SAXON IRON SMELTING AT CLEARWELL QUARRY, ST. BRIAVELS, LYDNEY, GLOUCESTERSHIRE

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An open area excavation carried out in advance of limestone extraction at Clearwell Quarry provides the first archaeological evidence for Saxon iron-smelting in the region. Of chief interest is the discovery of securely-dated Saxon iron-smelting features: thirty furnaces, both tap and slag-pit types; ten ore-roasting pits; and seven probable charcoal-clamps. Although datable finds were absent from these features, radiocarbon determinations on charcoal from three of the furnaces give consistent dates in the late 8th to 9th centuries. Chemical analysis of the slags showed them to be from the more inefficient end of the bloomery process in comparison to Roman slags from the same region. There was no evidence that blooms were being worked on the site after smelting. Mixed, but predominantly oak, charcoal was being used for fuel, and probably produced on the site. Other finds from the site included small quantities of prehistoric worked flint and medieval pottery: without the radiocarbon dates, there would have been nothing to suggest the furnaces were Saxon.

INTRODUCTION

This paper gives an account of the important first material evidence for Saxon iron-making by the bloomery process ever discovered in the Forest of Dean, part of the Bristol Channel Orefield (Young and Thomas 1998) and one of the main iron-producing regions of Britain (Hart 1971; Meredith 2006). The only previous evidence for early medieval iron-making in the Forest is documentary. *Domesday Book* speaks of a quantity of iron, plausibly from the Forest, being rendered to the Crown by Gloucester in the time of King Edward, and more certainly of blooms from Alvington, a village on the banks of the Severn Estuary not far below Lydney (Williams and Martin 2002, 445, 512). Iron has been smelted in the Forest of Dean and the surrounding area since Iron Age times, first by the bloomery batch process and later, from the 16th century onward, by the continuous and much-larger-scale blast-furnace method (Hart 1971; Meredith 2006). The Iron Age and Roman industries in the Forest and the wider area are well-attested (Walters 1992; Allen 2009), except for the ore-mines themselves, as are the extensive post-medieval activities (Hart 1971; Meredith 2006), as represented by scowles, slag-heaps and ruined furnaces in stream valleys. The discovery of evidence for Saxon iron-making therefore begins to fill a significant gap in knowledge of the industrial development of this distinctive region, which involved coal and timber as well as iron and iron products.

The archaeological investigation was undertaken by Thames Valley Archaeological Services at Clearwell Quarry, Stowe, St Briavels, Lydney, Gloucestershire (SO 5700 0660). Planning permission (app no DF/2238/X) had been gained from Gloucestershire County Council to extract stone from a 3.5 ha extension to the existing quarry, subject to a condition requiring the archaeological investigation reported here. Earlier evaluation (Bartlett 2001; OAU 2002) had revealed little of archaeological interest across the

Figure 1. Clearwell Quarry: Site location, showing evaluation trenches and geologies across the stripped area.

area, except in one place where features thought to be indicative of small-scale iron-production were found. No dating evidence was recovered but it was considered likely that these may have been of Iron Age or Roman date.

The site is a large, irregular parcel of land to the south-east of Stowe Green (Figure 1). The site is undulating with a high ridge formed by the Carboniferous Limestone Series (including the Lower Limestone Shale) (Welch and Trotter 1961), which is in the north-west at *c* 195 m above Ordnance Datum (BGS 1974). The Lower Limestone Shale passes up from the Upper Old Red Sandstone. The land slopes down gently to the south-east to 188 m OD with the underlying geology in this region being an iron-rich silty clay/clay which overlies the limestone. The iron content varies across the site with a particularly rich band including small outcrops of ore nodules

Figure 2. Plan of all excavated features.

running along the edge of the exposed limestone. Further to the east the bedrock contains a higher percentage of clay particles and is a mottled reddish blue-grey in colour. Further still to the east is a likely palaeochannel 1001 (infilled with a dark blue-grey reduced clay) this is cut by an extant channel 126 which is infilled with a humic sandy clay (Figure 2). This channel is either a deliberately cut water-management feature or formed by natural agency. Both features (126 and 1001) may mark a spring-line and/or active winterbourne channel which originates further to the north, observed sourcing at the retained tree-line. The southern continuation of this channel (1001) is observed as a deep gully in the pasture-field to the south and in recent times a concrete culvert has been located at the southern end of the palaeochannel running into the gully, indicating that water-management is still an issue (Figure 2). The dating of this channel (both 126 and 1001) is problematic.

A previous desk-based assessment (OAU 2001) summarizes the archaeological background for the area, which is not extensive. It was considered that a round-barrow cemetery was located within the field known as Phase 6. However, closer examination of the mounds during evaluation and also this stage of fieldwork indicated that they are more likely to be by-products of field-clearance or quarrying. Prehistoric worked flint has been recovered during fieldwalking carried out by both the Dean Archaeology Group and the Oxford Archaeological Unit (OAU) across the whole of the quarry extension (including but not limited to the site here).

THE EVALUATION

A geophysical survey (Bartlet 2001) and a evaluation (OAU 2002) preceded the excavation. Eight evaluation trenches largely revealed little of archaeological interest with just an isolated undated pit, a few sherds of Roman and later pottery and a few prehistoric struck flints recovered. The exception was an area with a gully, two slag-filled pits and two furnace-pits, considered to indicate small-scale iron production. No artefactual dating evidence was recovered but it was considered likely that the remains were of Iron Age or Roman date. This area was therefore targeted for excavation.

THE EXCAVATION

The excavation area of 3.5 ha was stripped of topsoil and subsoil using a 360^0-type machine fitted with a toothless ditching bucket, under constant archaeological supervision (Figure 2). The majority of features appear to be furnaces, together with a number of ore-roasting pits and the remnants of charcoal clamps. The majority of these features contained no dating evidence, and have mainly been phased by their geographic proximity and similar characteristics, to the three furnaces dated by radiocarbon, to the middle Saxon period. A small number of pits have been dated to the medieval period albeit by very small quantities of pottery: these could be considered quarry pits. All smelting furnaces were fully excavated. Other pits were half-sectioned as a minimum. The few linear features were sampled at 20% of their length, except those considered to be of post-medieval date which were sampled to 1% to confirm this interpretation.

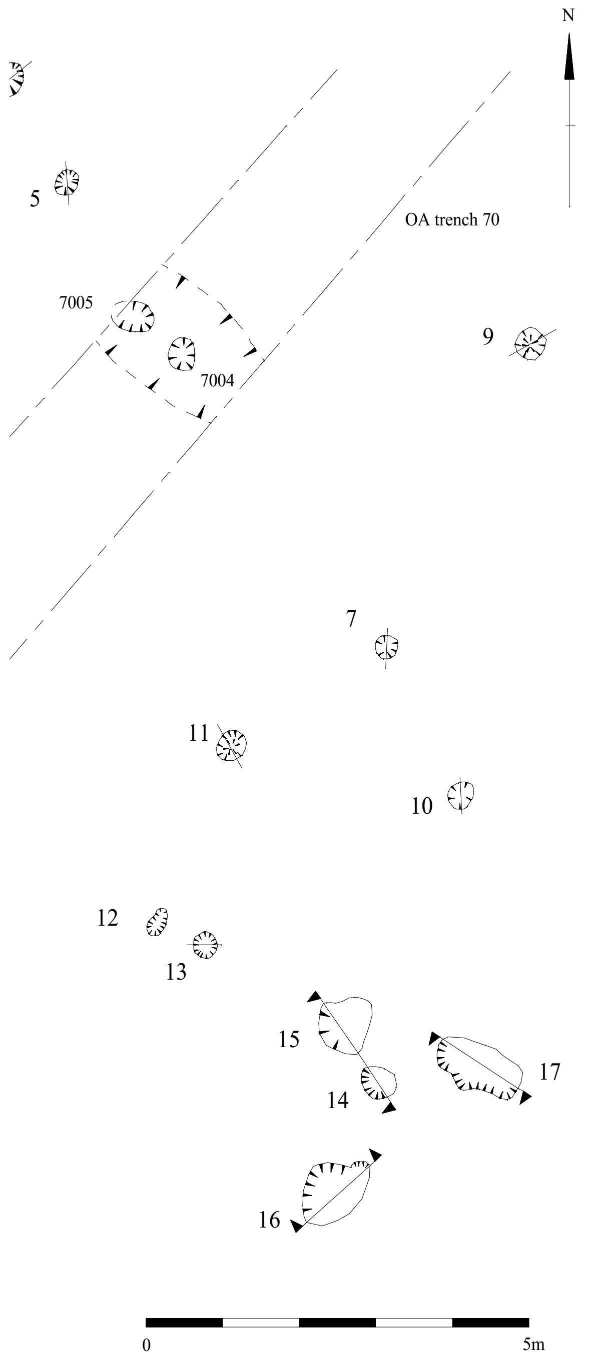


Figure 3. Detailed plan of southern furnace cluster.

FURNACES

Southern cluster (Figures 3 and 5, Table 1)

This area of furnaces surrounded two furnace pits recorded in Trench 70 of the evaluation (OAU 2002). Furnaces 4, 5, 7, 9–16 were cut into the light reddish pink silty clay, with furnace 6 offset slightly to the north and quarry pit 102 further off to the north-east. Most of these cuts had edges which showed signs of heating, either simple reddening of the deposit through which they cut, or of thermal gradient, the clay changing from white or grey on the sides to a dark red at the base. Where heating was evident, it was simple reddening of the sides and base unless noted otherwise below.

Furnace 4 The edges of this feature showed thermal gradient, the clay changing from white or grey on the sides to a dark red at the base. At the base of this furnace was a thin deposit of silt containing moderate amounts of charcoal, remnants of the fuel (Figure 4). Sealing this was a large fragment of tap-slag from a shallow cake (56) which took up the majority of the shape of the cut but had been truncated slightly to the west. This was partially covered by a thin silt deposit (57) which had some charcoal.

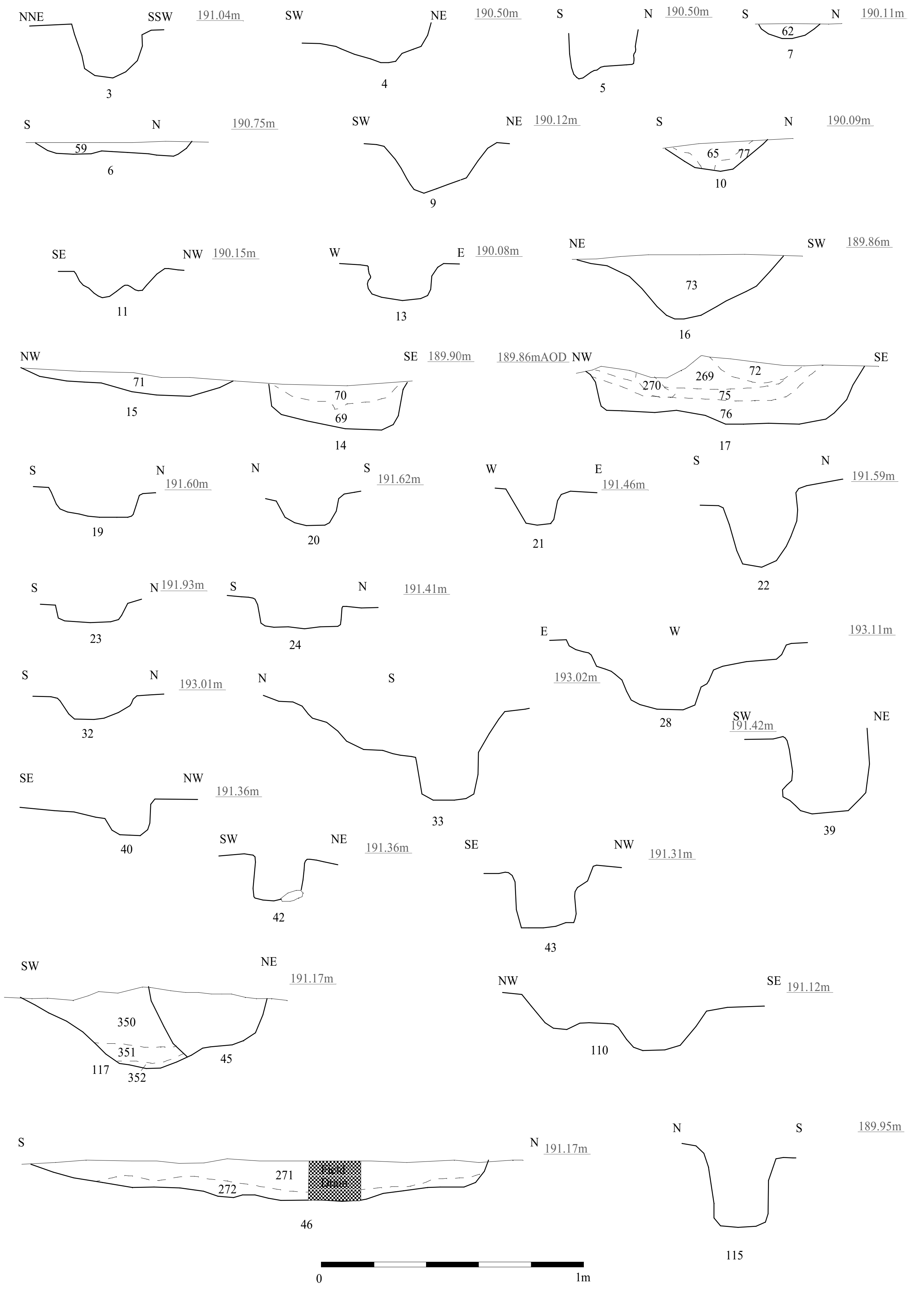
Furnace 5 Again the sides of this circular hollow were scorched by high temperature and the base was fire-reddened. At the base was a thin lens of charcoal in a sandy silt matrix. Overlying this were fragments of tap-slag (61).

