Field Notes

The furnace preheat — **Jonathan Prus**

Lunsford family connections — **Geraldine Crawshaw**

The closure of Ewood Furnace and Forge — **Jane Lilley**

The operation of Waldron Furnace 1690-1716 — **J. S. Hodgkinson**

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Cover illustration:
Pages from the Accounts of Waldron Furnace, Sussex
(photos: J. S. Hodgkinson).

FIELD NOTES

Bloomery slag in Aldington, Kent

Two large masses of bloomery slag have been found at about TR 0662 3492 on White's Wood Farm, Gigger's Green Road, Aldington. The larger mass is approx. 30cm across and may have been a 'bear' from a bloomery furnace. The other, apparently broken from a bigger piece, is layered indicating successive tapping over previously tapped slag. The size of the pieces suggests that a smelting site exists in the vicinity but has yet to be located. A quantity of pottery from a presumed medieval building has been found close by. The find site lies about 500m north of the edge of Romney Marsh and is equidistant from the Roman road (Margary Route 131), to the north east, which links the Roman fort at Lympne with Route 13 to Rochester.[1] The geology is Weald Clay, and pieces of bog iron have been noted in the bed of a nearby stream.

Our thanks to Mr and Mrs T. Body for notifying this discovery.

Field name evidence of possible bloomeries in Herstmonceux and Salehurst, East Sussex

Ernest Straker identified many potential locations of early iron-making from a study of the tithe apportionments and maps of the Wealden parishes, and many are noted in the pages of *Wealden Iron*. Recent revisiting of the apportionments for East Sussex parishes (available on the internet) has led to the discovery of four field names that suggest sites that Straker appears to have missed.[2]

Parcels of land named Sinderford Mead and Sinderford Shaw on the western boundary of Herstmonceux are numbered 76 and 77 in that parish's apportionment. Located at TQ 6061 1445, they lie about 400m from a bloomery site on Grove Hill Farm in Hellingly where Romano-British or Iron Age pottery was found. Also, south of Grove Hill Farm (now Grove Hill House), lies Cinderford Lane, its name perhaps being derived from this site.

1. I. D. Margary, *Roman Roads in Britain* (London, John Baker, 1973), 37.

2. https://apps.eastsussex.gov.uk/leisureandtourism/localandfamilyhistory/tithemaps/search

In the Salehurst tithe apportionment parcel numbers 1141 and 1142 are named as Cinderburys and Cinderburys Shaw respectively. Located at TQ 7616 2593, no other bloomery sites have been recorded within a radius of 2km.

Both sites deserve to be investigated.

A bloomery in Rolvenden, Kent

A concentration of bloomery slag has been discovered on the west bank of a ghyll north of Pookland Wood, part of Dingleden Farm, at TQ 82688 31239. Although a slag heap has not been identified, it possibly lying at some depth, pieces of furnace cinder up to 20cm across have been found as well as smaller pieces of wood-marked slag with a distinct dripped appearance suggesting non-tapping technology. The site lies on the Ashdown Beds which are exposed at the base of the ghyll, beneath the closely adjacent Wadhurst Clay. On the east side of the ghyll, opposite the slag, a small quarry may represent a source of the iron ore.

We are grateful to Stephen Lemon for notifying us about this site.

A bloomery in Rotherfield, East Sussex

A spread of bloomery slag has been noted in dense woodland at TQ 54921 31287 in Hornshurst Wood. The site lies on the Ashdown Beds.

We are grateful to David Brown for informing us of this site.

A possible bloomery in Guestling, East Sussex

David Staveley

The site, at Guestling Thorn, was discovered at TQ 8525 1582 while looking for a slag-metalled road. Slag was found on the surface, so a geophysics survey was undertaken (Fig. 1), but a possible bloomery rather than a road was discovered. The site lies next to a shallow valley, just to the south of the top of the Guestling-Icklesham ridge. The field in which the site was found was ploughed, so the earth and iron slag were visible when the site was surveyed. An amount of slag was visible on the surface, both around the site and downhill from it. The core extent of the site is 20m E-W and 15m N-S, with further features extending an additional 30m to the W and 8m to the S. Nothing appears on the lidar of the area. The underlying geology

Figure 1: Magnetometer survey of the Guestling Thorn bloomery; the diagonal line is a modern feature (David Staveley)

is Wadhurst Clay, samples of ferruginous sandstone pebbles from Pebble Beds associated with the clay and with the upper levels of the Ashdown Beds being noted amongst the slag.

Ore pits in Sedlescombe, East Sussex

Robert Turgoose

The report on the Footlands ironworking site in *Wealden Iron*, 2nd ser. 7 (1987) p. 27 recorded three ore pits near to the industrial area, at Cinderbank Shaw at TQ 7947 1998 and TQ 7731 2000 and in Footlands Wood at TQ 7694 1988. Recent field walking has revealed quarries nearby in Beech Wood TQ 7740 1970 and Combe Wood TQ 7780 1940. The Beech Wood pit is roughly 100 metres by 30 metres in extent and 8 to 10 metres deep.

Bartlet's Wood TQ 7794 1936, which lies immediately east of Combe Wood, was coppiced in the winter of 2024/25 and the entire wood is revealed to be a quarry with varying depths of 5 metres or more.

Wealden Iron, 2nd ser. 38 (2018), pp. 4-5 described a large quarry in Killingan Wood at TQ 7800 1900 which lies about 1.0 km south-east of the Footlands industrial area.

The sites database for Sedlescombe on the WIRG website presents LIDAR images of Austford, Cryall's, Hurst, Sandpit, and Ward's woods. These woods are to the east of Killingan Wood and comprise about 50 hectares of continuous woodland with both open quarries and shaft pits. The five woods together with Killingan, Bartlet's and Combe woods lie on a single outcrop of Wadhurst Clay extending 2.25 km eastward from the Powdermill reservoir.

In summary, the woodlands in the north of Sedlescombe parish obscure an extensive former mining landscape. Pits in the Weald have been dug for marl, clay for brickmaking, hard stone for building as well as for iron ore. The local geology, the sizes and depths of the quarries, and their proximity to iron working sites at Footlands, Oaklands, Chitcombe and Brede Furnace suggest that the Sedlescombe pits were dug to extract iron ore.

To the southwest of Footlands there are pits near Woodman's Green on an isolated outcrop of Wadhurst Clay. Nineteenth-century maps record two woods, Duckshall Wood TQ 7658 1937 and Parson Peat's Wood TQ 7644 1940, which now form a single area of woodland containing several connected quarries over 5 metres deep. This site is about 1.0 km uphill from the iron working site and linked to it by a present-day footpath.

THE FURNACE PREHEAT:
A short discussion of some thermal properties of experimental bloomery furnaces and of the associated chemical processes

Jonathan Prus

Overview

There is no doubt that many practitioners of experimental bloomery iron smelting find the preheat useful part of their process. However, the present writer is unaware of any written account that addresses the problems of the purpose, duration, economics, chemistry and limitations of the pre-heat *per se*. This note sets out to examine, where possible:

- The reasons for preheating
- Optimal preheat status

And also:

- To suggest possible archaeological signatures of effective pre-heating
- To estimate fuel efficiencies that might follow from effective pre-heating

A search of the technical literature suggests that there has been little direct discussion of heat flows in bloomery furnaces. An exception is Rehder (2000) where heat flows are discussed and, to some extent modelled. However, that work seems to treat bloomeries as systems in equilibrium whereas the arguments below are concerned with where that equilibrium is, and what happens when bloomery systems move towards it. Similarly, Joosten (2002) models heat loss using (explicitly) Fourier's Law in its original linear form and assumes that bloomery temperature decreases in a regular fashion as gas moves up the shaft.

Tholander (1987, cited by Pleiner (2000)) provides a picture, based on measurements, of the temperature of gases within a bloomery although this, almost certainly, does not represent a bloomery in equilibrium.

There is a body of work relating to heat flows within blast furnaces, for example Swartling (2010). Some of this work may have applicability to bloomeries. Much of this theoretical investigation of blast furnaces uses finite element analysis. If the arguments presented below can be supported by experimental evidence these methods of analysis might be used to investigate (and perhaps explain) some of the odder-shaped bloomeries that have been reported.

The lack of discussion of the bloomery preheat is a little surprising because, as will be shown below, varying the heat flows by preheating may have a major effect on the outcome of experimental smelts and hence, on the interpretation of archaeological evidence. Explicitly, or otherwise, experimental smelting influences the way in which bloomery sites are read. It is not the case that preheating bloomeries has gone unnoted. Even a casual search will yield plenty of references to preheating, and, in at least one area of study, acrimonious debate.

The use of units and numbers in the discussion that follows

In general, the arguments presented are developed using SI (*Système international*) units. (Mass in kilograms, kg, distance in metres, m, Temperature in Kelvin, K, Time in seconds, s, Energy in joules, J, Power in Watts, W, chemical quantity in Moles, Mol.)

Numbers are mostly expressed as a product of a number between 1.0 to 9.999… and an exponent of 10. This avoids some tendency to overuse prefixes such as kilo- and mega-.

The physical values for the properties of materials used below are taken from The Engineering Toolbox, a useful and reliable website to be found at https://www.engineeringtoolbox.com. The values for some materials vary from sample to sample and this must be borne in mind: local variations could affect the results obtained, but not the general arguments made. In some instances, the choice of parameters *is* critical: the differences between, for example, compressed loam and (say) brick can be enormous.

The formulae used can be found in The Engineering Toolbox. The results for CO-CO_2 equilibrium (Boudouard's Reaction) can be found in many chemistry textbooks.

Where might pre-heating a bloomery give little benefit?

Because there has been little discussion of the technical aspects of this problem, the answer to the question above depends, in part, on anecdotal evidence. Easy-to-smelt ores (such as high-purity bog-ore) have not made experimenters seek a boost from pre-heating. In some instance pure bog ore produces almost no visible slag. (pers. comm. Dr. P. Rondelez). One may hypothesise that pure and well comminuted ore will reduce and sinter more rapidly.

More difficult ores, like Wealden siderite, require pre-roasting and careful comminution. It is probably the case that an extended residence time in the furnace promotes a productive smelt. It is argued below that thorough pre-heating may reduce gas throughput, extending residence time.

It is notable that some modern smelters (e.g. Lee Sauder in the U.S.) use a thin-walled furnace and high blowing rates. The discussion below may have little relevance to their methods.

A simple model

Heat transfer through a straight wall is continuous and linear when the inside and outside surface temperatures reach an equilibrium. Heat loss through such a wall can be expressed as a linear relationship between temperature difference and the thermal conductivity of the wall's substance. This expression is Fourier's Law:

Box 1: Fourier's Law, thermal conductivity

Conductive heat transfer can be expressed with 'Fourier's Law'
$Q = (k / s) A\ dT$ where
Q = heat transfer (W)
k = Thermal Conductivity of material (W/m)
s = material thickness (m)
A = heat transfer area (m^2)
and
dT is the temperature difference across the material under consideration. This law is the underpinning of all the arguments developed here: the larger the temperature difference, the larger the heat flow and *vice versa*.

The operation of Fourier's Law, as it applies to a straight wall may be visualised in a simple diagram in which change in temperature across a partially insulating wall is shown as a straight-line between a hot interior and a cooler exterior wall surface. The gradient of the curve indicates the rate of heat transfer:

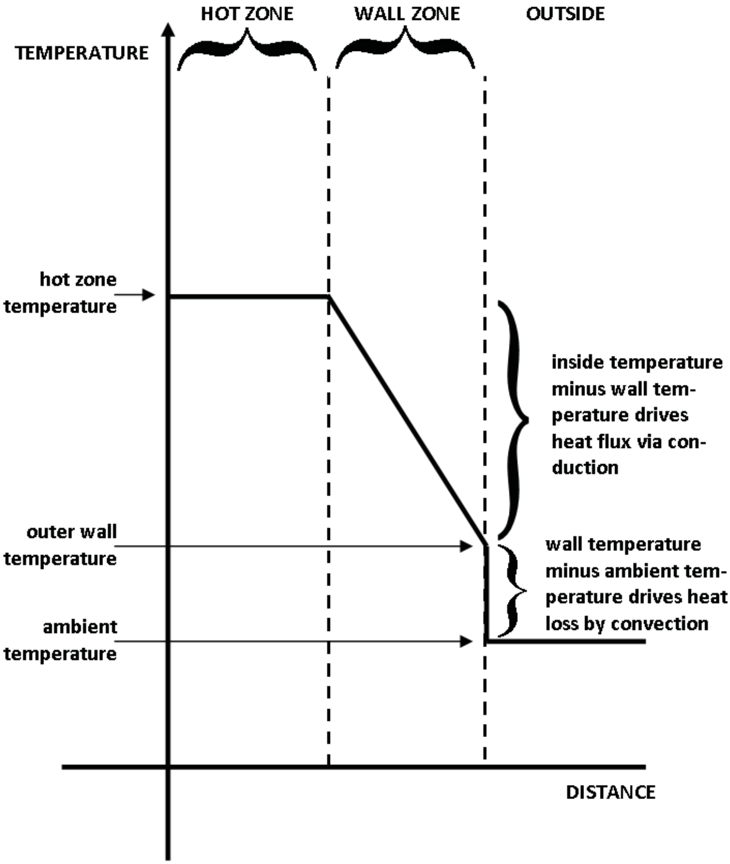

Figure 1. Idealised view of heat flux across a straight wall when the heat input equals the heat out. Input is by conduction on the inside. Output is by convection on the outside. The rate of convection varies with air-speed as well as temperature.

Model of a hypothetical bloomery.

