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Archaeometallurgical residues from Hartshill Copse (HCB01)

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Abstract

The archaeometallurgical residue assemblage from HCB01 comprised 82kg of macroscopic residue, including a 33.9kg in-situ 'furnace bottom' from furnace [3525], together with 67 samples sieved for microresidues. The residues were from both iron smelting and iron smithing. Most of the ironworking was Iron Age; a small quantity of blacksmithing residue was probably of Roman and medieval date, but no specific foci were identified for these later periods.

The programme of analysis proposed by the assessment in 2005 had to be amended, as the in-situ furnace bottom has been mislaid. Instead, elemental analysis was undertaken on two smelting slag samples from the base of the furnace pit [3525] that had contained the in-situ furnace bottom (and which were probably fragments from it) and on two smithing slag samples from a pit [2630] 140m to the east. This fresh analysis has been supplemented by a re-examination of the previously published evidence from the adjoining HCB03 area.

The two adjacent furnaces [3525] and [3579] are interpreted as bottle-shaped, non-slag tapping furnaces, with wide arches and ramps into the basal pit, which was packed with wood prior to use. They bear close comparison with examples of the 4th century BC, both from the local area (Fleethill Farm) and from Cornwall (Tregurra, Truro). Their only direct dating evidence is a 12th-13th century BC ^{14}C date from Furnace [3525], the significance of which is discussed, but which has no direct bearing on the age of the furnace. Other fills within the same cluster of features produced ^{14}C dates with a range from the mid-6th century BC into the beginning of the 4th century. A broadly 5th century BC date would correspond approximately with that of the Phase 3 enclosure, with its evidence for iron production, in the HCB03 area. The site appears, therefore, to extend the range of these substantial arched furnaces back into the later part of the Early Iron Age.

The elemental analyses of the smelting slags showed they were similar to those recorded from HCB03, indicating exploitation of a similar, if not the same, resource. This was probably a bog iron ore with a moderate manganese content and with a much lower phosphorus content than the ores exploited further east in the Wokingham region. Significant differences in trace element content also separate the slags from those of that eastern area. Thus, the Hartsthill smelting should not be considered as a part of the so-called 'Tertiary sands area'; instead, compositional affinities of the assemblage lie with slags from sites associated with river valleys (most particularly those with significant peat deposits) from across central southern England. It is likely that ores were extracted from the Kennet floodplain.

Microresidues from smithing were recovered sporadically across the site, with a major concentration immediately east of the smelting furnaces, and a lesser one approximately 140m of the furnaces, where pit [2630] contained an assemblage of smithing hearth cakes (SHCs). Analysis indicates that these SHCs derived from bloomsmithing associated with the smelting. No smithing hearths were identified during excavation and it is argued that several 'cryptic' smithing sites may be present.

It is suggested that further consideration should be given to the possibility that the previously published occurrence of hammerscale within late Bronze Age features (Phase 2 of HCB03) of the southern part of the site is due to downward movement of scale by worm action from one of these 'cryptic' smithing areas. Such an area might be associated with the nearby evidence for smelting in the area of the northern part of the HCB03 Phase 3 enclosure. This was dismissed during the earlier work, but it is suggested here as no less implausible than the published 10th century BC date for the smithing.

The project has thus confirmed that the use of large arched furnaces started as early as the late Early Iron Age, has showed the use a distinctive ore source, probably from the Kennet floodplain (and thereby strengthening the identification of an under-appreciated group of iron resources in the river valleys of the region), has suggested the use of old wood in the slagpit packing, and provided further evidence to suggest that a re-evaluation of the results of the HCB03 excavations is required.

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Methods

Project rationale and history

The material described here derives from excavations at Hartshill Copse, Upper Bucklebury, Berks., conducted by Cotswold Archaeological Trust (CAT), under site code HCB01, in 2001. The residues were not assessed until 2005 (Young 2005). The catalogue from the assessment is included, with minor amendment, in Appendix 1 of this report.

The assessment recommended a very detailed investigation of the in-situ block of furnace slag ('furnace bottom') from furnace [3525] (context (3549 find 228), together with a less detailed investigation of slags and microresidues from other contexts.

Between the excavation and the assessment of HCB01, the southern part of the site had been excavated by CAT, with site code HCB03. The archaeometallurgical material from those excavations was assessed (Young 2003) and analysed (Young 2004), before being published (Young 2006b).

Responsibility for post-excavation work on site HCB01 was subsequently transferred to TVAS.

In the fifteen years since the material was originally assessed, understanding of the residues from non-tapping ('slagpit') furnaces has improved enormously. Unfortunately, the principal item and focus of the proposed analysis phase work, the furnace bottom from [3525] (the only part of the archaeometallurgical collection not transferred to GeoArch in 2005), now appears lost. The remaining material was re-examined and the catalogue updated where required (Appendix A). A less ambitious programme of analysis has therefore had to be undertaken, involving elemental analysis of a two examples of iron smelting slags from the lower part of the same furnace ([3525]} and two of iron smithing slags (from the fill (2631) of pit 140m to the east) to improve characterisation of the residues. The samples are numbered HCB01-1 to HCB01-4 in this report.

In addition, the previously-published analyses of five samples of slag (HCB03-9 to HCB03-13), one sample of microresidue probably from iron smelting slag (HCB03-6) and 2 bulk analyses of smithing microresidue assemblages (HCB03-7 to HCB03-8) from HCB03 have been reconsidered and integrated with the new data. These old data are of poor quality, but are useful for comparison with the new analyses.

This project was commissioned by Steve Preston of TVAS. The analysis was undertaken in August/September 2020.

Analytical methods

The four selected samples (Table 1) were slabbed on a diamond saw and subsamples taken for crushing for preparation of a whole-sample elemental analysis.

Bulk elemental analysis was undertaken using two techniques. The major and minor elements (Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, P and S) were determined on a fused bead using wavelength-dispersive X-Ray-fluorescence (WD-XRF). Whole-specimen chemical analysis for thirty-six trace elements (Be, 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, Th, and U) were undertaken using a sample in solution by Inductively-coupled Plasma Mass Spectrometry (ICP-MS).

For XRF analysis, samples were ground using a tungsten carbide shatter mill, dried at 105 C overnight and then 0.5 g was mixed with 6.5g of 50:50 LiT/LiM flux and fused to produce a glass disk using a Claisse M4 Fluxy automatic fused disk maker. The samples were analysed using a Bruker S4 WDXRF using the default wavelengths for the elements identified. Calibration was via a selection of iron slag reference materials and geological reference materials. Both XRF and ICP-MS analyses were commissioned from ChemoStrat Ltd (Welshpool, UK).

Samples for ICPMS analysis were drawn from a second aliquot of the powdered material to establish trace element using the alkali fusion method (Jarvis & Jarvis 1992a and 1992b; Pearce *et al*. 1999). Once prepared, the samples were then all subjected to ICP-MS analysis using a Thermo Scientific XSERIES 2. Data quality was strictly monitored in terms of precision and accuracy by five international rock standards of known concentration and varying compositions which are run after every 20 unknown samples. In addition, external monitoring of data quality is carried out four times a year via the GeoPt round robin proficiency testing program (http://www.geoanalyst.org/overview.html).

The results of the chemical analyses are presented in Tables 2, 3 and 4 of this report.

For the smelting residues, HCB01-1 and HCB01-2, the analytical totals are too high (approximately 105% including the LOI). Comparison between the measured total and the modelled total suggests that measured loss on ignition (in fact a gain on ignition) was too low and that the samples were probably incompletely ignited. Even if the LOI figures are adjusted to the theoretical gain of all the iron as FeII oxidised to FeIII, the total is still slightly too high at approximately 102%. For the smithing residues, the analytical totals appear satisfactory.

For the previously-reported analyses of samples from HCB-03, elemental analyses were undertaken in 2004 by the laboratories of the School of Earth, Ocean and Planetary Science, Cardiff University. Major element analysis was undertaken using induction-coupled plasma optical emission spectrometry (ICP-OES) rather than by GeoArch's usual approach of WD-XRF, and trace elements by induction-coupled plasma mass spectrometry (ICP-MS). Unfortunately, the ICP-OES system was not able to measure silicon in the samples, and for some samples rich in magnetite the acid dissolution was incomplete. These issues led to some very poor-quality analyses. Analytical totals for the hammerscale samples, in particular, were very poor. For other, macroscopic, samples, the determinations are broadly in line with the recent HCB01 analyses, although the data for Na_2O, Zr and Pb are not. The determinations for La are of uncertain quality and absent for several samples.

Thus, with minor reservation, data quality for the major element analyses of samples from HCB-01 is acceptable (with adjustment to the LOI). Trace element analyses for both the HCB-01 and the earlier (2004) HCB-03 samples appear to be of good quality.

Archaeometallurgical background

The 'Tertiary Sands' iron production area
Early iron smelting has now been documented at many localities within and around the area of outcrop of the 'Tertiary sands', to the south of Thames in the western part of the London Basin (an area straddling a large part of southern Berkshire and some adjacent areas). This area was flagged as a potential iron source by Salter & Ehrenreich (1984), largely on the basis of the Brooklands site (Hanworth and Tomalin 1977) , who suggested this as one of the earliest sites known. The analyses of slags from the area were clustered by Paynter (2006) as the 'Surrey and Hampshire Tertiary Sands' group.

Four clusters of sites have been identified (Hardy & Young 2019; Young 2016b, 2018a) within the region (Figure 1):

- a western cluster, including Hartshill Copse (Collard *et al*. 2006; Young 2004, 2005) and sites at Coopers Farm and Dunston Park (Fitzpatrick *et al*. 1995; Fitzpatrick 2011), just 1.2km to the west and 1km to the south
- a cluster in the area south and west of Wokingam, including Fleet Hill Farm (Hardy & Young 2019, Young 2016b) , along with sites at Heckfield (Dungworth 2007), Baird Road, Arborfield (Hammond, 2011), Whitehall brickworks (Pine 2003), Three Mile Cross (Ford *et al*. 2013), Manor Farm (Platt 2013), Folly Court, Wokingham (Young 2018a) and Sadler's End (Lewis *et al*. 2013) and possibly Risely (McDonnell 1984),
- a third cluster in the Surrey Heath area, including sites at West End, Bagshot Village, one at Ashleigh Farm, Windlesham, another at Windlesham Arboretum and a large site at Lightwater (*http://heathhist.pbworks.com/ ArchaeologyIronAge, http://www.chobham.info/ashleigh_farm.htm*),
- and a fourth cluster lies in the Staines/Weybridge area, with published sites at Brooklands (Hanworth and Tomalin 1977) and Thorpe Lea (Starley 1998).

The locations of the sites within the eastern three groups correspond closely to the outcrop of the geological horizons identified by Barrott *et al*. (2014) as associated with iron-rich springs in their study of the central part of the area. They demonstrated that iron-rich waters issue from springs located at the base of the Bagshot Sands Formation (the lower part of the Bracklesham Group) where it overlies the impermeable London Clay (and also locally from spring-lines arising on boundaries higher in the geological succession). The iron is released by weathering of iron-bearing minerals within the sands, carried in solution and precipitated when the groundwaters oxidise. The precipitated iron minerals formed what might be termed bog iron ores, for ease of classification, although the host medium may well have been floodplain and other alluvial sediments rather than bogs.

The sites of the western cluster, including Hartshill Copse, do not, however, lie on the same spring-lines. The site of Hartshill Copse lies on gravels of Quaternary age (Bucklebury Common Gravel Member, a pre- or Early Anglian terrace deposit; Gibbard 1982), which in turn lie unconformably upon sands within the London Clay Formation. If the ore being smelted at Hartshill was local, then it cannot have shared the same geological origin as the ores from the eastern sites. This is discussed further below

Early to Middle Iron Age iron smelting
Recent years have seen great advancements in the understanding of iron smelting during the Iron Age. Many examples of Iron Age smelting sites are now known and there is a growing number of well-investigated furnaces.

The evidence now suggests that, certainly by the middle Iron Age and possibly earlier, a spectrum of furnace morphologies was in use ranging from small, probably cylindrical forms (as seen for instance in Crawcwellt, Crew 1998), through medium sized furnaces (such as those at Fleethill Farm (Hardy & Young 2019, Young 2016b) , Tregurra (Young 2016c), and probably the peripheral furnaces at both Folly Court (Young 2018a) and Sadler's End (Lewis *et al.* 2013), to large furnaces (probably with a dome-like form) such as those at Tolgarrick Farm (Young 2016a), Folly Court (Young 2018a) and Sadler's End (Lewis *et al.* 2013).

The sites of Fleethill Farm, Tolgarrick Farm, Tregurra, Folly Court and Sadler's End provide good evidence for the morphology of the larger furnaces of the Middle Iron Age. They were rather flat-floored, sunken-bottomed, furnaces, presumably with a so-called 'domed', bottle-shaped or 'cupola' superstructure and a wide furnace mouth. Indeed, this description also matches the available evidence for the apparently Early Iron Age furnace at Messingham (Clarke 2015). Other Middle Iron Age sites, including those at Folly Court and Sadler's End, appear to also provide evidence for narrow furnaces, with simple basal pits, producing little or no evidence for a frontal arch at the level of truncation. The detailed morphology of these smaller furnaces is currently, however, less well understood.

The residues suggest that whatever the size and morphology, there was a single underlying technology. None of these furnaces was slag-tapping; instead the slag flowed down into a pit or hollow below the nascent bloom. This pit or hollow was filled with an organic material prior to smelting, but this acted not as a fuel but as a support to keep void space open and ready for the descending slag. The presence of the moulds of the pit packing probably also assisted in the breakage of the slag to facilitate its removal as the furnace was cleaned between smelts. In most cases, this pit-packing was wood, and in most of these the wood was apparently split oak. Some furnaces show evidence for some use of roundwood (in contrast to one form of Roman furnace in which small-diameter roundwood was commonly employed). The other, much rarer, type of packing was the use of cereals or grass, only currently known in the Berkshire region from Folly Court. Unlike the Iron Age furnaces of Denmark where detailed archaeobotanical study has been made of this type of packing (Mikkelsen 1997) there has been no such study on any Iron Age furnaces with grass/cereal packing in Britain. The term 'cereal packing' is used in this report in the lack of a more precise botanical identification of the packing material.

Evidence for iron production in the early Iron Age is limited and almost always associated with problematic dating evidence. The sites with arguably the best claims to show Early Iron Age smelting furnaces in southern Britain are Messingham (Clarke 2015) and Hartshill Copse (Collard *et al.* 2006).