Furnace 6 This was 20 m to the north of the main cluster of furnaces (Figure 2). A dark grey silty clay with frequent charcoal (59) was excavated from this oval hollow. This feature is only tentatively identified as a furnace.

Furnace 7 This small circular hollow contained a black silty clay (62) with fragments of tap-slag and burnt clay, with frequent charcoal.

Furnace 9 This circular cut contained a black silty clay (266), in turn sealed by a deposit (265) which contained large lumps of tap-slag. This was sealed by a black silty clay (264). Above this was another layer (263) which contained lumps of tap-slag, some with charcoal impressions. The latest deposit excavated was a silty clay (63) which also contained fragments of slag, baked sandy clay and fuel-ash slag.

Figure 4. Furnace 4, looking north. Scale 0.1 m.


NNE
SSW
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3
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7
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193.11m
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191.36m
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42
SE
NW
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43
SW
NE
191.17m
350
351
117
352
45
NW
SE
191.12m
110
S
N
191.17m
271
Field Drain
272
46
N
S
189.95m
115
0
1m

Figure 5 (left). Furnace sections.

Furnace 10 The remains comprised an ovoid scoop, cut into a reddish pink silty clay. At the base of the furnace was a charcoal rich lens (94) which contained tap-slag. Stratigraphically above this were slag pilules and fragments of tap-slag (77) congealed around the edge of the hollow. Sealing this was a black silty clay (65) containing frequent charcoal together with fragments and pilules of slag.

Furnace 11 This circular hollow showed evidence of a temperature gradient. The lowest deposit consisted of a mid red-brown silty clay with moderate charcoal fragments (268). Charcoal from this deposit has been radiocarbon dated to 1231±24 BP (KIA38912; Cal AD 691–878). This also contained lumps of slag and fuel-ash slag. Above 268 were large lumps of tap-slag (267) 0.35 m in diameter and 0.08 m deep. Above this was a black silty clay with fragmented blocks of slag (64), which had within it fragments of tap-slag with some furnace-lining and a few slag pilules, within it.

Furnace 12 At the base of this steep-sided ovoid cut was a fragment of tap-slag (66) sealed by a dark brown/black silty clay with occasional charcoal (74).

Furnace 13 This comprised a circular shaft whose sides and base showed evidence of a temperature gradient. At the base was a charcoal lens (93) 0.04 m deep. This was covered by a 2.54 kg basin-shaped mass of tap-slag (67) with a tool-marked surface (see Allen 2009), together with large slag pilules, a little furnace-lining and vesicular slag.

Furnace 14 This was a circular cut with a hollow on the NW side, the edge marked by charcoal and heat-scorching of the clay substrate on the north-west edge. It is possible this was the remnants of a furnace. Fill 70 contained tap-slag whilst deposit 69 contained lumps of vesicular tap-slag, some with charcoal impressions.

?Furnace / Pit 15 The fill (71) of this oval cut was a mid grey-brown clayey silt and contained small amounts charcoal.

Furnace 16 This comprised an oval shaft, with vertical sides. The fill (73) was a mid grey-brown clayey silt and contained slag pilules, fragments of burnt clay and slag.

Furnace 17 The clay at the base of this shallow cut was deeply scorched. The lowest deposit consisted of a thin lens of red-brown silty clay with moderate charcoal fragments (75). Above this were large lumps of scoriaceous fuel-ash slag (270). Stratigraphically above came fragments of tap-slag, a few with entrapped ore; furnace-lining; highly vesicular potato-shaped lumps of fused lining material; and fragments of slaggy fuel-ash

Table 1. Details of furnace in southern cluster.

Feature type	Cut	Fill(s)	Length x breadth or diameter (m)	depth (m)	heated?
Furnace	4	56, 57	0.38 x 0.44	0.12	Y
Furnace	5	61	0.3	0.04	Y
Furnace	6	59	0.7 x 0.5	0.07	Y
Furnace	7	62	0.2	0.05	
Furnace	9	63, 263–5	0.4	0.05	
Furnace	10	65, 77, 94	0.20 x 0.28	0.12	Y
Furnace	11	64, 267–8	0.35	0.19	Y
Furnace	12	66, 74	0.26 x 0.18	0.06	Y
Furnace	13	93, 67	0.27	0.20	Y
Furnace?	14	69, 70	0.42 x 0.77	0.16	?
Furnace/Pit	15	71	0.64 x 0.62	0.07	
Furnace	16	73	0.78 x 0.69	0.25	base only
Furnace	17	72, 75, 269–70	0.90 x 0.30	0.12	base only

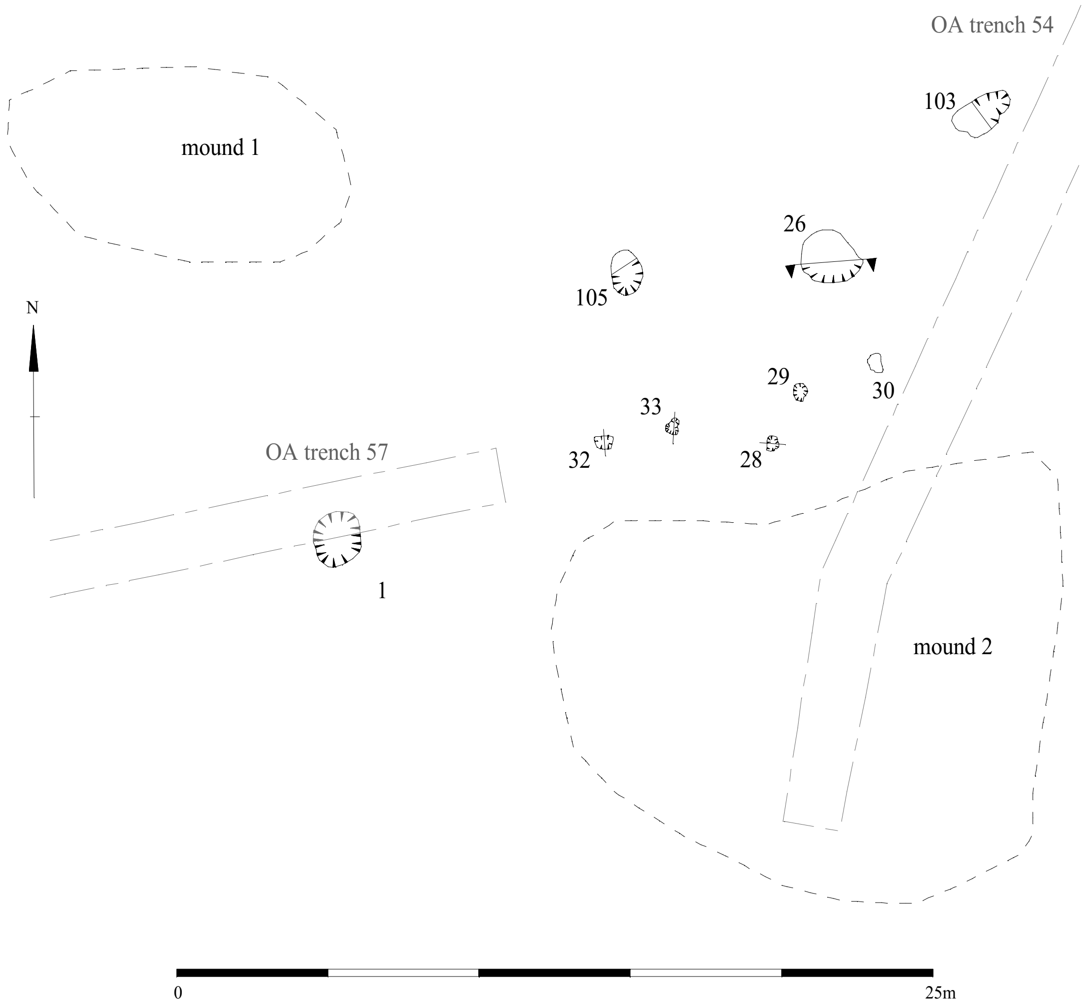

Figure 6. Detailed plan of north-western furnace cluster.

slag with moulds of charcoal (269) sealed by a black silty clay (72) which contained abundant fragments of slag and some of burnt clay.

North-west cluster (Figures 5 and 6, Table 2)

These features were recorded on the limestone substrate and include four furnaces (28, 29, 30, 32), quarry pits 1, 26 and 30, 103 and 105 (all of which may be later) (Figures 6 and 11) and mounds 1 and 2. The furnaces share the general characteristics of those in the southern cluster.

Furnace 28 This was an oval shaft excavated into the limestone, the edges and surface of which around the furnace had been changed to a pinkish colour by heat. A thin deposit of clayey silt (258) with occasional charcoal was excavated from its base. This was sealed beneath a 10 kg slag basin/cake/block (89) which was 0.26 m by 0.28 m and 0.14 m in depth. On its southern edge was a semicircular hollow 0.20 m in diameter. A thin silty clay deposit (88) partially overlay this, together with some loose fragments of limestone, which possibly may have been part of the superstructure (Figure 7).

Furnace 29 This hollow comprised very ephemeral characteristics which may suggest it was a furnace. There was no sign of burning, but substantial fragments of vesicular tap-slag were recovered from a mid grey brown clay silt deposit which also contained moderate amounts of charcoal (90).

Furnace 32 It comprised a circular hollow excavated into the limestone that had become fire reddened within and surrounding the hollow. Within the hollow was a basin of vesicular slag that moulded the shape of the furnace base (262). This was directly below the topsoil (50).

Figure 7. Furnace 28 before excavation, showing traces if possible superstructure: looking south-west. Scale 0.1 m.

Figure 8. Furnace 33, looking east. Scales 0.5 and 0.1 m

Table 2. Details of furnaces in north-west cluster.

