St Michael’s Church, East Peckham
(Jeremy Hodgkinson)

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Honorary Editor

David Crossley, 5, Canterbury Crescent, Sheffield, S10 3RW

Honorary Secretary

Dr Judie English, 2, Rowland Road, Cranleigh, Surrey, GU6 8SW

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HUNTSBANK AND HOOKS WOODS, HADLOW DOWN, EAST SUSSEX

VIVIENNE BLANDFORD

Huntsbank and Hooks Woods are located just north of the easternmost end of the A272 near the junction of the A267 (Fig. 1). The land is steeply sloping in places and is dissected by tributaries of the River Uck. The northernmost tributary flows north-east—south-west where it joins another tributary flowing south-east—north-west. In some places these tributaries flow through the typical steep sides gill valleys of the High Weald. The area falls within the area of the High Weald Area of Outstanding Natural Beauty (AONB).

The geology of the northern part of the survey area consists of Wadhurst Clay whilst the southern part, mainly within Hooks Wood, is of the Ashdown Beds with the south-east—north-west tributary marking the junction of the two beds. The woodland has been replanted with some conifers with stands of chestnut coppice. In Hooks Wood there are some good specimens of coppiced hornbeam with small oak standards and chestnut coppice. The northern boundary of Hooks Wood has a good example of a now outgrown laid hornbeam hedge. There were some areas that were unable to be surveyed because of the nature of the steep sided quarries and, in places, abundant patches of brambles which were growing on the disturbed quarried landscapes.

Bloomery sites

1. In a flattened, roughly circular area uphill of a track and gill edge a reasonable concentration of slag measuring approximately 10m by 10m (TQ 5519 2473). Larger pieces of slag were spread down the gill

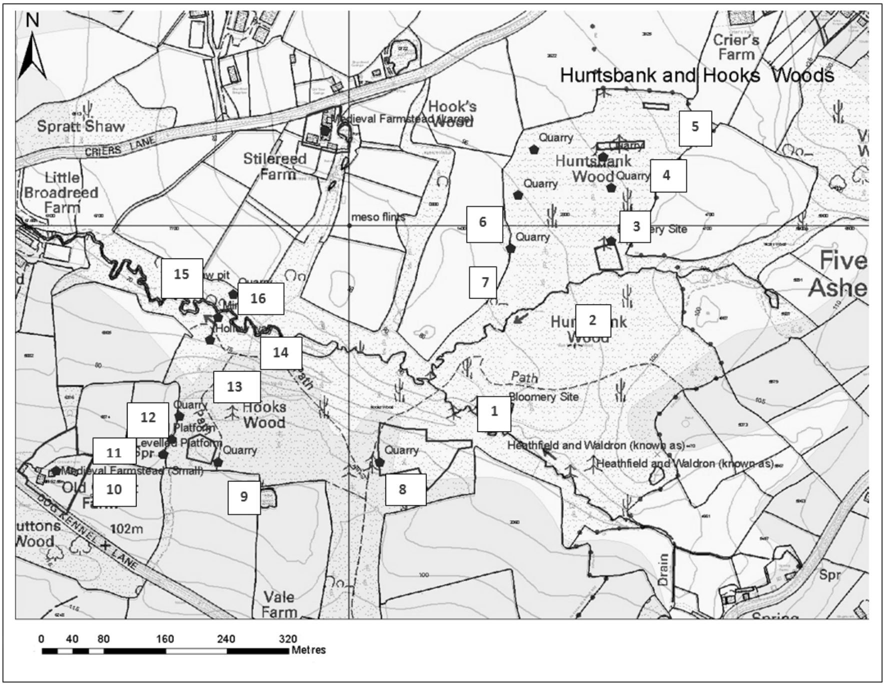

Figure 1 - Huntsbank and Hook Woods, Hadlow Down

side towards a stream, covering an area of roughly 15m by 15m, typical of raking slag away from the bloomery downhill. There was also a spread of mainly small pieces of slag spread out over a larger area. It is possible that after the iron smelting activities this now woodland was once a field and the iron has been scattered through ploughing or harrowing but there are no corresponding field boundaries or lynchets.

2. A flattened, roughly terraced area above the gill edge revealed a reasonable concentration of slag (TQ 5533 2498). A substantial amount of slag formed an artificially steep bank above the gill edge spreading down the gill side towards the stream and covering an area of roughly 30m wide with a drop to the stream of between 10-15 metres, typical of raking slag away from the bloomery. One large piece of slag found was estimated to weigh approximately 10kg. Also

there is a spread of mainly small pieces of slag spread out over a larger area. It is possible that, as in the first bloomery site, after the iron smelting activities what is now woodland became a field and the iron residue has been scattered through ploughing or harrowing but there are no corresponding field boundaries or lynchets present in this part of the wood. The field boundary close by to the north and east is also the parish boundary between Hadlow Down and Mayfield and is likely to have been a boundary for sometime. Tap slag was present. At TQ 5530 2497 is an area where the possible remains of roasted ore and charcoal were found at a depth of 10-15cm with some surface debris so this was obviously not a recent occurrence but was active some time in the past. The site is at top of confluence of two tributaries in very steep sided gills, made steeper at this location by the accumulation of waste.

Quarries

3. Quarry located in the Wadhurst Clay which was possibly used for iron ore extraction. The surrounding landscape was of disturbed ground with smaller mine pit type quarrying in the vicinity. One of the bloomery sites found nearby.
4. Linear quarry, possibly following seam of ore in the Wadhurst Clay. Smaller mine pit type surface quarrying; the quarry is within easy reach of the nearby bloomery sites. Nearby there was a possible ore roasting site with an abundant, 20m spread of roasted ore fragments.
5. A possible ore pit about 70m by 10m with the longer axis orientated E -W, in the Wadhurst Clay.
6. A possible ore pit about 10m by 8m with the longer axis orientated E-W, in the Wadhurst Clay.
7. A possible ore pit about 10m by 6m with the longer axis orientated N-S, in the Wadhurst Clay.
8. A large Quarry was recorded which lay partly in the Ashdown Beds with the majority of the quarry located in the Wadhurst Clay. This quarry is likely to have been used for iron ore extraction, and a test pit shaft at TQ 5515 2472 indicated a search for further ore after the pit was exhausted. Spoil heap with max height to 3m was noted in the middle of the pit with irregular surface quarrying within the pit. The

quarrying may have begun at the gill edge and worked backwards.

9. A large quarry located in the Ashdown beds, up to 15m deep, very overgrown and rough land with ill defined quarry edges. Probably part of a larger quarried area but the steep sides and overgrown nature of this quarry made it difficult to survey.
12. Large quarry in the Ashdown beds with squarish pond, water filled as possibly a later feature.
16. Large quarry in the Ashdown beds originally started as quarrying back from stream edge.
14. Single mine pit, close to stream and by a hollow way but part of a larger quarried area.

Other features

13. A short section of a hollow way, 2m deep and up to 2m deep which merges with flat woodland floor and drops down to stream level, closely passing a single mine pit.
10. Roughly oval level platform cut into woodland bank above a stream measuring 9m long and 4m wide, with obvious cross bank at right angle to stream and woodland bank, no evidence of charcoal. One of two found in close location to each other.
11. Roughly oval level platform cut into woodland bank above a stream measuring 9m long and 4m wide, no evidence of charcoal. One of two found in close location to each other. [1]
15. Saw pit 6m by 2m and up to 0·5m deep in an area of woodland with coppice hornbeam, oak standards and chestnut coppice. On the nearby field/woodland boundary good example of laid hornbeam hedge, now grown out.

Conclusion

Two bloomery sites were recorded, one of which had a significant amount of slag material tipped down the gill edge to form a substantial bank. At both sites it was noted that the smaller debris had been spread over a very large area and it was suggested this may have been spread by later agricultural practices. However no evidence of later field boundaries were found within this part of the wood which is unusual; where agriculture has receded, it usually leaves some evidence. The majority of the quarries found were likely to have been a source of ore for the bloomery sites and it is worth noting the Huggett's furnace site (operational in the 16th century) is reasonably close by although no evidence is visible of a connecting track way in the woods. Possibly all ore quarried in these woods was used in the woods and not transported out. It is difficult to judge what else may have been quarried here as some of the quarries in the Ashdown beds are large and may have been a source of material for the brickworks relatively nearby, in the same direction of Huggett's furnace. Perhaps some of the tiny unclassified local roads were used to transport material s to either of the sites. Surprisingly no charcoal platforms were found during this survey but this probably reflects that this woodland has been replanted and is recorded on the Historic Landscape Characterisation as replanted woodland.

FOREWOOD, CROWHURST, EAST SUSSEX

VIVIENNE BLANDFORD

Introduction

This woodland is owned by the RSPB and is on a south facing hillside and cutting through part of the woodland are steep sided sandstone gills to the south with flatter land to the north. The London to Hastings railway cuts through the wood in the north-east corner of the woodland. The geology is the Ashdown beds, with an outlier of the Wadhurst Clay cutting an irregular diagonal line through the southern part of the wood. The woodland, coppice with oak standards, is designated as semi-natural ancient woodland and it falls within the Area of Outstanding Natural Beauty of the High Weald.

The woodland has been planted, in the past, with sweet chestnut which was actively coppiced and charcoal made in situ. This was still being carried out in the 1950s-1960s and the charcoal was made in an iron clamp.[1] Today the RSPB is managing the wood and, once again, coppicing the chestnut. In some areas there stands of planted hornbeam which show signs of past coppicing. Along some of the woodland boundary banks there are fine examples of a now outgrown laid hornbeam hedge.

A partial woodland walk-over survey was carried out in Forewood, Crowhurst, in January and February 2014. The entire wood was not surveyed but concentrated around a known bloomery site, through the area of minepits and followed the older routes through the wood.

Previous Surveys

Straker recorded an extensive bloomery site of Roman type on the N side of a deep gill in Fore Wood at (TQ 7541 1297) where there was a large amount of cinder but no pottery had been found. A lump of impure iron, about 3 lbs. weight, some very pure ore, and beds of clay suitable for tamping were also found.[2]

In 1952 the Investigators comment, from a survey carried out by the Ordnance Survey Field Archaeology Division, said that there was no evidence of a bloomery at Straker's grid reference, an unlikely position. High above the nearest stream in a deep gill to the east at TQ 75521303, in the bed and banks of a stream immediately N of a point where it dropped into the gill, and S of the railway embankment, was a small but heavy concentration of bloomery slag, about 15m in diameter. It appeared to extend beneath the railway embankment.

In Cleere and Crossley another location was recorded, in a slightly different location at TQ 751130, where a small stream entered a deep gorge after falling over a low waterfall. On the north bank, where the gorge began to flatten out, there were a number of filled ore pits, surrounded by a scatter of slag. The slag continued along the top of the gorge for nearly 100 metres and there were several artificially levelled platforms. No dating material had been found then but an unworked bloom of iron weighing 1·25kg was found on site by Straker and subjected to metallurgical analysis.[3]

In the early 1990s a metal detectorist found a Roman coin approximately 50 metres north-west of the site, which was dated to between c.27 BC and AD c.260. Two excavations were undertaken in 1991 (no grid references supplied), one at each end of the site and no dateable evidence was found. In a later excavation in 1993, a small sherd of pottery, later identified as East Sussex Ware, dating to the late Iron Age or early Roman period, was found within the slag layer. Although the evidence is slight the site can be dated to within the first two centuries AD.[4] Further information on these excavations can be found on the Wealden Iron Research Group Database.

Historical Background

Crowhurst Forge was first mentioned as working in 1574, being held by a John Relfe but the Pelham family owned Crowhurst according to other documents. In the Crowhurst Court Roll of 1591 there is mention of an iron mill in Crowhurst said to be extant in 1556. The furnace was listed in 1653 and 1654, but the forge, in use in 1653 was out of action by 1664.[5]

A lease for 21 years at £160, dated March 25th 1629, between Thomas Pelham of Laughton and Peter and Richard Farneden of Sedlescombe, commencing on 3rd May 1627, concerns the lease of the manor house of the manor of Crowhurst, all outbuildings, orchards, gardens and land in Crowhurst, currently occupied by George Marten, which included the following:

> *Two iron mills which are the furnace and forge in Crowhurst, with bays, banks, walls, sluices, floodgates, waters, waterbays, coalplaces, (charcoal clamps)workmen's houses and iron houses, usually let with the iron works, and all the lands generally used with them.*

This included a piece of land and wood called the Forewood with coppice wood on it and stated that the wood could not be cut in the period three years before the lease expires; with an instruction to coppice and enclose Forewood, leaving 12 standards per acre; and to cut Brakes Coppice, Rackwell Coppice and Forewood Coppice. They could dig 600 loads of mine (ore) from the demised land and from the copyhold tenements in Crowhurst, filling in the pits to protect the copyholders and ensuring that they used the marl produced on their copyholds (not mining in any ancient meadow or sown land) paying Thomas Pelham £1.13s 4d every year for each hundred loads.

