence that the hearths had been used for any post-smelt processing of the blooms.

A further outcome of consideration of the mass balance, is the recognition that the ore exploited at the site must have had a very high iron content. Less clear is the manganese content of the ore, for the content of this element is rather variable in the analysed slag. This

implies that the exploited ore must have been a very oxidised form of the greensand ore, or perhaps mainly weathered crusts rather than the primary ore itself.

CHARCOAL ANALYSIS
By Dana Challinor

Introduction and methodology
Two samples from bases of adjacent slagpit furnaces F14 and F15 were submitted for analysis. With a random selection of 30 fragments of charcoal identified from each sample. For sample <16>, this represented almost all of the identifiable (>2mm) material. The charcoal was identified by fracturing and examining anatomical characteristics using a Meiji incident-light microscope at up to x400 magnification. Identifications were made with reference to Schweingruber (1990), Hather (2000) and modern reference material. Classification and nomenclature follow Stace (1997).

Results (Table 3)
Four taxa were positively identified, all consistent with native species: *Quercus* sp. (oak), *Alnus glutinosa* (alder), *Euonymus europeaus* (spindle tree) and *Ilex aquifolium* (holly). Some oak heartwood was identified in context 7, but the charcoal was too fragmented to determine maturity in the majority of fragments. No whole stems with bark and/or pith were observed, although a few fragments exhibited moderate ring curvature and were recorded as roundwood.

	Feature number	14	15
	Context number	77	66
	Sample number	17	16
Quercus sp.	oak	20h	28
Alnus glutinosa Gaertn.	alder	8r	
Alnus/Corylus	alder or hazel		1
Euonymus europaeus L.	spindle		1
Ilex aquifolium L.	holly	2r	
h=heartwood; r=roundwood			

Table 3: Charcoal from furnaces F14 and F15 (fragment count)

The assemblage of fill (66) was notably smaller, in quantity and size of material, than (77) which was quite abundant (>100 fragments). The condition of the charcoal was fair, albeit quite soft.

Discussion
The results of the analysis suggest that oak was the preferred fuelwood for iron smelting. Recent research at Calstock, and another site in Hemyock, suggest that assemblages of charcoal from early medieval furnaces tend to be more diverse in character, and significantly less oak-dominated. However, Oak was the main source of fuel at the Saxon iron-smelting site at Burlescombe (Gale 2006) and the undated iron smelting furnace at Kestor (Fox 1954).

The use of oak to fuel iron smelting furnaces is not uncommon and is probably due to two factors: firstly, the ready availability of oak in the local woodland; and, secondly, oak would have provided good quality charcoal, capable of achieving the high temperatures necessary for iron-working. The use of charcoal as a fuel is generally considered a requirement for the processes of iron smelting and smithing (Edlin 1949, 160; Cleere and Crossley 1985,

37). The presence of spindle tree, holly and alder in these samples indicate either that oak was supplemented with a range of other taxa and/or that the remains of kindling or roundwood clamps from the charcoal-making are represented.

RADIOCARBON DATING

There was a limited amount of material in the sampled furnace fills that was distinct form the overburden (4) and thus regarded as secure enough to be suitable for radiocarbon dating. Fill (66) in furnace F15 was a discrete deposit containing a large number of wood charcoal fragments and piece of *Alnus glutinosa* was selected for dating. Fill (77) in furnace F14 was a discrete deposit also containing a large number of wood charcoal fragments and piece of *Euonymus europaeus* (spindle tree) was selected for dating. These were selected as suitable short-lived material and submitted to the Scottish Universities Environmental Research Centre.

Material	**Context**	**Lab no.**	**Result BP**	**δC13 (‰)**	**Cal AD**
Euonymus europaeus	Fill (66) of furnace F15	SUERC-51250	1271±35	-23.3	662-864
Alnus glutinosa	Fill (77) of furnace F14	SUERC-51251	1197±35	-26.6	695-946

Table 4: Radiocarbon dating results (calibrated to 95.4% probability)

The AMS radiocarbon date results are given in Table 4. Calibration of the results has been performed using the data set published by Reimer *et al.* (2004) and performed using the program OxCal4 (www.flaha.ox.ac.uk).

The wide spread of the calibrated results indicates a Middle Saxon date for the smelting activity. The dates do overlap between AD 695 and 864 and assuming that the smelting in these two pits was roughly contemporary indicates a probable 8th to 9th century date. In addition the probability spread of the dates at greater than 80% overlap in the late 8th century (AD764-779) and provide a tentative focus for the dates.