Feature type	Cut	Fill(s)	Length x breadth or diameter (m)	depth (m)	heated?
Furnace	28	88, 89, 258	0.63 x 0.32	0.28	Y
Furnace?	29	90	0.36 x 0.50	0.06	
Furnace	32	262	0.70	0.07	Y
Furnace	33	56, 151–3, 155	0.36	0.37	Y

Furnace 33 This was a substantial furnace comprising a circular shaft cut through the limestone capping into the underlying clay, with both lithologies showing thermal-gradient colours, evidence of exposure to high temperatures (Figure 8). To the north was a joining shallow hollow 0.20 m by 0.35 m and 0.20 m deep. At the base of the shaft lay a black-brown silty clay (155) with frequent charcoal, radiocarbon-dated to 1213±31 BP (KIA38910; Cal AD 693–890) for its last firing. The clay contained small fragments of tap-slag and some of furnace-lining and fuel-ash slag; a few fragments of orange, fine-grained sandstone and one angular fragment of goethite ore (8.9 g) were also found. Overlying this was a deposit of slag pilules, fragments of tap-slag, fragments of orange burnt clay and weathered fragments of limestone (56). Above came a charcoal lens (151) sealed by a deposit of dark brown silty clay (153) that contained limestone fragments, possibly part of the superstructure, and many fragments of furnace-lining that also infilled the adjoining hollow. Finally, concentrated in the top of the south-eastern part of the feature, was a deposit (152) of fragments of furnace-lining, some with attached slag, and occasional tap-slag together with many fragments of orange-grey burnt clay.

Central cluster (Figure 9, Table 3)

Furnaces 3, 19–24, 39, 40, 42–45, 104, 109, 110, 115, with gully 117/119, formed a cluster all cut into silty clay.

Furnace 3 This was a substantial furnace comprising an ovoid hollow whose sides displayed a thermal gradient, with the clay being altered to a whitish grey on the sides alternating to a rich red further from the heat source (Figure 10). At the base of the cut the colour of the clay was a reddish orange. Directly above the base was a black-brown silty clay with moderate charcoal (275). Sealing this was metallurgical debris including slag pilules, many fragments of tap-slag, some with moulds of charcoal, and fragments of furnace-lining (276).

Furnace 19 This furnace comprised a shallow, almost circular hollow cut into the clay. The base appeared fire-reddened and sealing this was a thin lens of charcoal (167) above which was a slag cake/base (166); slag fragments were recovered (80) above this, and the shaft was sealed with a mid-grey silty clay with frequent charcoal (78).

Furnace 20 It comprised a circular shaft, the base having been slightly reddened due to exposure to heat. Fragments of tap-slag (81) were sealed by a black-brown clay with frequent charcoal (79). This latter deposit also contained slag pilules, fragments of slag and furnace-lining.

Furnace 21 This furnace comprised a shallow circular hollow with fire-reddened base and sides. Fragments of tap-slag were sealed by a black-brown clay with frequent charcoal (159); above this came fragments of tap-slag (160).

Furnace 22 This was similar to furnace 21. Above black-brown clay with frequent charcoal (174) were large lumps of tap-slag and masses resembling piled dung (173). Sealing this was a black-brown silty clay with frequent charcoal (171). Stratigraphically later were large lumps of tap-slag from a shallow basin (170). Above this was a dark grey silty clay with occasional charcoal (169).

Furnace 23 It comprised a very shallow circular scoop cut into the clay substrate. The eastern side appeared fire-reddened. A dark grey-brown clayey silt lens (83) 0.07 m deep containing occasional charcoal overlay this hollow and above were the remnants of a tap-slag base.

Furnace 24 This furnace comprised a fire-reddened circular hollow. At the base were fragments and lumps of tap-slag, some from a

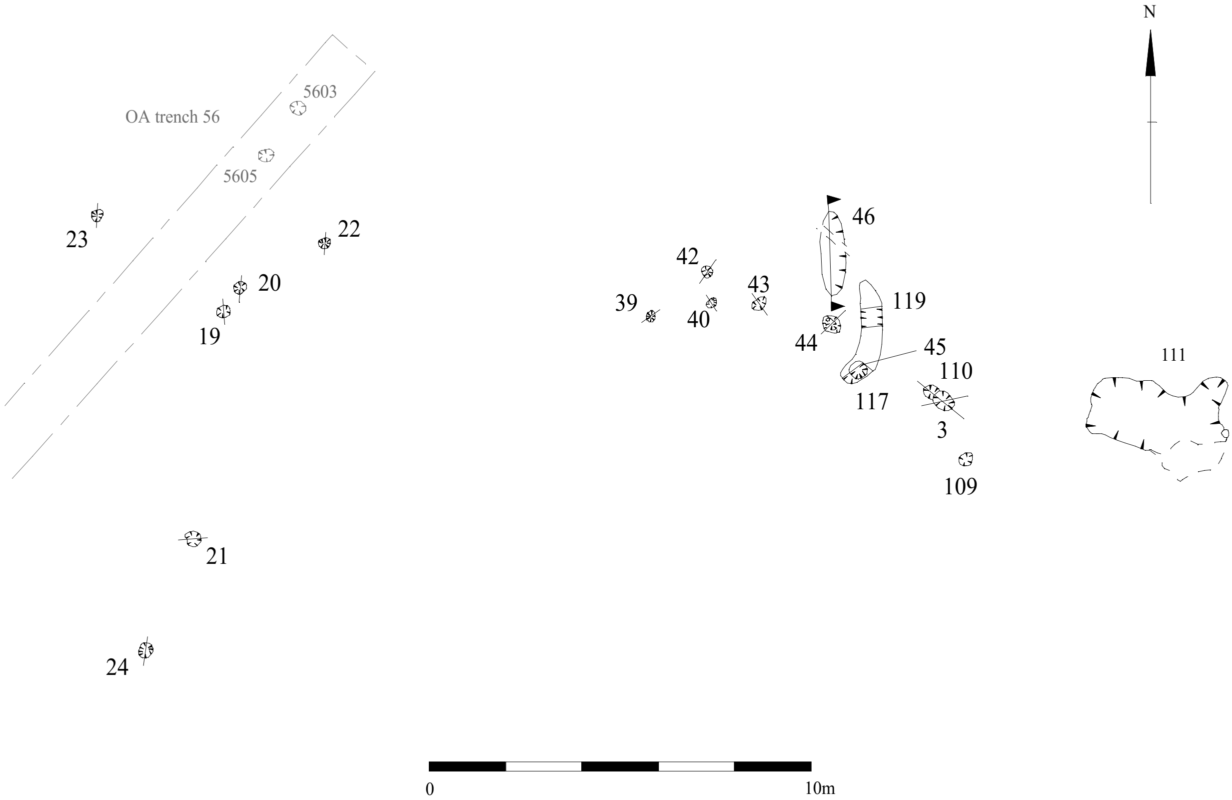

Figure 9. Detailed plan of central furnace features.

thick sheet (164) weighing just over 10 kg, that infilled the whole of the diameter of the hollow. Up the side of the hollow were tap-slag deposits (163). Above this was a mid grey clayey silt infill (165) which contained occasional fragments of charcoal and burnt clay.

Furnace 39 This comprised a circular shaft 0.23 m in diameter at the base, the top part of which had been disturbed, causing the clay to be squashed to one side, giving surface dimensions of 0.23 m by 0.14 m. There is a possibility of reuse of this furnace as there appeared to be multiple deposits of slag debris. At the base of the shaft, which was lightly fire-reddened, were small fragments of slag (177) pressed into the clay. Above this was a large slag block weighing 2 kg. This was sealed by deposit 180, a clayey silt with charcoal and also frequent burnt clay fragments, possibly elements of the furnace superstructure which had collapsed into the shaft. This deposit was then sealed by more small slag fragments (181). Above was a clayey silt with charcoal and also frequent burnt clay fragments (182), possibly further elements of the furnace superstructure.

Figure 10. Furnace 3, looking south-east. Scales 0.5 and 0.1 m.

Furnace 40 There was no sign of thermal gradient on or around this oval cut. Inside was a clayey silt with occasional charcoal (353). It is possible this is the remnants of a small furnace but it is doubtful.

Furnace 42 There is a possibility of repeated reuse of this circular shaft furnace as it appeared to hold multiple deposits of slag debris, separated by thin bands of clayey silt. The sides and base showed colour changes due to exposure to heat. At the base were fragments of slag and some furnace-lining within a clayey silt with frequent charcoal (187). Charcoal from this deposit was radiocarbon dated to 1215±33 BP (KIA 38911; Cal AD 691–890). This was sealed by large slag fragments and pilules, overlain by a clayey silt with frequent charcoal (185), in turn sealed by slag pilules and fragments of tap-slag (184). Above came a mid grey-brown sandy clay that contained slag pilules and frequent charcoal (183).

Furnace 43 The primary fill of this oval cut was a dark greyish-black silty clay (253) that contained frequent charcoal inclusions and burnt clay and slag pilules and fragments. Above this were slag pilules and lumps of tap-slag (252). Above this was a dark greyish-black silty clay (251) that contained frequent charcoal inclusions, slag pilules and fragments of furnace-lining and tap-slag. Above came a light greyish-brown silty clay (250) with frequent inclusions of charcoal and burnt clay.

Furnace 44 This furnace comprised a circular hollow with fire-reddened base and sides. At its base was a dark brownish-grey silty clay (281) with frequent charcoal inclusions and fragments of tap-slag and furnace-lining, a 5 mm smooth spheroid of slag with a dull lustre, and a 2 mm sphere of pale blue fuel-ash glass. Above this was a dark greyish-black silty clay (280) that contained frequent charcoal inclusions and furnace-lining. The infill was topped by a mid-grey clayey silt (279) with occasional charcoal, fragments of slag, burnt clay and fragment of dark grey furnace-lining.

Furnace 45 This deep shaft cut into an earlier gully (117/119). At the base was a silty clay with frequent charcoal (298) and fragments of tap-slag. Above 298 was a cake of slag (297), sealed by a silty clay with frequent charcoal (288) and a light grey-brown sandy clay with charcoal and burnt clay patches (291). Above came a large (6 kg), deep, basin-shaped mass of tap-slag with slag pilules and a few sandstone pebbles trapped on the surface (290). This was sealed by a dark brown-grey silty clay with frequent charcoal and slag, and fragments of furnace-lining (287).

Furnace 104 This circular hollow was very shallow with fire-reddened base and sides. Lumps of tap-slag from a large basin-shaped mass (256) protruded from the hollow.

Furnace 109 A 0.28 m diameter shaft cut 0.03 m deep into the geology showed signs of thermal change from white-grey on its sides to red at the base of the cut. The lower fill was a dark grey clayey silt with frequent charcoal (273) and fragments of slag. Lumps of tap-slag from a large basin-shaped mass were retrieved above this deposit (274).

Furnace 110 A circular hollow 0.30 m diameter and 0.13 m deep appeared to be truncated by furnace 3. The northern edge of the cut (110) showed heat alteration, being a light grey colour, and the base was fire reddened. Slag fragments were recovered from the base of cut (277).

Furnace 115 This circular shaft had sides showing the grey colours indicative of heat change. A deposit of unfired charcoal (296) 0.14 m thick was removed from the base of the furnace. Above this were slag pilules and fragments of tap-slag (295). Overlying this were fragments of tap-slag, fuel-ash slag with charcoal, furnace-lining, a potato of fused clay (293). Sealing 293 were orange clay fragments in a silty clay matrix, the fired clay possibly being remnants of a superstructure (292).

Two mounds were investigated that appeared to be piled topsoil/subsoil from some previous clearance of the area. It is possible this was related to the furnace-making activity, since the north-western cluster respected the mounds (or *vice versa*), though it is unclear why the soil would have needed to be removed from the work area, and it may be more likely that the mounds were created at some later date. Both were 0.37 m high, and comprised a modern turf line above a mid red-brown silty clay overlying fragmented limestone succeeding the limestone bedrock. Occasional fragments of tap-slag within the mound were probably inevitable inclusions in the

Table 3. Details of furnaces in central cluster.