Thomas Pelham could continue to operate the furnace and forge until his stock of coal, mine and iron is exhausted up to 24th June 1629.[6]

Mine Pits

From a map produced using the Environment Agency's LiDAR, flown in 2008, available for part of the woodland, an extensive area of mine pits can be seen stretching in a wide 'L' shape above the steep sided gills on the flatter land (Fig. 1). This corresponds, almost exactly to the irregular line of the Wadhurst Clay outlier at the junction of the Wadhurst Clay and

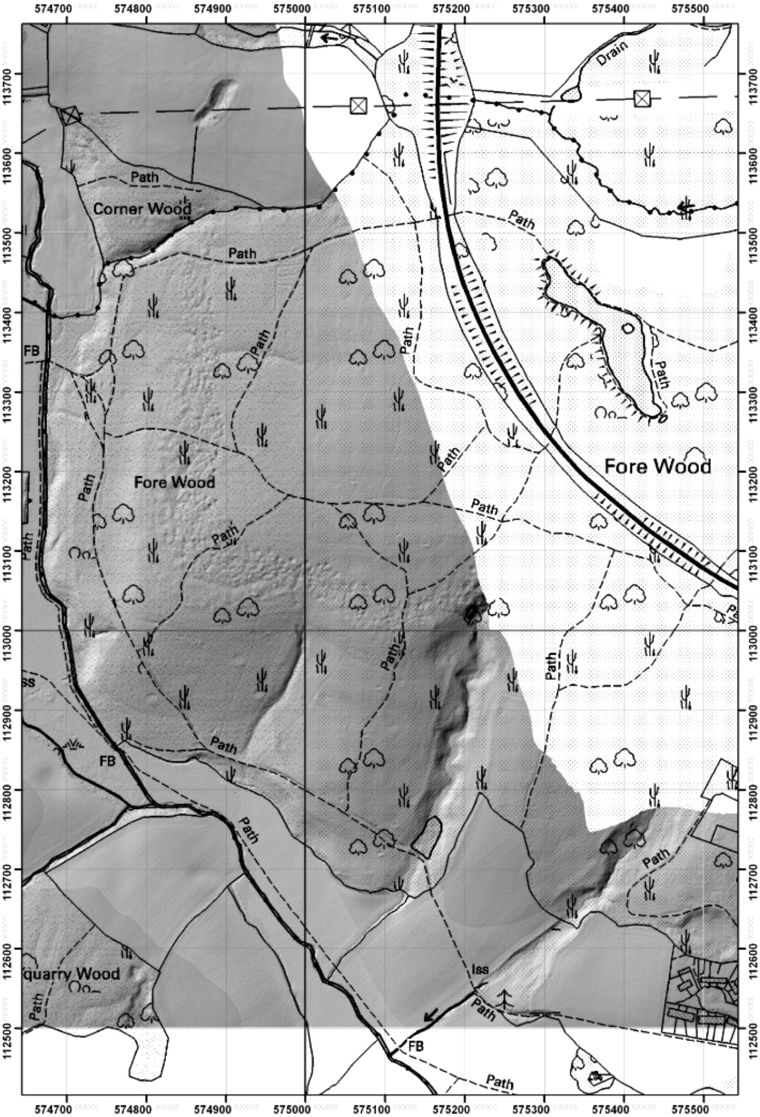

Figure 1 - Forewood, Crowhurst; partial LiDAR survey (Environment Agency)

Ashdown Beds. The landscape is typical of a mine pit type of shallow quarrying with a gently deformed pitted landscape, with some pits water filled and some dry. The majority are round pits some 2m in diameter and up to 2m deep. There is some evidence of shallow linear excavations where the seam of ore was followed horizontally. Around TQ 7553 1296 the mine pits stop at abrupt change of slope with random excavation with shallower pits down slope and deeper conical ones up slope in this location, indicative of following a seam of ore.

Sometimes the pits found towards the top of the slope are deeper and more conical with less evidence of an exit,, whilst those lower down the slope are shallower, sometimes linear or linked together and have drainage channels or exit paths. Spoil is often heaped haphazardly and overall there seems to be no overall systematic method of excavation. Possibly these pits were excavated during different periods. There are several hollow ways, now longer in use than run down slope from the mine pits to connect with a well established routeway, running roughly east west along the bottom of the wood. This is the connecting old 'road' towards Crowhurst in the east and towards Battle to the west.

Known Bloomery Site

The bloomery site is located on the western edge of a very steep roughly north south short gill at the bottom of which runs a small stream. For a short section it has precipitous sides up to 10m deep and the bloomery site is located at almost its highest point. Around the bloomery site, described by Cleere and Crossley[7] and centred on TQ 7520 1305, the ground is much disturbed through a mixture of mine pits, slag heaps, robbed out slag heaps and some possible working platforms. Some mounds of slag have been left in situ and are very attractive, moss covered lumps with relatively old stunted hornbeam growing on top of them. However because the site has been much disturbed through mining, bloomery production, the robbing out of slag and past excavation it is a difficult site to understand.

There are several mine pits very close to the gill edge and surrounded by slag debris. These mine pits tend to be more conical and often water filled. Those that are dry have slag debris scattered in them. It would be impossible to say whether these were contemporary with the

Figure 2 - Forewood, Crowhurst; bloomery site.

bloomery site or came later. However judging from the large amount of slag still in situ it might have been difficult to dig through the slag at a later period. At the bottom of the gill, cut back from the stream bed is a horseshoe shaped quarry at TQ 7521 1302 and perhaps this is the original location of the iron mining where the ore would have been exposed in the profile of the gill and could be contemporary with the bloomery site. The slag, unsurprisingly spreads all the way down the precipitous side of the gill and in the debris thrown up from a rabbit burrow, the slag appears to be at some depth, even at the bottom of the gill. At TQ 7519 3059 is a roughly circular, 5m by 5m levelled working platform covered with an abundant scatter of small pieces of slag (Fig. 2).

Unrelated Slag Heaps

At TQ 7540 1308, close to one of the tracks through the wood is a large, almost crescent shaped heap of moss covered slag. This is obviously a dump of left over slag which was used to metal many of the tracks through this wood. The survey was undertaken in the winter of 2014, the wettest on record since the 18th century, and it was clear that this is still a very wet wood with pathways that would soon become impassable unless some remedial action had been taken. The large number of saw pits found in the wood suggests that this was an active working wood for a long period of time and good tracks would have been needed to extract the sawn timber.

Hollow ways and Trackways

A hollow way which started at the southern part of the wood at TQ 7516 1268 and curved through the edge of the wood, close to the south-western boundary, was, in places, an excellent example of a well used hollow way of some antiquity. Looking into the wider landscape and the first edition OS map it was evident that this was once a direct route from Crowhurst village and the furnace and forge to the south and leads, in the north, to the Powdermills and Battle. A north-south smaller hollow way/track turns off, at TQ 7480 1298, from this track and leads north, uphill, directly to the area of mine pits. This track is no longer used and another one has been made, slightly to the west. Another north-south track leaves the east-west track at TQ 7504 1278 and heads uphill towards the eastern extent of the mine pits and the reserve. This track is still in use and has, in places, been cut into the hillside to level and suggests a path that has been in use for a considerable time. Many of these main paths contain varying amounts of slag which was probably taken from the bloomery site within the wood. As previously stated the bloomery site has been robbed out and dumps of slag can be found next to the tracks.

Charcoal Platforms and Sawpits

A number of charcoal platforms were recorded of similar build and had bluebells growing on the surface, perhaps an indication they had not been used for sometime and may date back to the 16th century iron working in nearby Crowhurst. Six sawpits, all close to tracks, and mostly in good condition, were found. The high number of sawpits, closely spaced together, along with the chestnut plantation this gives an indication of well managed woodland probably during the 18th and 19th centuries.

Conclusion

From the documentary evidence it is clear that Forewood was being used as a source of iron ore and charcoal and the hollow ways give a direct link out of the wood towards the furnace and forge in Crowhurst operating in the latter 16th through to the second half of the 17th century.[8] It is interesting to note how carefully their natural resources of wood and ore were managed and instructions given to make good both the land and the woodlands after extraction had taken place. There is good evidence that a by product of mining, marl, was used on the fields, whilst not mining any valuable agricultural land such as meadows and sown fields. We even have a cost for the ore, payable to the owner, Thomas Pelham, at £1 13s. 14d. every year for each hundred loads. It is rare when it is possible to link an existing site for ore extraction and charcoal making with such precise documentary records and find the archaeological evidence still existing in the same wood today.

The wood continued to be actively managed with evidence of plantations of sweet chestnut and some hornbeam. Six saw-pits were found close to the tracks and oral evidence suggested that the wood was being managed up to the second half of the 20th century with the production of charcoal in iron kilns.

The robbed out slag heaps are often moss covered and some have twisted, stunted hornbeam growing on them. In the wet winter of 2014 many of the mine pits were filled with water and in the late winter sunshine this is a very attractive, peaceful wood which once would have seen much industrial activity and presented a completely different atmosphere.

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A VIEW OF EXPERIMENTAL SMELTING PRACTICES AND AN INTERPRETATION OF SOME OF THE UNDERPINNING THEORIES

JONATHAN PRUS

The over-arching aim of the bloomery smelting experiments carried out by WIRG members has been to replicate the results achieved by Wealden smelters in the past. Really this means replicating ancient smelting residues whilst making a bloom "efficiently" (in this context *efficiency* means leaving very little free FeO in the slag; very little reducible material is found in Wealden bloomery slag). With the exception of one experiment that produced a bloom with a pre-processing mass of about 2.5kg., most recent attempts have 'failed' in the sense that they have not produced a significant amount of workable iron. However, this would be a rather dismal reading and neglects the value of negative results that compel a reconsideration of theories and assumptions employed.

Most of this note is concerned with such reconsideration, but before continuing there are two results to report, both important in assessing ancient practice. Firstly, several sets of measurements have established that convection will drive enough air through a bloomery to sustain the production of the carbon monoxide required (see note 1 below). Secondly, the most recent test smelt was run from beginning to end with no closed (or 'positive') connection between the air-nozzle and the tuyere (see note 2 below). The new tuyere was a trombone-ended tube inserted into the furnace wall. This worked perfectly well whether the nozzle was within the trombone-end or mounted 100 mm in front of it. These two results, taken together, actually increase the range of possible bloomery smelting practices; but that is a reality to be dealt with.

It has been suggested that the factors that have led to ‘good’ results in the past could be identified by means of statistical analysis. Unfortunately this approach is not available because the number of variables that have changed exceeds the number of experimental results. We may, however, identify the major changes that have occurred and then return to the underlying theory to search for better ways of rediscovering ancient practices. The most important change has been replacing the original shaft furnace with a new one based on excavations at Little Furnace Wood, Mayfield. This is a much larger domed furnace. The second major change has been the source of iron ore. Thirdly, in the absence of ‘good’ results the blowing rate has been increased to a point at which exceeds (the change in size taken into consideration) the rates applied to the dismantled shaft furnace. The fourth major change has been a change from hand-worked bellows draught to continuous electrically blown draught; although the net airflow has been comparable, the possible effects of changing from interrupted to continuous input have been neglected. Fifthly, tuyere size and position have been varied. Sixthly, the ore:charcoal ratio has been varied.

Aspects of smelting practice

The WIRG smelts do not take place in intellectual isolation. There is a community of experimenters that spans many countries and their comments, lore and publications are taken into account. Much of this work, like that of WIRG, is unpublished. To avoid presenting a misleading impression of reliance on published sources, no specific attribution is made for common ideas presented below.

It is widely believed that the production of a convincing bloom is marked by the production of slag that flows from the furnace. Such flows (either into a pit or from a slag tapping arch) are evidenced in every bloomery slag heap in the archaeological record. This is not a peculiarity of the Weald. It is a result of the ‘direct process’ method of making iron. The amount of flowed slag in recent WIRG tests has been miniscule. By and large the slag has frozen below the tuyere and much of the iron produced has been trapped as flakes in a slaggy matrix. This matrix is composed of ore that has been reduced (it has lost its magnetic attractiveness). Some of it appears to be Wüstite or FeO (this is the part in which iron flakes have been trapped). Some of it has partially melted, but not flowed as required. Iron flakes in a slaggy matrix rarely occur in the archaeological record; they are an aberration.

One possible interpretation of this arrested process is that not enough air has been introduced into the system and that insufficient heat has been generated. This view is no longer tenable. Although the new bell -shaped furnace is much larger than its predecessors and although (at first) blowing rates were proportionately lower, the last two trials have had blowing rates well in excess (all proportions duly guarded) of those that produced satisfactory blooms in the older shaft furnace. To summarise:

- More air and more charcoal are being consumed, and we observe that the upper parts of the charge are hotter than expected, reflecting the liberation of more heat
- The temperatures achieved are high enough to reduce the ore and make at least some iron
- The temperatures achieved are not high enough to sinter most of the iron into a bloom
- The temperatures achieved are not high enough to melt the slag, or to allow it to collect as a tappable body at the base of the charge.