The Messingham site is not fully published, so comment can only be made on the grey literature report. Furnace (215) is described as being 'horseshoe'-shaped in plan, 1.27m long and 1.00m

wide with the 'flat' end facing the slag mound (203) which is listed as yielding over 400kg of residue. Unidentified charcoal from the dump during the initial evaluation gave a date of 820-750 (87.5%)/690-660 (6.3%)/620-590 (1.6%) cal BC (SUERC-22401). However, better evidence may be from charcoal scraped from the internal furnace lining during excavation, which produced a date of 776-509 (95.1%)/498-494 (0.3%) cal. BC (SUERC-59289). If the material dated in these determinations was freshly cropped young fuel, then a date in the 6th-8th centuries BC seems indicated.

Hartshill Copse, the subject of this report, as well of an earlier investigation (Collard *et al.* 2006) has so far mainly been recognised as of significance because of the supposed early (10th century BC) date of some of the ironworking. However, investigation of the HCB03 area produced evidence for ironworking from two separate sets of contexts: firstly features associated with an enclosed settlement dated to the 5th-6th century BC and secondly from features forming part of an adjacent unenclosed settlement dated to the 9th-11th centuries BC (Figure 2). A reconsideration of the evidence forms the basis for the next section of this report.

The Hartshill HCB03 site reconsidered

A key importance of the sites at Hartshill and Cooper's Farm /Dunston Park, is that the ironworking (smelting and smithing at Hartshill, smithing only identified so far at Dunston Park) appears to be of a very early date. The activity has been dated to the sixth or seventh century BC at Cooper's Farm and Dunston Park (Fitzpatrick *et al.* 1995; Fitzpatrick 2011) and at Hartshill published as being in two phases, the first of the tenth century BC (Phase 2) and the second of approximately the fifth century BC (Phase 3). The extremely early date at Hartshill has been employed in recent narratives concerning the initial adoption of ironworking in Britain within what is conventionally considered the late Bronze Age. There are, however, considerable potential pitfalls with the interpretation of the Hartshill assemblage.

The most contentious issue with the previously-published work at Hartshill Copse, is that the metallurgical remains within the HCB03 Phase 2 contexts were entirely microresidues. Although 5690 fragments of hammerscale were recorded, they occur at only a maximum of 18.2 particles per litre of sample, with an overall average for the sampled Phase 2 features of just 3.1 particles per litre. The pit in Roundhouse D that produced the largest population of hammerscale (1196 counted particles), did so at an abundance of just 10.9 particles per litre of sample. These numbers are very low and well below the concentrations expected in primary metallurgical features, or indeed in features close to active smithing. Contrary to the conclusions of Collard *et al.* (2006), it would appear that an intrusive origin for these particles cannot easily be discounted. The complete absence of macroresidues is almost inexplicable, unless the materials are intrusive.

The mechanism for the intrusion of hammerscale would be the established behaviour of earthworms in moving particles within the soil. Bell's PhD thesis had demonstrated (Bell 1981. 83) that earthworms may carry particles of up to 5mm diameter to line their aestivation chambers and that in some species those chambers may be up to 2m below ground surface. This topic has also been taken up more extensively by Canti (2003, 142-143), who again notes the movement of particles of 2-6mm by worms to line their chambers for aestivation and that such particles may end up as 'pea-grit' on interfaces. This provides a simple mechanism for the removal of hammerscale from the surface, routinely to depths of 200mm, but in some circumstances to 2m. The situation of a light soil over free-draining gravel would be precisely that in which one might expect deep movement of worms in dry conditions, leading to accumulation of moved particles within the finer-grained, potentially damper and more organic-rich, fills of cut features.

The understanding of hammerscale has also evolved enormously in the last fifteen years. The interpretation offered in 2006 for differing ratios in the numbers of spheroidal and flake hammerscale particles leant heavily on previous work which had suggested a strong relationship between the production of spheroidal hammerscale and bloom compaction (e.g. Allen 1986). Improved understanding now recognises that spheroidal hammerscale is produced mainly when a quartz flux is employed during fire welding (also known as hammer or forge welding; Young 2011a, in review). The differential distribution of the two types of hammerscale within a smithy is also well understood, with spheroidal scale sprayed away from the anvil, but flake hammerscale falling close to it. Therefore, the differential distribution reported in 2006 could be reinterpreted (if it is a real distribution at all) as indicating patterns of dispersal around an anvil rather than by differing metallurgical processes, although an origin through selective movement of differently-shaped particles by earthworms cannot be excluded either..

The dating of HCB03 Phase 3 is pertinent to discussion of the present site and is thus also worthy of review. Bayliss *et al.* preferred to use the 1 sigma dates instead of the normal 2 sigma dates to argue a fifth century BC date for Phase 2, despite even the 1σ dates (i.e. only a 68% probability) merely placing the fifth century central a rather wider range of estimates: Roundhouse B being constructed 550-430 cal. BC and abandoned 390-320 cal. B.C. The accompanying pottery (Ceramic Phase 4) is described as 'All Cannings Cross/Meon Hill style' and assigned a 600 – 300BC date. Waddington *et al* (2019)., however, have argued for a much later inception of this style – somewhere between the mid-fifth and mid-fourth centuries. Two pits with small amounts of macroresidue were also dated, 'posthole' [322] to 550-360 cal. BC and pit [423] to 410-350 cal. B.C (74%) or 300-230 cal. BC (21%) (both standard 2σ dates). This suggests that HCB03 Phase 2 may be slightly younger than suggested (perhaps between late fifth and mid-fourth centuries BC).

In summary, the microresidues are indicative of forging of iron and welding (rather than necessarily iron production, as thought in 2006), the possibility of worm action introducing Iron Age hammerscale into Bronze Age cut features cannot easily be excluded and the apparently structured distribution of hammerscale within the various features could be as easily explained by a structured distribution of hammerscale on the surface (driven largely by distance from the anvil) as by distribution of activity within Bronze Age roundhouses. This is not say such worm action did occur, just that it cannot be lightly discounted, for it appears no less unlikely than a phase of ironworking of unexpected age leading to the deposition of no macroresidues whatsoever.

Results

General

The investigated assemblage comprised approximately 82kg of macroscopic residue, together with 67 samples sieved for microresidues. The residues (macro- and micro-) were from both iron smelting and iron smithing.

Of the macroscopic assemblage, 33.9kg was a single 'furnace bottom' from furnace [3525]. This was not transferred with the bulk of the collection for the assessment and its description in 2005 was based on brief inspection in the Cotswold Archaeology store. This key component of the assemblage was not available for inspection during the present work.

The remainder of the macro-residue assemblage has been re-examined (2020), but the account of the microresidues is based upon their description on 2005.

Distribution of residues

The distribution of residues across the site is illustrated in Figure 1.

94% of the assemblage by weight derived from just four features (including 6 contexts): pit [2630] (8.7kg), posthole [3163] (11.7kg), furnace [3525] (44.9kg) and furnace [3579] (11.8kg). No other context, out of the 36 contexts yielding macroscopic residues, produced more than 900g.

The contexts producing residues from iron smelting were localised within a concentrated cluster of features, including both the identified furnaces ([3525] and [3579]) and numerous postholes (including [3163]) and small pits. Samples processed for microresidues from the smelting area are dominated by fines from the smelting process (slag droplets, small slag flows, comminuted debris of other slags and furnace ceramic…), particularly contexts (3634) and (3635), the basal layers of furnaces [3535] and [3579] respectively. The deposits within the smelting furnaces yielded no hammerscale.

Pit [2630], which produced a significant assemblage of macroscopic residues from smithing, lay some 150m to the east of this. Apart from this pit, the very limited quantity of macro-residues from smithing showed no particular focus. Two pieces came from medieval contexts and one from a Roman-British context. Microresidues from smithing were widely encountered across the site (if in rather low density), with a focus on the area approximately 10m to the east of the smelting area (with a particularly rich assemblage from fill (3024) of pit [3023]).

Description of the furnaces

The two smelting furnaces were rather similar structures (Figure 2), but differed in history, furnace [3579] having been cleared of slag after its last smelt, but the slag cake ('furnace bottom') from the last smelt was left *in situ* in furnace [3525].

The cut for furnace [3525] was large, approximately 1m (axially) by 0.8m (width). The cut had a substantial clay lining. This is indicated on the plans as horseshoe-shaped in plan, approximately 180mm thick at the western end, 80-100mm thick to north and south, and not completely enclosing the eastern end. The working size of the furnace at the level of truncation was approximately pear-shaped, 450mm at its widest (approximately 400mm east of the western end of the cut) and 800mm long (reaching to the eastern end of the cut). The working pit depth is not certain from the recording but appears unlikely to have been more than 150mm below the truncation surface. The slag block ('furnace bottom' occupied the western part of this space and was 430mm wide at its maximum and 500mm in maximum length, with its upper surface having a semi-elliptical outline, with protruding flows at the eastern irregular termination.

The furnace can thus be interpreted as having a basal pit lined with clay (presumably to prevent collapse of the gravel substrate). The superstructure could be interpreted as an approximately 450-500mm internal diameter shaft with a 300mm -long expansion towards the arch, suggesting a somewhat bottle-shaped furnace.

The lower fill (3634) of this furnace produced a 14C date on charcoal of 1368-1359 cal. BC (0.7%) and 1286-1115 cal. BC (94.7%) (UBA-40581). The potential significance of a 12th-13th century BC date is discussed further below, but it has no direct bearing on the age of the furnace.

Furnace [3579] appears fractionally smaller than [3525]. The internal working dimensions at the level of truncation appear to have been approximately 430mm x 700mm and the primary constructional pit approximately 900mm by 750mm and 170mm deep. As with Furnace [3525] the eastern side appears to have been the furnace arch, but the clay lining to the pit appears slightly thicker to the north and south, than it does to the west.

Description of the iron smelting residues

The iron smelting residues from Hartshill are entirely typical of those from the British Iron Age.

The most significant assemblage is that which derives from Furnace [3525]. The large slag block in the basal pit of the furnace, of a type usually referred to as a 'furnace bottom', remained *in situ*. The block was asymmetrical, and layer within a furnace that was slightly elongate in an east-west direction. The slag block abutted the vitrified lining at the west end of the furnace, but the eastern end was unconstrained and apparently faced the furnace arch. The block as lifted (as sf <208>) apparently measured 380mm by 420mm, 130-150mm deep and weighed 33.9 kg (suggesting some loss to the block as it was prior to excavation). Some marginal fragments were removed separately, and these show the contact between the slag block and sloughed/melted furnace lining. The context overlying the slag block and between the slag and the arch (3549) was a dark silty deposit bearing lumps of orange flecks and lumps of fired clay, a typical furnace abandonment deposit.

The slag block itself was not available for detailed investigation.

Field records describe the context below the slag block and context (3549) as context (3634). This was interpreted simply as the fired clay lining of the basal pit, with small slag particles 'embedded' in its surface. It appears that compaction of the slag block onto the base of the pit had compressed the fine-grained

residues in the pit base into the lining. These fines included abundant isolated prills and spheroids of slag, together with a few fragments of residue of rusted appearance, containing abundant tiny charcoal moulds, small slag blebs and prills, together with small quantities of what may be sand-grade ore debris. The residues from (3634) also included some fragments of dense flow-slags, that had cooled to form moulds of the wood that been the pit-packing. These fragments presumably arose by fracture from the base of the main slag block, but there is insufficient detail in the field notes to exclude these being slag fragments from a previous smelt not part of the main slag block. Samples of slag from context (3634) were analysed as HCB01-1 and HCB01-2.

A similar furnace, [3579], lay 4m north of [3525]. This furnace had been cleared following its last smelt. Like furnace [3525], the fills comprised an abandonment deposit (3629) overlying what was described as the fired clay lining (3635). In fact, the residue assemblage from this contact suggests that some of the deposits of the basal pit survived. These included a very large block of amalgamated dense flow slag, with the moulds of wood fragments, probably split oak, of up to 120mm faces. A wide range of small fragments of flow slag were also recovered, together with rusty, porous residue, probably including sintered ore and ash. In total some 6kg of residues (excluding fired clay) were recovered.

The pit of this furnace also contained a large quantity of fired clay, almost all unvitrified, amongst which was a fragment of particularly strongly oxidised fired clay, slightly finer than the rest of the assemblage and with partial preservation of a smooth, but striated surfaced, void with a diameter of approximately 40mm. This is the sole potential fragment of a blowhole from the assemblage. 40mm is too large for the exit of a blowhole into the furnace, but this piece could be either from the passage of a thin-walled tuyère through the wall or perhaps a wider bore from the external part of a blowhole; alternatively, the piece might have been clay applied to a structural wicker former.

A third significant assemblage derived from the fill (3164) of a cut feature [3163] interpreted as a posthole lying 5m to the east of the furnaces. This produced approximately 11kg of slag, with representative material from all parts of a typical 'furnace bottom', including dense amalgamated flow slags with wood moulds, dense slags from the 'burr' region of the 'furnace bottom' (the zone of interaction of the hot slag with the furnace wall, in the area just below the blowhole), and porous, charcoal-rich, slags from the body of the slag mass.

The remainder of the site produced just approximately 1.8kg of residues identifiable as having been produced during iron smelting, all of which was similar to pieces recovered from the three principal features.

Description of smithing residues

Macroscopic slags identifiable as deriving from smithing are almost entirely examples of smithing hearth cakes (SHCs; typically plano-convex, but may be concavo-convex or bi-convex discrete slag masses that form in front of, and below, the blowhole in a smithing hearth).

The assemblage from pit [2630] includes seven SHCs, with a significant fragment of an eighth. The seven complete cakes have weights of 448g, 464g, 560g, 1075g, 1305g, 1920g and 2350g. The smithing microresidue assemblage from this context was not particularly abundant, so this appears to indicate some selective disposal of macroscopic slags, rather than a generalised smithy waste deposit.

The SHCs from pit [2630] shows a superficial layer of concretionary material (probably largely generated through the redistribution of iron following weathering of metallic iron inclusions with within the slag. This inhibits detailed external description. The broad morphology of the SHCs is diverse, with few little common features. The smallest well-formed SHC weighed 464g, measured 95x130x45mm, and was formed of loosely amalgamated large lobes protruding in all directions.

A second small SHC was of a very similar size (95x100x45mm, with the neat bowl being 35mm deep weighing 560g). It was subcircular in plan, concavo-convex in form, with a dished top, smooth in the centre with a raised marginal lip. Internally, this SHC has a dense core with marginal zones of rounded vesicles of up to 7mm, but mostly on a scale of one millimetre or less, both close the lower surface and upper surface of the SHC. A bulk elemental analysis was prepared from a section taken through the centre of the bowl of the SHC (sample HCB01-4).

The third cake of modest weight (448g) is of an unusual form, being a dense slag sheet, showing contact with an overhanging outwardly convex ceramic, and showing lobate slags apparently penetrating into the wall below that ceramic. It seems likely that this piece is not an isolated, discrete SHC, but a strong reaction with the wall of the hearth either associated with a now-removed SHC within the hearth, or possibly as a mass of slag that might have formed over a period of time during the formation of multiple SHCs.