Feature type	**Cut**	**Fill(s)**	**Length x breadth or diameter (m)**	**depth (m)**	**heated?**
Furnace	3	275–6	0.35 x 0.28	0.23	Y
Furnace	19	78, 80, 166–7	0.29	0.12	base only
Furnace	20	79, 81	0.28	0.13	base only
Furnace	21	159, 160	0.20	0.15	Y
Furnace	22	169–74	0.20	0.15	Y
Furnace	23	83	0.20	0.07	partially
Furnace	24	163–5	0.32	0.15	
Furnace	39	177, 180–2	0.23	0.38	
Furnace?	40	353	0.24 x 0.22	0.17	
Furnace	42	183–7	0.20	0.20	Y
Furnace	43	250–3	0.30 x 0.20	0.25	
Furnace	44	279–281	0.28	0.16	Y
Furnace	45	287–8, 290–1, 298–9	0.25 x 0.15	0.43	
Furnace	104	256	0.25	0.03	Y
Furnace	109	273–4	0.28	0.03	Y
Furnace	110	277	0.30	0.13	partially
Furnace	115	292–6	0.23	0.34	Y

soils from this area.

ORE-ROASTING PITS (Figures 2 and 11, Table 4)

Pits 18, 27, 115 and 116 clustered just to the south-east of the central group of furnaces presumably served to provide raw material for the latter. Pits 25, 31, 34, 36, 37 and 118 were scattered widely across the central part of the site, mostly on the silty clay, and could have served any of the furnaces. All of these had seen *in-situ* burning, which probably resulted from pre-treatment of the ore before smelting. Other pits (47, 48, 49, 100) which cluster around pits 18, 115 and 116 seem to have been clay quarries (see below).

Pit 18 This was oval in shape; the base was a rich red colour suggestive of great heat. Above this was a thin lens of charcoal (98) 0.07 m thick, succeeded by a mid brown-grey silty clay with frequent charcoal (91). This latter deposit contained fragments of slag and chips of roasted ore. It is likely that the pit may have served a dual purpose: the clay removed may have been used for the superstructures of the furnaces but then the pit may have been used to roast the ore as part of a stage prior to smelting.

Pit 25 This too was oval, and the natural clay was lightly fire-reddened. Above this was a deposit of reddish-brown silty clay with moderate charcoal flecks (86). Overlying 86 was a charcoal lens (85) 0.05 m in depth. Sealing this was a dark brown-grey silty clay (84) which contained moderate charcoal, fragments of slag and chips of roasted ore.

Pit 27 Again the clay at the base of this oval pit was a rich red colour indicative of high temperature. A light brownish-grey silty clay with moderate charcoal (150) lined the base. Above this was a firm dark blackish brown silty clay with frequent charcoal (60%). Again this may have been an ore-roasting pit.

Pit 31 This circular pit, with concave side and base cut into a highly fire-reddened clay substrate, which was partially excavated to confirm it was not deliberately lined (97). Above lining 97 was a charcoal-rich (90%) silty clay layer (98) which was 0.16 m deep and contained fragments of furnace-lining, burnt clay and chips of roasted ore together, with a few small slag spheroids with dull lustre. Above came a light brownish-grey silty

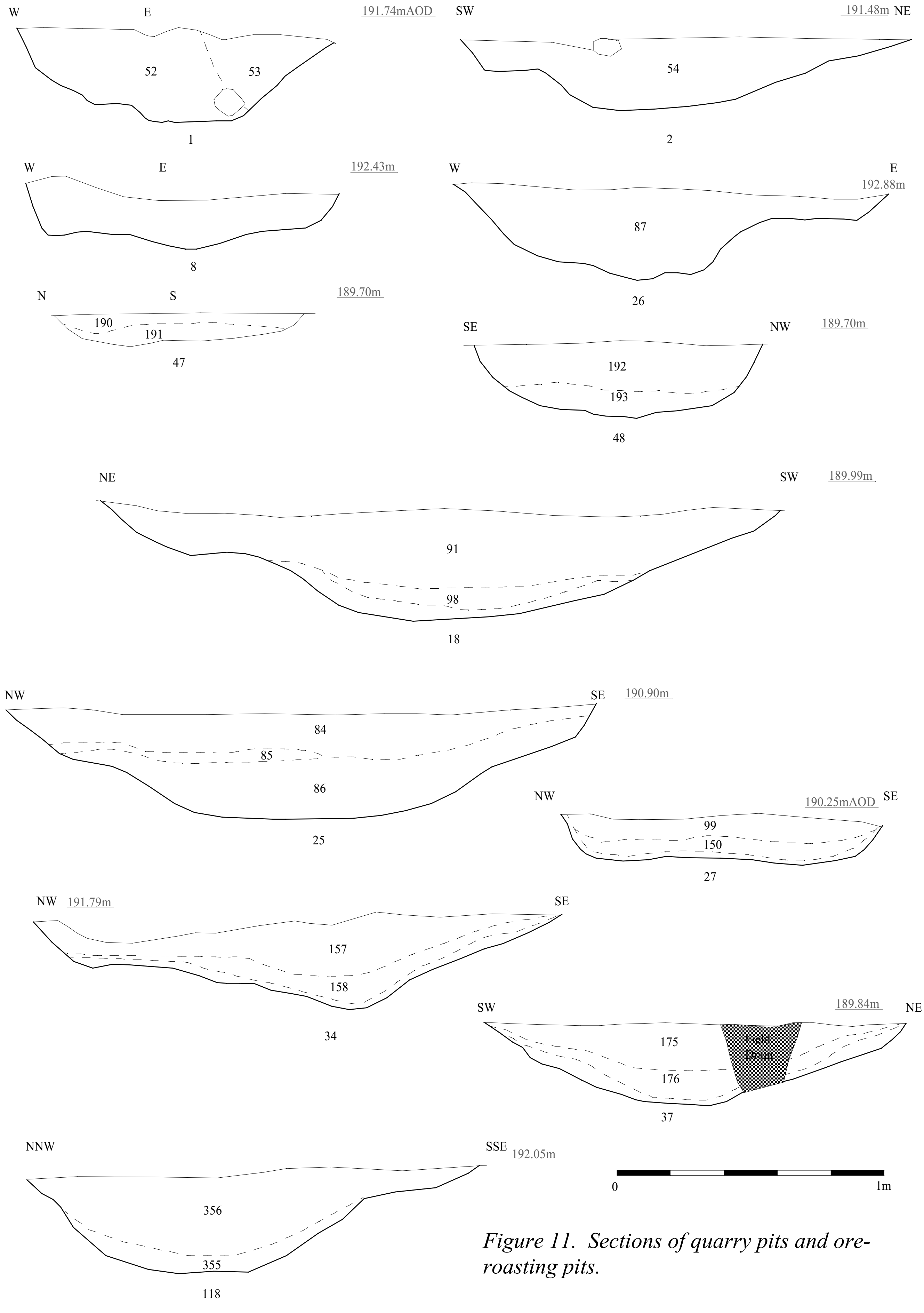

Figure 11. Sections of quarry pits and ore-roasting pits.

Table 4. Details of ore-roasting pits.

Feature type	**Cut**	**Fill(s)**	**Length x breadth or diameter (m)**	**depth (m)**	**heated?**
Roasting Pit	18	91, 98	2.60 x 2.50	0.31	Y
Roasting Pit	25	84–6	2.30 x 2.10	0.35	Y
Roasting Pit	27	99, 150	1.30 x 1.20	0.13	Y
Roasting Pit	31	95, 97, 98	2.24 x 1.59	0.24	Y
Roasting Pit	34	157–8	1.97	0.37	Y
Roasting Pit	36	162	0.96	0.12	
Roasting Pit	37		1.60 x 1.54	0.31	base only
Roasting Pit	116		0.63 x 0.45	0.08	
Roasting Pit	118		2.60 x 2.54	0.39	Y

clay with moderate charcoal flecks (95).

Pit 34 Again the base and sides of this circular pit appeared fire-reddened. At its base was a firm dark brownish-black silty clay with frequent charcoal (158). This yielded small fragments of burnt clay and chips of roasted ore. It was sealed by a mid brown-grey silty clay with occasional charcoal (157).

Pit 36 This comprised a shallow hollow 0.96 m in diameter and 0.12 m deep. It was filled with a friable dark brown-black silty clay (162) that contained frequent charcoal together with angular fragments of roasted ore, fragments of burnt clay and slag and fragments of tap-slag.

Pit 37 This pit, cut into the clay and over 80 m from the nearest furnaces (44, 45 etc. in the central cluster), was fire-reddened at its base, and again likely to be an ore-roasting pit. Its dimensions were 1.60 m by 1.54 m and 0.31 m deep and was truncated by a modern field drain.

Pit 118 Cut into the clay substrate, it was lightly fire-reddened at the base, and again likely to be an ore-roasting pit, as the sides appeared to be fire-reddened. It yielded tap-slag, fuel-ash slag, furnace-lining, and many fragments of burnt clay (chiefly grey).

QUARRY PITS (Figures 2 and 11)

A series of unburnt shallow pits/scoops were recorded cutting clay (pits 47, 48, 49, 100, 102 and 116) about 30 m south-east of the central cluster of furnaces. These were likely to have been quarry pits to extract clay for use for the furnace super structures or to be added to a furnace charge (see below). Pit 102 contained a angular lump of haematite ore (110 g).

Pits 1, 2, 8, 26, 30, 103, and 105 were mainly oval to irregular in plan and ranged from 0.60 m (pit 30) in diameter to 1.70 m by 1.50 m (pit 26), but were all less than 0.30 m deep. In some (e.g., 26) the irregular sides and base reflected the platy nature of the limestone. They may all have been quarry pits, though one or two might have been tree-throw holes. Only two of these features yielded any dating evidence, making both later medieval rather than Saxon. The others could be earlier and contemporary with the furnaces, but it seems just as likely that most or all of these belong to a single phase of limestone quarrying unrelated to the iron-smelting.

A single tiny sherd (1 g) of pottery dating from the 11th to 12th century came from pit 1. Pit 2 contained six sherds of pottery dating from the 13th century (or later) and lumps of tap-slag from a thick sheet. Three fragments of roasted ore were recovered from pit 26; pit 30 contained clinker fragments and slag; pit 103 had a small amount of tap-slag, while pit 105 was more convincing as a quarry, and yielded 2.8 kg of slag.

An undated gully (1002) was cut into the limestone bedrock aligned SW–NE. It was narrow (0.50 m wide) and shallow between 0.09 and 0.19 m deep, the sides showing the platy nature of the limestone. A shallow gully (117/119), 0.65 m wide and 0.3 m deep and 1.0 m long had been truncated by furnace 45.

Table 5. Details of charcoal clamps.