This is paradoxical, but there is a probable solution in three related parts. These will be dealt with in turn:

- Managing the heat liberated by burning charcoal
- Reconsidering the effect of abandoning the bellows in favour of a continuous blower
- Managing the length of time during which the ore is subject to reducing conditions.

How well does charcoal burn?

It is a matter of common observation that charcoals from different wood species have different properties. In particular it is often said that some charcoal species 'burn hotter' than others. It is very unlikely that, kilogram-for-kilogram, there are wide variations in the total heat liberated when different species burn: the variations will, almost certainly, be confined to variations in water, mineral and volatiles content. But burn differently they do. The differences between charcoal species are probably due to different mechanical properties, pore structure etc. The similarities in the energy released on combustion are due to uniformity of the bond energy released as each atom of carbon forms a molecule of carbon dioxide.

In the present context it is noteworthy that a small narrow blast on a single spot of charcoal can be observed to produce a higher local temperature than a larger more diffuse draught. Managing the shape and velocity of the blast may be of key importance.

We can represent the oxidation of carbon with the expressions below:

$C + O_2 \rightarrow CO_2$ (1)

$C + CO_2 \leftrightarrow 2CO$ (2)

The first of these releases heat. The second requires most of the heat released by the first (see note 3 for further discussion of this point.). If we consider (1) and (2) together as a heat releasing process, we find that they release less than one third of the heat of (1) alone. The excess energy is carried away as chemical energy in the carbon monoxide that burns off at the top of the bloomery. Because most of the air is relatively un-reactive nitrogen, simply adding more air to the bloomery system does not allow it to become hotter indefinitely; more and more energy is used up heating up the nitrogen throughput until all the heat generated goes to bring the input gas to the temperature of the fuel and there is a point at which no further temperature rise is possible. Although it depends on initial conditions, it is unlikely that the combined reactions (1) and (2) could heat a bloomery much above 1200ºC. We find evidence that, locally within the furnace, temperatures can exceed 1200ºC: it is widely accepted that cast iron can be produced, accidentally, within a bloomery furnace.

Charcoal is chemically highly reactive at the temperatures at which slag melts (say 1050ºC to 1200ºC) and, at these temperatures, almost all the carbon dioxide is transformed to carbon monoxide if there is excess carbon present. This reaction is quick, but not instantaneous, so there has to be a zone in front of the tuyere where reaction (1) is dominant and much higher temperatures can be achieved. The temperatures in this zone would also limited by the need to heat up nitrogen, but that limit is never reached because the charcoal becomes more and more reactive as it gets hotter and the production of CO is speedier.

WIRG members have never tested the temperature of this hot zone because of the exorbitant price of effective sensors. There appears to be no published description of a hot zone that bears on the present discussion, although Schmidt (1997) reported some measurements up to 1800ºC that fuelled a rather ill tempered debate. Consequently the *size* of this hot zone has never been measured, though experimental bloomery smelters are all agreed that blooms form below the tuyere and so must either pass through the hot zone or by-pass it.

However, we wish to get a higher temperature in this hot zone without increasing air throughput which would use more charcoal and so speed the charge though the furnace. How is this to be achieved? Part of the solution lies in the fact that net heat production in this system is a function of the amount of air input. If we can control the way in which the incoming air interacts with the hot zone we can control the size of that zone; all other things equal, the temperature gradient between the hot zone and the rest of the charge must be increased. The suggestion here is that the turbulence of the incoming gas must be increased so that there is a larger volume within which reaction (1) predominates. In part this could be achieved by increasing the velocity of the incoming air by reducing the diameters of the air nozzle and of the tuyere. There is anecdotal evidence from elsewhere that if the blast is changed in this way the bloom may adhere to the furnace wall opposite the tuyere.

What effect do the bellows have?

Although the data are not clear-cut, the change from hand-plied bellows to an electrically driven blower is associated with the production of fewer blooms. Although the established practice, using two pairs of bellows, was to make one blow follow another, the effect was to produce an intermittent draught. The measurements of this draught appear to have been quite accurate (to within a few percentage points) and cross-check well with the record of charcoal added.

An effect of varying the draught must have been to increase the turbulence of the furnace gasses. As argued above, increased turbulence will increase the volume within which reaction (1) predominates.

There is nothing special about air introduced by hand-plied bellows; any apparatus that supplied air in puffs would suffice. There is no necessity to seek 'authenticity' for its own sake, but it would be pointless and misleading to use apparatus delivering a result that could not be matched to any plausible ancient system. This sets a limit on the pressures that can be employed and this, in turn provides a lower limit on the internal diameters of both the air nozzle and the tuyere. These issues are discussed elsewhere (Prus 2011). Broadly, the pressure that can be raised by bag-bellows (and, for that matter board bellows) lies between 3000 and 4000 Pascals and the nozzle requires an internal diameter of at least 10mm. To test thoroughly the hypothesis that air velocity is a critical factor this nozzle diameter should be less than the 15mm minimum tried in one previous test (in a two-tuyere configuration). Note 2, below, suggests a tuyere cross-sectional area not much different to twice the nozzle's.

The retention time problem

One inevitable result of increased blowing rates is that the charge spends less time at the temperatures required for reducing ore to iron. This time must be maximised to allow several complicated processed to complete. These include:

- Reduction of Fe_2O_3 to FeO
- Reduction of FeO to Fe
- Formation of a fluid slag to carry away Si, Al and other gangue components
- Sintering Fe into blooms.

The shape of the new furnace and the recent increase in relative blowing rates means that this 'retention time' has been, very approximately, halved with reference to bloom-producing smelts in the older shaft furnace.

To double (for example) the retention time does not necessarily mean halving the blowing rate; the relationship between the two is by no means that simple. A huge proportion of the heat generated in the early stages of a test goes into the fabric of the furnace. The walls act as a huge heat reservoir. Once the furnace walls become hot (perhaps around 1000ºC) the temperature gradient across the inner 100mm drops quite dramatically and that layer begins to act as an insulating blanket. This is the beginning of a virtuous circle; less heat loss to the walls means less air needs to be introduced *via* the tuyere which in turn means that less of the non-reactive nitrogen carries off heat at the top of the apparatus.

The literature of Wealden iron contains several references to the bloomery process lasting a few hours (most notably and most recently Hodgkinson 2008, 23). There is no doubt that the bloomery process is ‘batch’ rather than ‘continuous’, but that gives us no information about the length of ‘a few hours’. The WIRG tests may well have been too short and successful tests may be used to supplement the meagre historical record. As a point of reference, perhaps the charging period should be set to the maximum in the WIRG test record (over forty smelts) but be preceded by a preheat to ensure that furnace wall temperature reaches 1000ºC before ore is added to the charge.

Tuyere position

The position of the tuyere relative to the throat and the tapping arch does not matter a great deal in the context of the augment developed above. However, it has become clear that the lower part of the body of fuel below the tuyere and the floor does not become hot enough to allow the free-flow of slag, even if the slag itself is liquid. This tuyere level was chosen as a possible interpretation of the Romano-British furnace excavated at Little Furnace Wood. Some part of this interpretation must be incorrect and lowering the tuyere may be indicated. An additional advantage of a lower tuyere would be a corresponding increase in retention time.

Note 1. Convection in bloomeries

Chimney effect and fuel beds

Chimney effect may be calculated from the equation:

$$\Delta P = cah\left(\frac{1}{\theta_{out}} - \frac{1}{\theta_{in}}\right)$$

where ΔP is the pressure change due to chimney effect, *c* is a constant with value 0.0342, *a* is atmospheric pressure (in Pa) and *h* is the effective height of the chimney (metres). Θ_{out} is ambient air temperature (in Kelvin) and Θ_{in} is average flue gas temperature (also in Kelvin).

The difference between ambient pressure and the pressure within the WIRG bloomery (with the blower off) has been measured on a number of different occasions. The pressure within the furnace is always lower than atmospheric when the blower is off and the values are always consistent with the expression above.

To use the information contained in the result ΔP, we need some insight into the work needed to get gas through the fuel bed. The resistance that the fuel bed offers to the passage of gas goes down as the cross-sectional area though which it passes goes up. The resistance offered is increased as the depth of the fuel bed increases. We can therefore represent the relationship between gas flow, pressure and fuel bed dimensions as follows:

$$Q = \frac{pak}{h}$$

where *Q* is the airflow (cubic metres per second) , *p* is pressure difference (Pa) , *a* is cross-sectional area (square metres) and *h* is the depth of the fuel bed (metres) (which may be different to the *h* of chimney height). *k* is a calculated constant. *k* has units $m^2s^{-1}Pa^{-1}$ and can be understood as the volume of gas that a pressure of one Pascal would move through a metre cube of fuel be in one second.

This is a linear function but we know from first principles that as gas speed increases the work required to move it faster increases in a non-linear fashion. Nonetheless, at low pressures within a narrow range, the gas behaviour is, effectively, linear.

k can be estimated from two data sets of pressure measurements with different bloomery furnaces. The first of these (Jake Keen, 24/2/13) was for a tall convection-only bloomery. The second (WIRG 6/7/13) was for a pump-blown bloomery. The former differed from the latter in that it was charged from 2·5m above the fuel bed which was not, therefore, in any way compacted or riddled like the latter. The calculated k-values are 0·006 and 0·004 respectively. The variance in the pressure measurements is such that we should perhaps say that, for the time being, we think k is about 0.005 for heterogeneously sized charcoal and pea sized ore.

From four separate tests of a convection-only furnace we know that enough air can be drawn through a bloomery by the chimney effect alone. However, it has become clear that the velocity of the input air through orifices of the requisite size is too low to create the hot spot needed for bloom formation.

Note 2. 'Open' nozzle-to-tuyere connections

The new tuyere was prepared by Mr. J. Baillie who beat the end of a section of steel pipe into the required shape. This was inserted into the fabric of the furnace and pre-tested on an uncharged and unheated furnace whose other entrances and exits (principally the tapping arch and the throat) were blocked. The pressure maintained in the sealed furnace was measured using a hand held electronic manometer. This pressure was consistent with that predicted from the expression:

$$P = \frac{1}{2} \cdot \mu \cdot \left[\frac{Q}{a} \right]^2$$

(where P is pressure given in Pascal, μ is the density of air given in kg per cubic metre, Q is the flow of air through the blast pipe given in cubic metres per second, and a is the cross-sectional area of the blast pipe).

Separate bench-top tests had confirmed that this is a reasonable model for the pressure developed at an open or non-positive connection. The present writer will supply the reasoning leading to, and dimensional analysis supporting this expression for critical comment; request jonathan@avens.co.uk.

It will be evident that the pressure developed is independent of the size of the tuyere but critically dependent on the velocity of air at the nozzle. Further inspection will show that the larger the tuyere the more likely that there will be unwanted egress of furnace gasses at that point. There was no such egress in the bloomery trial and it may be suggested that the cross sectional area of the tuyere should not exceed twice that of the nozzle.

Although a steel tuyere was used in this test, it quickly became apparent that a properly shaped hole in the furnace fabric would have the same effect. This observation should inform future archaeological investigation of Wealden bloomery sites.

Note 3. Carbon to carbon monoxide. The Boudouard Equilibrium

The enthalpies for the oxidation of carbon to carbon dioxide and carbon monoxide can be represented as follows:

$$C + O_2 \rightarrow CO_2 \quad \Delta H = -393{\cdot}5\text{kJ/mol} \qquad (1)$$
$$C + CO_2 \leftrightarrow 2CO \quad \Delta H = 283\text{kJ/mol} \qquad (2)$$

And the oxidation of residual carbon monoxide (at the top of the bloomery) as follows:

$$CO + (\tfrac{1}{2})O_2 \rightarrow CO_2 \quad \Delta H = -110{\cdot}5\text{kJ/mol} \qquad (3)$$

It will be seen that stage (2) uses up most of the heat that has been released in stage (1) and that this implies rapid cooling at the edge of the hot zone where the CO is formed. This chemical energy is released as heat in the flame at the throat of the bloomery. Re-arrangement of (1), (2) and (3) (using Hess's Law) shows that the heat liberated by combustion of C to CO is 110·5kJ per mol. This is just 28% of the heat liberated by burning to CO_2 alone.

This large difference between burning to CO and burning to CO_2 also explains why an 'air furnace' works (Hodgkinson 2008, 60-62) and why a temperature well in excess of 1200°C could be maintained in the hearth of a charcoal blast furnace.