Taking a cylindrical bloomery furnace, a special case of Fourier's Law may be applied. At the beginning of a 'smelt' the furnace walls are cool. The temperature gradient across the inner surface of the wall is very steep; much of the heat produced is absorbed by the material of which the wall is formed. How much heat is absorbed and how fast and at which temperatures are key questions for smelters. In the discussion that follows it is assumed that such a cylindrical furnace is being used. The size and construction of the hypothetical model assessed below are based upon the experimental furnace

Box 2: Heat transfer across the walls of a hollow cylinder

Fourier's Law is essentially one-dimensional, but it generalises easily and adapts to non-rectilinear shapes. A rule that yields a value for the equilibrium heat transfer across a hollow cylinder is of great value in modelling a simple bloomery furnace.

Conductive heat loss through the wall of a cylinder or pipe can be expressed as

$$Q = 2 \pi L (t_i - t_o) / (ln(r_o / r_i) / k) \qquad (1)$$

where

Q = heat transfer from cylinder or pipe (W)

k = thermal conductivity of Cylinder (W/mK)

h = height of cylinder or pipe (m, ft)

π = pi = 3.14...

t_o *= temperature outside (K)*

t_i *= temperature inside (K)*

ln = the natural logarithm

r_o *= cylinder outside radius (m)*

r_i *= cylinder inside radius (m)*

To develop this into a model of a simple bloomery it is necessary keep in mind that the expression above gives heat flux at equilibrium. Prior to reaching equilibrium the heat flux across the inner section of the cylinder will be greater because the distance t_i to where $t = t_o$ will be smaller. At least two other caveats apply. The first of these is that the value of t_i is the same for the whole height of the furnace. It is not. The second caveat is that Fourier's Law makes, implicitly, the assumption that the wall material is homogeneous. Both archaeological and experimental bloomery wall may be slightly fissured.

used by the Wealden Iron Research Group (WIRG) for a number of years before 2010.

Heat transfer across the walls of a cylinder is of general engineering importance and is the subject of well-established models. The temperature gradient curve is non-linear. The expression for heat transfer across such a structure is stated above.

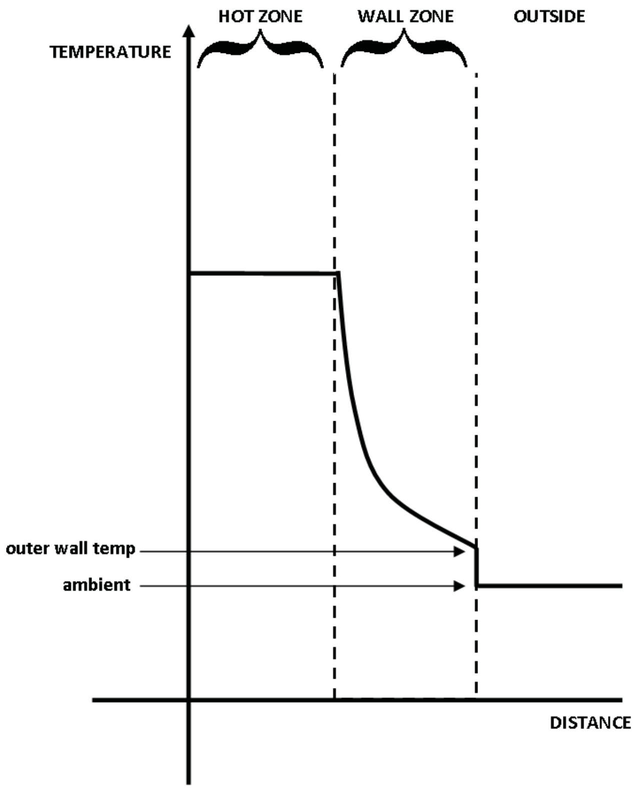

Figure 2. An idealised view of a model bloomery at an early stage of heating. The steep gradient of the curve at the inside-wall surface indicates a very large heat flow. We might also postulate a drop in 'hot zone' temperature in the vicinity of the inner wall. (Refer to text for comment on Tholander's isotherms)

The simple cylinder model of a bloomery must be slightly modified because heat will also transfer downwards. At a first approximation conduction of heat away should be increased in the ratio of the inner cross-sectional area to the inner-wall area. Within the framework developed below, this calls for a 7% adjustment.

The expected form of the temperature gradient curve before an equilibrium is reached is (shown in an illustrative only form) by Figure 2. As the heating process begins the temperature gradient across the inside of the wall is very steep indeed. We may be sure that the furnace gases next to the wall are at a lower temperature than the gases in the centre.

Box 3: A model and some modelling assumptions

The chosen model is a hollow cylinder with:

- Inner radius 0.14 m
- Outer radius 0.28 m
- Height of reaction zone 1m (with 0.5m additional height ignored in the modelling)
- Material of construction: sandy loam
- Thermal conductivity of walls $0.25 Wm^{-1}K^{-1}$
- Density of walls $1280 kgm^{-3}$
- Specific heat capacity of walls $837 Jkg^{-1}K^{-1}$
- Initial blowing rate $0.005 m^3s^{-1}$
- Target bloom-forming temperature: 1423K (although the probable existence of hotter zones is recognised)
- Ambient temperature $20^{o}C$ (293K)
- Air contains 20.9% oxygen
- 1 mole occupies 24 litres at RTP (Avogadro's Volume, approx..)
- Charcoal burned liberates 85% of the heat that is expected from pure carbon
- Carbon burning to carbon monoxide yields $9.21 \times 10^6 Jkg^{-1}$
- Carbon burning to carbon dioxide yields $3.28 \times 10^7 Jkg^{-1}$

Modelling assumptions

To achieve consistency in what follows, some assumptions about size, material properties, fuel, and blowing rates, are made. These modelling assumptions are set out below:

The approach taken here is to take *one* size and configuration of an experimental bloomery furnace (The model could be flexed using a spreadsheet, by randomising some of the parameters and/or by the adoption of more sophisticated mathematics, for example dealing with heat flow using systems of partial differential equations). However, here one takes a broadly familiar type of experimental bloomery made of familiar materials. One sees how it might behave under both a familiar and unfamiliar operating regimes.

The model is blown at 5 litres per second ($5x10^{-3}m^3s^{-1}$) which should result

Box 4: Heat lost in exhaust gases

Since nitrogen accounts for almost 80% of air, and since it does not participate in the combustion of carbon or the reduction of iron oxide to iron, it passes through the furnace chemically unchanged but emerges much hotter.

The specific heat capacity of nitrogen varies with temperature. For the purposes of this calculation it is assumed that exhaust gases exit at about 700K and that the following parameters apply:

- Specific heat capacity N_2, $1.098kJkg^{-1}K^{-1}$
- Specific heat capacity CO, $1.113kJkg^{-1}K^{-1}$
- Volume of N_2 introduced, $0.004m^3s^{-1}$
- Ratio of N_2:CO = 2:1
- Density of N_2 at RTP, $1.17kgm^{-3}$
- (*a priori*) Density N_2 and CO are equal.

Thus heat loss to exhaust gases, including CO, is about 3×10^3 W. The key to the argument in the main text, above, is that if the blowing rate is reduced because the walls are at full heat, there is a virtuous cycle: less blowing, less heat loss.

A further comment must be made at this point. The top of the charge in a bloomery furnace is an area of rapid heat-exchange. Incoming charge is heated rapidly by the exhaust gases. Moreover, as the surface of the charge increases, heat lost by infra-red radiation increases rapidly. Radiation varies with the fourth power of the absolute temperature of the radiant surface (see Box 5, below). The combination of rapid heat exchange and variable radiation appears to constitute an effective feedback system that can limit heat loss in exhaust gases.

in an energy output of about 9.6 x10^3W, about (say) enough for four electric kettles. Given its dimensions and the properties of the material of which this furnace is constructed, the entire heat output of the system for several hours would be required to bring the inside and outside temperatures into equilibrium. However, the entire heat output is not available for this purpose. Firstly, much of the available heat is lost in exhaust gases. Almost 80% of the input air, nitrogen, passes through chemically unchanged, but it carries away heat, as does the waste carbon monoxide produced. If the temperature at the top of the fuel stack is 427°C (700 Kelvin), the energy so lost is about 3x10^3W, (see Box 4, below). The temperature assumption (700 K) is close to that repeatedly observed in WIRG experiments.

Box 5: Radiative heat loss

Heat is also lost from the surface of the fuel bed (The amount of heat loss by radiation from the furnace outer walls is negligible).
This radiation is given by the expression:
$Q = \sigma e (T_i^{\,4} - T_o^{\,4})A$
Where:

- $\sigma = 5.6703\times10^{-8}$ $(Wm^{-2}K^{-4})$ − *The Stefan-Boltzmann Constant*
- e is the emissivity coefficient, disregarded here because it is near unity for charcoal
- T_i is the temperature of the top of the fuel bed (K)
- T_o is the ambient temperature (K)
- A is the surface area of the top of the fuel bed (m^3)

Taking a surface temperature of 700K and an ambient temperature of 293K this implies a radiative heat loss for the model of about 8 x 10^2 W.

Secondly, there is heat radiated from the upper surface of the fuel. The relationship between fuel surface temperature and radiant heat is set out in Box 5. At 700 K the radiative heat loss is about 8 x 10^2 W. These two factors appear to be part of a feedback system controlling the fuel stack surface temperature: heat loss rises disproportionately as this temperature increases.

Thirdly, before heating has been in progress for too long, the outer surface temperature of the furnace increases slightly, but perceptibly. At the equilibrium this predicted heat loss rises to 2.5x10^3W. This is the critical figure: before equilibrium is reached this flux is higher because the temperature gradient is higher. Loss across the inside wall *falls* as the system approaches equilibrium. However, loss by convection at the outside wall *increases* until an equilibrium is reached and the flux across the inside wall equals the flux across the outside of the wall.

Disregarding convective heat loss from the outer surface of the furnace it would take a minimum 7.4 hours to reach an equilibrium at which heat loss into (and out of) the walls equalled $2.5x10^3$W. postulated above (This calculation was performed in *Excel* using the formula from Box 2). During that heating-up period, less heat would also be lost to the atmosphere by convection. The coefficient of convection is highly variable, depending in part on wind speed. Thus, the heat lost and maximum time taken to reach equilibrium are very uncertain. It is reasonable to suggest that the time between first-firing and equilibrium would be over 10 hours.

From the above it is unlikely that many of the experimental bloomery systems with which we are familiar reach equilibrium temperatures, or that fuel and blowing regimes are optimised. *Reductio ad absurdum*; at the start of a smelt the heat demand of the inner 10mm. of the furnace would be almost three times the available heat to be at or near equilibrium with the next 10 mm. layer. There is a canonical depiction of temperature differences in the cross-section of and experimental bloomery, in which interior isotherms are shown, in Pleiner (2000, 134, original attributed to Tholander (1987)).

At this point it may be useful to question what is happening to the gas in the fuel bed of a bloomery. Given the amount of air blown, it is always surprisingly noisy. We may infer that the gases are in an extremely turbulent state and pretty well mixed. There is no reason to doubt the evidence presented by Tholander. We may attribute the isotherms he depicts to rapid heat loss in the vicinity of hot walls, across which there is a very steep temperature gradient. Conversely, as the fuel bed approaches an equilibrium, we might predict that those isotherms will flatten because the walls are experiencing a much-reduced heat flux.

It is striking that many experimentalists terminate their smelts whilst a lot of heat is still being added to their furnace walls.

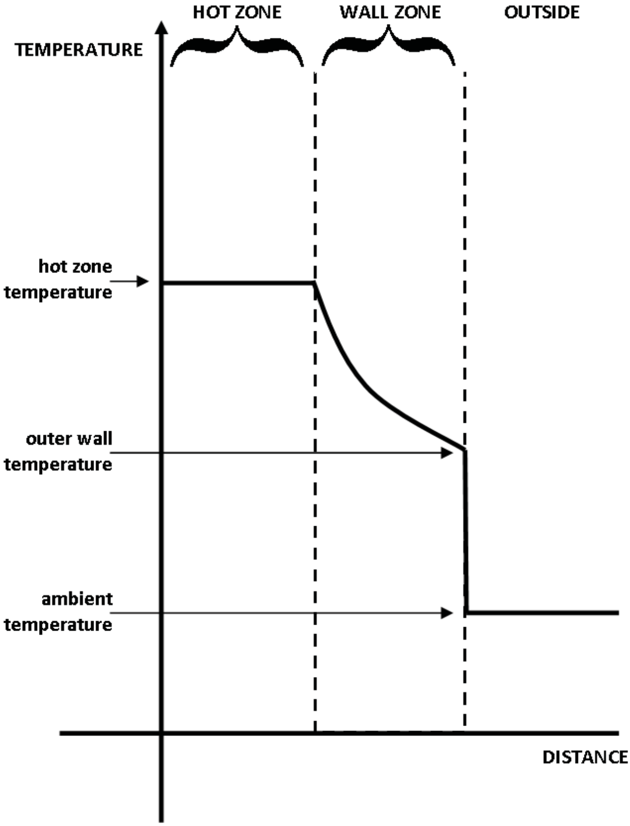

Figure 3. An idealised view of a model bloomery in equilibrium. The shallower gradient of the curve at the inside-wall surface indicates a reduced heat flow into the wall. Compare Figure 2: the larger difference between surface temperature of the outside wall and the ambient air indicates a higher heat flux due to convection from a hotter surface.

Digression into the chemistry of carbon oxidation.