DISCUSSION

The excavation provided extensive evidence for iron working on the site. Slagpit furnaces were present below a large spread of metal working debris. No evidence for buildings associated with the metal working was forthcoming. There was also little evidence to indicate that the site had been used for an extended period of time with each new furnace avoiding previous ones. Only the single posthole or pit F42 which had a clean fill may pre-date metal working activity on the site. The furnaces and pits were associated with gullies (F9, F10, F11, F18 and F29) whose purpose is not understood. They do not contained evidence for the roasting of iron ore prior to smelting and may simply be for purposes of drainage.

The site provides evidence for iron smelting of a greensand ore, possibly selectively smelting oxidised material, using a slagpit-style furnace. Firm identification of all the furnaces on the site requires re-examination and re-assessment of the excavation records, but it is likely there were at least eight, possibly as many as eighteen, most with a bowl-shaped slagpit of approximately 0.45m diameter and 0.25m-0.3m depth, but some with a larger slagpit of up

to 1.0m diameter. The site plan gives a suggestion that the furnaces may have been located in pairs. This has been observed on early medieval sites in Ireland (e.g. Hull and Taylor 2006) and Wales (Crane and Murphy 2010).

The pit packing employed was split wood, probably oak. This is the typical packing in both the Iron Age and early medieval examples in Britain. Just a few sites (such as Churchills Farm, Hemyock) employed the less common cereal packing (which is much better known in Denmark and eastern Europe; Mikkelsen 1997). Any discussion of the charcoal assemblages from slag pit furnaces needs to take cognisance of the potential presence of charcoal from both fuel and pit packing remnants.

The shape of the basal pits appears to have promoted slag and iron interaction with the wall ceramic, leading to development of large burrs, possibly formed during multiple smelts before the furnaces were rebuilt. A major part of the slag produced during smelting accumulated as large slag puddles, which formed below and around the split wood pit packing. This residue assemblage is distinct from those of other, slightly later, early medieval slagpit furnaces in the area, which typically lack large burrs and have only small slag puddles; much more of their slag is present in a prilly and charcoal-rich 'furnace bottom' higher in the furnace pit.

Large quantities of furnace ceramic in secondary contexts, probably dumped during periodic furnace reconstruction, indicates that the furnaces possessed substantial shafts, but he detailed form of the superstructure is unknown (although there is a possibility that the blowing wall was not strongly curved). The furnaces were blown through a single blowhole, close to ground level, indicating use of a forced draught.

Tentative mass balance calculations suggest that the overall yield of the furnaces may have been rather low for a bloomery furnace, but this may be an artefact of the analysis programme which focused on the basal dense slags and did not sample the friable, prilly, poorly-preserved slag accumulations from higher in the furnace.

The dating evidence indicates that smelting was in the period between the late 7th and late 9th centuries, overlapping between AD 695-864. This suggests the smelting activity was earlier on this site than at the nearby sites of Burlescombe (combined estimate of AD770-980) and Churchills Farm (current provisional Bayesian modelling suggesting smelting ranged from cal AD 790/870 to cal AD 1045/1105). Churchills Farm may include examples of both tapping and non-tapping furnaces, as does the site at Ramsbury, Wiltshire (Haslam 1980). The present site would appear broadly coeval with that at Clearwel, Gloucestershire (Pine *et al.* 2009) which gave similar late 7th-late 9th century dates. The site therefore presents an important contribution to the understanding of the development of smelting in the area.

CONCLUSIONS

This and neighbouring sites have shown that Hemyock was a focus for iron working in Saxon and later medieval times (Blaylock 1989, Hughes 2013, Tabor 2010; and Exeter Archaeology at Churchill's Farm, unpublished) and sits comfortably within the iron working industries of the broader Blackdown Hills area (e.g. see Griffith and Weddell 1996, Reed *et al.* 2006). The 12th century Hemyock church formerly of cruciform type, along with the late 14th century Hemyock Castle presumably reflect the importance of the locale, which is also matched by its royal ownership and the choice of Hemyock as a Hundredal centre.

ACKNOWLEDGEMENTS

The site work was carried out under the direction of Peter Stead assisted by Richard Sims, Paul Cooke, Naomi Hughes, Claire Hurst and Kieran Gibbons. The figures were prepared by Elisabeth Patkai. The work was commissioned by Mr Andy Lehner.

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