Reaction (2) is fully reversible. At around 400°C (or below) the gas mixture in the presence of excess carbon is in equilibrium when almost all the gas is CO_2. Above 1100°C it is in equilibrium when almost all of it is CO. This is known as the Boudouard Equilibrium, named for the chemist who elucidated it in the early twentieth century. As CO cools it releases both heat and particulate carbon, but this reaction is fastest at the high temperatures at which it wants to reduce CO_2 anyway. Particulate carbon is released in the columns of tall blast furnaces, but not in bloomeries in detectable amounts; the cooling from the hot zone is too rapid.

Practical proof of the fact that there is an asymmetry between the heating and cooling of bloomery gas throughput is that, almost as soon as the charcoal begins to burn white there is a combustible amount of CO that must be burnt off at the top of the furnace.

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WEALDEN ORES AND SMELTING POTENTIALS TO PRODUCE A BLOOM - A NOTE

ALAN F. DAVIES

Introduction

Smelting produces an iron bloom from available iron over and above that consumed with silica in forming most usually fayalite slag (Fe_2SiO_4 or $2FeO.SiO_2$) from low calcium ores. Silica is available mainly from calcined ore, from small quantities in charcoal burden charge and from eroding furnace walls during smelting. This combined silica demand for iron influences availability of excess iron in the ore to produce a useful bloom. This note shows results from ranking Wealden ores and their 'potentials' to produce a useful quantity of bloomery iron.

Background and Method

Using molecular weight proportions fayalite requires, in addition to oxygen, two molecules of iron plus one molecule of silicon. Iron to silicon ratio can be represented by (2x56): 28 = 112:28 or as 4:1 to make one molecule of fayalite slag. For example some results of bloomery furnace trials gave an average ratio of 4·05:1 for eight bottom melting slags produced using two different ores.[1] The premise is that if an ore cannot provide more than this 4:1 proportion of iron to silicon when calcined then no surplus iron is available for bloom formation however efficiently a furnace is operated.

Other analyses show charcoal can provide typically around 0·15% of its weight as silica compared with good calcined ore providing typically 10% to 15%. So this study focuses on main silica content being derived from mined ore alone and extent of exceeding the critical value.

However extra silica from charcoal/furnace wall erosion would reduce iron quantity still more for forming a bloom.

Eight siderite and three limonite Wealden ores, submitted by members for analysis over the past three years, were each re-assessed for potential to supply iron in excess of the critical ratio. As-mined ores and equivalent calcined compositions for total iron%, silicon proportion in silica+insolubles quantities and iron:silicon ratios were determined. (Silicon (Si) % content = 0·47 × silica (SiO_2) % content).

Findings

Table 1 shows the as received and calcined values for each ore type: Sid. = Siderite, Lim. = Limonite.

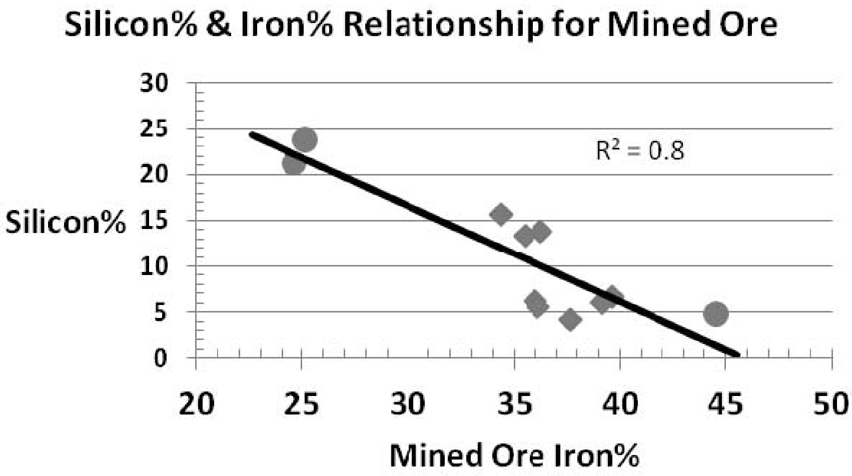

Figure 1 - Mined Ore Silicon% and Iron% Relationship

Using Table 1 data Figure 1 shows relationship between proportion of iron and silicon content from source rock environment. Siderite shows clustering over the range 34% to 40% total iron and from about 4% to 16% for silicon content. Limonite ores, shown by circles, follow the general trend but fall outside siderite range.

OreType:	Sid.	Sid.	Sid.	Sid.	Lim.	Sid.	Sid.	Lim.	Lim.	Sid.	Sid.
Ore Identity	**QW**	**Ashdown 3**	**Ashdown 2**	**Ashdown 1**	**NB Crust**	**BWS 1**	**BWS 2**	**LM W**	**Ashdown 4**	**SFB**	**NB Core**
Volatiles %	27	23·39	25·04	25·16	15·27	31·13	29·04	12·9	16·89	29·86	30·77
SiO_2+Insols. %	10·5	25·49	21·28	21·99	8·54	6·02	9·28	44	41·66	9·53	8·25
SiO_2 Factor in Insolubles	0·98	1	1	1	1	1	0·99	1	0·9	0·98	0·98
Total Fe %	**39·61**	**34·35**	**35·51**	**36·24**	**44·53**	**37·64**	**39·13**	**25·15**	**24·6**	**35·96**	**36·15**

Calcined Ore Values

Roasting Factor	1·37	1·31	1·33	1·34	1·18	1·45	1·41	1·15	1·20	1·43	1·44
Silica+Insols.%	14·10	33·27	28·39	29·38	10·08	8·74	12·95	50·52	45·11	13·32	11·68
Silicon %	6·63	15·64	13·34	13·81	4·74	4·11	6·09	23·74	21·20	6·26	5·49
Total Iron %	**54·26**	**44·84**	**47·37**	**48·42**	**52·56**	**54·65**	**55·14**	**28·87**	**29·60**	**51·27**	**52·22**
Iron:Silicon Ratio	**8·19**	**2·87**	**3·55**	**3·51**	**11·09**	**13·30**	**9·06**	**1·22**	**1·40**	**8·19**	**9.51**

Table 1 - As received and calcined ore analyses and iron:silicon ratios

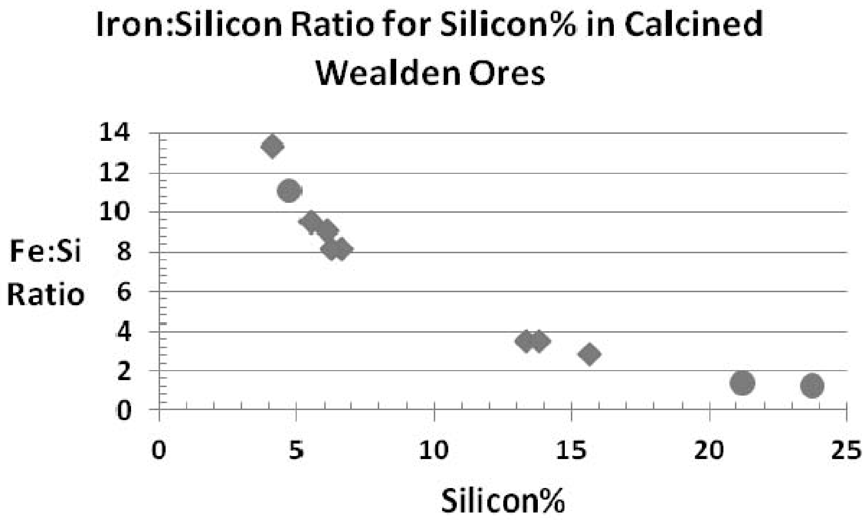

Figure 2 – Iron:Silicon Ratio for Silicon% Content in Calcined Ores

Figure 2 shows relationship between Iron:Silicon ratios and silicon contents plus, importantly, the critical Iron:Silicon ratio value of 4:1 for fayalite production. Significantly, five siderite ores and one limonite ore exceed this critical ratio with values from about 8:2 through to 13:3. All these indicate high potential for bloom formation.

Conversely three siderite Ashdown Beds and two limonite ores fall below the line. Even though Ashdown Beds ores each have total iron of about 35% their higher silica values of about 23% each prevent the required ratio being reached. Whilst two are very close it is unlikely their iron content would offset fully their silica contents to form a bloom. On this criterion they would be unsuitable for smelting. A similar reason applies for the two high silicon content limonite ores.

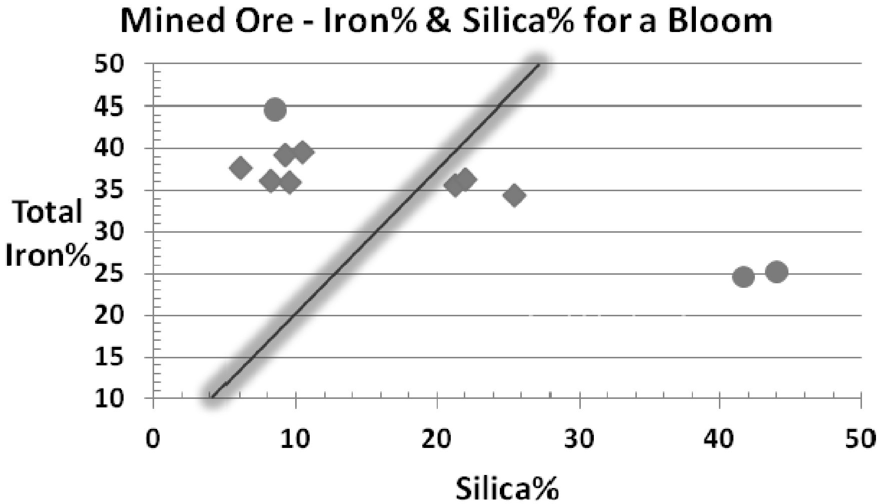

Figure 3 – Mined Ore Characteristics for Bloom production

Figure 3 shows analyses reinterpreted into as-mined ores for total iron% and silica% content. A clear dividing line shows those Wealden ores at top left well capable of producing a bloom and others unlikely to do so. Similarly Espelund expressed a view that 4% silica in bog iron ores may be a minimum for desired slag production whilst 20% or more silica gives fayalite slag but little or no metal.[2] However lower iron and silica ores, whilst potentially giving a bloom, would most likely be uneconomic from lower iron quantity available. So ores of less than 25% iron were unlikely to be used for bloomery smelting.

Ranking of Ores

Table 2 shows several Wealden calcined ores rank by Iron:Silicon ratios as likely to form a bloom.

Ore	Fe:Si Ratio	Ore Type	Potential
Beacon Wood Stream 1	13·3:1	Siderite	High To Good
New Barn Crust	11·1:1	Limonite	
New Barn Core	9·5:1	Siderite	
Beacon Wood Stream 2	9·1:1	Siderite	
Quarry Wood	8·2:1	Siderite	
Stepney Ford Bridge	8·2:1	Siderite	
Ashdown 2	3·6:1	Siderite	Unlikely to None
Ashdown 1	3·5:1	Siderite	
Ashdown 3	2·9:1	Siderite	
Ashdown 4	1·4:1	Limonite	
Lower Morgay Wood	1·2:1	Limonite	

Table 2 – Iron:Silicon Rankings for Wealden Ore Samples

Conclusions

Calcined siderite and limonite ores having Iron:Silicon ratios well above 4:1 show good/high potential for producing a useful bloom. However mined ores with less than 25% iron and 10% silica, whilst potentially capable in an efficiently operated bloomery, would most probably be uneconomic to smelt.

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EXPLORING HISTORICAL CALCINING EFFECTIVENESS FOR WEALDEN ORES

ALAN F. DAVIES

Introduction

Historical experience is that mined iron ores benefit from roasting or calcining to remove volatiles and impurities, fracture ore and increase weight proportion of iron as iron oxide. All this enables easier ore breaking and sizing for furnace charges, helps in furnace gas and particulate carbon penetration giving more efficient ore reduction to iron and well-regulated furnace operations.[1]

Extent of calcining is usually assessed visually by colour change. However furnace metal output and productivity will be lower if a weighed quantity of charged ore is assumed to be fully calcined just from colour alone. Whilst any under-calcined ore converts fully during smelting the actual iron weight content added for an under calcined furnace charge will be lower.

Practically, however, maintaining the right calcining temperature control during historical pit roasting may be challenging. Hot centres, cooler peripheral zones, fluctuating temperatures, variable lump ore sizes influencing internal heat flows, extent of any manual churning of pit contents or even covering in different ways are all factors influencing quality of lump ore conversion.[2]

This study explores and compares instances of historical calcination success by examining supplied calcined ore samples from a number of time periods. These include Romano-British 1st–3rd century, medieval 11th-13th century, mid-18th century and a 2012 specimen. Even for limited number of samples the null hypothesis adopted is no significant differences in calcining success between samples over periods. Historical context and physical characteristics of ore samples are considered as well as ore changes during calcination. Methods are shown for measuring calcining effectiveness for comparing calcining practices over time, as well as indicating a calcined ore's potential to produce a bloom.