The other SHCs from the context are significantly heavier. Unlike the smaller subcircular SHCs, three of these are more elongate. Only a 1920g example is approximately circular, 150x150x100mm, with a smooth base grading up into slag that is rather dimpled. Accretion conceals any other external features.

A 1075g example contains a semi-circular core, with a larger forward-sloping disk to a total size of 120x190x55mm.

An SHC measuring 160x120x65mm, is well formed and weighs 1305g, with a dished top 100mm diameter. It has lobes protruding on most sides. It has some attached vitrified oxidised lining, roughly 60mm in diameter, inclined at 70 degrees forward, forming a strongly overhanging margin. The SHC is elongate away from wall. This piece and the unusual 448g piece described above are both suggestive of the forward protrusion into the hearth of ceramic below the location of the blowhole. It is possible that this suggests the use of some form of block tuyère, but it is just possible that the overhang is the result of a built clay wall above a cut hearth pit.

The largest example is a 2350g SHC, measuring 150x200x90mm, the bowl of the SHC is 60mm deep. There are two very substantial tool marks on one side apparently passing through the whole thickness of the cake. This cake was sampled as HCB01-3. The cut section through the cake shows it to have tubular vesicles in a zone 30mm thick immediately above the

base, which also has some clasts of flint. The central part of the cake, 15mm thick, is dense, with spherical vesicles appearing in the upper 15mm of the bowl, which is then overlain by highly-weathered charcoal-dominated slag above the level of the top of the dense bowl. A bulk elemental analysis was prepared from a section taken through the centre of the SHC (sample HCB01-3).

A fragment of dense burr bearing tubular vesicles, potentially having some similarity with the 2350g piece from pit [2630] was recovered from fill (2358) of posthole [2357].

A further example of an SHC was recovered from fill (2958) of pit [2957]. This example was a small SHC weighing 320g, very rich in metallic iron, the corrosion of which is causing the piece to explode.

Other examples of SHCs were recovered from contexts which may suggest a later origin. A small, but very dense, SHC measuring 80x120x30mm and weighing 370g was recovered from fill (3416) of Romano-British ditch [3415]. This example had a dished top, with a fine scatter of flint fragments, and a base that was dimpled centrally, but smooth on the margins. A small SHC (100x90x30mm weighing 275g) with large charcoal inclusions was found in fill (3845) of medieval ditch [3844] and a large prilly mass, probably an SHC, weighing 872g was found in fill (4055) of medieval ditch [4054]. None of these three SHCs had any inherent evidence to suggest an age.

Small fragments probably from SHCs were recovered from fill (3806) of ditch [3805], but these gave little evidence as to the original nature of the cakes from which they derived.

Elemental composition of residues

Smelting slags

The two samples for which analyses were obtained were probably both from materials which formed low in the furnace. They were from context (3434) a deposit both underlying the lifted part of the 'furnace bottom' slag and perhaps lying between the slag mass and the furnace mouth. HCB01-1 was an amalgamated prilly slag, with moulds of fuel particles, suggesting an origin within the main 'furnace bottom' slag block. Sample HCB01-2 was an amalgamated flow slag indicative of slag flow into the wood-filled basal pit and thus on the periphery of the main slag mass. The elemental analyses are, however, extremely similar.

The two analyses of smelting slags show compositions that are relatively aluminous (SiO_2:Al_2O_3 of 5.2 and 5.4) compared with the smithing slags. Iron contents are moderately high, estimated at 71.5% and 68.9% expressed as FeO. Manganese is elevated (1.3% as MnO). The content of alkalis and alkaline earths is very low. The content of phosphorus is quite low (0.7% and 0.6%).

The low concentration of most other elements permits display of the analyses on the Feo-SiO_2-Al_2O_3 ternary diagram (Figure 3).

Amongst the trace elements vanadium is at slightly higher concentrations than typical for the area (73ppm and 97ppm; perhaps reflecting either binding onto organic matter or within phosphates), but most other elements are present in rather low concentrations. The total rare earth elements (Σ REE) is also moderately low (237ppm and 287ppm) compared with other slags from the region. Uranium and thorium (together with the U:Th ratio) are all at levels typical for the region (U = 2.2ppm and 2.6ppm, Th = 3.7ppm and 3.5ppm, U:Th = 0.58 and 0.76)

The upper crust-normalised REE profiles (Fig. 5; normalisation factors after Taylor & McLennan 1981) are humped about the middle REE (mREE; with a slightly double peaked shape, with maxima around europium and dysprosium). Maximum elevation of the profile occurs with europium (Eu_N = 2.68; for HCB01-1) and dysprosium (Dy_N =3.70; for HCB01-2). There are significantly lower concentrations of the light REE LREE), whereas the heavy REE (HREE) are only slightly depressed. The profile is rather flat across the LREE (La, Ce, Pr and Nd). When the HCB03 material is also considered, a trend can be observed towards flattening of the HREE part of the profile and eventually the upturning of the HREE end (Gd_N/Lu_N < 1).

Smithing slags

The analyses of smithing slags (HCB01-3 and HCB01-4, respectively examples of a large, 2.2kg and small, 0.6kg SHC) show a high iron content (62.6% and 79.9% respectively, expressed as FeO). The analyses are more silicic than the smelting slags (SiO_2:Al_2O_3 of 7.6 and 7.8 respectively). Manganese contents are low (0.42% and 0.14% respectively), but phosphorus contents are significantly higher than in the smelting slags (1.42% and 0.91% expressed as P_2O_5). As with the smelting slags, the content of alkalis and alkaline earths is very low. The trace element data for the sampled large SHC, HCB01-3 are broadly comparable with those from the smelting slags. Those from the small SHC show some significant differences: the high iron content means that most trace elements are strongly diluted compared with the large SHC, but a few are elevated, including cobalt, nickel, copper, molybdenum and tungsten, all elements potentially associated with metallic iron.

The analyses plot on the Feo-SiO_2-Al_2O_3 ternary diagram (Figure 3) with HCB01-3 in the centre of the fayalite field and HCB01-4 within the wustite field.

The upper crust-normalised REE profiles of the two smithing slag samples (Fig. 5; normalisation factors after Taylor & McLennan 1981) are humped about the MREE, but with a more symmetrical profile. The profile for HCB01-3 is very close to the profile from smithing slag sample HCB03-13.

Interpretation

Iron smelting

The evidence for the nature of iron smelting at Hartshill Copse includes both that provided by the remains of the smelting furnaces and by the associated archaeometallurgical residues. In both respects the evidence integrates tightly into what is known of Iron age smelting.

The residues from iron smelting bear particularly local close comparison with those from Fleethill Farm. The 'furnace bottoms' from that site weighed between 18.7kg and 19.6kg, but these were not *in situ*, having been dumped, or packed, into a ring gully. They had lost any more fragile outer parts and particularly had become separated from flow slags that had descended

lower into the pit. Their original weight is likely therefore to have been somewhat higher. One of the 'furnace bottoms' from Fleethill Farm was investigated in great detail, but the evidence for the precise form of the furnace was poor (Young 2016b; Hardy & Young 2019). The two sites thus provide complementary evidence. The smelting at Fleethill Farm was dated by a single 14C date from an associated deposit of 400–210 cal BC (SUERC-39932; pit 105363) and a single sherd of Middle Iron Age pottery.

Further afield, the Furnace [2398] at Tregurra, Truro, Cornwall, has a very similar morphology (Young 2105a, 2016c). It appears to have a maximum internal working width of 550mm and an internal length at the depth truncation of 850mm from face of the blowing wall lining to the tip of the ramp through the arch. An adjacent, but less well-preserved, furnace produced a date of 410-230 cal. BC (SUERC 64586).

Hartshill Copse appears, therefore, to extend the range of large arched furnaces from these well-established 4th century BC examples back into the later part of the Early Iron Age. If the form and age of the unpublished example at Messingham (Clarke 2015) are confirmed, then the type will have its origin pushed back still further into the 6th-8th centuries BC.

The process of smelting at Hartshill Copse was likewise similar to examples of middle Iron Age smelting from across southern Britain. The basal pit of the furnace was packed with split wood prior to smelting. The largest fragment of wood evidenced by the moulds preserved by flow slag (in an example from Furnace [3579]) was at least 120mm across the split. This is larger than typical, although certainly not without parallel. The role of the pit packing is not fully understood, but it appears likely that the packing support void space into which the slag could flow, before itself potentially becoming consumed by the fire as the main slag mass and bloom formed. The presence of the partially burnt wood and any voids left by any that became completely burnt would also provide lines of weakness for breaking the slag mass when the furnace was cleared after the smelt. Although it has usually been assumed that split green wood was employed, the regular occurrence of 'old' 14C dates from furnaces of this type does also raise the possibility that old wood might on occasion have been taken from the same wetland environments that the bog iron ores were extracted, potentially including very much older wood. Whether such a mechanism might explain the 12th – 13th century BC date for Furnace [3525] (UBA-40581) is unclear (see discussion below).

Mass balance, ore composition and yield

There are insufficient analyses from the smelting system to constrain a mass balance model. There are no analyses of ores, none of furnace ceramic and only two samples from smelting slags, both apparently from the basal flows of the furnace bottom. Figure 7 presents a view of how a graphical mass balance might be employed with the available data, following the methodology of Young (2016b). In this dataset, however, instead of using analyses to constrain a mass balance model, the few available analyses will be taken together with typical mass balance parameters for this sort of smelting to constrain the possible ore composition.

The red arrow on Figure 7 represents the dilution line of the slag composition with varying degrees of iron extraction. For a proper mass balance model the tip of the arrow should corresponds to the bulk composition of the residues from a smelt. In this instance, it is merely located at the mean of the two smelting slag analyses, which unlikely to be a particularly good estimate of the overall bulk composition of residue from the smelt. The blue line represents the ore-ceramic mixing line. The ceramic component has been modelled on the composition of the furnace ceramic from Fleethill Farm (Young (2016b). The red and blue lines intersect at the composition of the overall 'smelting mixture' (*sensu* Thomas & Young 1999a, 1999b). The relative length of the red line from the origin to the bulk slag composition and its length from the origin to the 'smelting mixture' defines an enrichment factor (the factor by which elements are more concentrated in the slag than the smelting mixture because of the extraction of the iron from the mixture to form the bloom). In this figure, the enrichment factor has been defined to be 2.2, a typical value for bloomery operations. The relative lengths of the blue line either side of the 'smelting mixture' is determined by the relative mixture of ore and ceramic in the smelting mixture, in this case 92% ore:8% lining has been chosen as a typical figure derived from other systems.

The figures that can be read from Figure 7, and those that can be calculated give an ore with the composition (modelled as an anhydrous material with iron expressed as FeO):

SiO_2	4.3%
Al_2O_3	1.7%
FeO	93%
MnO	0.6%
TiO_2	0.6%
P_2O_5	0.9%
ΣREE	112pp
U	1.1 ppm

These figures are only estimates of the composition, but indicate the likely general properties of the ore. This approach ignores both the small contribution to the 'smelting mixture' from the fuel ash (typically <2% and dominantly K_2O and CaO which are accordingly not used in calculating the balance) and the part of the enrichment of the elements in the slag from the loss of phosphorus to the metal (again typically such a small quantity that it is significant compared with other errors within the estimation process).

Some attention may be paid to the diagram for phosphorus however (Figure 7, lower right). It will be noted that the slag analyses fall well below the estimated course of the red line. This is because phosphorus is not entirely conserved in the slag, but much (in this estimation approximately half) may partition into the iron, making the iron phosphoric. There is insufficient data, however, to calculate a reliable graph for phosphorus.

The calculation of yield from the smelting requires making assumptions about the mass balance, just as for the back-calculation of the likely ore composition above. If the furnace cermaic had a content of 5% FeO, then the 'smelting mixture' would have a content of 89.6% FeO with the above model. An enrichment factor of 2.2 (as modelled in Figure 7) means that the slag represents 45.5% of the 'smelting mixture'. The other 54.5% of the smelting mixture was iron oxide extracted as metal (i.e. 42.4% expressed as iron metal). Thus, 920g of ore and 80g of lining generate 424g of iron and 454g of slag. A 33.9kg FB, as found in Furnace [3525] might thus correspond, at a very rough approximation, to the production of 31.7kg of

iron metal. This is likely to be an overestimate of actual bloom size, but nonetheless a substantial bloom is suggested. If the mixing line (blue) crosses the dilution line (red) much further from the origin than modelled (i.e. the enrichment was lower), then the analyses of smelting slags from HCB03 would start to lie below that line – which is not realistic if they derive from reaction of the same raw materials as those from HCB01. The calculation of yield is highly speculative. But it indicates, at very least, that a substantial amount of iron must have been made in each smelt.

A bloom of over 20kg would be a very difficult material to work, or even cut, with the known tools of the period. Blooms of over 8kg or so are actually very difficult to work by hand (Sauder 2016), so anything larger would need to be cut hot, to make it into smaller pieces for smithing.

Ore provenance

The major element composition of the smelting slags shows a marked difference to those of equivalent examples from the Wokingham and Finchampstead areas. The Hartshill slags are relatively enriched in manganese but have much lower phosphorus contents (Figure 6). This translates into a P_2O_5:MnO ratio (both measured in wt%) which is less than 1 (compared with a value of P_2O_5:MnO of greater than 2 for most slags from the eastern area).

A similar P_2O_5:MnO ratio may be observed (Figure 5) is slags from Romsey and Bestwall, whereas slags from Michelmersh and Bermondsey show even lower P_2O_5:MnO ratios, associated with strongly elevated manganese contents.

A similar story appears to emerge from interrogation of the upper crust-normalised REE profiles, although there are fewer sites for which such data are avialble. The profile shape has been illustrated by a plot (Figure 8) of Gd_N/Lu_N v Gd_N/Ce_N (i.e. a measure of the slope of the HREE v that of the LREE). This demonstrates the steeper slope of the light end of the profile and the flatter, becoming upturned heavy end, for smelting slags from Hartshill compared with other analysed slags, ores and furnace ceramics from the region. Available slag analyses show examples from Hartshill having Gd_N/Lu_N of less than 1.5, whereas those from Folly Court and Fleethill Farm show Gd_N/Lu_N of over 1.7.

The difference is a trend in the profile shape from humped shape towards an inclined shape (as seen in two of the analyses from HCB03). The driving factor for this profile is currently uncertain, but a trial analysis of an ochre deposit within an area of seepage in the Long Moor Bog (Figure 6 lower) shows some similarity with the more extreme Hartshill profiles. This sample comprised an ochre precipitate in largely organic host (partially decayed leaf matter from a small stream), rather than within siliciclastic sediment (as was the situation, for instance with the analysed ores from the floodplain sediments at Fleethill Farm). The Longmoor Bog sample also shows arguably closer affinities to the modelled ore composition from Hartshill, than it does to the Fleethill Farm ores from the Blackwater floodplain. The possibility that an organic host might influence some aspects of the elemental composition is worth further investigation.