In an ordinary fire charcoal will burn to carbon dioxide. If that fire becomes hot it will continue to produce some carbon dioxide (CO_2) for as long as there is an excess of oxygen present. However, as soon as the free oxygen is limited and the temperature exceeds about 600°C, carbon monoxide (CO) will be produced. As the temperature rises the proportion of CO to CO_2 also rises. Above 1000°C the oxidised carbon is almost all in the form of CO. Such conditions are created in a shaft furnace. The waste carbon monoxide will usually ignite spontaneously above the top of the fuel bed.

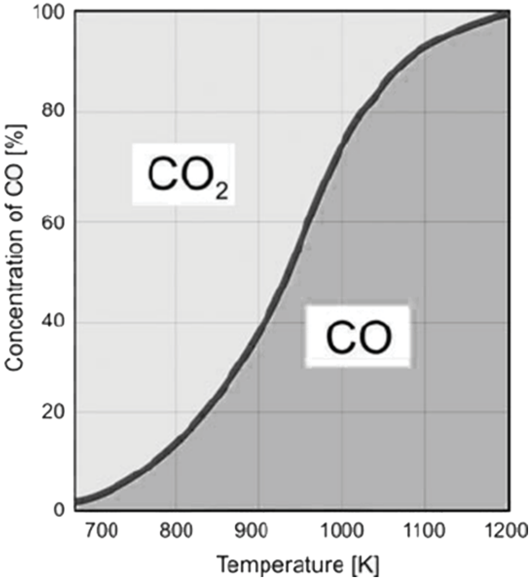

Figure 4. The Boudouard equilibria. This depicts the relative proportions of carbon monoxide and carbon dioxide are shown for different temperatures in the furnace. In principle the reaction is reversible, but in practice cooling at the top of the fuel bed is too rapid for much carbon to precipitate.

In principle the reaction:

$$CO_2 + C \rightarrow 2CO$$

is fully reversible. Equilibria between CO and CO_2 were measured by Octave Boudouard in the early 20th Century (see Fig. 4). As the carbon monoxide cools, elemental carbon can be precipitated as a soot into the gas. However, in bloomery systems this cooling is very rapid, reaction reversal very incomplete and the soot formation is only evidenced by occasional red sparks in the plume of exhaust gas. In short, bloomeries produce a lot of waste carbon monoxide bearing away most of the energy that might otherwise have been available. Burning carbon to carbon monoxide releases

$9.21x10^6 JKg^{-1}$. Burning carbon to carbon dioxide releases $3.28x10^7 JKg^{-1}$.

Charcoal is very well suited to the production of the carbon monoxide required to smelt iron from its oxides. It has a low autoignition temperature. Also, it is both porous and adsorbant which mean that oxidation takes place both on the exterior and on its interior surfaces. In a stream of pumped air it oxidises to carbon dioxide at a temperature that can be well over the melting point of pure iron. This carbon dioxide disperses rapidly, and the Boudouard Reaction ensures the production of carbon monoxide. The disadvantage of charcoal adsorbency is that merely keeping it out of the rain does not ensure that it stays dry. The weight of charcoal changes measurably in seconds as atmospheric humidity changes and stored charcoal may only yield 85% of the energy one would expect from the same mass of pure carbon.

The oxidation of dry wood produces in the region of $1.6x10^7 JKg^{-1}$, at least twice that of charcoal in reducing conditions. This oxidation is largely a surface reaction and does not normally produce much carbon monoxide. Thus, although dry wood is almost always unsuitable for smelting, it is suited for bloomery furnace pre-heating.

Implicit assumptions of a conservative nature.

There has been only the briefest mention of the heat required to bring added charcoal and ore to the reaction temperature. The addition of fresh charcoal and ore make a significant contribution towards keeping the fuel bed surface temperature low (observed to be in the region of 700K). This 'blanket' over the top of the charge has the effect of moderating heat loss with the exhaust gases. Alternatively, it might be described as a heat recapture mechanism. All other things equal, this should make no difference to the total heat budget of a bloomery furnace. However, in the region of 1200K the reduction of iron oxide to iron is well underway. The reaction:

$$3CO + Fe_2O_3 \rightarrow 3CO_2 + 2Fe$$

is moderately exothermic (about $-13.3kJMol^{-1}$). It releases the energy that charcoal combustion in a fully oxidising gas stream would have released. Similarly, the production of fayalite occurs freely above about 1420K. Fayalite is a common a component of slag:

$$2FeO + SiO_2 \rightarrow Fe_2SiO_4$$

This reaction is also moderately exothermic (about $-29kJMol^{-1}$). It does not seem to be known how efficiently a bloomery might run under optimum conditions. Consequently it is, as yet, impossible to quantify the heat that these two reactions might add to the available heat budget. However, both are exothermic and might, in principle, further reduce the gas throughput of the system in equilibrium.

Strong reasons for preheating a bloomery furnace

It is, of course, perfectly possible to run a bloomery smelt without a pre-heating stage: it just uses more fuel. Moreover, in the absence of usable written records of northern European bloomery smelting, it is unwise to assert that smelters always made a conscious decision to pre-heat. However, a hot bloomery uses less charcoal. This last assertion needs to be explored in a little detail.

In discussing the model posited above, three principal ways to heat loss to occur have been noted:

1. Loss from the outer surface of the furnace structure. This is the largest loss once the system is in equilibrium and, for this model, reaches a maximum of 2.5×10^3 W if the temperature of the reaction zone is held at 1150°C.
2. Loss by (infra-red) radiation from the upper surface of the furnace charge. It was noted that such radiation increases rapidly with temperature and that the feedback between increased radiation, increased exhaust gas temperature and furnace recharging appears to hold this temperature in check. Hence radiative loss for this model may be about 8×10^2 W.
3. Heat loss from exhaust gases is inevitable for as long as air is pumped into the system. In the model above air pumping at five litres per second would lead to the loss of about 3×10^3 W

If the system reached *an* equilibrium at 1150°C and *if* then the operators kept pumping air at the same rate, the system temperature would rise further. The temperature window for successful bloomery smelting is very narrow, so once the system was hot, the operators would be obliged to reduce air input and, so, reduce exhaust gas heat loss and charcoal consumption. It turns out that in the model considered, air input and hence charcoal consumption, should decrease by about 50% to maintain 1150°C. If increasing the charge of the furnace was slowed by 50% it would follow that the residence time of the ore in the reaction zone would increase.

The reduction of charcoal consumption whilst the system ran in equilibrium is the first strong reason for doing a thorough pre-heat.

It is likely that a large fraction of the effort in bloomery iron production went into cutting cord-wood, stacking it and turning a lot of it into charcoal. By weight the conversion ratio wood:charcoal is approximately 6:1. There are therefore considerable advantages of preheating with wood in a strongly oxidising gas flow. It will not escape readers' attention that the use of dry wood for pre-heating would require about one-twelfth of the input wood that the use of charcoal would require. Carrying out a pre-heat using wood in a fully oxidising fire would produce significant savings. This is a second strong reason for pre-heating, but not compelling.

There is a further way in which the same effects could have been achieved: if the smelting process was carried on continuously over many days the same effects would follow. From the smelters' point of view the process would be working properly once they had to reduce the blowing rate.

Possible technological consequences of full pre-heating

Some technological consequences seem to emerge from the foregoing:

- Ore residence times within the furnace could be doubled
- Less charcoal could be required on average
- In total less wood could be consumed

From these consequences other things may result. They may leave traces in the archaeological record:

- Bigger blooms could have been made and less ore gone to waste through incomplete reduction and sintering
- The extraction of bigger blooms may have involved partial demolition of the bloomery wall
- Protracted smelts could lead to the incorporation of most wood ash into slag.

The optimal pre-heat

It is hard to specify a perfect pre-heating regime using the type of calculation presented here. Real life systems are less regular than ideal models and getting *close* to the required temperature may be all that is needed. However, at least two criteria can be proposed for experimental testing. First, the minimum amount of fuel used for pre-heating must be sufficient to release enough heat to approach (if not quite attain) a temperature in the furnace fabric that approaches the theoretical equilibrium point. Second, the interior furnace wall must approach white heat, like that which can be observed through blowing orifices of a working bloomery.

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Acknowledgements

I am indebted to Dr. T. Young and Prof. V. Serneels for advising me on the existing literature of this subject and to Jeremy Hodgkinson for great assistance in the presentation of Figs. 1 – 4. Dr. P. Rondelez told me of some surprising results using high quality bog ore in experimental smelts.

LUNSFORD FAMILY CONNECTIONS

Geraldine Crawshaw

Looking at the relationships between four families in particular, all involved in the new sixteenth-century adventure in iron; members from the gentry dynasties of Pelham, Morley, Fynes and Lunsford.

Initially, ironworks set up using the new indirect or blast furnace process were established by the most wealthy land owners in the Weald – the Crown and the Church. The threat of invasion by the Scots was the initial impetus in the establishment of Newbridge in 1496.[1] However the usefulness of iron, able to be produced in large quantities, was realised from the early to mid 1500s by the gentry, most of whom had capital and lands available and/or the ability to set themselves up as industrial entrepreneurs able to manage on behalf of other people.

Between 1500 and 1550 ironmasters among the gentry included William Wybarne, John Barham, Thomas May, John and William Levett, John Baker, Richard Weekes, William Nisell, Nicholas Eversfield, Thomas Walsh, John Lunsford and Anthony Pelham.[2]

We begin the web of family connections with the relatively little-known John Lunsford of Wylye, East Hoathly. He was born in about 1520 and was only 11 years of age when his father William died in 1531.[3] The Westminster Denization Roll for 1544 includes three Frenchmen working "in master Lunsford's Ironworks".[4] Awty has suggested that John Lunsford may have been working Catsfield Furnace "at a very early period" (pre 1549).[5] However

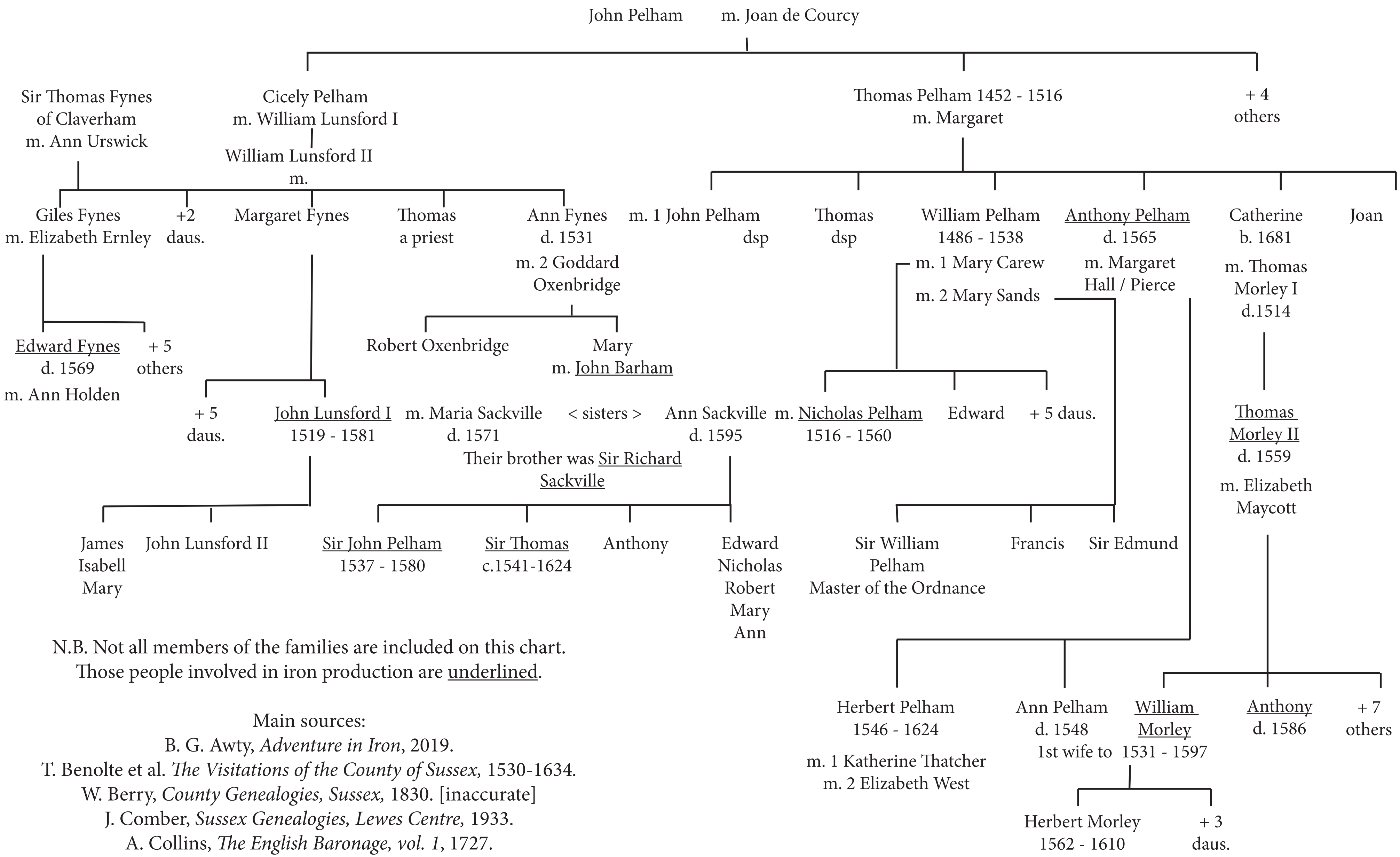
1. H. R. Schubert, *History of the British Iron and Steel Industry* (Routledge, London, 1957), 170; B. G. Awty, *Adventure in Iron* (Tonbridge, WIRG, 2019), 195.