Acknowledgements

The author would like to thank WIRG members Jeremy Hodgkinson (Bardown, Wadhurst, Sussex sample) and Mark Withers (Oaklands Park, Sedlescombe, Sussex sample) for kindly providing Romano-British calcined ore samples. Also to Judie English for providing the Alfold Surrey Medieval sample, Robin Barnes for kindly providing a mid-18th century sample from Fernhurst furnace roasting pit and WIRG smelting team for the Beacon Wood Stream (BWS) sample.

Historical Context

Romano-British Sites[3]

By the end of the 1st century Roman iron making was in progress at most coastal sites e.g. Oaklands Park and then by mid-2nd century at some High Weald sites such as Bardown. However by mid-3rd century strong indications were many other sites had stopped, including Oaklands Park, probably from over-exploitation of accessible ores. Excavations show Bardown used advanced types of pit roasting methods with clay lined floor and stone walled fire pits. Evidence suggests these were filled with crushed and sized layers of charcoal and ore and allowed either to burn out naturally or assisted by using bellows.

Alfold-Medieval[4]

Located near Alfold, Surrey the Wildwood estate, a high status medieval settlement site in the Weald of Surrey, lies in an area of Weald clay with a narrow band of alluvial deposits on either side of a small stream. Samples of calcined ore were found adjacent to Wildwood in association with shell- tempered pottery, dated AD 1050-1250, as well as bloomery slag and baked clay.

Fernhurst-Mid 18th Century (Northpark Furnace)

Northpark, near Haselmere, Surrey, is known to have been operating in 1653 and in 1660 followed by changes in ownership and activity. According to title papers Northpark finally ceased iron production before 1785. A 1992 Site Plan refers to a possible former ore roasting area approximately 40m north of the furnace location.

Present - 2012

Members of WIRG experimental bloomery Furnace group produce calcined siderite ore for experimental bloomery smelting trials at their Ashdown Forest site. A sample of BWS calcined siderite ore was used as representing present day calcining practice.

Calcined Ore Sources and Properties

Table 1 (overfleaf) gives summary of structures and properties for as-received calcined ore samples.

This preliminary examination shows samples comprise either siderite or iron claystone ores specific to a location and time period.

Ore Transitions on Calcining

Bardown, Fernhurst and BWS siderite transforms differently during calcining from Oaklands Park and Alfold claystone ores. However for both groups the end iron product is hematite iron oxide.

Siderite Ore

Siderite, a ferrous carbonate, transforms through a sequence of temperature dependent iron oxides. General equations for core siderite changes up to about 400°C are $FeCO_3 \rightarrow FeO + \uparrow CO_2$ followed by $3FeO + ½O_2 \rightarrow Fe_3O_4$ (or $FeO.Fe_2O_3$) [magnetite]. As temperature rises through 500°C it is shown that magnetite is converted into magnetic brown γ-iron oxide by the reaction: $2Fe_3O_4 + ½O_2 \rightarrow 3(\gamma\text{-}Fe_2O_3)$ [maghemite].[5] At around 600°C maghemite starts converting to non-magnetic red α-Fe_2O_3 [hematite] which is completed around 700°C.

Historical Period & Location	Roasted Ore – Summary Structure & Properties	Indicative Ore Type
Present Day Beacon Wood Stream (BWS) ore	• Fine dull dark brown microcrystalline fracture surface with some evidence of fissuring • Hardness Mohs 6/7 • Crushed colour 10R 3/3 - Dusky Red • Response to 200 gauss magnetic field	Siderite
18th century Fernhurst - North Park Furnace site	• Fracture shows an extremely fine microcrystalline structure with dull brown reddish thin crust and a dull brown core • Hardness Mohs 6 • Crushed colour 5YR 4/3 - Dull Reddish Brown • No magnetic response	Siderite
Medieval 11th - 13th century Wildwood Moat – Alfold, Surrey. Clay Alluvial site	• Friable fine earthy orange sandy-clay matrix containing opaque white, dark brown and black grains • Small banded zones of darker brown mineral • Hardness Mohs 3/4 • About 5% of small charcoal granules • Crushed colour 7.5 YR 4/6 - Brown • About 5% of crushed granules reacted to magnetic field	Iron Claystone
Romano-British 1st - 3rd century Bardown – Wadhurst, Sussex. High Weald site.	• Fracture surface of fine dark brown uniform microcrystalline with some cleavage • No porosity or fracture lines • Hardness Mohs 5/6 • Crushed colour 7.5R 2/1 - Reddish Black. • No magnetic response	Siderite
Romano-British 1st - 3rd century Oaklands Park– Sedlescombe, Sussex Coastal Site	• Broken and uneven very fine sandy/clay matrix. Pieces show mix of lighter and darker brown banding or zones • Some porosity and fracturing • Hardness Mohs 3 • Crushed colour 2.5YR 2/3 - Reddish Brown • No magnetic response	Iron Claystone

Table 1 – Summary of Calcined Ore Sample Characteristics

Claystone Ore

In contrast Oaklands Park and Alfold samples originate from limonite in a sand/clay matrix. Limonite, or ‘brown hematite’, is a mix of hydrated iron oxide-hydroxide of variable (n) water composition. For n = 0 the mineral is goethite and for a higher value (can be decimal) the mineral is limonite of mixed composition. On calcining this chemically combined water is lost leaving red α-ferric oxide. An illustrative conversion equation is: $2[FeO(OH).nH_2O] \rightarrow Fe_2O_3 + \uparrow(2n+1).H_2O$. Total weight proportion of water evolved depends upon mix of hydrated limonite and quantity in the ore.

Geologically siderised rock exposed to weathering effects can be transformed to goethite by the reaction: $2FeCO_3 + H_2O + \frac{1}{2}O_2 \rightarrow 2FeO(OH) + \uparrow 2CO_2$. Further weathering then converts goethite to brown limonite found either as sedimentary iron stone or mined as claystone iron ore. Also the brown crust on siderite is formed by this weathering conversion.

Measuring Calcining Effectiveness

This study tests effectiveness of original historical calcining practices for each ore by identifying any additional weight loss from a second full roasting of a dry calcined sample. No weight change indicates effective first calcining. How siderite and claystone ores lose weight is described next.

Siderite Ore Transformations

Iron content for a good grade siderite ore is reasonably consistent. For example six siderite ores with Specific Gravity of 3·2 or more and from different Wealden locations had an average 36·5% iron with a 95% confidence range of +/-1·4%.

Figure 1 shows findings from author’s trials of calcining siderite. Siderite shows significant changes over a critical 400°C - 500°C with a total weight loss of 27%. A second weight loss over 530°C - 700°C represents magnetite converting to magnetic maghemite and then to non-magnetic hematite around 600°C+. This gives a combined total weight loss of 32% by 700°C.

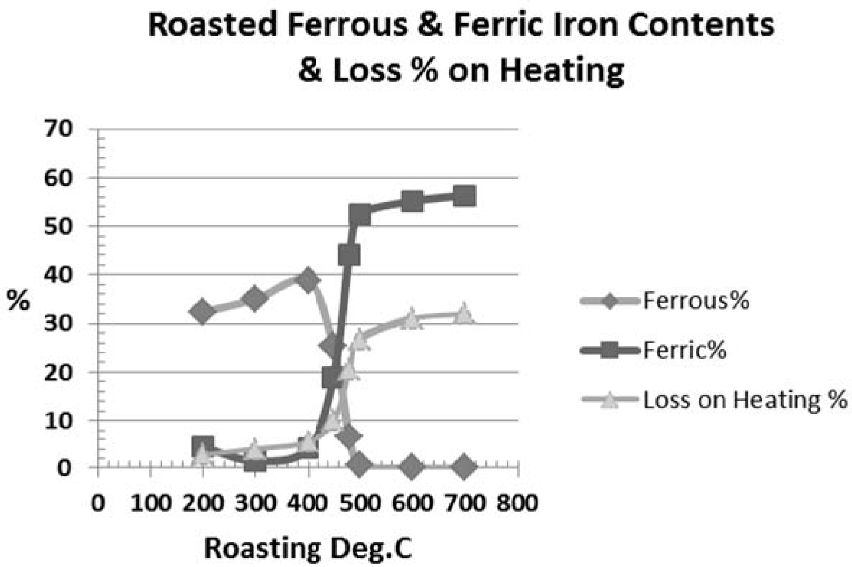

Figure 1 – Siderite Ore Ferrous to Ferric Iron Changes & Weight Loss

Calcining Deg. C	Munsell Colour	Munsell Colour Description
700	10R 2/3	Very Dark Reddish Brown
600	2.5YR 3/1	Dark Reddish Grey
500	2.5YR 3/2	Dusky Red
480	2.5YR 2/2	Very Dark Brown
450	2.5YR 3/3	Dark Reddish Brown
400	5YR 4/6	Reddish Brown
300	5YR 5/6	Bright Brown
200	2.5Y 6/4	Dark Yellow

Table 2 – Siderite Cold Ore Colour after Calcining

Colour Changes

Table 2 shows cold calcined ore colour alone needs judgment for estimating temperature achieved.

Claystone Ore Transformations

No original historical claystone ore site samples were available from which to construct a weight loss curve. So instead a Wealden claystone limonite ore, extracted by the author from Grinstead Clay formation, was used as a proxy mined ore. Comparative properties are shown in Table 3 with notes.

Ore	Mined Ore Iron %	'n' Factor	Expected Water Loss %	Actual Water Loss %	Calcined Munsell Colour	Calcined Munsell Description
Alfold	40	0·36	13·2	12	2·5YR 3/4	Reddish Brown
Wealden (Proxy)	***42***	***0·66***	***15·6***	***14·4***	***2·5YR 3/4***	***Reddish Brown***
Oaklands Park	43	0·70	15·9	15·1	2·5YR 3/2	Dusky Red

Table 3 – Comparison of Historical Ores with Proxy Wealden Claystone

Notes: Mined Ore Iron% determined either by analysis for Wealden proxy ore or for historical ores by factoring fully calcined iron% for calculated original sample weights. **'n' Factor**, representing unit of hydration of limonite ore, calculated by 'goal seek' function in author produced Excel model for determining weight of limonite in a sample satisfying jointly actual water loss% and iron% content. **Expected water loss%** calculated from limonite stoichiometric water weight content for comparison with actual water loss%.

Figure 2 shows a proxy ore calcining weight loss profile compared with that for BWS siderite.

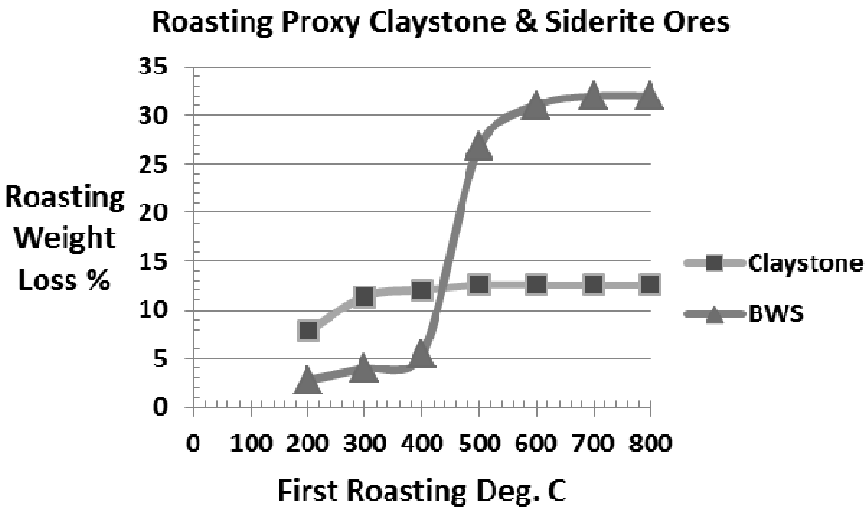

Figure 2 – Weight Loss Profiles for Wealden Claystone and Siderite Ores

Unlike siderite, claystone ore shows a progressive profile achieving a maximum weight loss in this trial of just 13% by 500°C and cold Munsell hue of 10R showing hematite formed. Siderite displays this hue after 700° C treatment.

Historical Samples Analyses

This stage compares findings from duplicate analyses of ferrous/ferric iron content for each of the five historical samples including any weight change after calcining a separate small portion of each at 800°C for 20 minutes.