Bloomsmithing

The weight-frequency distribution of SHC assemblages can be a powerful tool for their comparison. The assemblage from pit [2630] (seven complete cakes of 448g, 464g, 560g, 1075g, 1305g, 1920g and 2350g; mean 1160g) would, until recently, have been considered exceptionally large for examples of Iron Age date, but several comparable assemblages are now known and allow confident assignation of this assemblage to bloomsmithing.

The large size of the SHCs compared with some published expectations of Iron Age SHC size is related to the large size of the blooms (or bloom pieces) being worked (and thus in turn to the large size of the furnaces).

Crew (1998) attributed SHCs with weights of 300-400g from Crawcwellt to bloomsmithing, but this is a site with particularly small furnaces. Middle Iron Age Sites with bloomsmithing residues and with larger furnaces include Tregurra (Young 2016c; SHCs range from 890g to 2050g), Folly Court (Young 2018a; SHCs range from 332g to 1120g).

Large SHCs are common on very Late Iron Age and Roman bloomsmithing sites: sites from the late Iron Age at Kingstone (Young 2012; 15 complete SHCs ranging from 230g up to 1035g) and Lockleaze (Young 2018b; no complete SHCs, but one very incomplete fragment was of 956g) and of Roman age from Miskin (SHCs range up to approximately 2400g), Lyonshall (Young 2006a; SHCs range up to 2077g), Kingswood (Young 2017; SHCs range up to 1350g) and Dymock (Young & Kearns 2010b; SHCs range up to 3885g).

Despite the significant assemblage, the SHCs from [2630] only present the bloomsmithing f a fairly small amount of bloom, although any calculation of that amount would be highly speculative. The loss of iron from bloom to bar has been assessed at approximately 65% in experiments (Crew 1991, Sauder 2006), but it appears likely the yield is greater the better quality the bloom. The loss is split between iron lost at the anvil (mainly as hammerscale) and iron lost to the hearth as slag. No good experimental data is available on the relative size of these losses during bloomsmithing, but some work suggests the two losses re similar during blacksmithing. The 8.1kg of SHCs from [2630] would approximate to 4kgs of iron lost to the hearth. Thus, the work periods forming them perhaps involved a total loss of approximately 8kg of iron. This might, on the basis of a 65% loss, represent the bloomsmithing of approximately 12kg of bloom to bar. This might approximate to the working down of just half of one of the blooms generated in furnaces like [3525] and [3575].

All of these assemblages contrast strongly with sites producing SHCs solely from blacksmithing, with have assemblages of much lower weights (less than 800g, with many less than 250g).

The SHCs from other contexts at Hartshill Copse are rather smaller (275g, 320g, 370g and of 872g). Of these four, only the very iron-rich 320g example came from a probable Iron Age context (pit [2957]); the others came from later contexts and may be of later date (although residuality cannot be excluded). These smaller SHCs, with the possible exception of the iron-bearing example from pit [2957], are more typical in form and weight of blacksmithing slags.

The elemental analyses of samples HCB01-3 and HCB01-4 also support their derivation from bloomsmithing, with good indicators of a contribution to their composition from smelting materials. On Figure 7, for all elements other than phosphorus, the SHC analyses plot above a line connecting the origin with the cermaic composition (the line of simple mixing of iron from workpiece and molten ceramic from the hearth wall – a line along which simple blacksmithing slags might lie. Only the smallest of the sampled SHCs (HCB01-4) plots close to this line. That all the analyses plot above the line shows the influence of included slag, which is least in the smallest slag (i.e. HCB01-4 was produced from the working of low-inclusion iron, probably almost finished iron (or just conceivable a finished, but 'dirty', slag-rich iron).

The shape of their REE profiles is illustrated on the lower plot of Figure 6. The profiles show a slightly shallower depression of the LREE and a slightly more marked depression of the HREE compared with the smelting slags from the site, but all the SHC analyses plot close to the smelting slag field.

The residues from iron production from Hartshill Copse thus comprise material from both main components of the process: the smelting of iron ore to bloom and the primary smithing (bloomsmithing) of the raw bloom down to usable iron. Although the bloomsmithing is not very well dated, the materials they were working are very similar to those smelted and thus it is likely that they represent the same Iron Age phase of activity.

Discussion

The Hartshill site

The evidence from the HCB01 area at Hartshill Copse clearly indicates that both iron smelting and bloomsmithing were undertaken within this sector of the site. Direct dating evidence for the ironworking is very poor, but nearby pits [2477], [2645], [3068], [3273] and [2365] have produced 14C dates suggestive of an origin within the period between the mid-sixth century and mid-fourth century BC, with pit [3450] probably being slightly earlier. Furnace [3525] produced a much earlier date from the 10th-13th centuries BC and the significance of this is discussed further below.

The dates for these pits in the northern part of the site are broadly similar to the dates recorded for Phase 3 of the HCB03 sector of the site to the south. Phase 3 was probably within the period of the mid-sixth century and mid-fourth century BC, as discussed above.

The evidence for iron production during HCB03 Phase 3 comprises a scatter of finds of iron smelting slags across the eastern part of the Phase 3 enclosure. Within that enclosure, the fill of 'posthole' [322] (sampled in two parts as contexts (323) and (422)) produced a significant quantity of probable smelting fines (small prills, slag spheroids and other debris). This residue evidence was insufficient to demand re-interpretation of the feature as a furnace, but nonetheless the occurrence of fine-grained smelting residues in this quantity is unusual. Although it is conceivable that a container might have been used to carry such material from a waste accumulation to act as a post-packing this does appear rather unlikely, when larger pieces of slag would presumably have been available to fulfil that role (and even more unlikely that such material should be brought over 250m from the smelting area in HCB01). Nearby iron smelting is much more likely. This context was dated (GrA-24524; 2375+/-45 BP; using charcoal of *Prunus spinosa*, Blackthorn) 749 – 687 cal. BC (8.9%), 666 – 641 cal. BC (3.9%) and 569 – 378 cal. BC (82.6%).(recalibrated at 2σ with Oxcal 4.4 with IntCal 20) Calibration at 1σ gives a range of 516-395 cal. BC. Thus, it would appear likely that the 'posthole' is of a date close to the 5th century BC (or perhaps was filled with material taken from an iron smelting waste deposit of the 5th century BC). This is broadly in keeping with the analysis of the age of Roundhouse B within the enclosure by Collard *et al*. (2006).

Very close (c.1m) to posthole [322] lay posthole [324], of which the fill (325) produced a small SHC weighing 175g. This increases the probability that this section of the site hosted both smelting and smithing activities. These particular features lie very close to the northern margin of the area excavated as HCB03 (the northern part of the Phase 3 enclosure remains uninvestigated) thus it is not known whether an ironworking centre might lie in this area, close to these features, in the unexcavated zone between the HCB03 and HCB01.

To the east of the Phase 3 enclosure, lies the Phase 2 Late Bronze Age settlement with its problematic hammerscale assemblage. The unenclosed settlement produced only microscopic residues, including spheroidal hammerscale (ranging up to 2mm, mostly much less), comminuted flake hammerscale (of up to 1mm) and finely comminuted slag of a similar grainsize. Much was made of the occurrence of these residues in features firmly dated to the late Bronze Age by radiocarbon techniques, despite a complete lack of macroscopic evidence for ironworking. It is possible to hypothesise that the hammerscale in the Bronze Age features arrived there by downward action from worm activity (perhaps for the lining of aestivation burrows) from an Iron Age smithing area lying to the east of the smelting associated with posthole [322], in the same way that the smithing evidenced by pit [2630] lay 150m east of the smelting activity of furnaces [3525] and [3579]. Such a hypothesis is not currently testable, but seems no less unlikely than the existence of a 10th century BC iron smithing site.

Iron technology

If the circumstantial evidence for the dating, but better evidence for the technology, of the smelting in HCB01 is taken with the better evidence for dating, but weaker evidence for the technology, from HCB03, then there seems reasonable grounds for dating the furnaces to the 5th century BC (or just very slightly before or after).The site appears, therefore, to extend the range of the substantial arched furnaces better known within the Middle Iron Age back into the later part of the Early Iron Age. The unpublished example from Messingham may push this style of furnace towards an even earlier origin. This would indicate a sophistication of Early Iron Age smelting technology that has been previously under-appreciated.

The ore source and its implications

The chemical evidence suggests that the ore sources for the two smelting areas within Berkshire (West Berkshire and Wokingham) were quite distinct. The eastern, Wokingham area, has already been linked to bog iron ores associated with groundwaters rising

around the periphery of the outcrop of the Bracklesham Group where it overlies the London Clay (Hardy & Young 2019; Young2018a).

At Hartshill, although a spring-line at 120-125m aOD does issue from the base of the Quaternary gravels (the Bucklebury Common Gravel Member) where they overlie the London Clay, the catchment area seems too small (4.4km E-W and 1.7km N-S) to have generated sufficiently iron-rich groundwaters. The locations of the nearby Cooper's Farm and Dunston Park sites suggest that metallurgical activity was also concentrated much lower in the valley, close to the floodplain of the Kennet – and this may provide a much more viable potential ore source.

The existence of likely bog iron ore sources in the region that were distinct from the locations around the Bracklesham Group outcrop was flagged by Young (2011b), during investigation of a substantial deposit of bog iron ore (albeit with no indication for exploitation) near Reigate. The Reigate ore shows some similarities with the likely composition of the Hartshill ore (figures 5 and 6).

The identification of other early iron smelting operations across central southern England with residues having chemical similarities to those from Hartshill, raises the possibility of some broader scale control on the development of such resources. Comparison of the location of these sites with bedrock geology hints at a possible connection with more acidic groundwaters, but comparison with the distribution of peat deposits within the region (Natural England 2010, Map 1) provides a potentially stronger connection (Figure 8). The coincidence between the smelting sites and floodplains mapped as 'deep peaty soils' is remarkable.

Although iron ores precipitated into superficial deposits are commonly generically referred to as bog iron ores, many are not directly hosted by, or lie adjacent to bogs. Bogs provide just one mechanism for the concentration of FeII in solution in porewaters that may then oxidise and precipitate the insoluble FeIII -bearing minerals as the oxidation state of the water changes – from seasonal variation or from flow into a different environment. At Fleethill Farm, granular bog ores were developed within the terrigenous sediments of the Blackwater floodplain from waters rich in reduced iron after percolation through the strata of the Bracklesham Group, for instance. The formation of peat in areas of restricted drainage on the floodplains of the region would present another environment suitable for iron concentration.

The Quaternary sediments of the valley of the Kennet (south of and below Hartshill) have been intensively studied by Collins (Collins 1994; Collins *et al.* 2006). In the Flandrian, the Kennett valley floor became widely covered with peat-forming environments, that generated the peats deposits of the Midgham Member, dated to c.11,000-9,800 cal. BP. These environments became transformed into small lakes within which localised tufa deposits were formed in the periods up to around 8000 cal. BP. Changes to agricultural practice in the Bronze Age may have increased run-off and increased channel activity. This phase of development in the floodplain sediments was termed MM5 and dated at 5000-2400 cal. BP. Subsequent stabilisation of the floodplain led to the development of structureless calcareous silts and sands (MM6). The peats of the Thatcham area have been worked extensively.

The wetter conditions following the Bronze Age agricultural changes produced renewed peat formation in the Lambourn Valley west of Newbury, with peat forming between 3932–4144 cal years BP and ca. 332–513 cal years BP (Newell *et al.* 2016). This suggests that further peat formation may also have occurred in areas without significant terrigenous input further down in the Kennet valley too. No records of bog iron ores in the Kennet valley have been identified, but much of the peat of the Kennet valley was extracted in historical times and there is thus relatively limited opportunity for modern observation of any iron enrichment, even if current hydrological conditions permit its survival.

The possibility of an organic host sediment for the ore raises a possible link with the old wood 14C date from Furnace [3525] of 1368-1359 cal. BC (0.7%) and 1286-1115 cal. BC (94.7%) (UBA-40581). This date cannot refer directly to the age of the smelting. It could be residual material, but similar 'old' dates are known from slagpit furnaces elsewhere (most notably in Ireland; Young 2020 Table 2, includes a brief survey identifying six sites where dates on oak and other species from the same furnace produced non-overlapping calibrated dates) and the possibility exists that wood from peat deposits was incorporated into the furnace either as inclusions within the bog ore or, more likely, as bog wood used specifically in the pit packing. Further investigation of this phenomenon is desirable.

The recognition of a spatial association between early smelting sites and peat occurrences in central southern England is important for understanding the development in the supply of iron and may assist with future prospection for such sites.

More specifically, the relationship with the distribution of peat is associated with sites of Iron Age and early medieval date. These periods show, on a super-regional basis, an engagement with the exploitation of bog iron ores rather than rock ores. The intervening Roman period exhibits a major expansion into rock ore sources, with the Weald eclipsing other sources in this area.

Some of the localities show quite significant amounts of exploitation. The valley of the River Test, for instance, showing Iron Age exploitation at both Mickelmersh (De'Ath *et al.* 2013, Girbal 2010) and Romsey (Green 1994), followed by a major smelting centre at Romsey in the early medieval period (McDonnell 1988, Scott 1996). Closer to Hartshill, the major early medieval iron smelting operation at Ramsbury (Haslam 1980) can be postulated to have exploited a deposit in the upper Kennet valley. Other areas so far lack significant finds of iron smelting but might potentially be expected to have similar bog ores, for instance the valley of the Itchen in Hampshire and the valley of the Allen (which has produced evidence for early medieval iron smelting at Wimborne minster, Orczewski *et al.* 2018, but not Iron Age) below the major Iron Age metallurgical activity at Gussage All Saints in Dorset, would appear likely areas.

Illustration Captions

Figure 1. Summary plan of Hartshill Copse, with distribution of the different classes of the metallurgical residues, showing the extent of the HCB01 (this report) and HCB03 (Collard et al. 2006) areas.

[Note that the backdrop mapping of the site is a scanned version and approximate only]

Figure 2. simplified plans of the iron smelting furnaces.