Feature type	Cut	Fill(s)	Length x breadth or diameter (m)	depth (m)	heated?
Clamp	38	168	1.20	0.06	Y
Clamp	101	197	0.85 x 0.62	0.02	Y
Clamp	120	361	0.76 x 0.38	0.10	Y
Clamp	121	362	0.80 x 0.32	0.10	Y
Clamp	122	363	0.40 x 0.35	0.14	
Clamp	123	364	0.40 x 0.35	0.08	
Clamp	125		0.70 x 0.50	0.02	

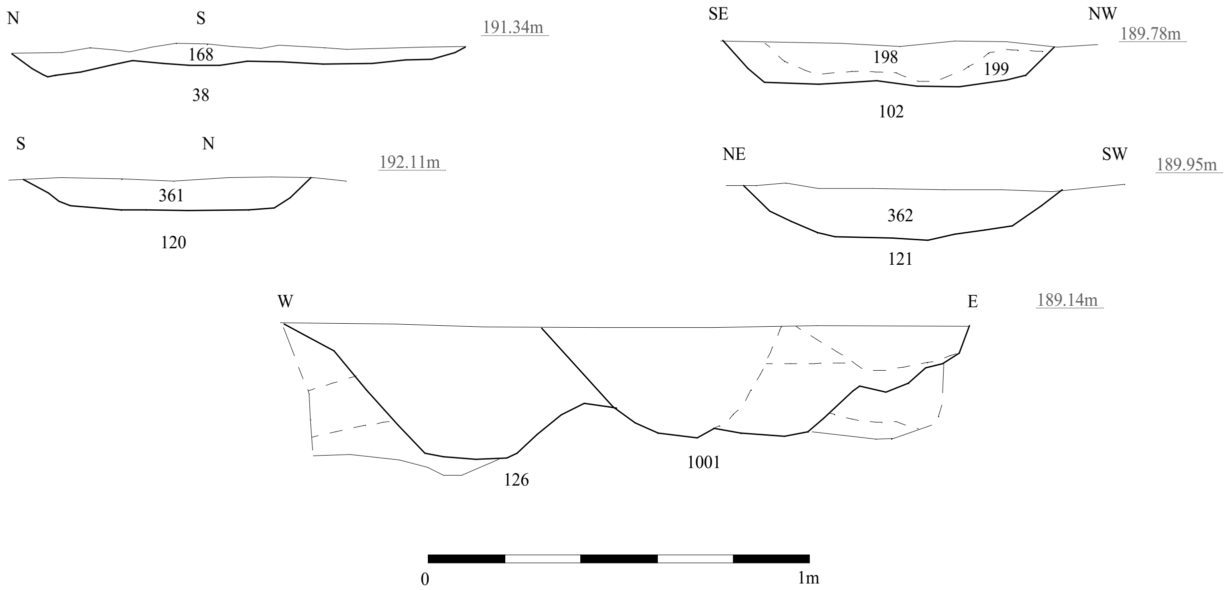

Figure 12. Sections of charcoal clamps and palaeochannel.

HOLLOW 111

A shallow irregular hollow 2.20 m by 3.40 m and 0.14 m deep was recorded immediately to the east of the central furnace cluster (Figure 9). It is possible this hollow was the by-product of quarrying for suitable material for construction of the superstructures, which would have sealed the below-ground furnace hollows, and was then used as an area to dump by-products of the smelting process, possibly from all of the central cluster of furnaces. Its fills contained specimens of virtually all the categories of metallurgical debris from the site: fragments of tap-slag, vesicular slag (some with charcoal moulds) and fuel-ash slag, fragments from a deep basin-shaped mass of tap-slag with moulds of large charcoal fragments on the upper surface, fragments of furnace-lining in various states, occasional charcoal, angular lumps of orange to pink fine-grained sandstone, and burnt clay.

POSSIBLE CHARCOAL CLAMPS (Figures 2 and 12, Table 5)

These shallow features were little more than spreads of charcoal. Their silty, charcoal-rich fills varied in colour from black, to reddish-grey to blue/grey. They were mostly located in the north-east (ie downwind) of the excavated area, (121–23, 125), with others widely dispersed along the northern edge (38, 120), and just one (101) in an area with other features. This isolation from other types of feature is quite marked and seems to have been deliberate, so clamp 101 may be earlier than the cluster of pits around it. The clamps were typically oval in plan, 0.40 m to 1.20 m by 0.35 m to 0.60 m, and no more than 0.10 m deep. In this area there were also several small lumps of iron ore on the stripped surface of the site. A sherd of pottery was recovered from clamp 38, which unfortunately could date from any time between the Iron Age and the medieval period. The charcoal from these clamps could not be distinguished from the charcoal in the furnaces; there was no evidence of selection or sorting. There was no evidence of heat around the clamps, but a charcoal fire can leave little or no trace.

SLAGS AND OTHER METALLURGICAL DEBRIS

Some 130 kg of metallurgical debris was recovered, over 110 kg of it from the furnaces (Table 6). Samples were examined with the aid of a hand-lens or binocular microscope, supplemented by the use of a streak plate, magnet, steel knife and acid-bottle.

Iron ore

Pieces of iron ore are rare at the Clearwell site, and almost all show signs of having been roasted. They range from (1) chips found in many of the pits, to (2) walnut-sized fragments conventionally regarded as suitable for a furnace charge, to (3) as-mined angular lumps varying in weight from a few hundred grams to a few kilograms that have yet to be broken down to a smeltable size. The ore that was roasted appears to have been chiefly goethite, a hydrous form of iron oxide and the rich ore typical of the Forest of Dean within the wider Bristol Channel Ore Field (Sibly and Lloyd 1927; Young and Thomas 1998). Only one fragment of raw haematite – rare in the Forest of Dean – was encountered.

Carbon fuel

Charcoal fuel (see below) is chiefly represented by moulds on many fragments of slag, and occasionally by entrapped lumps, as well as by grains in a number of residues.

Furnace-lining

Furnace-lining is distinctive (Allen 2009) and indicative, in association with the appropriate slags, of iron-making. Residues from Clearwell classed as furnace-lining are either (1) fragments of vesicular, almost glassy dark grey clay or (2) generally larger lumps of clay with brick-like hardness that display a partial or full gradation from (a) hard pale grey clay or orange/red clay to (b) almost glassy dark grey vesicular clay to (c) a smooth purple black vesicular surface in some cases marked by drip-like features. This sequence reflects the temperature gradient within the walls of a furnace, from *c* 300–400º C somewhere in the

Figure 13. Slag block from furnace 45 (290), viewed from above. Scale 0.1 m.

Figure 14. Slag block from furnace 28 (89), viewed from above. Scale 0.1 m.

Table 6. The slag finds by context type.

Cut	***Deposit***	***Weight (g)***	***Description***
			Furnaces
3	275	1494	Many fragments of tap-slag, some with moulds of charcoal; slag pilules; fragments of furnace lining
3	276	772	Slag pilules and lumps of tap-slag
4	55	132	Fragments of slag
4	56	9843	Lumps of tap-slag broken from a large, shallow, saucer-shaped cake
4	57	18	Fragments of slag and burnt clay
5	61	515	Fragments of tap-slag
7	62	179	Fragments of tap-slag, Fragments of slag and burnt clay
9	63	972	Lumps of tap-slag, baked sandy clay, fuel-ash slag
9	263	2252	Large lumps of tap-slag, some with charcoal impressions
9	264	406	Small fragment of slag, furnace lining and burnt clay
9	265	4530	Large lumps of tap-slag
10	65	33	Fragments and pilules of slag
10	77	660	Slag pilules and fragments of tap-slag
10	94	66	Fragments of slag including tap-slag
11	64	2485	Fragments of tap-slag with some furnace lining; slag pilules, fragments of slag with charcoal moulds
11	267	5000	Large lumps of tap-slag
11	268	4	Fragments of slag and fuel-ash slag
12	66	1120	Fragments of tap-slag
13	67	5829	A large basin-shaped mass of tap-slag mouling a tool-marked surface (2.54 kg), large slag pilules of slag, a little furnace lining; Vesicular slag
13	93	26	A few small slag spheroids with a dull lustre
14	69	679	Lumps of vesicular tap-slag, some with charcoal impressions
16	73	93	Slag pilules; fragments of burnt clay and slag
17	72	226	Abundant fragments of slag and some of burnt clay
17	269	2182	Fragments of tap-slag, a few with entrapped ore, furnace lining, highly vesicular potato-shaped lumps of lining material; fragments of slaggy fuel-ash slag with moulds of charcoal
17	270	4250	Large lumps of scoriaceous fuel-ash slag
18	93	20	Fragments of slag and potato-like masses of fused clay
19	78	122	Slag pilules and framents of tap-slag
19	80	1286	Fragments of tap-slag
19	166	3964	Large lumps of tap-slag from a shallow basin
19	167	146	Pilules and fragments of slag
20	79	230	Slag pilules, Fragments of slag and furnace lining
20	81	892	Fragments of tap-slag
21	159	281	Slag pilules and fragments of tap-slag
21	160	630	Fragments of tap-slag
21	161	150	Fragments of tap-slag
22	170	8592	Lumps of tap-slag from a shallow, basin-shaped deposit
22	172	540	Fragments of tap-slag and furnace lining
22	173	3494	Large lumps of tap-slag and masses resembling piled dung
22	174	212	Many slag pilules and some fragments of tap-slag

Table 6 continued...

Cut	***Deposit***	***Weight (g)***	***Description***
23	82	118	Fragments of tap-slag
24	163	1182	Fragments of tap-slag
24	164	12500	Fragments and lumps of tap-slag, some from thick sheet (Figure 14)
24	165	128	Fragments of burnt clay
28	33	5	Slag pilules and fragments
28	83	24	A 4 mm smooth spheroid of slag with a dull lustre
28	88	649	Slag pilules and fragments
28	89	2674	Fragments of tap-slag, some with fuel-ash
28	258	129	Slag pilules and some furnace lining, a long, irregular finger of tap-slag
29	90	1592	Fragments of vesicular tap-slag, one large
32	262	1030	Fragments of highly vesicular tap-slag
33	152	3250	Fragments of furnace lining, some with attached slag, and occasional tap-slag; many fragments if orange/grey burnt clay; weathered fragment of limestone
33	153	323	Many fragments of furnace lining and orange burnt clay
33	155	888	Small fragments of tap-slag and some of furnace lining and fuel-ash slag; a few fragments of orange, fine-grained sandstone and one angular fragment of goethite ore (8.9 g)
33	156	2082	Slag pilules; fragments of tap-slag, fragments of orange burnt clay; weathered fragment of limestone
39	177	963	Fragments of tap-slag
39	178	1760	Lumps of tap-slag
39	180	128	Fragments of slag and furnace lining, Orange burnt clay
39	181	506	Fragments of tap-slag
42	182	160	Slag pilules
42	184	324	Slag pilules and fragments of tap-slag
42	185	48	Slag fragments and pilules, burnt clay
42	186	1676	Slag pilules and small fragments of tap-slag
42	187	115	Fragments of slag and some furnace lining
42	188	732	Small basin-shaped mass of tap-slag
43	251	220	Slag pilules and fragments of furnace lining and tap-slag
43	252	3200	Large slag pilules and lumps of tap-slag
43	253	835	Slag pilules and fragments
44	279	31	Fragments of slag and burnt clay, Fragment of dark grey furnace lining
44	280	208	Fragments of furnace lining, some with a little slag
44	281	342	Fragments of tap-slag and furnace lining; a 5mm smooth spheroid of slag with a dull lustre; a 2mm sphere of pale blue fuel-ash glass
45	287	140	Fragments of slag, burnt clay and furnace lining
45	288	101	Fragments of slag
45	290	9008	A large deep basin-shaped mass of tap-slag with a few sandstone pebbles trapped on surface; Slag pilules (Figure 13)
45	298	14	Fragments of tap-slag
104	256	2204	Lumps of tap-slag from a large basin-shaped mass
104	257	4	Fragments of slag
109	273	32	Fragments of slag

Table 6 continued...