2. Awty, *Adventure in Iron*, 439.

3. ibid., 451-2; J. G. N., 'The pedigree of the family of Lunsford and Wilegh, co. Sussex', *Collectanea: Topographica et Genealogica vol. 4* (London, J. B. Nichols, 1837), 141.

4. B. G. Awty, 'Provisional identification of ironworks among French Immigrants listed in Denization Rolls of 1541 and 1544', *Wealden Iron*, 1st ser., **16** (1979), 6.

5. Awty, *Adventure in Iron*, 438.



N.B. Not all members of the families are included on this chart.
Those people involved in iron production are underlined.

Main sources:
B. G. Awty, *Adventure in Iron*, 2019.
T. Benolte et al. *The Visitations of the County of Sussex,* 1530-1634.
W. Berry, *County Genealogies, Sussex,* 1830. [inaccurate]
J. Comber, *Sussex Genealogies, Lewes Centre,* 1933.
A. Collins, *The English Baronage, vol. 1*, 1727.
History of Parliament online.org

Figure 1: Some Fynes, Lunsford, Pelham and Morley connections

his ironworks have now been identified as Cowden Paddock, though its location has yet to be identified, and was managed by Lunsford's first cousin Edward Fynes for an unknown period until 1559, when Lunsford brought Fynes into partnership with him.[6]

Who helped this young gentleman (of a Sussex family established since at least the fourteenth century) into his position as an ironmaster?

In the will of William Lunsford lands for his heir John were put in a trust until he reached 21. The trustees were: Thomas Fynes, clerk, incumbent of Burwash Church;[7] Thomas Darell (d. 1557/58), a lawyer living in Scotney Castle, Lamberhurst;[8] Thomas Cheney, probably of Warbleton, gent., whose will was dated 1542;[9] Robert Oxenbridge of Brede, (1508-1574) MP and Constable of the Tower;[10] and John Levett, the younger (d. 1554) lived at Little Horsted, East Sussex, owner of Pounsley Furnace bef 1547 to 1555.[11] Might any of these trustees have influenced the young heir? Thomas Fynes the priest, was the brother of John's mother Margaret. William Lunsford's will includes "To Sir Thomas Fynes, clerke, xiij^{s} iiij^{d} to pray for me and to the aydinge and helping my wiff and my childerne". Robert Oxenbridge was John's cousin, the son of his aunt Ann Fynes and her second husband Sir Goddard Oxenbridge. Oxenbridge's sister Mary later married the ironmaster John Barham. John Levett the younger inherited money from the ironworks his father John had established, which were run by his uncle William Levett after his father's death in 1535.

While William Lunsford had no interest in ironworking that we know of, Awty has suggested that his servant and executor John Fanton may be the alien finer John Vynton (who worked for Thomas Morley and Anthony Pelham at Hawksden ironworks).[12]

6. J. S. Hodgkinson, 'Cowden Paddock Furnace and Forge', *Wealden Iron*, 2nd ser., **44** (2024), 23-7.

7. Lambeth Palace Library, Cranmer's Register f407 v-8.

8. https://www.historyofparliamentonline.org/volume/1509-1558/member/darrell-edward-1523-73, accessed 6 May 2025.

9. M. A. Lower, 'Notes on old Sussex families', *Sussex Arch. Colls.*, **25** (1873), 110.

10. https://en.wikipedia.org/wiki/Robert_Oxenbridge_(died_1574), accessed 6 May 2025.

11. www.wirgdata.org/searchsites2.cgi?siteid=637; accessed 6 May 2025.

12. Awty, *Adventure in Iron*, 452.

Potentially, the clue to solving the identity of Lunsford's ironworks could lie in his family connections. Indeed, the whole mesh of a few family relationships, with many members entering into iron production is quite astounding, though it may have been quite normal for entrepreneurs of that age. Gentry families closely related to John Lunsford were the Fynes, Pelhams, Morleys and Sackvilles, all involved to varying degrees in the new boom industry of iron production. Reference to the partial genealogical chart (Fig. 1) aids the following descriptions.

To the members of the gentry iron working was mostly a lucrative sideline.[13] Even Anthony Pelham, who became involved in the running of several ironworks, was keen to continue the role of agricultural landowner.

This writer believes Anthony Pelham of Buxstepe in Warbleton to be the most likely candidate for helping Lunsford into the iron industry. Anthony was the youngest of four boys, born in about 1487 to Sir Thomas Pelham (1452-1516) and his wife Margaret. He is known to have been a forgemaster before his brother William died in 1538 and took on several iron concerns during his lifetime.[14] These include Hawksden Forge (of which more below), the Ashburnham works, Bivelham Forge, Steel Forge and Warbleton Priory Furnace near his seat at Buxstepe. He is listed as employing aliens as iron workers in these years (see Fig. 2).[15]

1544 – Location not listed

1549 – Hundreds of Hawksborough, Netherfield and Foxearle

1550 – Hundreds of Foxearle, Shoyswell and Netherfield, and Bivelham Borough

1551 – Borough of Tottingworth

1552 – Hundreds of Foxearle, Shoyswell and Netherfield[16]

13. J. J. Goring 'Wealden Ironmasters in the age of Elizabeth' in E. W. Ives, R. J. Knecht and J. J. Scarisbrick (eds.), *Wealth and Power in Tudor England* (London, Athlone Press1978), 212, 272. By 1574 the Wealden Industry was no longer in the hands of major landowners, the peers and gentry, but had filtered down to the yeomen and lesser gentry – the middle tier of Tudor Society.

14. Awty, *Adventure in Iron*, 428.

15. www.wirgdata.org/searchpro2.cgi?personid=219, accessed 24 March 2025; Awty, *Adventure in Iron*, 438, 450, 451; although Awty claims Anthony Pelham's Hawksden works were sold to Thomas Morley in 1551.

16. Awty, *Adventure in Iron*, Appendix II, 824, 827, 830, 831 and 832.

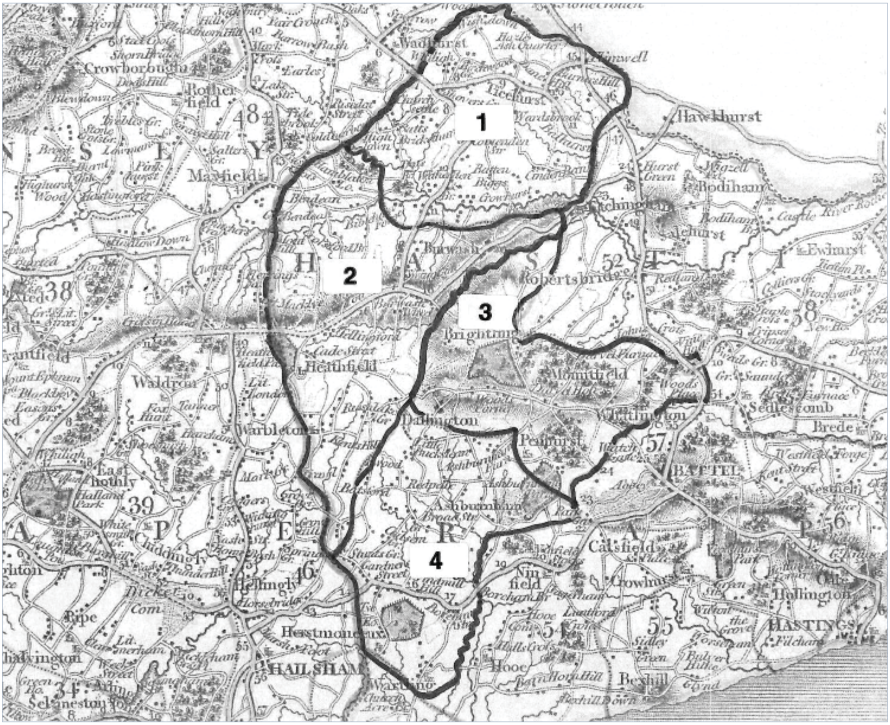


Figure 2: Hundreds where aliens who worked for Anthony Pelham resided, 1544-52: 1. Shoyswell; 2. Hawksborough, which included the boroughs of Tottingworth and Bivelham; 3. Netherfield; 4. Foxearle

In 1554, Anthony Pelham bought a half share in the newly established ironworks in Newdigate, Surrey.[17] This appears to be the only ironworks he left to his son Herbert before he died in 1565. Anthony's eldest brother John Pelham had married Ann Fynes (her first husband). Ann's sister Margaret had married William Lunsford. They had five daughters, John Lunsford being their only son. Ann and Margaret Fynes had a brother, Giles, whose son was Edward, thus first cousin to John Lunsford. The Fynes' family home at this time was the moated mansion at Claverham, just over a kilometre east of Chalvington.

17. M. S. Giuseppi, 'The Manor of Ewood and the ironworks there in 1575', S*urrey Arch. Colls.*, **17** (1902), 31.

The Lunsfords were directly related to the Pelhams in another way. John's father William (II) was the son of William Lunsford (I) and Cicely Pelham (b. c1450, married 1470).[18] Cicely or Cicelia was Thomas Pelham's sister and therefore the aunt to his children, John, Thomas and William, Anthony, Catherine and Joan as well as being John Lunsford's grandmother. William Lunsford, John's father, was therefore cousin to those Pelhams.

This helps to explain why Anthony Pelham in his will, proved in 1566, refers to John Lunsford as his cousin (actually second cousin).[19] That these two men were close is shown by Pelham appointing Lunsford as one of the overseers of his will along with William Morley (his son in law) and Barnard Randall (a lawyer). Edward Fynes was one of the witnesses to Anthony Pelham's will, along with John Pelham (b. 1537), Anthony's great-nephew. John Lunsford also appears in documents such as the marriage settlement of Anthony Pelham's only daughter Ann to William Morley of Glynde in 1560.[20]

William Morley's father was Thomas Morley (II) whose father was another Thomas Morley (I). This elder Thomas was married to Catherine Pelham and therefore Anthony's Pelham's brother-in-law. Thomas Morley II was, thus, Anthony Pelham's nephew.[21] It was Thomas Morley II who took particular interest in Hawksden Park (near Mayfield), family land inherited from his ancestors, the Waleys of Glynde. There, on the river Rother, Thomas established and ran an iron furnace and forge.[22] The appearance of French workers for Anthony Pelham in Hawksborough Hundred in 1550 suggests that Morley's uncle, Anthony Pelham was operating these ironworks then.[23]

It is likely the improvements made to the moated mansion (TQ 6184 2674) just 400 metres to the west of the new Hawksden iron works were made by Thomas Morley II between 1531 and his death in 1558/9. This former

18. *Pedigree of Lunsford*, 141.

19. TNA PROB 11/49/69, Will of Anthony Pelham of Warbleton Sussex (1567)

20. East Sussex Record Office (hereafter ESRO), GLY/104, 108, and 109.

21. J. Comber, *Sussex Genealogies, Lewes Centre*, (Cambridge, W. Heffer and Sons Ltd 1933), 190.

22. ESRO, GLY/1/6/184, Probate of will, 1559 of Thomas Morley of Glynde esq.

23. Awty, *Adventure in Iron*, 124.

Figure 3: The inner courtyard, Glynde Place, East Sussex (photo: author)

hunting lodge was converted to a more comfortable dwelling.[24] Ownership of Hawksden ironworks passed to William Morley, Thomas' son who had married, as his first wife, Anthony Pelham's daughter Ann thus becoming Anthony Pelham's son in law; his second wife, Margaret Roberts, was John Lunsford's niece by his sister Isabel.[25] Profits from the iron industry enabled William to rebuild the family home at Glynde in grand Elizabethan style. His coat of arms, with a date of 1569, looks over the inner courtyard (Fig. 3).

Returning to other family connections within the wider circle, Nicholas Pelham, eldest son of Anthony's brother William was born c. 1513, while John Lunsford was born in 1520. They both married into the prestigious Sackville family – Nicholas to Ann and John to Maria/Mary, daughters of

24. D. Martin, 'Three Moated Sites in North East Sussex part 2, Hawksden and Bodiam', *Sussex Arch. Colls.*, **128** (1990), 89-116.

25. Comber, *Sussex Genealogies,* 192-193.

John Sackville of Buckhurst and sister of Sir Richard Sackville. the ironmaster living at Buckhurst.[26]

Following are listed some of the works owned or run by ironmasters from the families discussed above, taken from the WIRG database:

Richard Sackville of Buckhurst:

Horsted Keynes Furnace – Lessee/ironmaster 1566
Newbridge Furnace and Forge – Lessee 1563-1566
Sheffield Furnace and Forge – Lessee before 1560-1566
Worth Forest Furnace – Lessee before 1553-1566

Edward Fynes

Cowden Paddock Furnace and Forge – Ironmaster before 1559-1569

Thomas Morley (1512-1560)

Hawksden Forge and Furnace – Owner/Ironmaster bef. 1549-1559

William Morley (1532-1597)

Hawksden Forge and Furnace – Owner 1559-1598

Anthony Morley (d.1586) younger brother of William

Freshfield Forge – Owner
Horsted Keynes Furnace – Lessee 1574

Anthony Pelham

Warbleton Priory Furnace – 1540s[27]
Ashburnham (Dallington) Furnace Lessee 1550
Hawksden Forge and Furnace – Lessee/Ironmaster 1549-1551
Ewood Furnace and Forge (Surrey) – co-owner 1554-1566

Nicholas Pelham (b. c1513–1560)

Probably operating Waldron Furnace in 1543[28]
Glaziers Forge, Brightling up to 1549[29]

John Pelham (son of Nicholas Pelham, great nephew of Anthony Pelham)

Bivelham Forge – owner 1560-1580

26. W. Berry, *Pedigrees of the Families in the County of Sussex* (London, Sherwood, Gilbert & Piper, 1830), 300.

27. Awty, *Adventure in Iron*, 439.

28. ibid., 58.