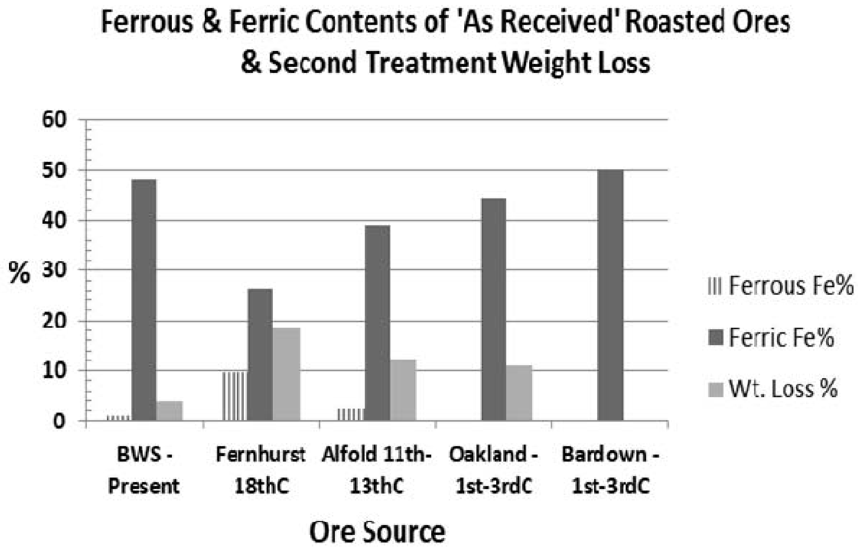

Figure 3 – 'As Received' Ores Ferrous/Ferric Proportions and Treatment Weight Losses

Iron Proportions & Weight Loss

Apart for Bardown sample giving just a 0·2% weight loss, indicating very successful initial calcining, Figure 3 shows how the other four samples each lost some additional weight from second treatment. Fernhurst especially still contained about 10% ferrous iron following first calcining and gave the highest additional weight loss of 19% on second treatment indicating significant original under calcining.

Comparative Second Calcining Profiles

Whilst Figure 3 shows overall weight changes, Figure 4 (overleaf) shows, from further trials, how each ore transforms. Bardown and BWS ores show little change from original calcining. Fernhurst ore shows partial siderite transition curve and further volatiles loss. Alfold and Oaklands Park show profiles like Wealden proxy ore, Figure 2, signifying low original calcining effectiveness.

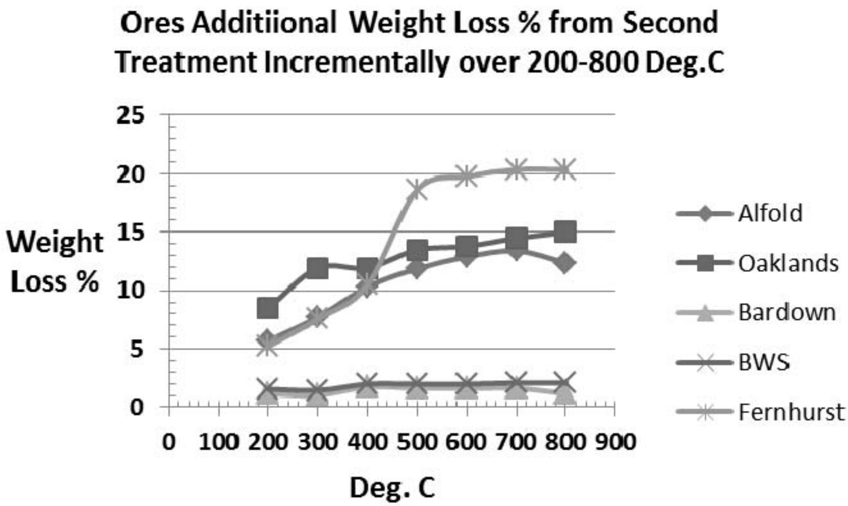

Figure 4 – Comparison of Second Treatment Weight Loss Profiles

Total Iron Contents of Ores 'As Received' and 'After Second Treatment'

Table 4 shows that apart for BWS especially and Bardown ores, others showed beneficial increases in iron proportion following second roasting.

Calcined Ore	'As Received' Total Fe%	Total Fe% 'After Second Treatment'
BWS - Present	49·3	49·4
Fernhurst – 18th C	36·1	48·2
Alfold 11th-13th C	41·6	47·2
Oaklands - 1st-3rd C	44·1	50·9
Bardown - 1st-3rd C	50·0	51·5

Table 4 - Total Iron% of Ores 'As Received' and 'After Second Treatment'

Determining Calcining Effectiveness

Siderite Ores

Ease of calculating secondary treatment weight loss of calcined siderite ore enables calculation of original calcining success. However, as original sample weight of each as-mined ore is unavailable against which to measure change, the following method provides a calculated value.

A small piece of ‘as received’ dried calcined ore sample was weighed to give ‘as-received sample weight’. This sample was heated at 800°C for 20 minutes to complete any original partial calcining. Re-weighing gave sample ‘fully calcined weight’ and which now represented 68% of an ‘unavailable’ original sample weight. Using this value and a 32% total weight loss, steps in Table 5 were applied to estimate original Calcining Effectiveness. Table 6 gives average results from duplicate analyses.

Step	Calculate:	Using:
1	original weight of sample =	‘fully calcined weight’ x (100/68)
2	original calcining loss decimal fraction =	(‘original weight of sample’ – ‘as-received sample weight’) / ‘original weight of sample’
3	**Calcining Effectiveness % =**	(original calcining loss decimal fraction / 0·32) x 100

Table 5 – Determining Calcining Effectiveness % for Siderite Ores

Siderite Ore	As Received Sample Wt. gms	Fully Calcined Wt. gms	Original Loss %	Est. Calcining Effectiveness %
BWS - Present	0·75	0·73	29·9	92-96
Fernhurst - 18thC	1·09	0·86	14·2	42-46
Bardown - 1st-3rdC	0·59	0·59	32	98-100

Table 6 – Estimated Calcining Effectiveness for Siderite Ores
(95% Confidence Interval for estimated Calcining Effectiveness is value +/- 2·0%)

BWS magnetic response in the received sample ore indicates original calcining reached around 600°C giving magnetite with some non-magnetic hematite. Bardown heated originally well into the hematite region giving no magnetic reaction.

Claystone Ores

Alfold and Oaklands ores show under calcining characteristics from only a small increase in dried 'as received' iron content over 'as-mined' values – compare Tables 3 & 4. The proxy ore shows fully roasted weight loss for these is 14% and provides the parameter for claystone ore calculations shown in Table 7. Effectiveness range percentage represents 95% confidence interval taken from observed variations.

Claystone Ore	As Received Sample Wt. gms	Fully Calcined Wt. gms	Original Loss %	Est. Calcining Effectiveness %
Alfold - 11th-13thC	1·39	1·21	1·4	8-12
Oaklands - 1st-3rdC	0·89	0·79	3·2	21-25

Table 7 – Estimated Calcining Effectiveness for Claystone Ores

Compared with siderite ore finding these results show much lower roasting effectiveness values. Even by 300°C the proxy ore weight loss is about 11% giving about 85% calcining effectiveness. These low calcining weight losses, compared against extrapolated proxy ore profile, suggests temperature for Alfold was below 60°C and for Oaklands just less than 100°C. This concurs with other later historical opinion that pre-calcining hydrated ores was unnecessary.[6] Even so indications are Oaklands ore has experienced slightly higher temperatures at some time possibly causing slight loss of its higher combined water content.

Moreover separate heating trials on proxy ore caused orthogonal micro-cracking between 150°C-200°C which became more extensive by 400°C. No evidence for this distinctive effect was found in claystone ores examined. So without additional archaeological or site information there is no real evidence these ores had been calcined. At the most they may have been dried at low temperatures.

The isolated magnetic effect found in Alfold ore suggests intermediate maghemite formed before hematite. However a temperature over 225°C is needed for this. So without further evidence the conjecture is sample contamination possibly from pieces of raked out furnace ore.

Calcined Ore Potential to produce a Bloom

Smelting produces an iron bloom from available iron over and above that consumed with silica in forming preferentially fayalite slag ($2FeO.SiO_2$). Silica is available during smelting mainly from calcined ore, from eroding furnace walls and small amounts in charcoal. Using molecular weight proportions fayalite requires an iron to silicon weight ratio of 4:1. The premise is that if a calcined ore cannot provide, as a minimum, more than this proportion then no surplus iron is available for bloom formation however efficiently a furnace is operated. Table 8 shows, from ore analyses, calculated bloom potential ratios for each of these five calcined ores.

Calcined Ore	BWS	Fernhurst	Alfold	Oaklands	Bardown
Iron:Silicon Ratio	11:1	5:1	5:1	6:1	10:1

Table 8 – Comparative Potentials for Bloom Formation

Siderite Bardown and BWS ores are well above critical value followed by Fernhurst above the critical value but potentially producing rather less iron. Of the limonite ores Oaklands Park shows fair potential whilst Alfold ore is more marginal for producing a bloom.

Statistical Analyses

The null hypothesis is 'no significant differences in calcining success between samples over periods'. In practice two ore types were received which calcine in different ways. Two-way balanced Analysis of Variance (ANOVA) duplicated statistical analysis of all data results showed significant differences between ore types especially, across periods and some interaction effects. Results are summarised in Table 9.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F Ratio Calculated*	*F Ratio Critical*
Between Ore Types	11767	1	11767	339	6
Between Periods	1569	2	784	23	5
Interaction	1794	2	897	26	5
Within	208	6	35		
Total	15338	11			

Table 9 – Calculated and Critical F Values (0·05 Level of Significance)

Taking out effects of differences between siderite and claystone ore types, as claystone ores were not calcined and invalid interaction effects because results are known to be independent and re-applying an ANOVA test for just siderite ores gives Table 10.

Source of Variation	*Sum of Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio Calculated*	*F Ratio Critical*
Between Periods: **Present, Mid 18C & Roman**	3361	3	1120	158	19
Within Periods	14	2	7		
Total	3375	5			

Table 10 – Results for Calcined Siderite Ores (0·05 Level of Significance)

Even with limited data statistical significance of differences is found in ore calcining effectiveness for siderite ores over periods and so the Null Hypothesis is rejected – i.e. there is a real difference.

Conclusions

This exploratory work shows that a second high temperature treatment of calcined Wealden siderite ore provides a practical and consistent way to assess effectiveness of original ore calcining. Calcining siderite core ore involves a complex set of temperature dependent progressive chemical and colour changes with significant weight loss of carbon dioxide. Empirical results show the ideal siderite calcining temperature should be around 600°C for full conversion to ferric oxides. In practice, exceeding 500°C is critical and above 530°C gives 90% or more ore conversion. However using cold calcined ore colour alone may not be a sufficient guide for effectiveness. Variable calcining effectiveness is a factor influencing furnace productivity.

Historical siderite ores received were of comparable grade with medium to high calcined hardness as a proxy for structural strength. Roman Bardown especially and BWS ores were originally calcined effectively into hematite and maghemite respectively with both showing high potential for bloom production. Interestingly excavations at Bardown, reported by Cleere, revealed advanced roasting pit design giving effective calcining conditions. The Bardown sample provides convincing evidence of this success. In contrast 18th century Fernhurst ore with around 45% change shows an instance of less critical control over process and a much lower potential for a bloom. So, as shown by this study, methods could be variable where good grade ores could be calcined into either excellent, good or partly calcined ore.

Findings for Roman and Medieval claystone samples show a much lower measure of effectiveness for each compared with siderite ores. Even allowing for different conversion chemistry these low values as well as physical examinations gave no evidence for any pre-calcining activities. At the most they may possibly have had low level heat exposure for drying. Of the two ores Oaklands Park showed a reasonable potential for bloom production whereas Alfold ore showed only marginal potential. This work suggests any assumption about a bloomery site using pre-calcined claystone ores needs to be verified using this formal method along with any site or other local evidence.

Variation in siderite calcining effectiveness depended on local methods and controls and could influence furnace productivities. However each result in this study is an average value for each sample from a single historic calcining event and must be used in that context only. More importantly additional material from other locations and periods should be examined to consolidate these initial conclusions.

Finally whilst archaeological findings at Bardown Roman site concluded very well-ordered siderite calcining methods, in contrast, a contemporary account of ore roasting at Barden in Kent circa 1646 describes a different situation: "*Varieties of ore were scattered, seemingly haphazardly, onto open fires of wood and mixed ore and roasted until ore turned red*".[7] This instance might suggest good Roman practice for siderite ores became lost over time.

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THE IRON MEMORIAL IN ST. MICHAEL'S CHURCH, EAST PECKHAM, KENT - A CORRECTION

J. S. HODGKINSON

The memorial, said to relate to William Bansor, in the now disused church of St Michael, north of the village of East Peckham, was previously described by the present author,[1] who stated that it comprised a stepped iron cross set in a stone slab, with an inscription on a brass plate. It has been pointed out that this is incorrect, and that the slab is, in fact, of cast iron (Fig. 1).[2] The slab responds to a magnet across its entire surface, which is crude and uneven. This contrasts with the surface of the cross, which is smooth, and which appears to have been formed in the casting sand by assembling the shape from several pieces of wood, the strip forming the cross being impressed after, and more deeply than, the others.