Cut	***Deposit***	***Weight (g)***	***Description***
109	274	152	Fragment of tap-slag
110	277	400	Fragments of slag
115	292	0	Fragments of orange/grey burnt clay
115	293	876	Fragments of tap-slag, fuel-ash-slag with charcoal, furnace lining, a potato of fused clay
115	294	104	Fragments of tap-slag
115	295	1246	Slag pilules and fragments of tap-slag
Pits			
2	54	974	Lumps of tap-slag from a thick sheet
15	71	12	Fragments of slag and burnt clay
18	91	20	Small fragments of slag and chips of roasted ore; one scale-like particle with a submetallic lustre
25	84		Fragments of slag and chips of roasted ore
26	87	93	Three fragments of ?roasted ore
31	96	4	Fragments of furnace lining, burnt clay; chips of roasted ore; few small slag spheroids with dull lustre
34	158	69	Small fragments of burnt clay and chips of roasted ore
36	162	39	Angular fragment of roasted ore; fragments of burnt clay and slag; fragments of tap-slag
38	168	8	Fragments of burnt clay
102	199	111	Angular lump of haematite
103	254	748	Lumps of tap-slag
118	354	55	Fragment of slag; many fragments of burnt clay, chiefly grey
Hollows			
105	255	2799	Fragments of tap-slag, one lump from a shallow basin-shaped mass; the corner from a ?squared block of orange fine-grained sandstone
111	282	182	Fragments of tap-slag and fuel-ash slag
111	283	74	Fragments of furnace lining
111	285	1234	Fragment from a deep basin-shaped mass of tap-slag with moulds of large charcoal fragments on upper surface
111	286	2566	Fragments of tap-slag, furnace lining, potato-shaped lumps of vesicular fuse lining material; angular lumps of orange to pink fine-grained sandstone; vesicular slag with moulds of charcoal; a potato-shaped mass of vesicular fused clay; large fragment of furnace lining with colour grading from orange to grey and vesicular
Other contexts			
117	350	12	Fragments of fuel-ash slag
	natural		Irregularly elongated furnace bottom
	Mound 1	67	Fragments of tap-slag
	Mound 2	498	Fragments of highly vesicular tap-slag
	Subsoil	1676	Lumps of tap-slag with moulds of charcoal
	206596N/ 357015E	1810	Fragments of tap-slag
	20660N/ 35700E		Four angular lumps of roasted ?goethite ore (323–2097 g)
	2065945N/ 357015E	334	Angular fragment of fine-grained sandstone
	205633N/ 356992E	39	Roasted ore

middle to *c* 1200º C at the inner surface exposed to the hot gases. The outermost clay, heated to lower temperatures, remains soft or can be softened, and so is seldom recognizable. The innermost clay is raised to a temperature sufficiently high for it to soften and melt, allowing it to drip off or flow down the furnace wall.

Occasionally at Clearwell are found potato-shaped masses, up to several centimetres across, of fused, vesicular clay. These could represent either lining material that had melted off the furnace walls or lumps of clay deliberately added to the charge (Allen 2009).

Tap-slag (Figures 13 and 14)

Tap-slag is one of the commonest, and certainly the most distinctive, of residues at iron-making sites and represents remains of the liquid residue that has been allowed to run from a tappable furnace (Tylecote 1986). At the Clearwell site it occurs as dark grey to black, dense, vesicular masses typified by finger-like flow markings chiefly on the upper surfaces exposed to the air, as described by Bayley *et al* (2001). The form of the masses varies from sheets a few centimetres thick (rare) to masses weighing up to many kilograms that chilled in hollows varying from shallow, saucer-shaped depressions (common) to deep, circular to oval basin-shaped pits (common). A few lumps of tap-slag have the appearance of a pile of dung, suggesting that a relatively narrow flow had become very viscous. The internal structure of the larger masses indicates that they consist of the slag from multiple smelts. Some of the masses preserve on the underside the moulds of tools used to dig the hollows into which the slag was directed (Allen 2009).

Slag pilules

Common at Clearwell are slag pilules. These vary considerably in size and shape but typically resemble distorted peanut shells. They have a number of possible origins. Some could represent drips of viscous slag at the exit from a furnace or around the rim of a slag pit. Others may be splashes of viscous slag. Probably most represent viscous slag that had dripped through the lower, cooler parts of the charge in a furnace.

Other forms of slag

Clearwell yields many fragments of slag which cannot with certainty be assigned a particular origin but which are compatible with iron-making. One very rare form is the basin-shaped furnace bottom, representing slag that had accumulated at the base of a non-tappable bowl furnace (Tylecote 1986). Much more common is fuel-ash slag. This is a comparatively light, scoriaceous, vesicular material that displays the moulds of straw and twigs and pieces of charcoal, and in some cases entraps the charcoal itself. Fuel-ash slag typically blends the fused mineral matter present in charcoal with a modest amount of iron slag.

Burnt clay

This kind of debris takes the form of hard, irregular particles, up to a few centimetres across, of pale grey/orange clay. A number of origins are possible: (1) pieces of clay dewatered by heating preparatory to being added to a furnace charge (Allen 2009), especially if found in ore-roasting pits; (2) fragments detached from the walls of ore-roasting pits; (3) debris from the demolition of furnaces; or (4) burnt daub from buildings.

Hammerscale

The bloomery process has a second stage in which the slag-contaminated bloom produced in the first stage is purified by forging out as much as possible of the slag (Sim 1998). A distinctive by-product of the forging is hammerscale, a variety of microscopic residues that represent slag forced out of, or off the surface of the bloom undergoing purification. These particles are a range of generally magnetic spheres, spheroids, scales and flakes of slag typically with a metallic to submetallic lustre (eg Fulford and Allen 1992). The only microscopic particles with a resemblance to hammerscale recovered from Clearwell Quarry are occasional slag spheroids with a dull lustre, found in a few of the very many wet-sieved residues provided. None match typical hammerscale and are most likely to represent splashes of tap-slag as it was released from the furnace and flowed over the ground to the accompaniment of the escape of gasses.

Metallic items

No metallic items were recorded from the Clearwell site.

Stone

Occasional small fragments and larger lumps of stone are present in the samples. These are of pale orange to pale pink, laminated, very fine to fine-grained, well-sorted, pure quartz sandstone similar to the local Drybrook Sandstone (Lower Carboniferous) that outcrops *c* 1.5 km to the north-east of the site (Welch and Trotter 1961; BGS 1974). As noted above, the site itself lies on the outcrop of the Lower Limestone Shales lying lower in the Carboniferous sequence.

GEOCHEMISTRY OF THE SLAGS

In order to gain insights into the comparative quality of Saxon bloomery iron-smelting at Clearwell Quarry, chemical analyses were made of samples of five representative slags, one from each of the large masses from 28/89 and 45/290 and three others randomly selected. Using appropriate international standards, this was done using a Phillips PW 1480 x-ray fluorescence spectrometer with a dual anode Sc/Mo 100Kv x-ray tube. Analysis for major and minor elements was carried out on fusion beads using a lithium tetraborate flux as dilutant, samples and flux having been dried overnight at 110° C. Trace elements were analysed on pressed powder pellets. Table 7 gives the overall raw results.

Table 7. Chemical composition, expressed as oxides (major and minor elements) and trace elements, of tap-slags from Clearwell Quarry.

	Sample (Cut/fill)	**Sample (Cut/fill)**	**Sample (Cut/fill)**	**Sample (Cut/fill)**	**Sample (Cut/fill)**
Oxide (wt. %)	28/89	45/290	19/166	22/170	24/164
Na_2O	0.54	0.54	0.92	0.50	0.34
MgO	0.60	0.28	1.07	0.42	1.11
Al_2O_3	2.69	1.55	4.22	1.46	2.60
SiO_2	25.71	13.81	23.18	7.71	16.79
P_2O_5	0.22	0.07	0.10	0.24	0.15
K_2O	1.35	0.51	1.63	0.56	1.01
CaO	1.68	0.40	0.90	0.86	1.59
TiO_2	0.20	0.14	0.28	0.10	0.18
MnO	0.12	0.12	0.11	0.14	0.14
Fe_2O_3	79.25	96.01	79.88	102.25	88.06
LOI*	-6.56	-7.40	-6.20	-7.52	-6.85
Total	112.35	113.45	112.19	114,23	111.9
Element (ppm)					
V	41	29	45	39	55
Cr	44	30	48	31	43
Co	43	49	36	56	46
Ni	-	-	-	-	-
Cu	40	51	48	54	40
Zn	6	14	6	10	7
Pb	19	-	-	-	14
Rb	28	16	41	-	25
Sr	43	17	39	26	42
Y	15	20	20	22	21
Zr	88	77	132	40	90

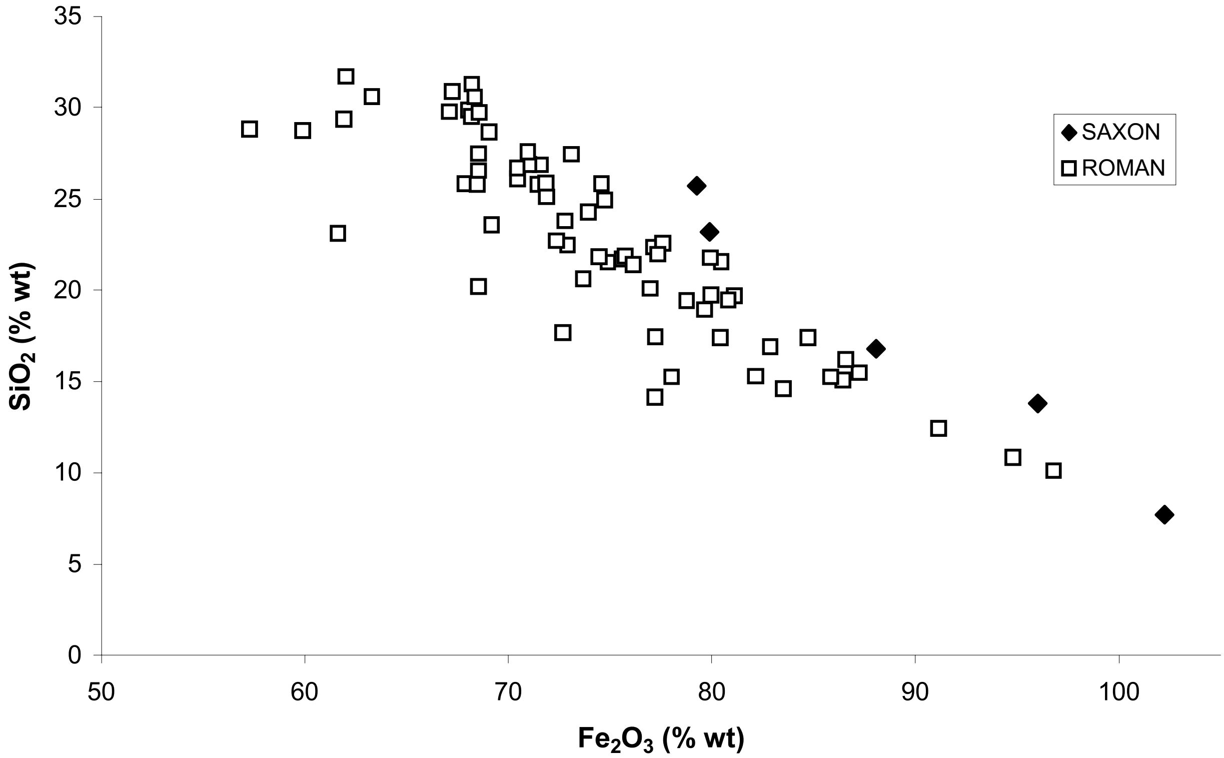

Figure 15. Chemical comparison (SiO_2 vs Fe_2O_3) of Saxon tap-slags from Clearwell Quarry with Romano-British tap-slags from the Severn Estuary Levels (Allen 2009, App. A).

The trace-element composition leaves no doubt that iron-making and not copper-smelting, which can yield superficially similar slags, was being practised at the site. Copper ranges from 40 to 54 ppm, zinc from 6 to 14 ppm, and lead up to 14 ppm, three slags yielding no detectable amounts of this element. The amount of strontium is low, ranging from 17 to 43 ppm with an average of 33 ppm, a strong indication that, although the site lies on the outcrop of the Carboniferous Limestone Series, limestones or dolomites are unlikely to have figured among the materials making up smelts.

The results of the major element analyses (Figure 15) clearly position the Clearwell process toward the chemically inefficient end of the bloomery process as compared to Romano-British practice using the same ores in tappable furnaces in the wider Forest of Dean (Allen 2009). The raw percentage of SiO_2 at Clearwell ranges from 7.71% to 25.71% (av. 17.44%) and of Fe_2O_3 from 79.25% to 102.25%. The proportion of Fe_2O_3 in Romano-British tap-slags varies from *c* 60% *to c* 95% and of SiO_2 from *c* 10% to over 30% (Allen 2009, App. A, fig 8). The Saxon slags are slightly more siliceous, in terms of the raw analyses, for a given content of iron oxide than the Romano-British examples (Figure 15). The Fe_2O_3/SiO_2 ratio at Clearwell averages 6.40 and stretches from 3.45 to 13.26; these values lie within the range for Romano-British tap-slags but occur toward the high end (Allen 2009, table 12).