Figure 3: SiO_2-Al_2O_3-FeO *ternary diagram (after Schairer & Yagi 1952) for analyses of samples from Hartshill Copse.*

Figure 4: the upper crust-normalised REE profiles for analyses of samples from Hartshill Copse. (normalisation factors after Taylor & McLennan 1981)

Figure 5: Plot of MnO (wt%) against P_2O_5 *(wt%) for samples from Hartshill Copse and for some comparative datasets.*

Sites with Group A slags
Hartshill Copse (IA): this study; Collard *et al.* 2006.
Bestwall (EM): McDonnell *et al.* 2012
Bermondsey (EM): Bowyer & Keys 2013; Young
Romsey (EM): Scott *et al* .1996; McDonnell 1988
Michelmersh (IA): De'Ath *et al* .2013; Girbal 2010

Sites with Group B slags
Crosfields School (IA): Ford 2019a
Folly Court (IA): Young 2018a
Fleethill Farm (IA): Hardy & Young 2019, Young 2016b
Heckfield (IA): Dungworth 2007
Sindlesham (IA): Lewis *et a*l. 2013
Brooklands (IA) Hanworth 7 Tomalin 1977
Risely (IA) McDonnell 1984, Taylor 2018, 2019
Grazeley Road (IA) Ford et al. 2013
Thorpe Lea (IA): Starley 1998

Sites with other slags
Shooters Hill (IA): Dungworth & Mepham 2012

Sites with bog iron ore (MnO > P_2O_5*)*
Reigate: Young 2010

Figure 6. plot of Gd_N/Lu_N *v* Gd_N/Ce_N*. (elemental concentrations normalised to upper crust after Taylor & McLennan 1981) for samples from Hartshill Copse and for some comparative datasets.* Gd_N/Lu_N *is a measure of the slope of the heavy end of the REE profile and* Gd_N/Ce_N *of the light end.*

Upper: plot of analyses of smelting slags from Hartshill (HCB01 and HCB03), with analyses from Folly Court (2 different furnace types) and Fleethill Farm (from the Wokingham area) for comparison.

Lower: plot of other pertinent analyses from the region, including Hartshill smithing slags (HCB01), furnace ceramics from Fleethill Farm, ore from Fleethill Farm and LMB2, a modern ochre from Longmoor Bog. (fields of the smelting slags shown in grey tone).

For references to individual sites, see Figure 5.

Figure 7. Mass balance modelling (after Young 2016b) for smelting slag samples from Hartshill (HCB01). Analyses of smelting slags from HCB03 and of smithing slags from HCB01 and HCB03 are shown for comparison. There are no furnace cermaic analyses from Hartshill. Analyses of ceramics from Fleethill Farm and Folly Court are shown; those from Fleethill Farm provide a consistent mass balance solution, so are used in the calculation. The illustrated model shows the smelting mixture with 8% lining:92% ore (blue line), with an enrichment (E value) of 2.43 from extraction of iron (red arrow).

Figure 8. map of central southern England showing the distribution of iron smelting sites of Iron Age and early medieval age (excluding those exploiting Wealden and Greensand sources). Sites are classified by the relative concentration of MnO and P_2O_5*. The high-P sites (green markers) lie around the outcrop of the Bracklesham Group (and related deposits;), the high-Mn sites (red markers) lie in river valleys, with a particular association with the occurrence of peat (after Natural England 2010).*

Sites with Group A slags (MnO > P_2O_5*)*
Hartshill Copse (IA): this study; Collard *et al.* 2006.
Bestwall (EM): McDonnell *et al.* 2012
Bermondsey (EM): Bowyer & Keys 2013; Young 2011b
Romsey (EM): Scott *et al.* 1996; McDonnell 1988
Michelmersh (IA): De'Ath *et al* .2013; Girbal 2010

Sites with location as for Group A
Ramsbury (EM): Haslam 1980
Romsey (IA): Green 1994
Wimborne (EM): Orczewski *et al.* 2018
Worgret (EM): Maynard 1988, Hinton 1992.
Coopers Farm (IA): Fitzpatrick 2011; _ *et al.* 1995
Dunston (IA): Fitzpatrick 2011; Fitzpatrick *et al.* 1995
Basingstoke, Rucstalls Hill (IA): Oliver & Applin 1978
Basingstoke, Riverdene (EM): Hall-Torrance, M & Weaver, S, 2003
Basingstoke, Rooksdown (IA):

Sites with bog iron ore (MnO > P_2O_5*)*
Reigate: Young 2010

Sites with Group B slags (MnO < P_2O_5*)*
Crosfields School (IA): Ford 2019a
Folly Court (IA): Young 2018a
Fleethill Farm (IA): Hardy & Young 2019, Young 2016b
Heckfield (IA): Dungworth 2007
Sindlesham (IA): Lewis *et al.* 2013
Brooklands (IA) Hanworth 7 Tomalin 1977
Risely (IA) McDonnell 1984, Taylor 2018, 2019
Grazeley Road (IA) Ford et al. 2013
Thorpe Lea (IA): Starley 1998
West End, Bagshot Village (IA):
Lutine Farm, Bagshot (IA):
Queen's Farm, Bagshot (IA):
Ashleigh Farm, Windlesham (IA):
Windlesham Arboretum (IA):
Lightwater Iron Age (IA):

Sites with location as for Group B
Whitehall (IA): Pine 2003
Baird Road (IA): Hammond 2011

Other sites
Shooters Hill (IA): Dungworth & Mepham 2012

Glossary

Blacksmithing: the working of iron and steel. Often restricted to the secondary smithing – i.e. the smithing of iron to produce or repair artefacts, as opposed to the smithing involved in the production of billets or bar iron from raw iron blooms.

Bloomery: a furnace for smelting iron from ore in which iron is produced as a solid material. The bloomery process was employed mainly prior to the introduction of the later blast furnace from the late 15th century.

Bloomsmithing: The process of reworking a raw bloom, through repeated reheating and hammering, to reduce its content of slag, to remove unwanted inclusions and to draw out the remaining slag into elongate inclusions. The end product may be a bar or billet. Usually taken as an alternative term for bloom-refining.

Blowhole: A hole through a furnace or hearth wall through which air is blown.

Cotectic: crystallisation of a liquid to produce two phases at the same time.

Dendrite: a branched crystal form, often associated with rapid growth.

End member: a limit of a solid solution. E.g. forsterite and fayalite are the magnesium and iron end-members of the substitution forming solid solution in the Fe-Mg olivines.

Euhedral: a crystal shape in which the crystal has developed its faces, indicating its growth was unobstructed by previously formed phases.

Fayalite: the iron-rich end member of the olivine group, Fe_2SiO_4. Abbreviated to Fa.

Flake hammerscale (FHS): fine, thin flakes, of iron oxides spalled from the surface of the workpiece. They result from the oxidation of iron at high temperature. They typically have shiny surfaces.

Forsterite: the magnesium-rich end member of the olivine group, Mg_2SiO_4. Abbreviated to Fo.

Furnace bottom (FB): the slag mass that forms in the base of a furnace, particularly one that does not employ slag tapping.

Hammerscale: material, usually detached, formed by oxidation of the surface of hot iron. Closely related terms forge scale and mill scale are also often sued for modern materials.

Haematite (hematite): anhydrous iron (III) oxide, Fe_2O_3

Hercynite: an iron-aluminium member of the spinel group of minerals: $FeAl_2O_4$

Lining Slag: Slag formed from the complete or partial melting of hearth or furnace lining.

Liquidus: the liquidus is the line on a phase diagram above which a particular composition is completely liquid (molten).

Magnetite: ideally Fe_3O_4; the iron end member of spinel group

Olivine: a group of silicate minerals of the form $(M^{2+})_2SiO_4$ where M can commonly be iron, magnesium, calcium (up to half the M^{2+} ions) or manganese.

Phosphoran: a mineral name qualifier for a phosphorus rich variant (usually in substitution for silicon). Applied to iscorite and olivine (including fayalite) amongst others. Phosphoran olivine has >0.03 atoms per formula unit phosphorus (Boesenberg & Hewins 2010).

Pit packing: organic material, usually either wood or cereal/grass stems, placed into the basal chamber of a furnace (usually a slagpit furnace). The material probably serves various purposes: to support the charge above, whilst maintaining open void space for slag descent, to be combustible to create space for slag storage, to provide lines of weakness to assist fracturing of the slag during clearance of the pit in a multi-use furnace.

Slagpit furnace: a non-slag tapping furnace in which the slag drains into a pit below the shaft during use. In most varieties the pit is filled with an organic pit packing before use.

Smelting: a process involving the reaction of raw ore to produce a metal,

Smithing: the activity involved in forming a metal object, including, but not limited to, forging metal and joining metal by welding.

Smithing hearth cake (SHC): a typically plano-convex slag mass that forms below the blowhole in a smithing hearth from the reaction of iron/iron oxides lost from the workpiece, melted hearth ceramic and fuel ash.

Solidus: the solidus is the line on a phase diagram below which a particular composition is is completely solid (crystallized).

Spheroidal hammerscale (SHS): are very small (<2mm diameter) spheroidal droplets, with a shiny surface, formed by chilling in air of droplets of melted iron oxides forcibly expelled from workpiece during hammering. They may be generated purely from the melting of the superficial oxide film (as generated the flake hammerscale), from the expulsion of melted slag included within the iron, and their generation may be enhanced by the use of a smithing flux

Spinel: a mineral group with the general formula $X^{2+}Y^{3+}{}_2O_4$, which includes, amongst many others, the minerals hercynite and magnetite.

Subhedral: a form of crystal growth which is impeded by some pre-existing phases to permit only some of the crystals faces to be developed.

Substitution: the process or pattern of replacement of one ion by another within a crystal lattice.

Vesicle: a void or pore, usually rounded and formed as a preserved gas bubble in a solidified melt.

Wustite: an iron II oxide, nominally FeO, but frequently non-stoichiometric.

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Table 1: samples selected for analytical investigation, together with samples from previous work elsewhere on the site

Sample	C	Context notes	Notes
New			
HCB01-1	3634	fill of furnace [3525]	amalgamated prilly slag, with moulds of fuel particles
HCB01-2	3634	fill of furnace [3525]	amalgamated flow slag
HCB01-3	2631	fill of pit with multiple SHCs [2630]	complete section through centre of SHC, c.2350g with accretion
HCB01-4	2631	fill of pit with multiple SHCs [2630]	complete section through centre of bowl, c.560g with accretion
Previous			
HCB03-9	323	fill of posthole [322]	amalgamated flow slag, with wood impressions
HCB03-10	407	fill of posthole [406]	dense slag, with wall contact
HCB03-11	588	fill of tree bole or posthole	small piece of grey slag with charcoal impressions
HCB03-12	821	fill of posthole [820]	amalgamated flow slag
HCB03-13	1076	fill of ditch [1075]	large fragment from large plano-convex SHC
HCB03-6	422 (=323)	fill of posthole [322]	smelting slag spheroids, bulk analysis of 8 particles
HCB03-7	1667/1660	postholes of LBA Gp 44, roundhouse D	spheroidal hammerscale, bulk analysis of 33 particles
HCB03-8	1667/1660/1665	postholes of LBA Gp 44, roundhouse D	flake hammerscale, bulk analysis of 23 particles

Table 2: major element analyses by XRF expressed as wt%. Raw numerical values, except for calculated columns (grey tone) for FeO (as an alternative to Fe_2O_3), S (as an alternative to SO_3) and the overall total recalculated using these calculated values instead of the LOI. LOI = loss on ignition. For the historic data from HCB03, the analysis excluded SiO2, which has been rpesented here as a modelled value (100% minus the total determined major elemental oxides).

Sample	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	SO_3	S	LOI	Total + LOI	Total (with FeO and S)
HCB01-1	22.81	4.40	79.49	71.54	1.26	0.62	0.72	0.03	0.47	0.20	0.67	<0.052	<0.02	-5.59	105.08	102.72
HCB01-2	25.81	4.82	76.52	68.87	1.27	0.57	0.74	0.04	0.49	0.17	0.63	<0.052	<0.02	-6.23	104.83	103.41
HCB01-3	28.57	3.75	69.54	62.59	0.42	0.56	0.62	0.07	0.38	0.23	1.42	<0.052	<0.02	-5.7	99.86	98.61
HCB01-4	12.25	1.57	88.75	79.88	0.14	0.39	0.60	0.09	0.37	0.09	0.91	0.21	0.08	-5.14	100.23	96.37
HCB03-9	*27.46**	3.87	69.79	62.80	1.01	0.49	0.64	1.68	1.07	0.25	0.73					
HCB03-10	*21.27**	3.16	78.55	70.68	0.69	0.29	0.83	1.69	0.54	0.22	0.63					
HCB03-11	*27.22**	3.51	71.33	64.19	0.93	0.45	0.63	1.67	0.48	0.27	0.65					
HCB03-12	*21.64**	4.37	76.15	68.52	1.10	0.36	1.10	1.29	0.65	0.22	0.75					
HCB03-13	*17.91**	3.37	82.20	73.97	0.75	0.29	0.69	1.61	0.55	0.22	0.64					
HCB03-6	*23.07**	3.27	75.50	67.93	1.31	0.54	0.74	1.57	0.03	0.31	1.22					
HCB03-7	*46.04**	1.18	52.04	46.83	0.04	0.24	0.64	4.08	0.20	0.26	0.48					
HCB03-8	*80.23**	0.95	16.27	14.64	0.05	0.26	1.27	1.56	0.35	0.37	0.32					

Table 3: trace element analyses by ICP-MS (part 1). Raw numerical values in ppm.

Sample	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba
HCB01-1	6.90	72.51	71.16	9.52	14.64	6.47	57.71	6.15	15.84	42.36	53.63	92.84	3.81	0.99	4.01	0.57	157.67
HCB01-2	7.64	96.78	88.84	11.44	12.35	6.89	51.51	5.97	26.14	37.16	71.76	80.74	3.35	0.77	1.81	0.85	143.97
HCB01-3	5.01	68.23	44.00	10.81	8.13	4.58	49.04	4.53	28.80	41.93	37.96	77.59	3.58	0.66	1.34	0.54	194.27
HCB01-4	0.12	10.80	13.13	65.65	32.40	24.07	46.97	2.89	4.66	18.73	4.24	48.08	1.35	3.76	2.64	0.01	68.88
HCB03-9		85.82	71.74	5.45	36.43	33.03		4.70	39.75	36.96	56.84	198.58	5.39				250.55
HCB03-10		69.52	80.71	3.37	31.23	35.35		4.20	22.15	36.92	39.62	217.33	5.02				179.16
HCB03-11		83.88	64.42	5.70	3.75	20.39		4.39	17.85	27.70	45.13	199.27	5.23				157.76
HCB03-12		62.82	79.58	5.87	11.16	57.09		4.22	23.14	46.46	50.10	150.87	4.48				183.53
HCB03-13		69.27	79.15	9.00	20.40	40.92		4.14	21.85	43.00	43.14	211.18	4.72				179.55
HCB03-6		112.88	101.32	7.12	11.31	97.81		4.57	19.61	33.41	57.91	206.51	5.59				188.01
HCB03-7		42.62	47.49	33.35	110.37	21.87		4.74	35.03	32.97	37.94	357.51	12.03				281.58
HCB03-8		43.14	77.25	41.44	181.60	185.94		5.63	6.60	74.91	5.86	696.12	9.59				488.55

Table 4: trace element analyses by ICP-MS (part 2). Raw numerical values in ppm. For the HCB03 data, the determinations of La are of uncertain quality.