Minimal details were given previously. Precise measurements are as follows: the main plate is 64.5cm wide by 117.3cm long; the cross is 23cm wide by 85.6cm long and is approximately central in relation to the sides of the slab. The inscription is 15.4cm wide by 7.1cm high, 9.5cm from the bottom edge of the slab and 5cm from the bottom of the cross; it, too, is approximately equidistant from each side of the slab.

There are two other examples in Wealden churches of early iron slabs with brass plates fixed to them: at St Margaret's church, Horsmonden, Martha Browne, wife of the celebrated gunfounder, lies beneath a plain iron slab with an affixed brass inscription plate dated 1644; and at West Hoathly, in the church of St Margaret of Antioch, Agnes Faulconer's memorial of 1635, fixed to the wall, is similarly

Figure 1 - St Margaret's Church, East Peckham, Kent; iron memorial slab

constructed. In both cases, the inscriptions on the brass plates are in Roman lettering. The plate naming William Bansor, who was noted as incumbent of St Michael's before 1420,[3] is inscribed with gothic lettering. The use of a cross and no other inscription has been noted on one other graveslab in the Weald, at Rotherfield parish church.[4] There also it was suggested that the graveslab was that of a cleric. As cast iron was not available in England until after 1490, it would seem impossible that the iron slab at East Peckham is contemporary with its dedicatee. A likely scenario is that the slab replaced an earlier memorial, perhaps entirely in brass, there being other brasses in the church. The brass inscription plate may have formed part of this earlier presumed memorial and has been reused by fixing to the iron slab.

The church is now open daily.

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PERSONNEL AT ST LEONARD'S FOREST IRONWORKS 1587-8

KATHLEEN LANGLEY

The litigation between Roger Gratwick, Edward Caryll and Walter Covert concerning the disputed tenancy of the forges and furnace in St Leonard's Forest in 1587-8 was described in some detail by Ernest Straker.[1] The papers which document this case include the names of many individuals who were closely connected with the works in the forest or with one or more of the litigants; some provided depositions.[2] Miss Langley, of Mannings Heath, has compiled the following lists of workers and servants of Roger Gratwick and Edward Caryll, some of whom it has been possible to identify as carrying on trades relating to the ironworks. Some clearly had connections with other works that the litigants operated: Roger Gratwick was involved in operations at Gosden Furnace in Beeding, Cuckfield Furnace and Forge, and Bewbush Furnace and Ifield Forge; Edward Caryll was also involved at Gosden, and at Knepp Furnace in Shipley; Walter Covert owned Slaugham Furnace and had an interest in the Cuckfield works.

WORKERS AND SERVANTS OF MR EDWARD CARYLL, WORKING IN ST LEONARD'S FOREST 1588

Some may have worked for Walter Covert, and some gave evidence of leases held by them and may not have been workers. Those marked * gave evidence in court proceedings in favour of Edward Caryll.

NAME	PARISH	EMPLOYMENT		AGE
AETHNIE, Michael				
ALISON, George				
ALLINGHAM, Stephen				
*APPLEFORD, Richard	Shipley	miner		50
ASHDOWNE, Jacob				
AWOOD, John	Nuthurst	yeoman	Lessee, South end; Carrier to Gosden	45
BANNISTER, William				
BARNARD, Christopher				
*BASSETT, Richard	Shipley	miner		40
BASTIAN, Thomas				
BAYDRY, Robert				
BEGELL, George				
BIDERDAY, Nicholas				
BRIDGE, -				
BROOKES, Thomas				
BULLER, Edmond				
*BURLEY, Roger	Ifield	miner & husbandman		30
COMBER, Richard				
COOKE, Richard				
COWFES, John	Nuthurst	yeoman	lessee	60
COWPER, Edward				
COXESON, William	Beeding			
DANIEL, John	Horsham	founder	1602 at Gosden[3]	40
	Beeding	founder	1610 at St Leonard's[4]	
DUDLIE, Edward				
*DUFFIELD, John	Beeding	miner		23

NAME	PARISH	EMPLOYMENT		AGE
DUFFIELD, Michael				
DYMON, Roger				
EASEY, John				
EASTY, Richard				
ELLSON, Richard				
ELLYS, John				
ENDLIE, Edward			may be Henley	
*FELMONGER, Richard	Beeding	Miner		28
FULLER, John				
FFYFFENS, Thomas				
GAGGE, Stephen	Horsham	founder	1602 at Gosden[5]	
*GARDENER, Anthony	Horsham	sawyer		50
GATES, John				
GATES, William				
GERRARD, John				
GREEN, John				
GRIFFIND, -		carrier	to Gosden	
HALLE, George	Horsham	Gent.	evidence as lessee	
HALLER, Edward				
*HARDINGE, Richard	Shipley	Husbandman		44
HARMAN, John				
*HENLEY, Philip	Shipley	yeoman		
ISEMONGER, Richard				
KNIGHT, John				
LEDGER, Nicholas				

NAME	PARISH	EMPLOYMENT		AGE
*LEE, William	Shipley	husbandman		24
LIDGER, Richard				
LONGE, John				
MARSHALL, Thomas		servant		
MAXMAN, John				
*MERRIE, William	Beeding	gent.	clerk to Walter Covert; prob lived at Hammer pond House	40+
MICHIBOURNE, -				
MILLES, Henry				
MILLES, Richard				
MITCHELL, John		servant		
MITCHELL, Richard				
*MOORE, Giles	Shipley	clerk	clerk at Gosden 1578 clerk to Edward Caryll 1588	34
*NEWMAN, William	Horsham	miner		
*PARKER, Edward	Beeding	miner		50
PARKER, Gerrard				
PEGGE, -	West Grinstead		associate, maybe not a worker	
*POE, William	Horsham	miner		40
POORLEY, Richard				
POTTINGTON, William		carrier	to Gosden	
*POWLTER, Robert	Beeding	miner		40
*PURTON, Richard	Roffey, Horsham	brickmaker		40
QUAYFE, William				

NAME	**PARISH**	**EMPLOYMENT**		**AGE**
QUINDLEY, Edward	Beeding	miner		26
QUYNNE, Thomas	West Grinstead	householder	associate, maybe not a worker	
SEALE, John, jun.		carrier	to Gosden land, south end	
*SEALE, William	Nuthurst	yeoman	lessee	54
*SHARPE, Richard	Horshan	gardener		50
SNAYFFE, William				
*STEMPE, Richard	Horsham	gardener		80
STERN, John				
STREATER, Thomas	Shipley	husbandman		36
STRETFIELD, Richard				
SUDLIE, Edward				
SYMOND, Roger				
TAYLOR, James				
TONGE, John				
TIE, Edward				
TYE, William				
WESTE, Henry				
*WHYTING, William	Horsham	yeoman		50
WISE, Henry				
*WOOD, Henry	Shipley	servant	also yeoman	40
WOOELEY, Richard				

WORKERS AND SERVANTS OF ROGER GRATWICK, WORKING IN ST LEONARD'S FOREST 1588

Those marked * gave evidence in court proceedings.

NAME	PARISH	EMPLOYMENT		AGE
ADAMS, William		carrier	of mine & ore	
BANESTER, John	Nuthurst	miner		30
BILLINGHURST, John		carrier		
*BOOKER, Edward	Beeding	miner		26
*BURGESS, John	Horsham	miner		27
BURRELL, John				
BURRELL, Stephen	Sinfold	carrier		
COWTON, Edward	Slinfold			
DENYSE, Ralfe		miner		
*FRUMMINGE, John	Beeding			40
FULLER, William		carrier		
*GAWTHORN, Richard	Cowfold	ship board maker		50
*GRAYME, Edward	Horsham			
*HARRISON, Robert	Beeding	carrier & miner		35
HEWES, John		carrier		
HOLLAND, Henry			lived south end of forest	
*MYTTON, John	Beeding	collier		24
POTTER, Lawrence		carrier	(using horses)	
*SAWYER, James	Slinfold	servant		17
SAYERS, James	Slinfold	servant		
SMYTH, John	Horsham	collier		

NAME	PARISH	EMPLOYMENT		AGE
*SMYTHE, Thomas	Horsham	husbandman		40
*SOWTON, Edward		carrier		24
STAPLEY, Thomas				
STEMPE, Thomas				
TOWNSEMAN, John				
*WHITEBREAD, Richard	Slinfold	yeoman		38

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COWDEN FURNACES IN THE LATE 16TH CENTURY – SOME FURTHER COMMENTS

J. S. HODGKINSON

The lists of Cowden ironworks compiled between 1588 and 1590 present a confusing picture of ownership and occupancy which has only been partially resolved.[1] In the list of 1588, John Swaysland of Cowden is noted as having a gun-casting furnace in the parish for which the founder was Francis Johnson, and John Knight, also of Cowden, is noted as having a furnace where only sow iron was cast. In the list of 1590, in which are recorded the names of those entering into a bond of £2000, John Swaysland is again noted as occupier of the "the furnace in Cowden", but Thomas Burre, of Cowden, yeoman, is recorded as occupier of the "upper furnace" in the parish. Each acted as surety for the other. In addition, and this is where it gets confusing, Francis Johnson is also listed as entering into a bond as occupier of Scarlets furnace in Cowden (not Francis Knight as stated by Cleere & Crossley[2]). John Knight is not mentioned in the 1590 list. John Swaysland left his furnace to his brother, Edward, in whose will of 1624 it was bequeathed to his son, Robert. As Woolcombs, or Lower Furnace Farm, the property descended through the Swaysland family until it was sold in 1732.[3]

The list of Kent gunfounders in 1589 includes John Swaysland and John Knight *or* Francis Johnson, all working in Cowden parish; clearly the compiler of the list was uncertain about Knight and Johnson. Given that Scarlets, the 'upper furnace', was stated as only casting sows, and that Knight's ownership of Scarlets is confirmed by his will of 1618 in which left his furnace to his son, Jonas,[4] and that Francis Johnson had earlier been recorded as casting guns for Swaysland, with obligations to two London merchants, Knight can be discounted as a gunfounder at that time. But was the bond Johnson entered into as occupier of Scarlets furnace evidence that he had moved from one furnace to the other, or that he was working at both furnaces, or was his association with Scarlets an error?

The person so far unidentified is Thomas Burre. Scarlets furnace lay adjacent to the manor of Leighton-in-Cowden which, in the years in question, was owned by the Burgh family (pronounced as in 'borough'), of Gainsborough, Lincolnshire, who had acquired the lands through marriage with the Cobhams of Starborough, near Lingfield, in the previous century. In 1590 the lord of the manor was Thomas Burgh, 3rd Baron Burgh (c.1558-1597), a courtier. He had succeeded to the title and lands in 1584, but his activities at court probably kept him away from the day to day management of his property, for in 1591 his brother, Sir John Burgh, and his mother, Lady Katherine, widow of the 2nd Baron, alienated the lands of the manor by mortgage to the Streatfeild family of Chiddingstone, Thomas having run up considerable debts in the service of the Queen.[5] Could Thomas Burgh and Thomas Burre be one and the same? Burre can certainly be pronounced phonetically as 'borough'. As a peer it is unlikely that Thomas Burgh would have been described as 'yeoman', but other anomalies appear in the lists. Also, in the 1590 list, it had been intended that John Burre's name was to be written as having been bound, but it was crossed out and the entry begun on the next line with Thomas Burre's name instead.[6] If Thomas Burgh had been busy at Court, leaving his mother and brother to handle local affairs, perhaps John's name had been inserted, only to be corrected to that of the owner of the estate. Sadly, the court rolls for Cowden Leighton manor in the 1590s have not survived, or more evidence of Thomas Burgh's involvement might be forthcoming.

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BIDDENDEN HAMMER MILL: SITE SURVEY

J. S. HODGKINSON

Biddenden Hammer was built in 1570 by Sir Richard Baker of Sissinghurst. By 1590 he also had a furnace, though this was at a separate location in the Frith, in Hawkhurst parish. However, a furnace at the Hammer Mill site was in existence by 1606 when it was mentioned as part of the same landholding as the forge in the marriage settlement of Sir Richard's son, Henry, who had succeeded his father to the estate in 1596. In 1606 the works were in the hands of Peter Courthop and Thomas Washer. When Sir Henry Baker died in 1624, Thomas Courthop was occupying the works. The furnace was recorded as still active in 1664 and the forge in 1667, when the tenants were Thomas Plummer, Robert Drayner and Alex Homesbe, but by 1674 work at the site seems to have ceased.[1]

The ironworking site had been laid out by constructing a dam, of about 220 metres, across the valley where two tributaries of the River Beult met to form what would consequently be called the Hammer Stream. The pond so formed was one of the largest of any of the ironworks in the Weald, covering as much as 130 acres (52 hectares). Such a prodigious area of water was ample for the supply of two ironworks simultaneously, few other ponds having such a capability, though it cannot have been very deep. In the early 19th century its, by then, former extent was proposed as a reservoir for a canal planned to join the Rother and the Medway, but the plan was abandoned.