29. ibid., 31.

Glaziers (Brightling) Forge – owner 1560-1580
Crowhurst Furnace and Forge – owner bef. 1574-1580
Waldron Furnace – owner 1560-1580
Nicholas Pelham's other son, Thomas (1540-1624) also later held the above furnaces and forges.

Looking at these family connections can only suggest those people who may have influenced John Lunsford, but no link to his ironworks has emerged. The aliens Lunsford employed, John Deford, Gilham Nufyld and Everode Pynyon, likewise have no evident connections to other ironmasters in his

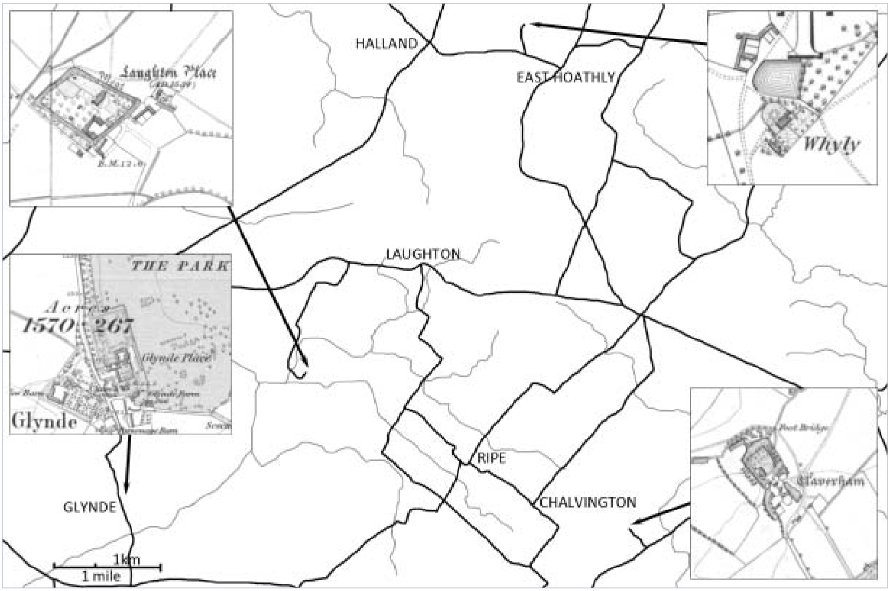


Figure 4: The family homes: Laughton Place, Glynde Place, Claverham and Whyly

wider family.

It will come as no surprise to find that the Pelham (Laughton), Morley (Glynde), Fynes (Claverham) and Lunsford (Wylye) main family homes were geographically close – within about 6 miles (10 kilometres) of each other (Fig 4). We know very little about social interaction between local gentry families during this period. Buying and selling land was still important as well as issues of law. Did they meet in their homes or perhaps town houses in London or

Lewes, or at the law courts? Just one example is that at the Lewes Sessions in April 1569; those sitting as magistrates were Richard Covert, John Pelham, John and Thomas Culpepper and John Lunsford.[30] That they did meet up and sign documents such as witnessing wills and marriage settlements is well-established. We can only guess that they talked about the importance of the new iron industries, their locations, method of working and employment of aliens who brought their knowledge with them. Several of these family members were public figures and those of the younger generation expected to enter the legal profession or go to university. John Lunsford himself was a Justice of the Peace from 1560-81. His son John (b.1547) went to Grays Inn, was knighted in 1610 and became Sheriff of Sussex and Surrey that year.[31] William Morley was a fellow of Queen's College, Cambridge (1548-50) and later in life a J.P. and Sheriff of Sussex 1580-1.[32] Many Pelham family members were also involved in public duties for the county.[33]

Keeping the ironworks in the wider family may have made good sense when so much trust was involved. Partners outside the close circle of families were not usual in the early sixteenth century.[34]

The Tudor era these families were living through were times of great uncertainty. Henry VIII declared war on France in 1512, then dissolved the monasteries in 1538 and effectively changed the country's religion. By 1544 war with France was again imminent, requiring alien workers to take out letters of denization or leave the country. Changes caused by the accession of the boy king Edward VI, followed by his sister Mary, then Elizabeth, with the possibility of invasion from Spain, would have been worrying times for the Sussex gentry. Disseminating their knowledge acquired of the new iron industry, with riches to be gained, perhaps they were wise to 'keep it in the family'.

30. J. S. Cockburn (ed.), *Calendar of Assize Records, Sussex Indictments, Elizabeth I* (London, HMSO, 1975), 64-5.

31. J. E. Mousley, Sussex County Gentry in the Reign of Elizabeth, unpublished PhD Thesis, University of London (1955) Appendix 18, 335, https://discovery.ucl.ac.uk/id/eprint/1317933/ accessed on 20 January 2025.

32. ibid., 621.

33. bid.

34. Goring, *Wealth and Power*, 206.

Acknowledgements

Malcolm Lill for arranging a visit to Glynde Place with permission from the owner Francis, Viscount Hampden, to whom also my grateful thanks for allowing me to photograph the building included here. Also I am grateful to Jane Seabrook for the references to Thomas Fynes.

THE CLOSURE OF EWOOD FURNACE AND FORGE

Jane Lilley

Ewood, in the northeast corner of Newdigate parish, Surrey, had a relatively short-lived ironworks. The furnace may have started operation in 1551-2, as the lay subsidy rolls list no aliens in Newdigate in 1551 but two in 1552,[1] and land was bought in Leigh for a forge in 1551, implying a furnace nearby.[2] It was a going concern when on 24 March 1553 the Park of Iwood with all buildings, ironworks and offices was sold by Lord Abergavenny to George and Christopher Darrell.[3]

The date at which it closed has always been uncertain; it existed in 1604 when the Crown relinquished control but was not mentioned in the 1667 petition and was not present in 1677-8.[4] Indirect evidence from an indenture of 1606 and the later history of Ewood is here interpreted as indicating that the works closed immediately after the Crown handed control back to the Darrell family, and Ewood was then remodelled as two agricultural estates with extensive coppice woodland, which were sold.

The 1575 Exchequer survey of the manor refers to "the Iron mylle and woorkes a Furness a Forge and Hammer" together with a great pond containing an estimated 80 acres, a colehouse and some cottages and houses for the workmen.[5] It is unlikely that both forge and furnace could have operated at the same time, so possibly the forge was replacing or had just replaced the furnace at the time of survey. The bay of the Great Pond was raised at an unknown date, as shown by the very deep Floodgates Hole (now

1. B. G. Awty, 'Aliens in the ironworking areas of the Weald: The Subsidy rolls, 1524-1603', *Wealden Iron*, 2nd ser. **4** (1994), 74.

2. The National Archives, C 54/506, cited in E. Straker, *Wealden Iron*, (G. Bell & Sons 1931), 455.

3. M. S. Giuseppi, 'The Manor of Ewood and the Iron-works there in 1575', *Surrey Arch. Colls.* **17** (1902), 30.

4. Straker, *Wealden Iron*, 454.

5. Giuseppi, 'The Manor of Ewood', 34-40.

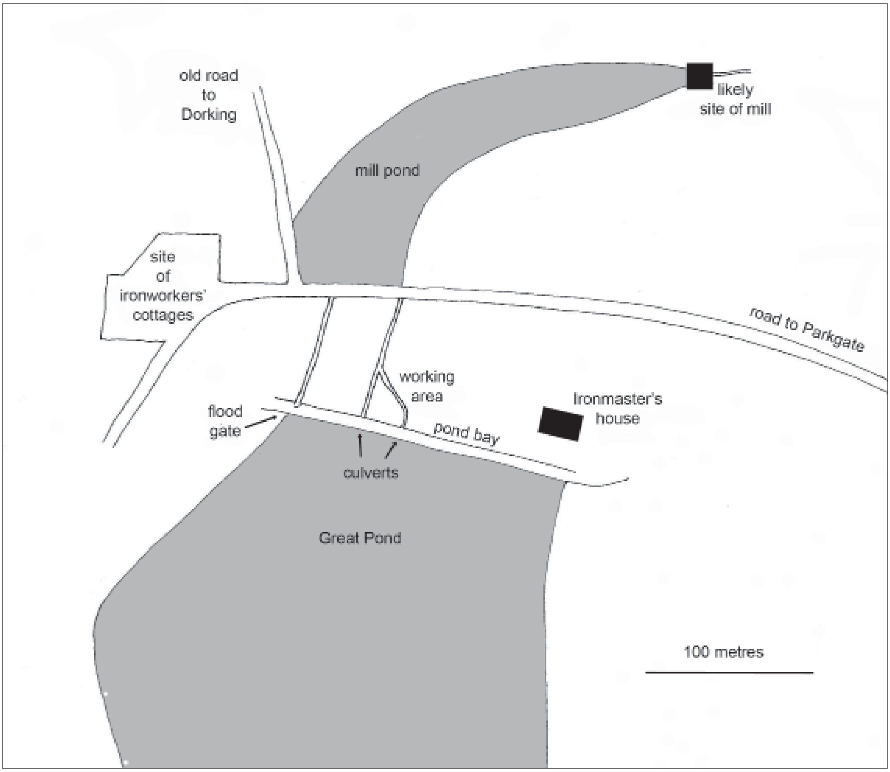


Figure 1: Sketch map of Ewood ironworks site pre-closure

partially filled with dredgings from Mill Cottage's garden pond) close to the west end of the bay, but there were only two culverts in the working area, and the pond was shallow and fed only by seasonal streams (Fig. 1). Despite a number of pen ponds (there were certainly more than the eight currently identified) the water supply must always have limited operation.

The ironworks were bought in 1553 by the recusant Darell or Darrell family of Scotney, and despite several changes of ownership they maintained an interest in the site.[6] Their financial difficulties resulted in control passing to the Crown, which remained in possession until 1604. Straker comments that

6. Straker, *Wealden Iron*, 451.

it quite probably then closed down, but he clearly had no definite evidence.[7]

An indenture dated 14 August 1606 can be interpreted as indicating that Straker was correct and the ironworks closed down in 1604 or 1605.[8]

The indenture relates to the sale of land within the Manor of Iwood, the parties being Henry Darrell of Scotney, Sussex, Esquire and Sir Thomas Bludder of Flaunchford, Surrey, and his son Thomas. Confusingly, two other men are separately named as vendors: the indenture

> *Witnesseth that whereas James Thatcher of Presthames in the County of Sussex esquire and Barnabe Goche Doctor of the Lawse by their Indenture bearinge date with theis presentes for the consideracon therein expressed have graunted bargained and sold unto the said Thomas Bludder knight and Thomas Bludder…*

The connection of Thatcher and Goche is otherwise unknown and it is possible that they had been responsible for the remodelling of the estate.

The property conveyed consisted of three houses with land, all let out. In addition there was a little coppice on the east side of the Whappell Way abutting the lands of Sir Francis Stidolph, unspecified coppices and woodgrounds in the tenure of the same three men as the messuages, a pond called Hammons Pond, and a little pond called the Old Mill Pond. A parcel of pasture called The Rayles was excluded, and there is no mention of either the Great Pond or the corn mill.

The exact identification of the property conveyed is not straightforward. It is stated to be part of the Manor of Iwood (Ewood), to lie entirely within the parish of Newdigate, and to contain 240 acres. There are no extant records of Iwood Manor, so it is not known what proportion was here sold, but it is clear that it was the property later known as Ewood Park, which contained the eastern side of Ewood.

The first messuage had a barn, close, garden, orchard, two little crofts, and 33½ acres, mostly of "woody, stubby or bushy ground" but with three named meadows. It reappears in a second indenture of 1613 when the lease to Matthew Bishop, husbandman of Newdigate, of a messuage and 35 acres was renewed, and is there named as Batts and Hawks Ridon alias North

7. ibid., 454.

8. Surrey History Centre (hereafter SHC), K77/18/1.

Ridon, and stated to be in Newdigate and Leigh.[9] The house can be identified with Old Joe's, schedule no. 90 in the Newdigate tithe apportionment survey, which stood at the south end of the present Hammonds Copse, with the land extending south to Partridge Lane and eastwards across a finger of Leigh parish to Northridens, north of Halesbridge.[10] This is consistent with the statement that the pond called Hammons or Hamonds Pond, which lies in Hammonds Copse and was reserved to Sir Thomas Bludder, was "near adjoining".

The second messuage had an unspecified amount of farmland, with parcels of pasture and arable and a little meadow, and its bounds included the mill dike and a little pond called the Old Mill Pond.

The mill was not mentioned in the 1553 sale, but in 1575 it had two pairs of stones for wheat and malt, a pond, and half an acre of land and pasture on the east side.[11] The pond is clearly not the 'great ponde' which powered the forge and furnace and was estimated at 90 acres extent, so the mill cannot have been on the site of the later one, which was within the working area of the ironworks immediately below the bay of the Great Pond, adjacent to the western culvert and close to Mill Cottage.

The tithe apportionment survey includes two small, very level fields, both called Mill Meadow, on the west side of the stream north of the working area, (schedule nos. 55-56). Although there is now no clear evidence of a bay it is probable that the stream was dammed very close to the parish boundary so that the waste water from the ironworks flooded what became the Mill Meadows, creating a large shallow pond which powered the watermill. This would plausibly put the boundary of the second property at the mill dike on the parish boundary and close to a little pond which survived at the lower end of Mill Meadow (tithe no. 55) after the mill's bay had been breached.The mill and the Great Pond were not included in the sale to Sir Thomas Bludder, but the reference to the Old Mill Pond without mention of a mill implies that the mill had been relocated to its later site adjacent to the bay to the Great Pond. This could not have taken place when the ironworks was operating.