The minor elements, especially when combined in ratios (Buccianti *et al* 2006), also point to a comparatively inefficient process in comparison with Romano-British practice. The total alkali/alumina ratio, $(Na_2O+K_2O)/Al_2O_3$, varies at Clearwell from 0.519 to 0.726 and averages 0.646, whereas most Romano-British tap-slags afford a much lower value, of order 0.4 (Allen 2009, fig 9). At Clearwell, the ratio of the alkali metals themselves – Na_2O/K_2O – is comparatively high, with an average of 0.651 at a range from 0.337 to 1.06 (Allen 2010, fig 1). In contrast, the great majority of Romano-British tap-slags take values for the ratio of less than 0.4. A third ratio of interest is that for total alkaline earths/alumina, $(CaO+MgO)/Al_2O_3$. However, this ratio at Clearwell, varying from 0.439 to 1.04 with an average of 0.734, is not substantially different from the Romano-British range of *c* 0.5–1.0 for most tap-slags (Allen 2009, fig 10). The difference is with Romano-British furnace bottoms, produced in non-tappable furnaces, for which the ratio mainly lies below 0.25.

Chemically, the Saxon tap-slags from Clearwell Quarry resemble Romano-British furnace bottoms more than they do the tap-slags, and the major-element composition definitely suggests a less effective process. If the Na_2O/K_2O ratio has been interpreted correctly (Allen 2010), the Saxon furnaces attained lower temperatures or were run for shorter periods than their Romano-British counterparts.

INTERPRETATION OF THE FURNACE AND SLAGS

The Clearwell Quarry site was unquestionably the location of a considerable level of iron-smelting, using the rich, mainly goethite, ores of the Forest of Dean (Sibly and Lloyd 1927; Trotter 1942), part of the wider Bristol Channel Orefield (Young and Thomas 1998). Iron has been smelted in the Forest of Dean and the surrounding area since Iron Age times, first by the bloomery batch process and later, from the 16th century onwards, by the continuous blast-furnace method. The major late Iron Age to Roman industry (Walters 1992; Allen 2009), and the equally important early modern to modern enterprise (Hart 1971; Meredith 2006), are fairly well known. What happened in early medieval times, however, is shadowy to say the least, but the important discovery at Clearwell Quarry begins to fill this gap.

The small amount of ore recovered from Clearwell points to the smelting of the rich ores - goethite and some haematite – of the Forest. Whereas goethite is a hydrous form of iron oxide, haematite includes no combined water. The character of the ores as recovered, and the abundance of chips of treated ore in the pits, suggests that beneficiation by roasting was practised prior to loading the furnaces. Roasting at a moderate temperature drove off the combined water from the hydrous ore and would have allowed a more efficient smelting.

Neither goethite nor haematite from the Forest of Dean contains any significant proportion of silicate minerals. The presence of these during smelting by the bloomery process is essential for the self-fluxing of the ore and the creation of a wustite-fayalite slag. It has been shown using geochemical calculations that the necessary silicate minerals were secured either by the melting of the furnace walls during smelting or by the addition of clay to the charge (Fulford and Allen 1992; Thomas and Young 1998a; 1999b; Allen 2009). The frequent presence of fragments of burnt clay in the Clearwell Quarry pits could be evidence for the practice of adding clay. It would have been advantageous to have dehydrated any clay that was to be added at the same time as the ore. The pits reported could therefore have served a dual purpose.

Charcoal appears to have been the carbon fuel used for smelting at Clearwell Quarry, judging by the frequency with which moulds of lumps occur on fragments of slag (see below). Coal, abounding in the Forest of Dean (Trotter 1942), is unsuitable for smelting because of the volatile content, but could have been used, along with straw and wood, to fire up furnaces.

The tap-slags occur in masses of up to many kilograms. A few of these are in the form of thin sheets, but most occur either as fragments from shallow, saucer-shaped masses or deep, basin-shaped lumps, the latter tending to be the heaviest. All show the characteristic flow structures. The range of forms suggests that more than one type of furnace was in use at Clearwell Quarry. The sheets, and perhaps also many of the saucer-shaped masses, suggest the use of shaft furnaces from which the slag could be tapped horizontally into a suitable depression to one side of the furnace. The deep, basin-shaped lumps weighing many kilograms are consistent with the employment of slag-pit furnaces, traditional from the Iron Age on the north-west European mainland, and therefore not unexpected on a Saxon site. In these the slag is allowed at the end of each smelt to fall for some decimetres into a hollow beneath the furnace, presumably after the bottom of the furnace had been broken through. The slag does not chill in contact with the charge (*cf* bowl furnace yielding furnace bottoms). In addition to the form of the larger masses, two other features of the slags are consistent with the uses of slag-pit furnaces: the abundance of slag pilules (drips of viscous material) and the presence of some dung-like slag accumulations (viscous slag that dripped for some time onto the same spot). Both shaft furnaces and slag-pit furnaces can in principle be relined, but there is as yet no direct evidence of furnace relining at Clearwell Quarry.

It is interesting to note that, despite the very large quantities of smelting slag recovered, there is no convincing hammerscale at Clearwell that would indicate that blooms were being converted at the site into billets of useable metal. The local tradition could therefore have been to sell blooms on from smelting sites, to be purified elsewhere. In the time of King Edward it was blooms that were rendered from Alvington, although (refined) iron in the form of rods for the making of ship-fastenings was provided by Gloucester, plausibly from a source in the Forest (Williams and Martin 2002, 445; 512).

Evidence for Saxon iron-making in Britain is rare. In contrast to the tappable furnaces used at Clearwell Quarry, those reported from Ramsbury, Wiltshire (Haslam 1980), Milbrook, Ashdown Forest (Tebbutt 1982), and Burlescombe, Devon (Reed *et al* 2006) were non-tappable types. The operation at Clearwell may therefore reprsesent a technological step up from what was practised regionally. The Burlescombe site lies in the Blackdown Hills, where there is extensive evidence for iron-making from the Roman period onwards.

PRODUCTIVITY

It is impossible to arrive at a firm view of the maximum productivity of the furnaces at Clearwell Quarry. Experiments teach, however, that the yield of the bloomery process is poor, perhaps only 10-20% of the iron in the ore being recoverable in metallic form, the remainder going into the slag (Tylecote 1986). The *c* 130 kg of slag excavated at the site from an identified total of 30 furnaces may therefore represent a *minimum* production of no more than tens of kilograms of metallic iron from a quantity of goethite ore comparable to the slag in weight. At least a similar weight of charcoal would have been needed to smelt this amount of ore. The non-ferruginous components of the slags are likely to have come from a number of sources: the mineral ash in the charcoal, the linings of the furnaces, and fragments of baked clay, recorded from many of the pits, which could have been deliberately added to the charges. Production could have been much higher than the quantity of recovered slag would seem to suggest, given that it was the practice, once the blast furnace arrived in the Forest of Dean, to mine bloomery slag dumps for what amounted chemically to ore (Meredith 2006). The number of potentially re-usable furnaces identified certainly suggests a substantial rate of production, with implications for the woodland resource needed to sustain it.

WOOD CHARCOAL

Sixty samples were taken during the excavations at Clearwell Quarry for the recovery of charred plant remains and charcoal and processed at Thames Valley Archaeological Services. The majority of the samples came from the mid-Saxon (*c* AD 763–878) furnaces and related deposits in pits, and rare gullies/hollows. The aim for the charcoal analysis was to examine the fuel used for smelting. An initial rapid assessment of the charcoal revealed that preservation was variable, with some samples producing few identifiable fragments of >2 mm in size and some very rich assemblages coming from the pits. A selection of 15 furnaces and pits form the focus of this report (Tables 8 and 9), although the rapid assessment results from others may be alluded to.

Methodology

The rapid assessment of the material revealed that many of the samples contained predominantly one taxon. Examination of 50 or more fragments from these samples might add the odd additional species to the list, but would not significantly alter the understanding of the assemblage composition. For this reason, the following methodology was adopted. The sample was scanned under a binocular microscope at up to X45 magnification and a selection of charcoal fragments were examined in transverse section only, with twenty fragments confirmed at high magnification. An estimate of the abundance of each taxon was made. The maturity of the wood was noted where possible and the presence of roundwood, sapwood and heartwood is noted in the tables. Identifications were made with reference to Schweingruber (1990), Hather (2000) and modern reference material. Full quantities are recorded in the archive. Classification and nomenclature follow Stace (1997).

Results

The results are presented in Tables 8 and 9. The preservation was generally good, although some charcoals were infused with sediment which obscures anatomical characteristics, or very soft, which inhibited fracturing. Eight taxa were positively identified; these are listed below with notes on identification.

FAGACEAE: *Quercus* spp., oak, large tree, two native species, not distinguishable anatomically.

BETULACEAE: *Betula* spp. (birch), trees or shrubs, two native species, not distinguishable anatomically.

Corylus avellana L. hazel, shrub or small tree, only native species.

SALICACEAE: the genera *Salix* spp. (willow) and *Populus* spp. (poplar) are rarely possible to separate. Both are trees although there is variation within the genera.

ROSACEAE: *Prunus avium* L., wild cherry, tree or shrub, native. *P. avium* was distinguished from other *Prunus* species on its narrower ray widths.

MALOIDEA: subfamily of various shrubs/small trees including several genera, *Pyrus* (pear), *Malus* (apple), *Sorbus* (rowan/service/whitebeam) and *Crataegus* (hawthorn), which are rarely distinguishable by anatomical characteristics.

ACERACEAE: *Acer campestre* L. field maple, tree, sole native species. The presence of *A. campestre* was also confirmed by ray width.

OLEACEAE: *Fraxinus excelsior* L. ash, tree, sole native species.

It was not always possible to determine the maturity of the charcoal, but tyloses, indicating heartwood, were noted in many of the oak fragments. Sapwood tends to be under-represented since its identification in fragmented pieces is based upon the absence of tyloses, a somewhat unreliable characteristic. Fragments of

Table 8: Results of the charcoal analysis from furnaces: X=dominant; x=present; r=roundwood; s=sapwood; h=heartwood.

	Feature	17	21	33	42	42	45	45	115
	Context	72	159	155	185	187	288	290	296
	Sample	9	26	25	35	36	53	55	51
Quercus spp.	oak	x	Xhs	Xh	Xh	x	Xhr		Xh
Betula spp.	birch	x					x	Xr	
Corylus avellana L.	hazel			xr					
Populus/Salix	poplar/willow	x							
Prunus avium L.	wild cherry				x	Xr			
Maloideae	hawthorn group	x					x		

Table 9: Results of the charcoal analysis from pits: X=dominant; x=present; r=roundwood; s=sapwood; h=heartwood.

	Feature	18	25	31	34	36	38	118
	Context	91	85	96	158	162	168	354
	Sample	18	17	22	23	27	32	59
Quercus spp.	oak	X	xr	Xh	Xr		xr	
Betula spp.	birch		xr					
Corylus avellana L.	hazel			x				xr
Maloideae	hawthorn group	x	xr	x	xr			xr
Acer campestre L.	field maple		xr					xr
Fraxinus excelsior L.	ash		xr			Xhsr	Xr	

roundwood (based upon ring curvature) were noted in many samples, but complete stems were rare. In the absence of pith or cambial surface, it is not possible to determine reliable age data, so comments on the maturity of the wood or the possibility of woodland management are based upon the likely derivation of the material. With the exception of two samples, the assemblages were characterized by mixed trunk and branchwood.