The Hammer Mill, for the grinding of corn, was established in the 18th century and a more modest pond was built, taking water from just one of the streams. The corn mill has not been active since the 1930s.

Ernest Straker noted the site and the presence of a small amount of cinder, suggesting that the mill race might have been the hammer dyke and, thus, placing the forge at the western end of the site.[2]

The first active investigation of the ironworking site took place in 1970 when the Wealden Archaeological Research Group, under the leadership of Mr A. B. Cardwell, obtained permission to excavate an area at the eastern end of the site where a ditch feature met the pond bay.[3] Over the course of three years, mainly on Sundays, but for a concerted fortnight in the August of the first year, amounting to about 40 days in all, the site of the furnace was partially uncovered. After the first season it was reported that the probable locations of the furnace and of the wheel pit had been identified at the eastern end of the bay. A surviving site notebook accompanied by a contour plan (Fig. 1) recorded the progressive discovery and interpretation of the debris beneath the soil.[4] Brick and tile was much in evidence, some of which had apparently collapsed into the wheel pit, suggesting a roofed building adjacent to the pit, consistent with a casting or blowing house. The pit had had a timber lining. A small number of artefacts were recovered, including several fragments of clay pipes, but their present whereabouts are not known.

The WIRG Field Group visited the site in 1975, reporting on its findings the following year.[5] Apparently unaware of the excavations that had ended three years earlier, its conclusions were that the forge had been at the eastern end of the bay, where the excavations had indicated the furnace had been sited, though the report did note the quantity of blast furnace slag in that area. It is possible that disturbance caused by the 1970 -2 excavation had confused later interpretation.

The occasion of WIRG's Summer Meeting visit to the Hammer Mill in July 2012 coincided with a particularly low level of water in the Hammer Stream immediately to the north of where it cuts through the pond bay. This enabled close examination of the stream bed and the discovery of substantial quantities of forge slag there. This prompted a further measured survey of the site (Fig. 2).[6]

The survey is confined to the former orchard at the eastern end of the Hammer Mill Farm property, east of the Hammer Stream and facing the A262 Sissinghurst-Biddenden road. While the survey conducted for the 1970s excavation showed the contours of the site, it was felt that a

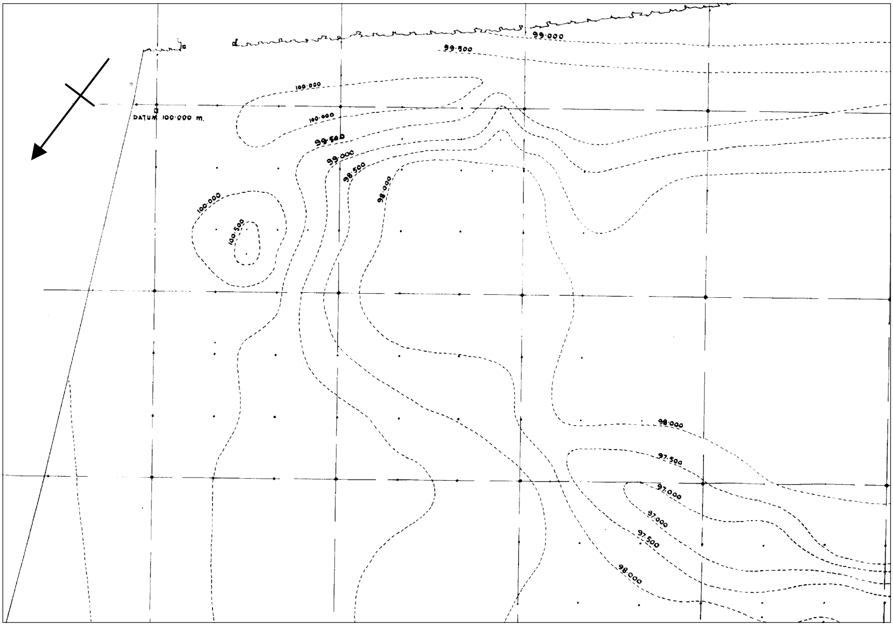

Figure 1 - Biddenden Hammer Mill furnace site; 1970 plan

more subjective approach to the topography would be helpful. The evidence of the 1970s excavation and the discovery of forge slag in the Hammer Stream clarify the organisation of the site when it was active, and the redundant ditch that traverses the site can now be shown to have had a dual purpose.

It is unclear to what extent the 1970s excavation was backfilled when it stopped abruptly. It is presumed that some backfilling took place to prevent grazing animals from falling into the trenches. However, it is inevitable that some of the ground features may be residual from that time. Nevertheless, the location of the furnace at the east end of the site conforms with traditional practice in siting the furnace stack close to higher ground to allow easy access to the top of the stack for the charging of ore and charcoal. The dip in the top of the bay south of the furnace site seems to have been the site of the sluice that controlled the water powering the bellows. Fragments of an iron ratchet were discovered west

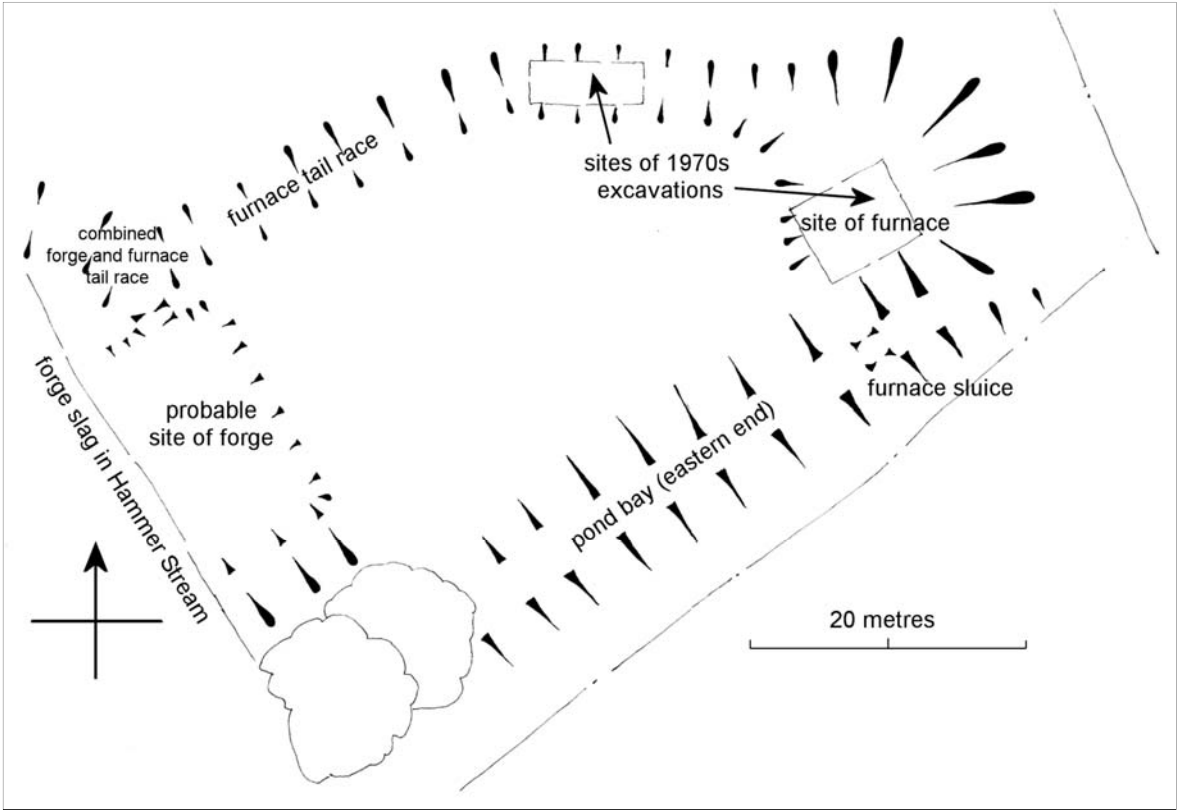

Figure 2 - Biddenden Hammer Mill furnace and forge site; 2013 plan

of the wheel pit during the final season's dig in 1972. The site of the excavation is still evident as a boggy patch, and a 'bear' identified at the time can still be located by probing in its midst. Although the form of the ground around the furnace site may have altered as a result of the excavation, the purpose of the ditch that runs north from the site of the sluice and curves to the west towards the Hammer Stream is clearly to act as a tail race for the furnace water wheel.

Just south of where the ditch meets the Hammer Stream, and level with the accumulation of forge slag in the stream, there is a rectangular depression with its long sides parallel with the stream. This would seem to have been the site of the forge building, its approximate dimensions conforming to other forges noted in the Weald. At the end of the depression nearest the furnace tail race there is a gap in the side of the race which might be the remains of a tail race for one or other of the forge wheel channels that would have been close to the sides of the forge building. The present breach in the bay where the Hammer Stream cuts through would undoubtedly have been closed off with a sluice and/or spillway, providing the water supply to the water wheel(s) on the west side of the forge. A channel through the bay serving the east side of the forge is not apparent owing to trees growing on the bay. It is not known whether the forge at Biddenden had one or two fineries, but a minimum requirement of three water wheels, for the finery, chafery and hammer wheels, would have made it essential for there to be water channels on both sides of the building.

As a considerable length of bay remained further to the west, where the present farmhouse and former mill now stand, it is likely that the overflow spillway, that allowed surplus water to flow out of the pond at times of heavy rain or when the forge and furnace were not in use, followed the course later used by the corn mill and was the subject of a complaint when the 'new' bridge taking the road over it was damaged in 1583.

References

1. Cleere H. and Crossley, D., 1995, *The Iron Industry of the Weald* (Cardiff, Merton Priory Press), 315-6; www.wirgdata.org (accessed 20 March 2014).

2. Straker, E., 1931, *Wealden Iron* (London, Bell), 282.

3 *Archaeologia Cantiana*, **85** (1971), 192.

4. WIRG is grateful to Mr Cardwell for loaning this notebook, and to Tony Singleton for scanning its contents.

5. *Wealden Iron*, Bulletin of the Wealden Iron Research Group, 1st ser., **9** (1976), 17.

6. The collaboration of Shiela and Chris Broomfield, Vivienne Blandford and Tony Singleton in the survey is gratefully acknowledged; from the site notebook it is apparent that the first named had visited the excavation in 1970.

ERRATA

In Alan F. Davies' article, 'Estimating 18th century cannon boring times and throughputs' in *Wealden Iron*, Bulletin of the Wealden Iron Research Group, 2nd ser., **33** (2013), 38-47, a table and a figure were omitted. we apologise to Dr Davies for this error. The missing items, which related to text on p.45, are as follows:

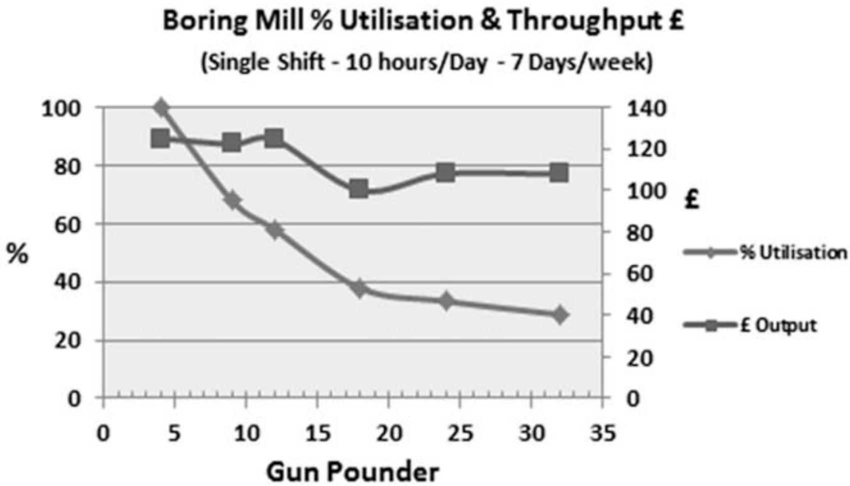

Figure 5 - Mill utilisation & weekly output value for gun size

		---------Small/Med Guns---------				-----Great Guns-----				
Gun Size Pdr.		4	6	9	12	18	24	32	Totals	Measure
Nos. Guns Bored		2	2	0	2	2	0	2	10	Total Guns Bored
Boring Capacity Hrs.	70	4.3	5.8	6.9	7.3	7.4	7.9	8.3	66.2	Total Boring Hrs.
Selling Price/Ton £		13.7	13.7	13.7	14	14	15	15		
Gun Debenture Value £		7.5	15.0	17.8	22.4	28.0	36.8	44.3	234.4	Total Value £
									95	Boring Utilis'n %
Average Pdr. Value =	14.4								31.4	Great Gun Boring Hrs.
									34.8	Small/Med Gun Boring Hrs.

Table 3 - Single mill - Single shift - Example weekly mixed schedule

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