In 2013 the writer noted that the present large garden pond below the

9. SHC, K77/19/1.

10. SHC, 889/1.

11. Giuseppi, 'The Manor of Ewood', 37.

pond bay was drained and dredged, and the wheel pit and spillway below the western culvert were exposed. The spillway was floored with heavy timbers containing mortices for vertical timbers in their centres, and these must have supported a timber covering to the stream, allowing free movement across it. The brickwork of the wheel pit showed that at some time it had been reduced in width by 14 inches from its original 6 ft 4 in width, and reduced in depth by flooring it with heavy timbers, probably replacing a breast-shot wheel with a smaller undershot one and reducing both the power and the amount of water used. This is most likely to have taken place immediately after the ironworks closed when the mill was relocated to its later site. The water supply was always a problem; a survey for the Duke of Norfolk in 1791, when the pond was used for fishing, stated that the miller was not allowed to draw down water to below 3 feet deep against the bay, and in 1717 the miller at Ewood had 'lately' erected a windmill on Shellwood Common, probably to give him an alternative source of power.[12]

The third messuage had barns, meadows, pasture and arable land; the area was not stated. This is probably the farm later known as Chittys, which lay between the Great Pond and Broad Lane and abutted the other two properties. Its farmhouse and outbuildings, between the old manor house and the pond bay, are unlikely to have been built there when the house was occupied by the ironmaster and the works in full production, and so were probably erected immediately prior to the sale.

If this interpretation is correct the mill, with its dike and pond, was sited downstream of the ironworks in 1575. In 1606 its dike and a little Old Mill Pond formed part of the property sold by Henry Darrell to Sir Thomas Bludder, and there is no mention of a mill in the sale. The implication is that the ironworks had ceased functioning at the time of the indenture and the site had been cleared, with the mill relocated to its later position close to the western sluice in the bay of the Great Pond.

The remodelling of the site in c.1604-5 is consistent with the likely date of building of Ewood Old Farmhouse and its farmstead. This is just west of the working area, on a level raised platform which is the probable location for "iiij cotages with garden plotts convenyent for the workmen of the said

12. Arundel Castle Archives (hereafter AC), MSS D5571. SHC, 196/4/1.

Woorkes to enhabytt in".[13] The Surrey Domestic Buildings Research Group dated the building to 1623, but that was based on a misinterpretation of a documentary source; they had previously dated it as late sixteenth or early seventeenth century, and it includes reused timbers. As a new farmhouse and its buildings it would have formed the nucleus of the second agricultural estate called Ewood Park formed by the remodelling of Ewood, but in the absence of a dendrodate this does nothing to establish the date of the remodelling.

Sir Thomas Bludder appears to have bought half the area of Ewood Manor or Park. Although there is insufficient information to know whether the ironworks working area was included in the sale there is no mention of the works and it is inconceivable that they could have continued to operate without half of their coppice land. The implication must be that the ironworks had closed and the site had been remodelled, but the abuttals of the area sold to Sir Thomas Bludder refer to features which cannot all be identified.

The indenture names the landowners of property on the north and eastern sides of the land sold, and a survey of the manor of Shellwood in 1636 includes the same names and confirms the known or conjectured boundaries of Ewood on those sides.[14]

The south-eastern and southern side abutted the King's Highway from Charlwood "to the gate of Iwoode parke called the pownd gate'" and the south-western and north-western sides to "the highe waye leadinge from the same gate through Iwood Parke to Leigh Church". The King's Highway is the present Partridge Lane and becomes Parkgate Road at the junction with Broad Lane, but the site of the pound is unknown. One entrance to Ewood Park was at the end of Broad Lane, which is now the obvious route to Leigh church, but there is far less than 240 acres of land east of the road and within the bounds of Ewood.

A possible alternative is that the highway to Leigh church was part of an ancient north-south route from the south of the parish to Dorking which left Parkgate Road at the bend by Reffolds, about a kilometre from Broad Lane. This was flooded and closed or diverted by the creation of the Great Pond, but its junction with the road had a large triangular green which could easily

13. Giuseppi, 'The Manor of Ewood', 35.

14. West Sussex Record Office, HCC/Acc 1771A/Box51/Bundle7/1.

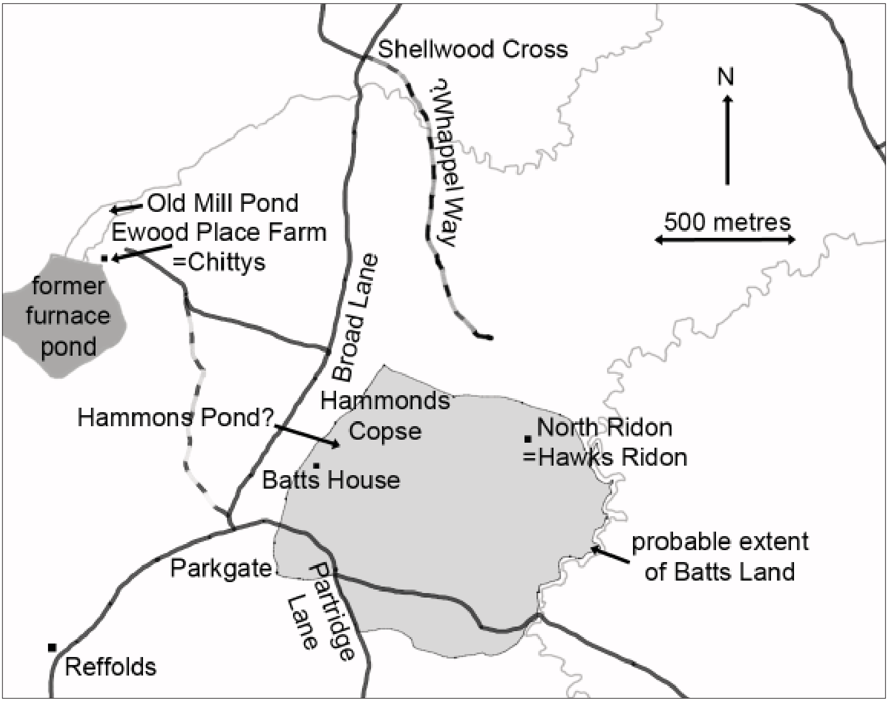


Figure 2: Locations of the places named in the 1606 sale of the eastern half of Ewood, including the property later known as Batts

have included a pound. In 1608 an indenture selling that green includes as one boundary a little lane leading into Iwood Park, which must be the remnant of the old road.[15]

Interpreting it as the highway to Leigh church assumes that the bounds given in 1606 followed the common practice of repeating those given in older documents, and that the present footpath from the north edge of the ironworks site to Shellwood Cross then formed part of a highway. Both are possible, and would put the western boundary of the property sold to Sir Thomas Bludder at the old north-south road from Parkgate Road through the Great Pond to Ewood, not far from the known later edge of that estate. The mill and pond appear to have been excluded from the sale.

15. Property of the owners of Reffolds, Newdigate.

Later ownership confirms that the division of Ewood passed roughly through the ironworks working area. Sir Thomas Bludder's half passed through several hands before being bought by Thomas Grinstead in 1768.[16] His 1769 survey map shows that his western boundary passed through the old ironworks site, but also included a small area west of the old road, with his boundary largely following the parish and Hundred boundary, so a little extra land had apparently been bought at some time.[17]

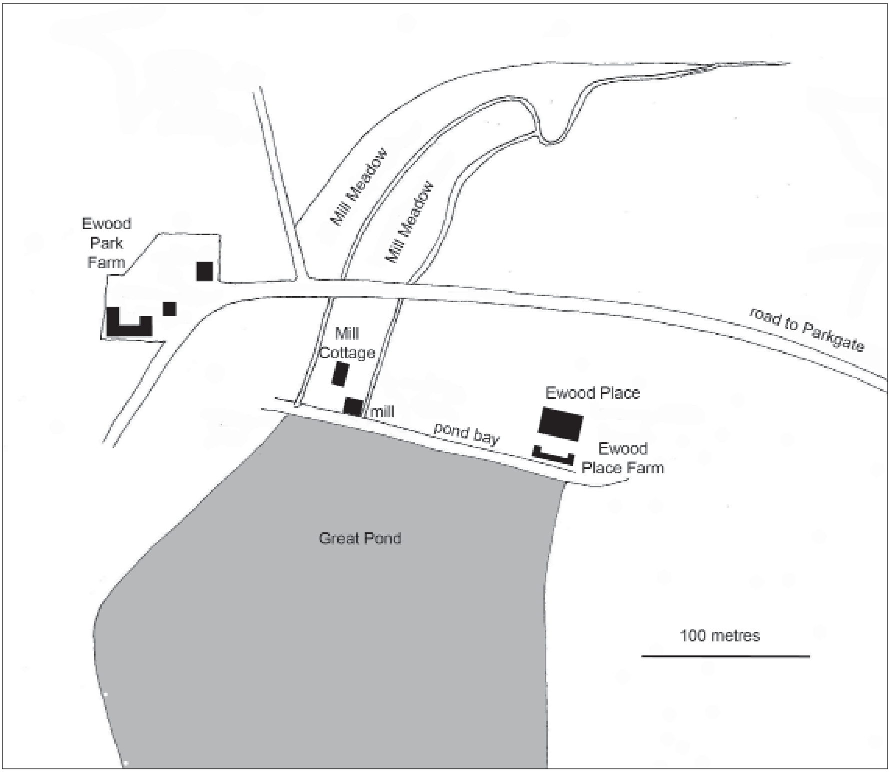


Figure 3: Sketch map of the ironworks site after remodelling c. 1604-5

16. H. E. Malden (ed.), 'Parishes: Newdigate', *A History of the County of Surrey: Volume 3,* (London, 1911); British History Online https://www.british-history.ac.uk/vch/surrey/vol3/pp310-315 [accessed 12 June 2025].

17. AC, PM42.

The two halves of the Ewood estate were reunited when they were sold to the Duke of Norfolk in 1786 and 1789.[18] Thomas Grinstead's property then included the old manor house of Ewood Place, 147 acres of farmland and 138 acres of coppice woodland, the Great Pond and three smaller ponds, Ewood Mill, and the wheelwright's shop at Parkgate (later the Surrey Oaks public house). The other half, belonging to General Smith, included Ewood Park Farm, 168 acres of farmland and 107 acres of coppice, most of which was in Capel parish.

It is certain that the division of Ewood took place after the closure of the ironworks, and that the boundary between the two halves passed through or adjacent to the former working area between Ewood Place and the new farmstead of Ewood Park. This cannot have taken place while the ironworks was operating. The 1606 references to the mill dike and little Old Mill Pond imply that the mill was no longer at its old site at the northern boundary of Ewood and had been relocated to its later position immediately below the bay of the Great Pond. And the ironworks would have been unviable without a large part of their coppice woodland, which was sold in 1606 (Fig. 3).

In the absence of further evidence it can be concluded that when the works were returned to Henry Darrell by the Crown in 1604 they were deemed no longer viable and were closed. Ewood Park was then remodelled, with the ironworks buildings and workmen's cottages being demolished, the mill relocated, and Ewood Park and Ewood Place (Chittys) farmhouses and farmsteads built. The two halves were then sold separately as two agricultural and woodland estates.

18. AC, MSS D5570 & D5571.

THE OPERATION OF WALDRON FURNACE, EAST SUSSEX, 1690-1716

J. S. Hodgkinson

In 1690 Thomas Moore took over from a Mr Glyde or Glydd as clerk to the ironworks owned by Sir John Pelham (1623-1703). These were Waldron Furnace and the forges at Brightling and Bivelham, the last of these being in Mayfield parish. The accounts that he kept are preserved in two volumes among the extensive Pelham archive in the British Library.[1] The earlier records of the forges, from 1624 to 1680, are in a further volume.[2] The accounts would have been compiled from a day-book or waste-book in which daily transactions would have been recorded before being organised into categories and copied for presentation in the form in which they now survive.

The accounts are mostly laid out in the same form from year to year, Michaelmas (29th September) being the beginning and end of the accounting period. First are listed receipts, although at first only occasionally is it stated to what they refer. Payments from Ambrose Galloway seem to be an exception as are those made by country blacksmiths for small quantities of bar iron made at the forges. Later more detail is given about the nature of the receipts. Frequent receipts from Sir John and later from Sir Thomas Pelham may be for moneys paid to him personally rather than to Thomas Moore, the clerk. Next, a small number of receipts of rents are noted. These include payments from the finers and hammermen at Brightling and Bivelham who evidently operated the forges on a semi-independent basis, while the furnace was run 'in house'.

The wages of the founders and fillers at Waldron included payments to the principal founder for the duration of each campaign together with payments for quantities of specific castings, such as sows, anvils, forge hammers, hursts and plates. Payments for wood, its cutting, coaling and carriage, and for

1. British Library (hereafter BL), Add Ms 33156, and 33154 ff.39-153v.
2. BL, Add Ms 33155.

mine, its drawing and carriage, were itemised. Miscellaneous payments to individuals who carried out specific tasks were listed as "necessaries". These varied from making the furnace hearth to cleaning away rubbish, making faggots or supplying lime, and providing drink for workmen or laying hedges. Woodland management constituted a significant element in some years' accounts. Sometimes major refurbishment was needed, such as the provision of new bellows, or the rebuilding of the furnace in 1710-11. Carpenters' and masons' piece work was separately accounted for though seldom itemised. Further expenditure from 1701-2 onwards were rents and poor taxes, which were not specific to the operation of the ironworks, nor was expenditure on Park Mill, Burwash, in 1691-2, 1694-6 and 1697-8. Finally the totals for the foregoing detailed accounts were summarised. Although at the end of each year's accounts a gain, or occasional loss, was recorded, it did not represent a working gain or loss specifically for the ironworks because of the other estate expenditure (and unspecific income) included in the accounts. So it is not possible to ascertain with any accuracy if iron production was profitable.