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Th	U
HCB01-1	41.84	93.08	10.94	45.69	10.16	2.35	9.72	1.59	9.31	1.78	4.99	0.71	4.42	0.64	2.37	0.24	0.33	<	1.21	3.69	2.15
HCB01-2	44.21	113.65	12.85	55.22	12.85	3.06	12.91	2.19	12.95	2.56	6.98	0.98	6.17	0.90	2.08	0.22	0.43	<	1.03	3.46	2.62
HCB01-3	30.48	99.31	11.99	51.98	12.12	2.77	10.79	1.69	9.34	1.77	4.76	0.67	4.17	0.60	2.18	0.20	0.45	<	1.20	4.57	1.18
HCB01-4	4.15	9.36	1.15	4.84	1.03	0.24	0.99	0.12	0.84	0.15	0.43	0.06	0.41	0.06	1.21	0.09	1.69	<	1.03	0.94	0.31
HCB03-9	41.60	78.58	9.72	37.88	8.75	2.08	9.22	1.39	8.07	1.64	4.25	0.60	4.04	0.61	5.29	0.42			9.93	3.35	2.39
HCB03-10		47.80	7.26	26.87	6.09	1.31	5.92	0.90	5.23	1.05	2.84	0.42	2.83	0.45	5.70	0.40			8.65	3.85	1.25
HCB03-11	27.73	52.18	6.30	24.57	5.88	1.35	6.32	0.98	6.08	1.30	3.57	0.52	3.70	0.58	5.48	0.45			8.32	3.06	1.58
HCB03-12	37.80	66.86	9.32	35.02	7.81	1.79	7.64	1.16	6.69	1.34	3.58	0.51	3.54	0.55	4.11	0.33			7.20	3.74	1.32
HCB03-13		69.57	9.27	34.79	7.54	1.69	7.47	1.10	6.14	1.21	3.13	0.44	2.95	0.46	5.66	0.40			8.67	3.51	1.55
HCB03-6	25.54	50.03	5.81	22.78	5.68	1.34	6.81	1.18	7.62	1.67	4.78	0.72	4.96	0.81	5.58	0.48			25.54	5.81	22.78
HCB03-7	18.16	38.80	5.30	21.31	5.51	1.86	6.06	1.00	6.25	1.29	3.39	0.49	3.40	0.52	4.33	0.82			18.16	5.30	21.31
HCB03-8		13.99	1.26	4.16	0.76	0.21	0.94	0.12	0.75	0.16	0.48	0.06	0.44	0.09	19.95	0.93			n.d.	1.26	4.16

Figure 1

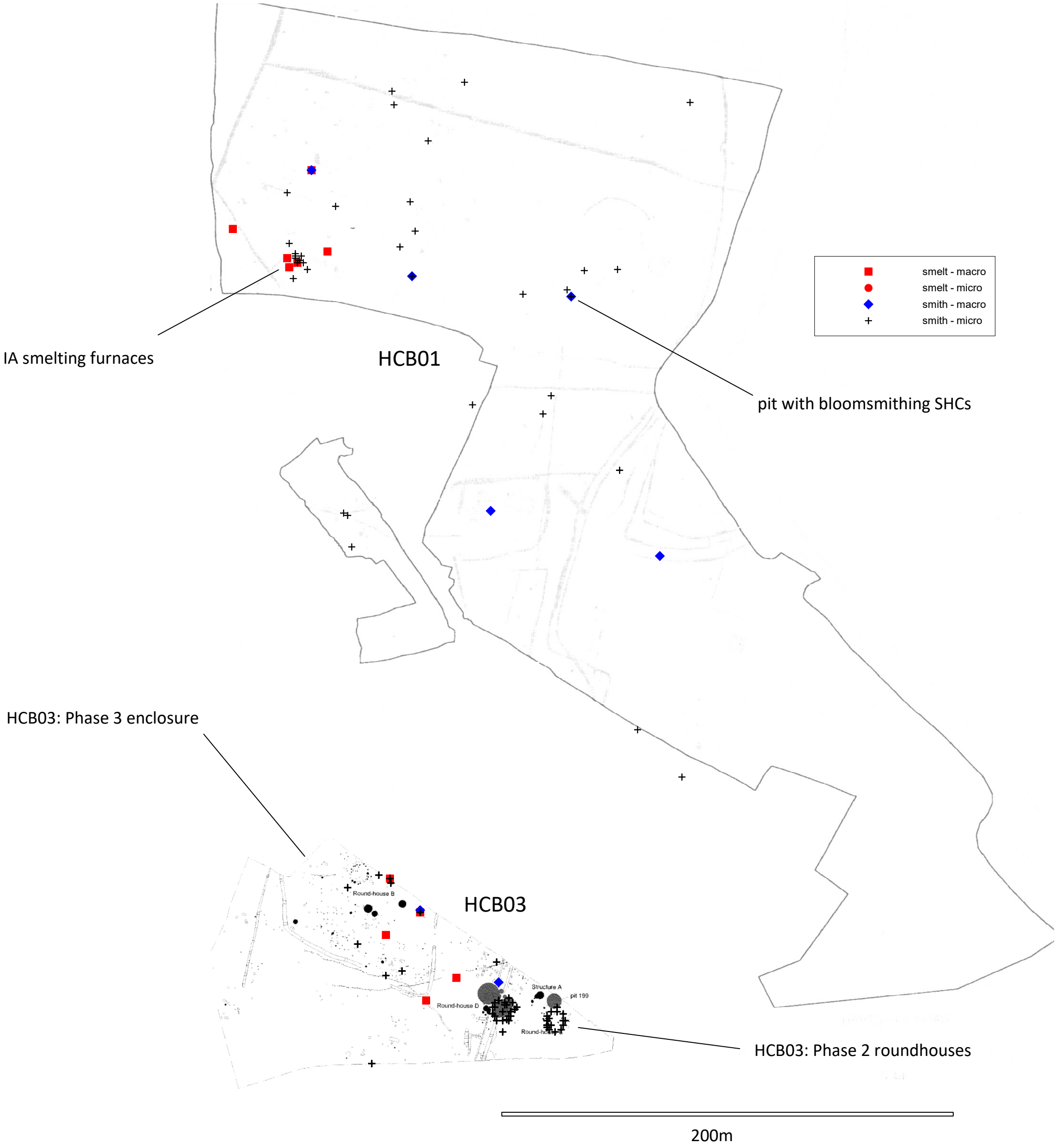
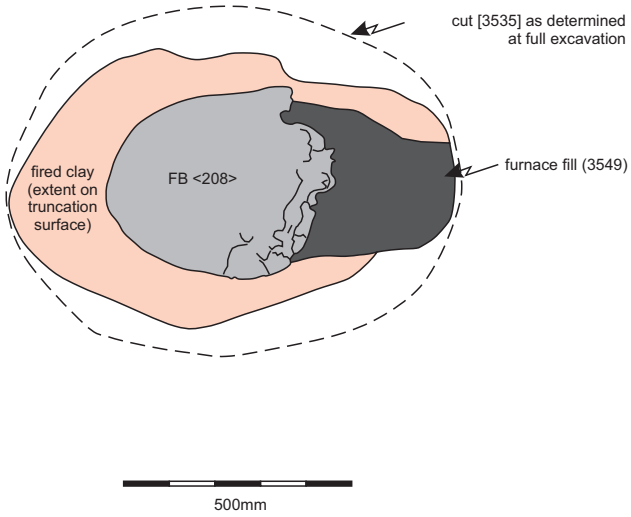

smelt - macro
smelt - micro
smith - macro
smith - micro
IA smelting furnaces
HCB01
pit with bloomsmithing SHCs
HCB03: Phase 3 enclosure
HCB03
Round-house B
Round-house D
Structure A
pit 199
HCB03: Phase 2 roundhouses
200m

Figure 2

Furnace [3525]



Furnace [3579]

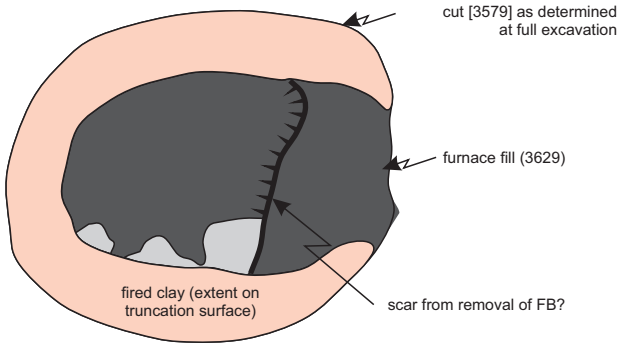
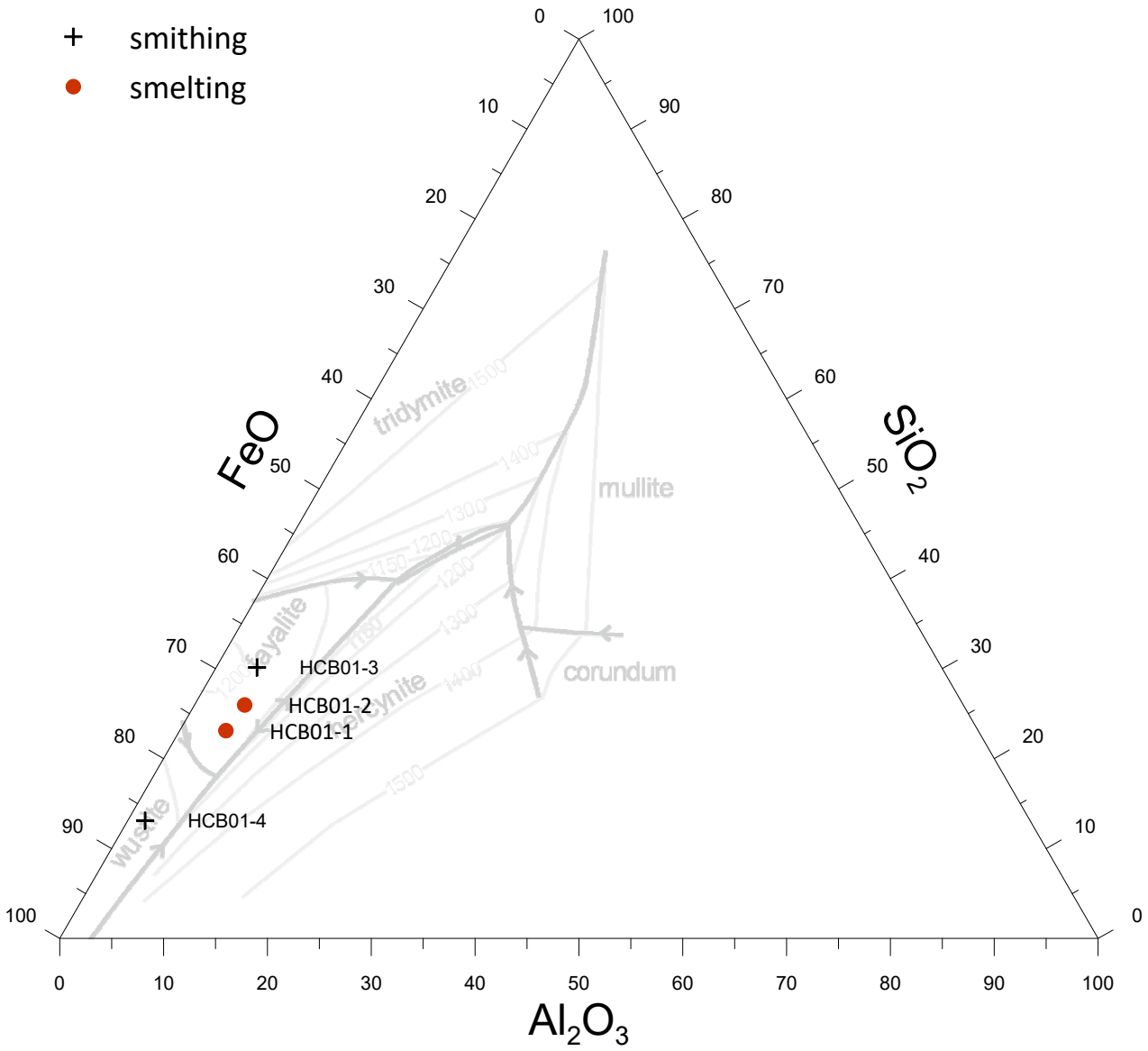
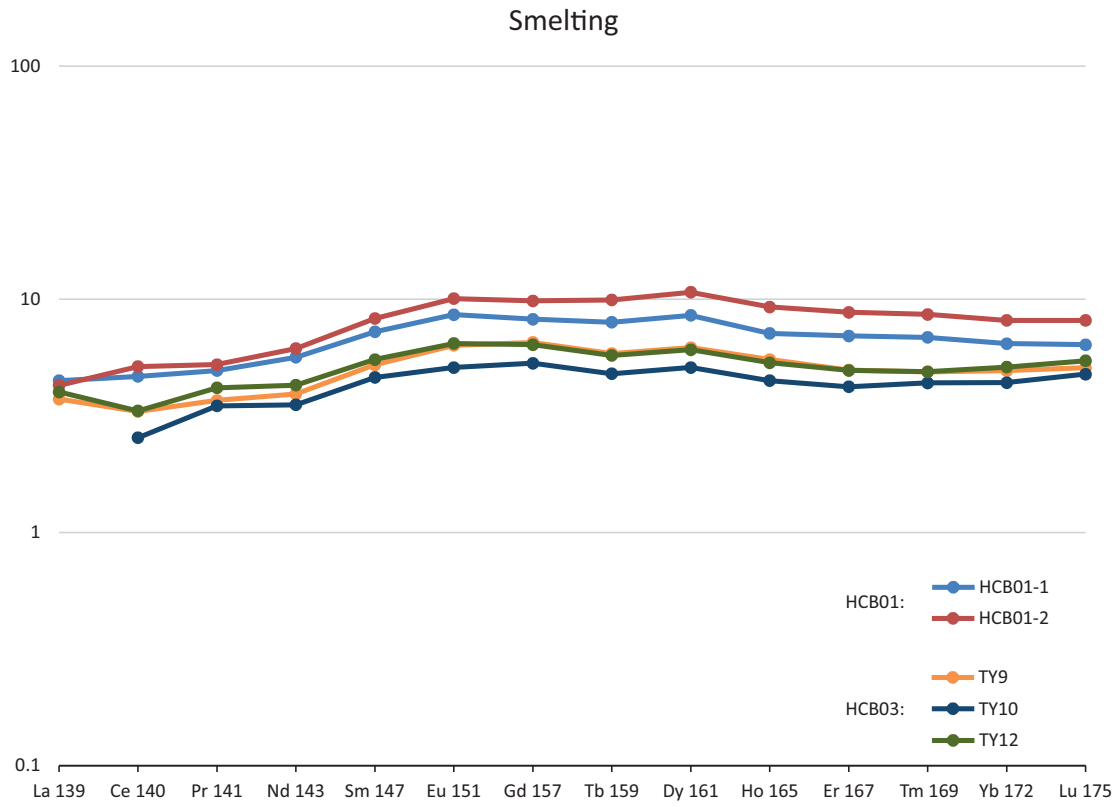