With the exception of number 17, all of the furnace assemblages were dominated by a single taxon. In most cases, this taxon was *Quercus* sp. (oak), and included some mature heartwood. Two furnaces, 42 and 45, produced the best preserved charcoal, with notably different assemblages from two deposits within each feature. In 42, context 187 was dominated by *Prunus avium* (wild cherry), while 185 was mainly oak, and in 45, context 290 was dominated by *Betula* sp. (birch) roundwood, with oak predominating in the fill 288. Interestingly, another fill from furnace 45 (287) produced a more mixed assemblage, including oak, birch and Maloideae (hawthorn group). The charcoal from furnace 17 was more diverse in character than the other samples, producing four taxa, *Quercus* sp, (oak), *Betula* sp. (birch), *Populus/Salix* (poplar/willow) and Maloideae (hawthorn group). There was no clearly dominant component to the assemblage. Furnace 17 was found in a cluster of features in the southern part of the excavation area, distinct from the other groups of furnaces under discussion (Figure 3). No other samples from this area merited full analysis, although the assessment revealed that furnace 10 contained *Quercus* sp. (oak), furnace 11 contained *Fraxinus excelsior* (ash) and *Populus/Salix* (poplar/willow), and furnace 14 produced *Quercus* sp. and *Alnus/Corylus* (alder/hazel). There was too little charcoal to determine the relative abundance of each taxa.

The pit assemblages tended to be richer, as might be expected from deliberate deposits of spent fuel wood and some were more mixed in species composition than the furnace samples. Three of the deposits were dominated by oak, while two were dominated by *Fraxinus excelsior* (ash). Pits 25 and 118 produced mixed assemblages of several taxa, including birch, hazel and hawthorn group, most of which came from small diameter roundwood. In addition to the taxa already mentioned, *Acer campestre* (field maple) was recovered from these two pits.

Discussion

The samples recovered from Clearwell Quarry fall into two probable categories of deposit formation; the furnace charcoal representing the final *in situ* firing, (although those with successive charcoal-rich fills might represent later dumping of material as well), and the pit samples comprising redeposited fired debris. The fact that many of the furnace samples were so poor in charcoal (only 6 out of 29 merited analysis) indicates that the features were generally cleaned of material after firings. Although two different types of furnaces were identified at the site, there seems to be no correlation with the charcoals.

Until the 18th century, when the use of coke became common, charcoal was the fuel generally used for iron-smelting (Goffer 2007, 174), firstly because it provides a high heat and, secondly, because it produces less smoke than wood fuel. Archaeological fuel residues associated with iron working tend to be dominated by oak, which makes a good charcoal fuel (Edlin 1949). Oak forms the chief component of the fuel at Clearwell Quarry, being present in 12 out of the 15 analysed samples, but there is clearly some variation in the wood types used. According to Rackham (2006, 203), the species of wood used for conversion to charcoal is not always significant, although there are differences in the yields from different taxa. It is possible that this affected the quantity of charcoal used in the furnaces, contributing to the comparative inefficiency of the smelting at Clearwell (see above). Charcoal production usually utilizes young branch type wood, as this is easy to collect, does not require laborious chopping and reserves large trees for timber. Coppiced underwood would also have provided a ready and easy supply, and although there is no direct evidence to substantiate this at Clearwell Quarry, the use of coppiced wood is indicated at Roman-British sites in the area, where a larger number of taxa also tends to be recorded (Allen 2009, table 4). The preservation at Clearwell did not extend to the larger roundwood pieces recovered at other sites, but there is a fair quantity of oak heartwood, which indicates either a long coppicing cycle (20 years+) or the use of a mature

Table 10. Radiocarbon dates.

Lab No.	Furnace/sample/fill	Depth (m)	Age (BP)	Age range	
				1σ (68.3%)	2σ (95.4%)
KIA-38910	33, 25, 155	0.30	1213±31	775-870	693-748 (15.3%) 765-890 (80.1%)
KIA-38911	42, 36, 187	0.20	1215±33	773-875	691-750 (18.1%) 763-890 (77.3%)
KIA-38912	11, 44, 268	0.15	1231±24	714-745 (21.9%) 767-783 (13.0%) 787-822 (23.2%) 842-861 (10.2%)	691-750 (31.5%) 763-878 (63.9%)

timber tree. To avoid unnecessary transportation, charcoal was usually made in the woodlands whence the wood was collected, and located near to any industrial activity.

The plentiful supply of fuel resources in the Forest of Dean had been exploited during Roman times and the area was one of the foremost iron-working centres in Britain in the medieval period (Meredith 2006; Rackham 2006). By the 13th century measures were taken to protect the woodland from the prolific charcoal-production and iron-working industries (Currie *et al* 1996). To what extent the large-scale medieval iron-working industry at Dean had its roots in the Anglo-Saxon period is unclear, since there is at present little archaeological or documentary evidence. This in itself might suggest a smaller-scale industry in this period, compared with both Romano-British and later periods. The procurement of fuel for smelting on a large scale at least would have required woodland management, and it is likely that some form of management was practised throughout the 8th and 9th centuries. The charcoals from Clearwell are consistent with the use of oak, and secondary woodland species such as hazel and birch, which were noted at Roman sites in the area (eg Figueiral 1992; Allen 2009), although it appears that more mature wood was used. There is no evidence for the use of beech which would have grown in the limestone valley of the River Wye, although the willow/poplar would have favoured damp/riverine conditions.

In conclusion, the analysis of the charcoals at Clearwell Quarry shows that oak, along with some other taxa such as birch, wild cherry and ash, were used for fuel in the furnaces. The taxa are consistent with the mixed wood pasture of the Forest of Dean, with classic secondary woodland species. Some mature trunkwood as well as younger branchwood was used, but the condition of the material did not allow for examination of management practices. While there are Roman comparanda and medieval evidence, the site provides an important record for the Anglo-Saxon period, which is not generally well represented in charcoal analyses (Smith 2002).

RADIOCARBON DATING

Three samples of wood charcoal were submitted to the University of Kiel (Germany) for radiocarbon dating. Details of methodology and assessment of the reliability of the results are held in archive. In summary, all three produced results that are closely comparable and considered to be reliable. Calibrations use CALIB rev. 5.01 and data set Int Cal 04 (Reimer *et al* 2004). The three results are summarised in Table 10.

POTTERY
(Paul Blinkhorn)

The pottery assemblage comprised just eleven sherds with a total weight of 202 g (Table 11). Where possible, the fabrics were cross-referenced to the classification system for the pottery industries of the Severn Valley (Vince 1984). The following fabric types were noted:

Gloucester TF41B: Saxo-Norman Oolitic limestone ware, 11th–12th century. 2 sherds, 4 g.

Hereford Fabric A7b (Herefordshire glazed fine micaceous ware). 13th–16th century. Usually oxidized red with an oxidized exterior. Very sparse rounded quartz grains, generally less than 0.3 mm. Rare red or black micaceous sandstone fragments and rounded brown clay pellets, 1.0 mm to 3.0 mm. Painted white or brown slip under

Table 11. Pottery occurrence by number and weight (in g) of sherds per context by fabric type.

		SHL		*T41B*		*A7b*		*SMW*	
Cut	*Deposit*	*No*	*Wt*	*No*	*Wt*	*No*	*Wt*	*No*	*Wt*
	Mound 1			1	3				
1	52			1	1				
2	54					6	31		
38	168	1	1						
	Total	1	1	2	4	6	31	2	167

a clear glaze. One kiln known, at Weobley, Herefordshire. Similar wares are common over much of Herefordshire and northern Gwent. 6 sherds, 32 g.

Staffordshire Manganese Mottled Ware (SMW). Late 17th–18th century. Hard buff fabric with distinctive purplish-brown mottled glaze. Usually fine drinking pottery, but chamber pots and other more utilitarian vessels also known. 2 sherds, 167 g.

Unidentified Shelly Ware (SHL). A single crumb of ceramic material weighing less than one gram was recovered from context 168. It is in a shelly fabric, and is impossible to identify with confidence. It has been given an extremely tentative Roman date, but could conceivably date to any time between the Iron Age and the medieval periods.

The sherd classified as fabric T41B from the subsoil in Mound 1 is extremely abraded, with the inclusions entirely leached out. The date assigned to this is also tentative, and it could easily be a century or more earlier than the given date. The sherds of A7b are all from a single jug with vertical white slip stripes under a clear glaze which shows up as dark green on the body clay, a typical product of the industry. These are also slightly abraded.

STRUCK FLINT
(Steve Ford)

Just eight struck flints were recovered. These comprised two blades, two flakes, a spall (a piece less than 20x20 mm) and three flake cores. All pieces were unstratified, except the spall, which was recovered from pit 36 during sieving. A blade, a flake and a core were patinated but otherwise the pieces were in good condition. One of the cores is quite small and is made from a pebble suggesting a drift deposit origin. The large patinated blade, though, may have been made from a nodule direct from a chalk source. The two blades are large and well made and are likely to be of Mesolithic or Neolithic date, whereas the remaining pieces have no distinctive chronological attributes.

BURNT BONE
(Ceri Falys)

A small amount of burnt bone (just 6 g) was recovered from pit 118 (354). The preservation was poor and all pieces demonstrated a fully oxidized blue-white colour. The fragment size was small, with a maximum measurement of 15 mm, and did not permit any species or skeletal element identification. It is probably animal rather than human but even this is unclear.

DISCUSSION

The fieldwork has confirmed low intensity use of the area during the Mesolithic and Neolithic attested to by discovery of worked flints. No prehistoric cut features were recorded and the flints were probably accidental losses during hunting activities in this riparian environment.

Of much greater significance, regionally and nationally, is the discovery of iron-smelting unequivocally dated to the late 8th or 9th centuries AD. While only three of the 30 securely identified furnaces have been dated, this includes one from each 'cluster', and the similarity of the radiocarbon dates (Table 10), the features and the processes strongly suggests that they do not represent more than one period of use. Although the ranges for the calibrated radiocarbon dates are wide (AD 763–890 for the most likely dates, and wider still for the full range of possibilities) the raw determinations all come within a generation of one another, and a shortened timescale seems likely on all grounds, as smelting at all times until the introduction of the blast furnace would have been a partly mobile, probably seasonally shifting, process. In all probability, each 'cluster' represents one season's work, and the three could all have been created in three years, or perhaps represent three visits to the same resource over the course of, say, ten or fifteen years. There is so far no evidence of a Saxon settlement at or near the Clearwell Quarry site.

While Saxon iron-production in the area has always been assumed, there has been no previous archaeological evidence for it, and indeed evidence of Saxon iron-working in general is very rare across the West Country and Wessex, with just Ramsbury to cite from the literature (Haslam 1980). A search of the British and Irish Archaeological Bibliography, the Archaeology Data Service (ADS) database of radiocarbon dates, and the ADS 'grey literature' database suggested no other securely dated metal-working sites of the period in these regions, and just two very tentative examples of sites in Wiltshire (Tidworth and Collingbourne Ducis) producing tiny quantities of slag amongst Saxon rubbish deposits, with no real evidence of production (Godden *et al 2*000; Pine 2001). There is only a little more evidence for this period from Somerset, Dorset and Devon (summarized by Webster 2007, 172; see also references cited above).

The features excavated at Clearwell include what appear to be charcoal clamps and ore-roasting pits as well as the furnaces themselves, showing that the work was organized within a small space, from producing the fuel to the bloom. The features interpreted as quarry pits here all appear to be later, but it can probably be assumed that the ore was mined, or at least collected, very locally too. Clearly, charcoal was being produced from whatever wood was to hand, and mostly branch wood, reserving felling trees for structural use.

It is also worth highlighting that without the radiocarbon dating, there was not the slightest evidence for the Saxon date of this activity (although possibly the lack of finds itself might have hinted at a Saxon date?). The sparse ceramic evidence, such as it is, would not have been taken as providing anything like a reliable date, and all came from the quarry pits, but might have suggested this was primarily a medieval site. The value of, and need for, routine radiocarbon dating is once again emphasized by these results: according to a recent review there were only five Saxon radiocarbon determinations from the whole of Gloucestershire (Webster 2007, table 8.1). The results from Clearwell Quarry should stimulate a search for more evidence of early medieval iron-making sites in the region.

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