The accounts for the two forges included similar payments for wood, necessaries, carpenters' and masons' work and carriage of the finished bar iron. Specific payments were made for the fining and forging of the quantities of iron at the two hearths at each forge. Details of the operation of the forges will be the subject of a future article.

At the end of each year's accounts the amounts under each category at each works were listed and totalled, together with a memorandum of the length and production of the furnace campaign, and the account was then examined by Sir John, and later Sir Thomas Pelham and signed off, although this became intermittent after 1705. Over the quarter of a century that these accounts were maintained the consistency of the structure of the accounts, the amount of detail and the legibility of the handwriting deteriorated.

Waldron Furnace had been Pelham property since before 1574 and possibly as early as 1543. When it was recorded in the lists of 1574 it was under lease to Thomas Stollyan but had been taken in hand before the death of Sir Thomas Pelham in 1624 and the absence of receipts for iron sold that might otherwise have been recorded in the clerks' accounts shows that from then on the Pelhams were personally involved in its management until the furnace was leased again in 1717. Detailed accounts for the furnace prior to 1690 have not survived.

Furnace campaigns

Waldron Furnace operated, as most Wealden furnaces did, as a Winter furnace, being blown in after the harvest in the Autumn and continuing in blast until supplies of ore, charcoal and/or water ran out in late Spring. The details of each campaign were recorded in the accounts:

Blown in	Blown out	Campaign (days)	Production (t – tons / c – hundredweight)
25 Oct 1690	5 Jun 1691	223	193t (100t shot 90t sows 3t plates, anvils, hammers)
25 Nov 1691	4 Jul 1692	247	171t+ (168t sows 3t anvils, hammers, forge plates + Wm. Benge's castings)
29 Oct 1692	13 May 1693	196	192t (56t sows, hammers, anvils 61t shot, shells (Wm. Benge) 75t shot, shells (Tho. Western))
20 Nov 1693	6 Jun 1694	198	201t (157t sows c.44t shot, shells (Wm. Benge))
5 Oct 1694	5 May 1695	212	192t (151t shells, carcasses 38t sows 3t shell moulds)
16 Oct 1695	30 May 1696	242	185t (100t shot 82t sows 3t shot moulds)
10 Nov 1696	13 May 1697	215	197t sows, hammers, anvils, plates
23 Oct 1697	9 Apr 1698	158	180t
8 Nov 1698	25 Apr 1699	159	179t 6c
14 Nov 1699	12 Apr 1700	150	146t 13c
31 Oct 1700	29 May 1701	210	224t 6c
20 Nov 1701	11 May 1702	152	169t 17c
29 Oct 1702	8 May 1703	184	200t 17c
11 Nov 1703	15 May 1704	185	169t 10c

Blown in	Blown out	Campaign (days)	Production (t – tons / c – hundredweight)
1704	1705	not recorded	
29 Nov 1705	10 May 1706	162	160t 4c
9 Oct 1706	2 May 1707	205	209t 10c
1707	1708	not recorded	
26 Oct 1708	4 May 1709	170	198t 1c
1709	1710	not recorded	
1710	1711	not recorded	
1711	1712	not recorded	
1712	1713	200	194t 5c
1713	1714	not recorded	
1714	1715	131	

For 1704-1705, 1707-1708 and after 1709 the dates of the campaigns were not recorded in the accounts; the lengths of the campaigns ending in 1713 and 1715 were derived from the payments to the founder. The average length of a campaign for those that were recorded was 189 days, and the average output 188 tons.

Pig iron and other castings

The output of the furnace was predominantly pig iron in the form of sows. There was also intermittent casting of hearth plates, anvils and hammers for the forges, and a small number of firebacks. For a brief period from 1690 to 1696 production was focused on round shot and shells and the moulds in which they were cast. Details of the production of these are set out below.

Iron sows for the forges at Brightling and Bivelham constituted 70 percent of the iron cast at Waldron but a small trade was carried on supplying other

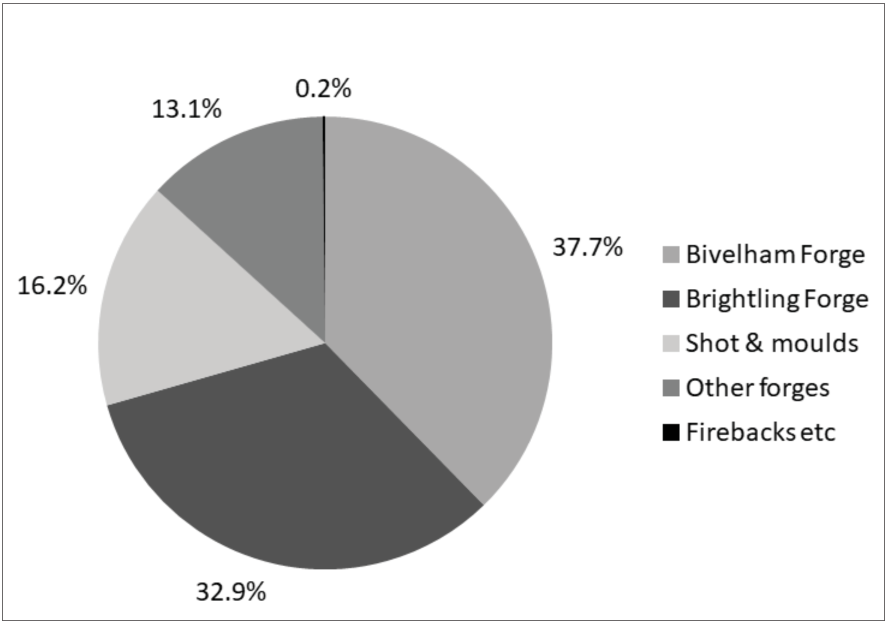


Figure 1: Waldron Furnace: destination of castings 1690-1715

forges (Fig. 1). These were Maresfield (76 tons 1690-3, John Newnham), Ardingly (59 tons 1695-1706, Ambrose Galloway), Etchingham (52 tons 1693-4, John Nicoll), Woodcock (106 tons 1698-1701, Jeremiah Johnson), Eridge (10 tons 1700-01, Henry Weller) and Hawksden (74 tons 1702-09, John Sands).

A range of replacement castings for the forges at Brightling and Bivelham were made at Waldron as well as for the furnace itself. Hammers, anvils and hursts were made in nearly all of the years for which records have survived, as were forge plates. Schubert listed six different plates that lined each of the finery and chafery hearths at forges.[3] Other parts for the hearths, chimneys and bellows, such as hammer and bellows braces, gudgeons and the boits they rested on were cast frequently. Each was itemised separately under the list of annual payments to the founder, although this list is absent for 1704-5, 1707-

3. H. R. Schubert, *History of the British Iron and Steel Industry* (London, Routledge, 1957), 421-2.

8, 1709-13 and 1714-15. Some anvils and hammers were destined for other forges: Etchingham in 1693-4, and in several campaigns to Ardingly. Other plates mentioned were evidently chimney plates or firebacks. Although these were few in number, their buyers or destinations are mentioned in several instances, some to the Pelhams' house at Halland, others to local farms including tenants of the Pelhams' estate. Two in particular, in 1703, were for Sir Nicholas Pelham who lived at Catsfield Place,[4] and in 1716 a large back was sold to Chyngton Farm, near Seaford. Several firebacks have survived which bear the buckle badge of the Pelham family, some of which may have been cast in the period of these accounts. A series dated to 1642 may well have continued to be cast for several decades while the wooden pattern or model remained available. In 1708 an andiron mould is mentioned as being brought to the furnace from Halland.

Shot and shells

Although accounts for Waldron Furnace in the 1670s and 80s have not survived it has been noted elsewhere that Sir John Pelham had supplied shot to Portsmouth during the Third Dutch War (1672-4).[5] Later, payments to him from the Treasury that were authorised in May 1690 indicate that shot had been cast probably in the previous year.[6] This was before details began to be recorded in the surviving accounts for Waldron Furnace, which began at Michaelmas in the same year. Thereafter, for the next six years, the production of round shot, granadoes (fused shells) and carcasses (a type of incendiary shell[7]) figured significantly in the output of the furnace (Fig. 2). Inevitably, production of sows and consequently of bar iron was reduced

4. B. H. Lucas, 'Sussex Firebacks', *Sussex County Magazine*, **24**, *11* (Nov 1950), 515 notes a fireback at Catsfield Place, home of Sir Nicholas Pelham, dated 1703 and another of 1685 decorated with the initials NP and Pelham buckles.

5. R. R. Brown, 'Notes on Wealden furnaces in the records of the Board of Ordnance, 1660-1700', *Wealden Iron*, 2nd ser., **13** (1993), 29.

6. 'Entry Book: May 1690, 1-5', in *Calendar of Treasury Books, Volume 9, 1689-1692*, ed. William A Shaw (London, 1931), pp. 607-613. British History Online http://www.british-history.ac.uk/cal-treasury-books/vol9/pp607-613 [accessed 23 December 2022].

7. E. Chambers, *Cyclopædia, or an Universal Dictionary of Arts and Sciences Vol. 1* (London, James and John Knapton, 1728), 159; https://search.library.wisc.edu/digital/A4C5AV6Q7LZ5DY8E/full/A5QZ3NNP5ZCDTP8T [accessed 30 December 2022].

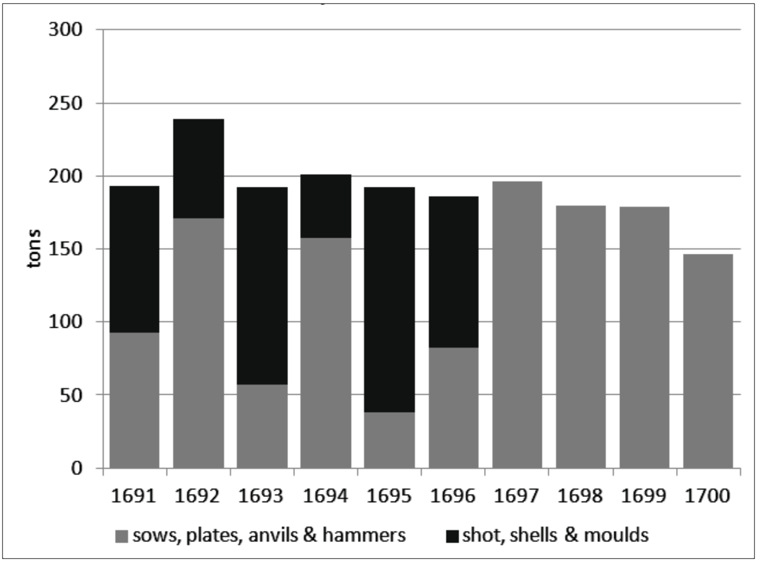


Figure 2: Graph of output at Waldron Furnace 1690-1700

when shot and shells were cast.

The demand for ammunition by the Office of Ordnance at this time was stimulated by Great Britain's involvement in the Nine Years' War that had begun in 1688 and involved land campaigns against French, Scottish and Irish supporters of the deposed king James II and VII and later, on the continent, in support of the alliance against Louis XIV, and naval actions against the French which included the bombardment of several French channel ports for which mortar shells and carcasses would have been an important weapon.

Over 600 tons of shot, shells and shot moulds were cast at Waldron in the six years from 1690. In the first year a detailed breakdown exists of the moulds that were made by Joseph Mittell, who was probably the under-founder to John Wimble. Mittell is recorded as producing 128 pairs of moulds for 24-, 12- and 9-pound shot and for casting 100 tons of shot in them.[8] Most shot were then transported to Lewes. Old shot moulds were sent to Bivelham and Brightling Forges where they were remelted. The bottom half of one such

8. BL, Add Ms 33156, f.5.

Figure 3: Lower part of a shot mould found at Brightling Forge (10cm scale)

mould has survived at Brightling (Fig. 3).

In the 1691-2 furnace campaign, which began on 25 November, casting was taken over by William Benge, of Wadhurst, for 68 days from 10 April to 27 June for which he paid £544, although it was not recorded whether he was making shot in that period.[9] He "had the metal" again during the next campaign, for 61 days, specifically from 11 o'clock in the evening of 29 December 1692 until 28 February at the same time for casting 61 tons of grenado shot and moulds, after which Thomas Western, who also had leases of the furnaces at Ashburnham and Robertsbridge, took over the use of Waldron for 74 days for the same purpose, casting 75 tons 16 cwt 1 qr.[10] Benge is recorded as having delivered quantities of shot to the Office of

9. op.cit., f.27v.

10. BL, Add Ms 33156, f.36v.

Ordnance from other furnaces in this period: Coushopley, Cowden, Hamsell, Hawkhurst and Conster. This temporary use of Waldron Furnace may have been his practice at the other works. [11] In November of 1692 William Benge had been appointed 'Brass and Iron Gunfounder to the King' in succession to John Browne.[12] Benge took over at Waldron for 44 days 6 hours during the 1693-4 campaign but that seems to have been the last time. However, he continued to cast shot and shells at three other furnaces, Pounsley, Darwell and Scarlets, in the winter campaign of 1694-5.[13]

Without either Benge or Western paying for furnace time 154 tons of shells, carcasses and moulds were cast at Waldron during the 1694-5 campaign.[14] A further 100 tons of shot were cast in the following campaign which ended in May 1696, the last time ammunition was cast at Waldron until after the furnace was leased to Thomas Hussey in 1717.