Figure 3


smithing
smelting
FeO
SiO2
Al2O3
tridymite
mullite
corundum
HCB01-3
HCB01-2
HCB01-1
HCB01-4


Smelting
100
10
1
0.1
La 139
Ce 140
Pr 141
Nd 143
Sm 147
Eu 151
Gd 157
Tb 159
Dy 161
Ho 165
Er 167
Tm 169
Yb 172
Lu 175
HCB01:
HCB01-1
HCB01-2
HCB03:
TY9
TY10
TY12

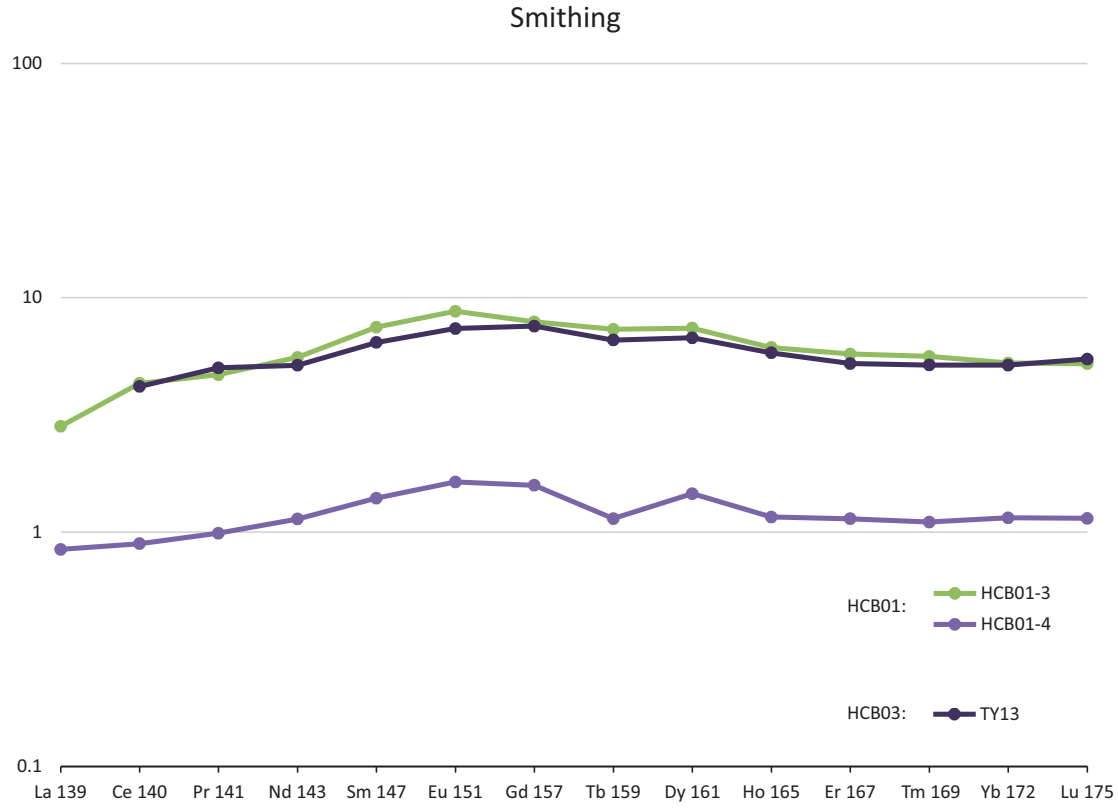

Smithing
100
10
1
0.1
La 139
Ce 140
Pr 141
Nd 143
Sm 147
Eu 151
Gd 157
Tb 159
Dy 161
Ho 165
Er 167
Tm 169
Yb 172
Lu 175
HCB01:
HCB01-3
HCB01-4
HCB03:
TY13

Figure 5

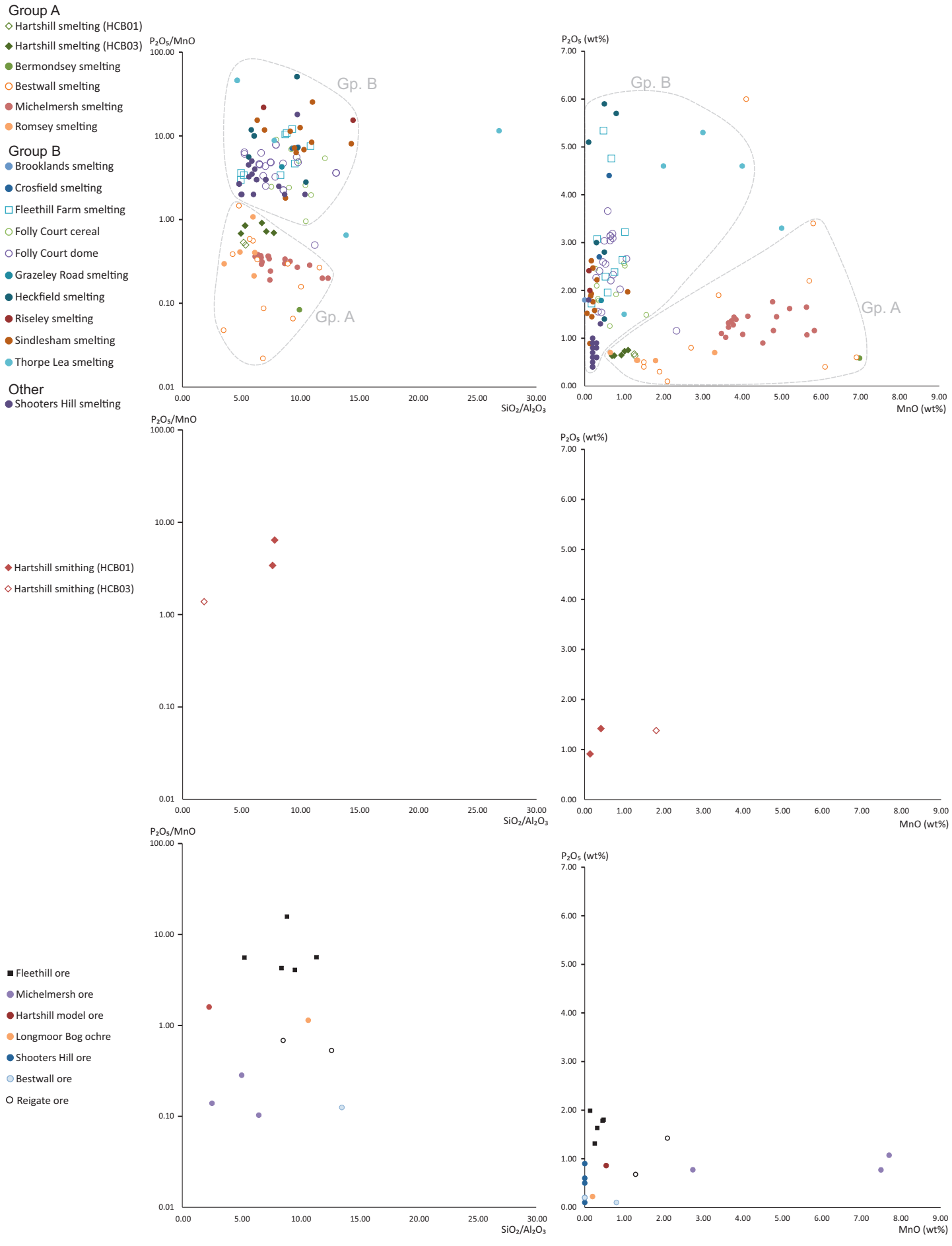
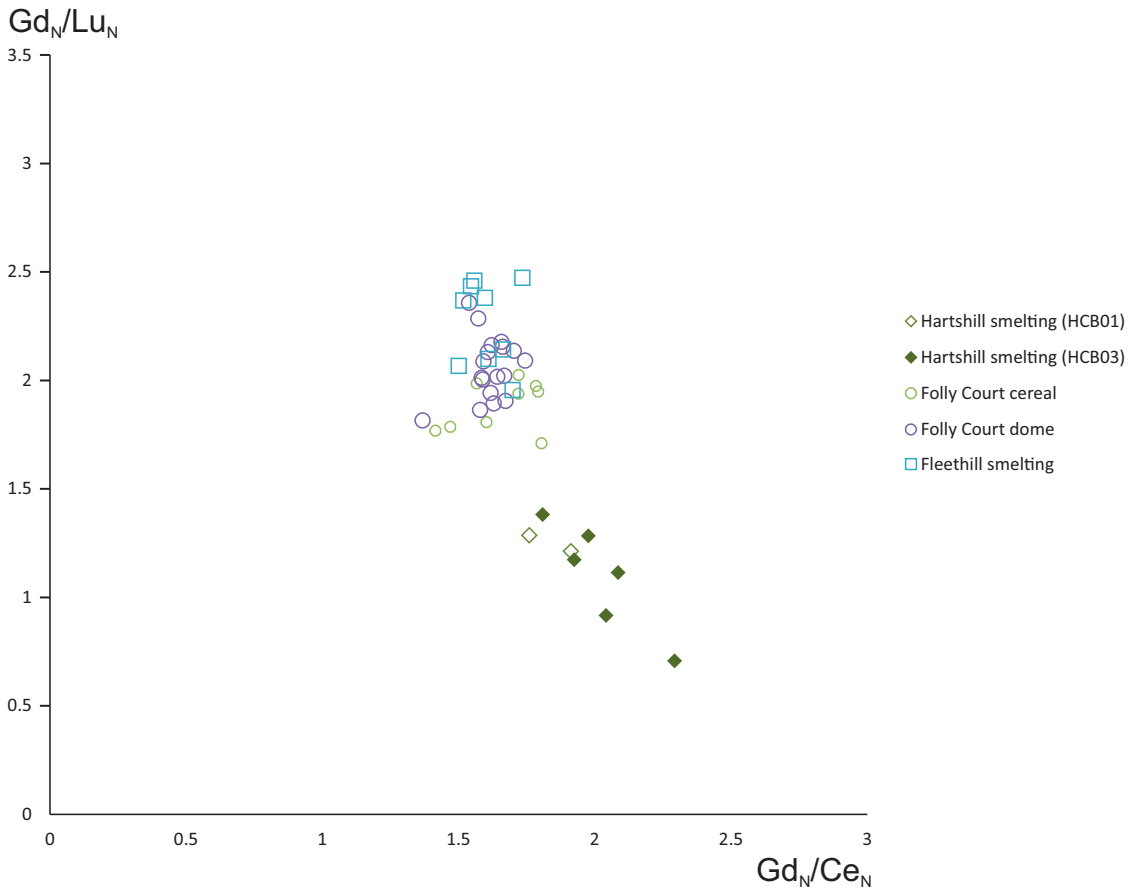

Group A
Hartshill smelting (HCB01)
Hartshill smelting (HCB03)
Bermondsey smelting
Bestwall smelting
Michelmersh smelting
Romsey smelting
Group B
Brooklands smelting
Crosfield smelting
Fleethill Farm smelting
Folly Court cereal
Folly Court dome
Grazeley Road smelting
Heckfield smelting
Riseley smelting
Sindlesham smelting
Thorpe Lea smelting
Other
Shooters Hill smelting
Hartshill smithing (HCB01)
Hartshill smithing (HCB03)
Fleethill ore
Michelmersh ore
Hartshill model ore
Longmoor Bog ochre
Shooters Hill ore
Bestwall ore
Reigate ore
P2O5/MnO
SiO2/Al2O3
P2O5 (wt%)
MnO (wt%)
Gp. B
Gp. A

Figure 6


Gd$_N$/Lu$_N$
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Gd$_N$/Ce$_N$
Hartshill smelting (HCB01)
Hartshill smelting (HCB03)
Folly Court cereal
Folly Court dome
Fleethill smelting

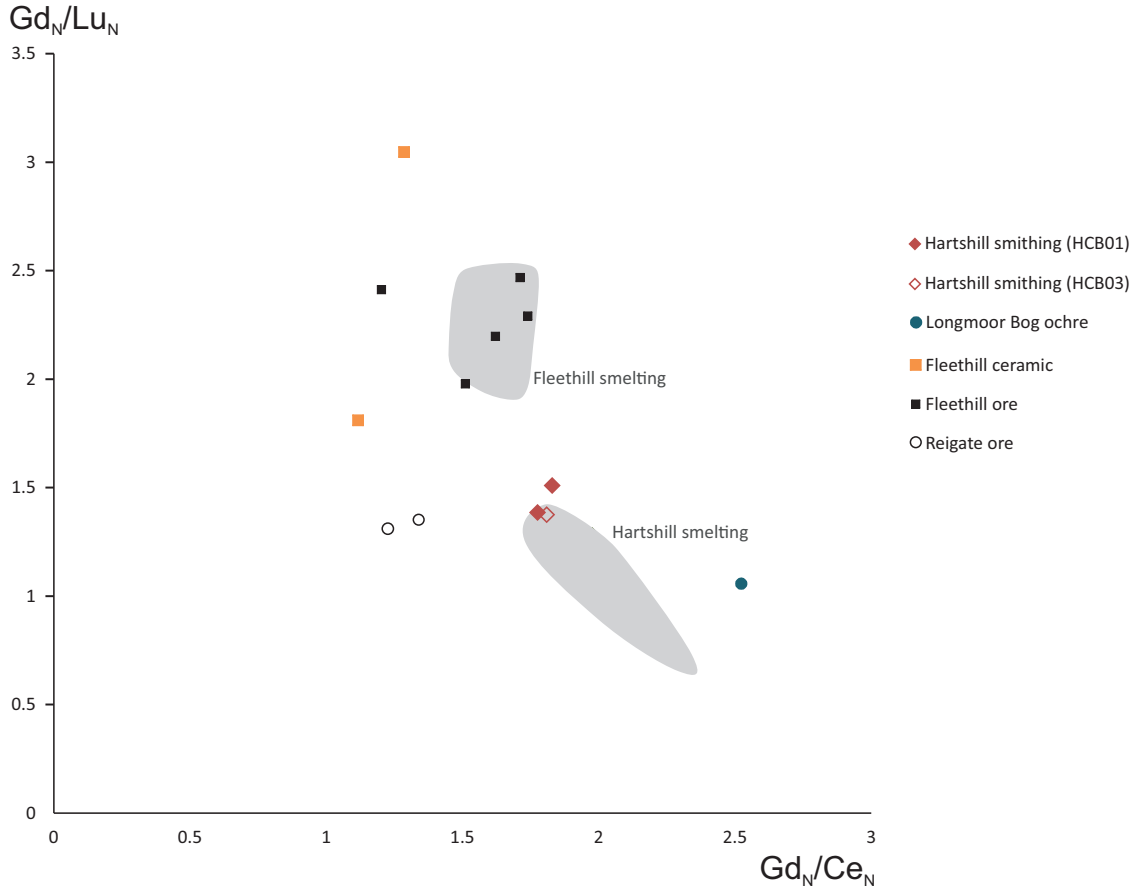

Gd$_N$/Lu$_N$
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
Gd$_N$/Ce$_N$
Fleethill smelting
Hartshill smelting
Hartshill smithing (HCB01)
Hartshill smithing (HCB03)
Longmoor Bog ochre
Fleethill ceramic
Fleethill ore
Reigate ore

Figure 7

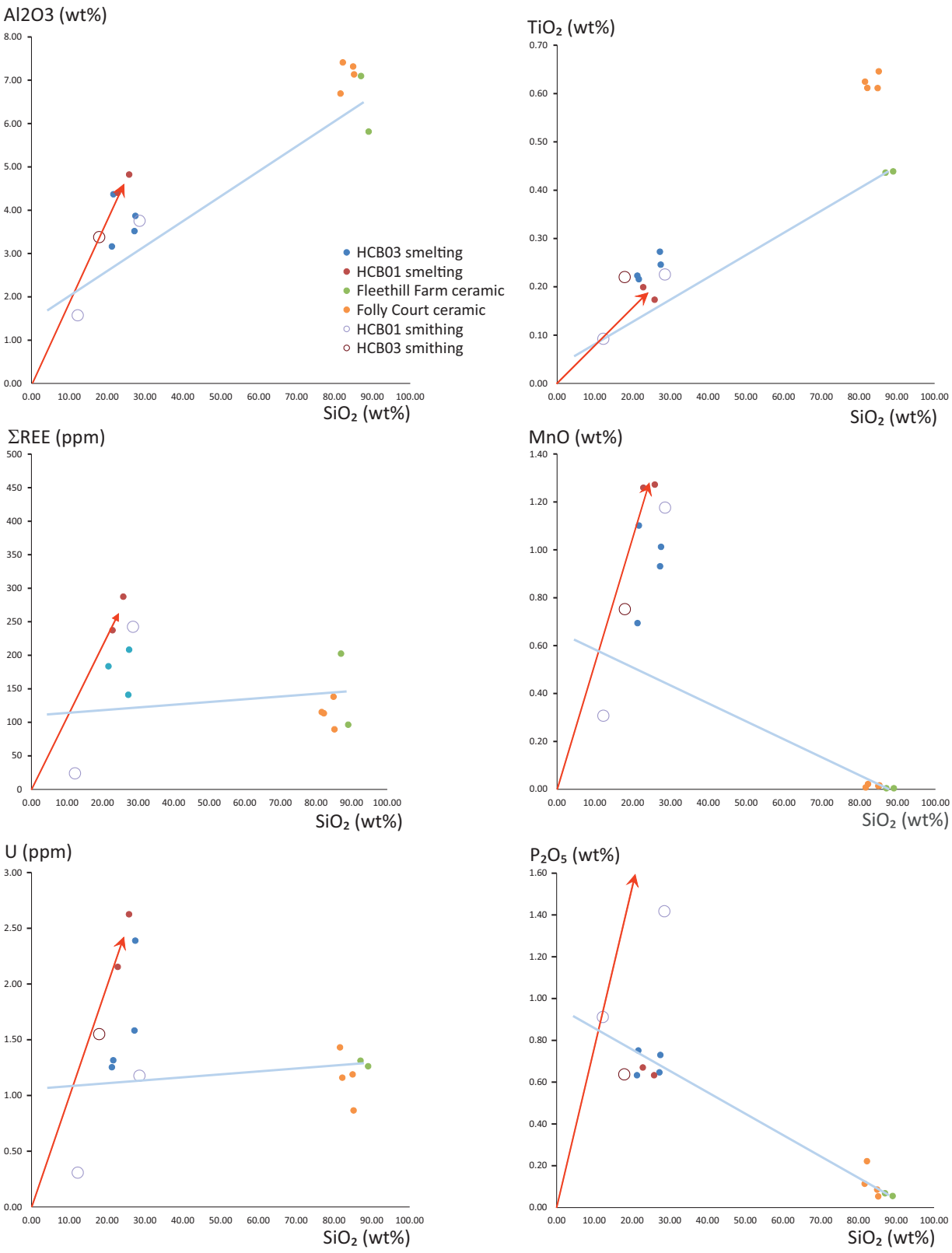
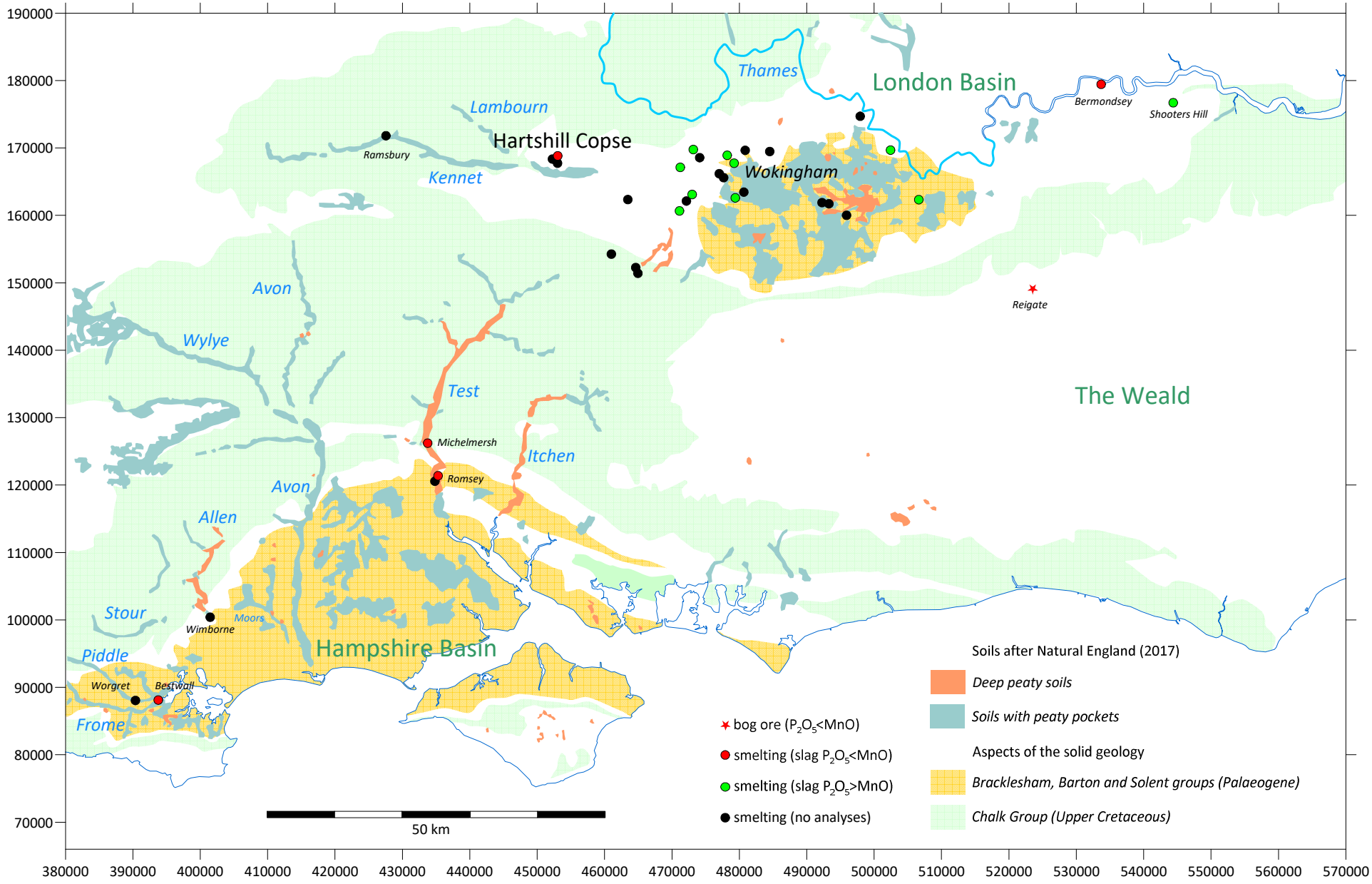

Al2O3 (wt%)
SiO2 (wt%)
HCB03 smelting
HCB01 smelting
Fleethill Farm ceramic
Folly Court ceramic
HCB01 smithing
HCB03 smithing
TiO2 (wt%)
SiO2 (wt%)
ΣREE (ppm)
SiO2 (wt%)
MnO (wt%)
SiO2 (wt%)
U (ppm)
SiO2 (wt%)
P2O5 (wt%)
SiO2 (wt%)

Figure 8


Thames
London Basin
Lambourn
Hartshill Copse
Ramsbury
Kennet
Wokingham
Bermondsey
Shooters Hill
Reigate
Avon
Wylye
Test
The Weald
Michelmersh
Itchen
Romsey
Avon
Allen
Stour
Moors
Wimborne
Hampshire Basin
Piddle
Worgret
Bestwall
Frome
50 km
bog ore (P_2O_5<MnO)
smelting (slag P_2O_5<MnO)
smelting (slag P_2O_5>MnO)
smelting (no analyses)
Soils after Natural England (2017)
Deep peaty soils
Soils with peaty pockets
Aspects of the solid geology
Bracklesham, Barton and Solent groups (Palaeogene)
Chalk Group (Upper Cretaceous)
190000
180000
170000
160000
150000
140000
130000
120000
110000
100000
90000
80000
70000
380000
390000
400000
410000
420000
430000
440000
450000
460000
470000
480000
490000
500000
510000
520000
530000
540000
550000
560000
570000

Appendices

Appendix A:
Summary catalogue

Table A1: Summary catalogue by context od material submitted as archaeometallurgical macroresidues (after Young 2005)

context	weight	sample	notes
15	225		slag - smelting
2124	75		3 slag fragments
2149	40		slag piece
2193	15		slag piece
2289	375		broken nub of slag with large charcoal
2307	25		slag piece
2358	310		massive worn burr fragment (smelting slag)
2458	335	220	fired clay
2481	120		smelting slag
2631	8700		11 p-c smithing hearth cakes and fragments (448 to 2350g)
2634	50		slag piece
2673	5		cinder?
2690	10		piece of dense slag
2958	310		small p-c smithing hearth cake
3022	370		broken slag pieces, 230 dense, 140 light
3024	200		slag sheet
3047	165		smelting slag
3051	30		lining
3069	25		slag nub
3107	445		probable smelting slag
3116	50		4 slag pieces
3118	25		flowed slag fragment
3164	11120		smelting slags and lining
3218	20		2 slag pieces
3258	155		9 balls of corrosion
3268	170		smelting slag
3278	5		2 slag pieces
3416	365		small p-c smithing hearth cake
3549	34940		furnace bottom, plus collection of fragments and 810g of fired clay
3629	1325		830g of slag debris and 495g of fired clay
3634	10190		3350g slag fragments, mainly burr area, with 6840g of fired clay
3635	9765		1760g large furnace bottom fragment, approximately 3500g other slag debris and 4500g of fired clay
3806	185		4 irregular slag pieces
3845	275		small p-c smithing hearth cake
4055	865		slag/concretion

Table A2: Summary catalogue by context of subsamples submitted as archaeometallurgical microresidues (after Young 2005)

context	sample	notes	Flake h/s	Spheroids & spheroidal h/sl	Comminuted slag
2029	202	stone flake?	y		
2029	202	rust?			
2035	204	stone flake	y		
2165	209	stone flake slag	y		y
2169	210	stone slag flake sphere	y	y	y
2179	211	stone slag spheres flake	y	y	y
2185	212	stone rust flake	y		
2193	214	stone flake slag	y		y
2203	215	stone flake sphere	y	y	
2236	216	stone sphere		y	
2290	217	stone			
2389	244	clay stone			
2413	218	stone slag			y
2418	245	stone			
2418	245	clay stone			
2423	219	stone			
2458	200	stone clay rust			
2480	227	stone sphere flake	y	y	
2508	221	stone rust			
2616	224	stone flake	y		
2624	222	stone slag			y
2631	223	stone flake			
2644	225	stone flake sphere	y	y	
2646	226	stone slag sphere?		y	y
2724	228	stone slag spheres flake	y	y	y
2747	230	stone			
2843	229	stone slag sphere flake	y	y	y
2884	258	flake sphere stone rust	y	y	
2891	247	stone rust			
2895	246	stone slag spheres flake	y	y	y
2937	269	stone slag?			y
2956	232	stone slag			y
2958	233	rust slag flake sphere	y	y	y
3022	270	stone slag?			y
3024	262	stone flake sphere (large assemblage)	y	y	
3038	271	stone slag spheres flake	y	y	y
3059	234	stone slag spheres flake	y	y	y

3069	263	stone slag spheres flake	y	y	y
3071	235	stone flake sphere	y	y	
3089	257	clay stone			
3109	236	stone			
3114	261	stone slag spheres flake	y	y	y
3116	260	stone slag spheres flake	y	y	y
3118	259	stone slag flake	y		y
3164	268	stone slag sphere flake	y	y	y
3182	266	flake clay stone sphere	y	y	
3184	264	stone slag spheres flake	y	y	y
3191	265	stone slag sphere flake	y	y	y
3195	267	stone slag flake	y		y
3274	237	stone slag spheres flake	y	y	y
3451	254	stone flake	y		
3549	249	clay stone spheres		y	
3605	250	stone slag spheres flake	y	y	y
3628	253	stone clay slag flake	y		y
3629	256	clay slag spheres (big bag)		y	y
3634	281	clay stone slag big spheres (big bag)		(big)	y
3634	282	stone clay slag?			y
3634	283	stone slag sphere		y	y
3634	284	stone big spheres		(big)	
3635	279	stone clay slag (big bag)			y
3635	280	clay slag (big bag)			y
3639	255	stone flake	y		
3667	273	stone slag spheres flake	y	y	y
3719	276	stone flake sphere rust	y	y	
3847	277	flake stone sphere	y	y	
3880	278	stone slag spheres flake	y	y	y
3913	285	sphere flake stone rust	y	y	

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