Casting of shells was exacting work and although it is not possible to quantify the failure rate it is evident from the records of defective shells being sent to the forges for recycling into bar iron that a proportion of those cast did not reach the standard that the Office of Ordnance required. Between Michaelmas 1694 and 1695 35 refused shells were taken to Bivelham and 62, together with nine pieces of shell mould, were taken to Brightling. Thomas Sands, of Mayfield, bought shot moulds and defective shells in 1695 and 1696, though it is unclear whether he was one of the many Thomas Sands who occupied Hawksden Forge or the Thomas Sands who moved from Hawksden in 1694 to become the finer at Bivelham. Later payments to the latter for making bar iron from old shot moulds make it likely that it was Sands, the forgemaster at Hawksden, who was the purchaser. Another forgemaster who bought unusable shells was Ambrose Galloway, the Lewes merchant, for his forge at Ardingly in 1697.[15] Finers were paid at double the usual rate for working up scrap iron.

11. Brown, 'Wealden furnaces', 25.

12. The National Archives, WO 55/393, f27; this John Browne was the great-grandson of his namesake who had been royal gunfounder during most of the first half of the 17th century.

13. Brown, 'Wealden furnaces', 28.

14. BL, Add Ms 33156, f.58v.

15. op.cit., f.59v.

The accounts for Waldron Furnace in this period include several payments to workmen for other jobs associated with the production of shot and shells, and it is not always clear what some of these were. Examples include the payment to Joseph Mittell, the founder, "for setting the Broad R" on the 128 pairs of shot moulds he made in 1690-1.[16] Another was the payment to John Homes "to keep in the stopper 18 weeks when we cast shot". Was it his job to plug the hole through which the molten iron flowed to prevent iron being wasted when ladles were not being filled? In 1694-5 James Dryver was paid for two dozen candles used at the furnace when they cast shells.[17] Shells being hollow, were these to assist in examining the condition of the castings? Other references in the accounts record payments to workmen to prove the shells 'before they were burnt', including some that had been returned from Lewes, and for the provision of two pipes used in the proving. Hair was purchased and sacking, and 4s 6d was paid for a new box to cast the shell moulds.[18] Another material needed was black lead, 18 lb of which was purchased in 1690-1.[19] In 1694-5 cotton was purchased "to macke ye workemen Coofes and Sleeves when they cast ye Shelles".[20]

While casting round shot was relatively easy by ladling the molten iron into two-part metal moulds, casting hollow spheres for shells and carcasses was altogther more demanding. Because the moulds for the shells could be cast at the furnace and later recycled at the forges they must have been made of iron and in two parts like round shot moulds. However, to make the projectiles hollow a spherical core would have to be positioned accurately and held firmly in position with a rod, the sacrifice of which would form the aperture through which the core would be broken up and removed and, later, the explosive contents fed in (although this last task was not undertaken at the ironworks). On the production of carcasses, where there were at least three holes in the metal, and where the projectile was usually oblong or oval, contemporary descriptions of their casting are conspicuously lacking.

Waldron Furnace continued to be noted as a producer of round shot.

16. op. cit., f.5.
17. op. cit., f.50.
18. op. cit., f.49.
19. op. cit., f.5v.
20. op. cit., f.49v. 'Coofes' may have been protective cuffs.

In the accounts drawn up by his trustees following the death of William Harrison in 1745, the output of the furnace since Harrison had entered into partnership with John Legas in 1741 included small quantities of mill cases, garden rollers and firebacks but 92 per cent of production in the three years until Christmas 1744 had been 750 tons of round shot.[21] The furnace continued in blast during the two-year period of the trust with a further 610 tons of shot made there, 97 per cent of its output.[22]

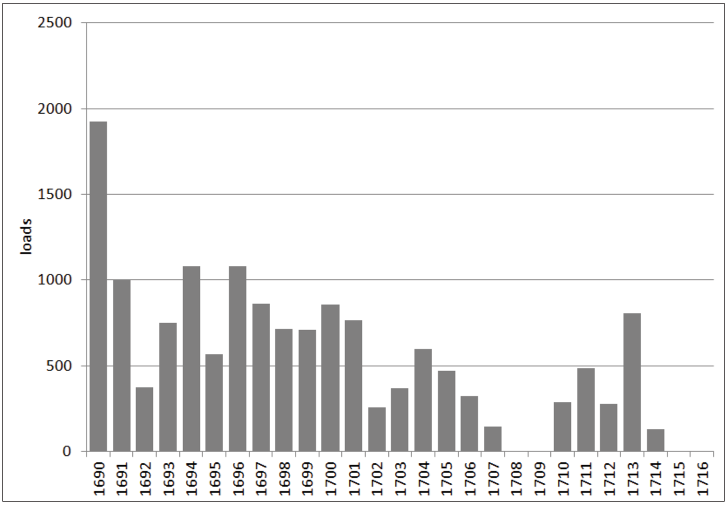


Figure 4: Ore purchased for Waldron Furnace 1690-1716

Iron Ore

For each of the furnace campaigns details are given in the accounts of the quantities of ore – always referred to as mine – that were purchased from a number of sources (Fig. 4). Predominantly these were local landowners, and named labourers were employed by the ironworks to dig, or draw, the ore from their land. Although the land holdings where the ore was dug are often named the actual locations where digging took place are seldom identified. In a small number of cases, labourers employed by the ironworks drew ore

21. London Archives (hereafter LA), CLC/B/111/MS03736/002, p.11.

22. LA, CLC/B/111/MS03736/003, p.9.

from waste or common land, most notably Hawkhurst Common Wood, which presumably belonged to the Pelhams. Finally, payments were made to individuals who transported the ore from where it had been drawn to the furnace. Ore was also purchased from landowners and others who had taken it upon themselves to draw it and then deliver it to the furnace. Over two short periods, from 1708-10, in anticipation of the furnace being rebuilt, and from 1715-17, no ore was purchased.

Three payments were usually made in the acquisition of ore: to the landlord for the ore itself; to the men digging the ore from the ground; and to the people who transported the ore to Waldron Furnace. Each was reckoned per load of ore. Acquiring the ore from the landlord cost between 1shilling and 1s 6d. Digging the ore ranged between 2 shillings and 3 shillings. The lowest rate for carriage was 6 pence and the highest 3s 10d. A cover-all payment of between 5 shillings and 5s 6d was made to those who dug and transported their own ore, delivering it to Waldron although, exceptionally, in 1696 Henry Tomsett of Mayfield charged 3s 6d for the ore and the digging and a further 2s 6d to carry it to the furnace. For none of the payments was any clue given that might explain the variations between one cost and another. A landlord was free to charge what they wanted but considerations might include whether access to the land where digging was to take place interfered with other land use. The cost of drawing the ore was more obviously susceptible to variation as the depth of the minepits and the number of seams of ore and limestone would have been factors influencing how much they charged or were paid. In one instance one of the regular diggers, Richard Sanders, was referred to by Thomas Moore, the clerk, as "our workman" implying that he, and probably several other diggers whose names appeared regularly in the accounts, could be called upon to dig wherever negotiations with landlords had made land available for mining. Who fixed the rate the diggers were paid cannot be deduced from the accounts. Carriage charges would have been determined by the distance from where the ore was dug to the furnace but because most of the locations of minepits are not specified, or can no longer be identified on maps, correlation of payments and distances is seldom possible. One example that can is Gildings Pit, which is identified as Goldens Pit on the 1841 Tithe map (TQ 5489 1848). It lies 1.4 miles (2.3km) from the furnace and carriage was 1 shilling a load.

Ore for Waldron Furnace was obtained from within the parishes of

Waldron, Heathfield, Warbleton and Mayfield. A few specific locations where ore was dug are mentioned but only a very few of those are identifiable on maps; two examples are Stumlet Wood and Clearhedge Wood in Waldron, belonging to Philadelphia, the widow of Sir Thomas Dyke of Horam, which were dug in 1710-11. On a few farms, such as Newick Farm, Old Mill Farm and Bungehurst Farm, all of which are in Mayfield, areas of mining can be identified from lidar surveys. Most frequently noted as a source of ore was Iwood Farm in Warbleton, which seemed to have a fairly rapid turnover of tenants, a situation also noted by John Fuller nearly half a century later.[23] Round Wood (TQ 6357 1747) was particularly thoroughly exploited from both shaft minepits and large opencast workings (Fig. 5). Landowners did not limit digging on their land to supply only one ironworks. In 1694 Sir Thomas Dyke let Major John Fuller draw 155 loads of mine from his Cobford Land in Waldron for Heathfield Furnace; the Pelhams had drawn 11 loads from the same three years earlier for Waldron and 80 loads in 1706.

For each quantity of ore dug from a landowner's property one or two named individuals were paid for the work and it is probable that these payments were made to one person who then paid others who worked with him.[24] No indication is given of the time the digging took, instead the payment being made by the number of loads dug. On average, for the 23 campaigns for which ore was dug between 1690 and 1715, 645 loads were dug a year, the total amount for the same period being 14,835 loads. John Fuller stated that a load of ore, at 12 bushels a load, weighed about 16 hundredweight.[25] This converts to over 500 tons of ore a year and more than 11,800 tons during the period of the accounts. Taking the figure of an average annual output of 188 tons of cast iron noted above, the ratio of the tonnage of ore to iron produced was about 2.7:1.

Throughout the history of the iron industry in the Weald in the post-medieval period there are references to the requirement by landowners for

23. D. Crossley and R. Saville, *The Fuller Letters: Guns, Slaves and Finance 1728-1755* (Lewes, Sussex Record Society Vol. **76**, 1991), 133.

24. The late Dennis Beeney, an experienced digger who, singlehanded, re-excavated a minepit 2.8m deep reckoned that it would have taken two days to dig it originally; *Wealden Iron*, 1st ser., **14** (1978), 6-7.

25. H. Blackman, 'Gunfounding at Heathfield', *Sussex Archaeological Collections*, **67** (1926), 30.

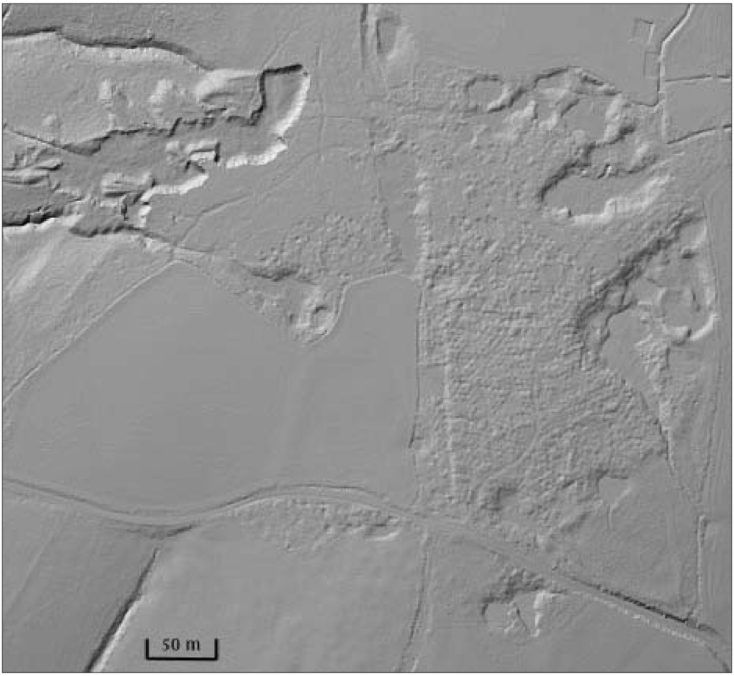


Figure 5: Lidar image of Round Wood, Warbleton; ©Environment Agency 2020; reproduced under Open Government Licence v2.0.

the pits dug for ore extraction to be filled in again afterwards. In 1562 Sir Edward Gage had complained that Sir Richard Sackville's miners had failed to fill the pits on Sir Edward's land after they had dug the ore from them, and in 1695, contemporary with the Waldron accounts, Lord Ashburnham expressed the view that those who dug ore from his land, rather than he, should bear the cost of filling the pits again afterwards.[26] Later, John Fuller was to comment on the individual costs incurred in backfilling: "sixpence a Pitt vizt Two pence a Pitt for throwing in the Clays & four pence for levelling the ground".[27] Payments in the accounts in 1690-1 for "levilling ye mine

26. J. Brent, 'A dispute over iron ore between two county grandees', *Wealden Iron*, 1st ser., **11** (1977), 23; R. Gunnis, 'Letters of the first Lord Ashburnham', *Sussex Archaeological Collections*, **88** (1949), 10.

27. Crossley and Saville, *The Fuller Letters*, 143.

pittes against Mr Woodes land for fower days" and in 1695-6, when 1s 4d was paid for a man to help Richard Sanders, one of the regular miners, to fill the open minepits in the waste next to the land belonging to Iwood Farm in Warbleton, are rare in the Waldron accounts. They were probably itemised separately because someone other than the diggers who had made the pits was filling them in.[28] In a few instances specific reference was made in the accounts to 'marlpit mine' where a quantity of ore had been extracted during the digging of a marl pit. The quantities in these instances were always smaller than were drawn from the ground in the normal way, and the total amount of ore recorded in the accounts that was obtained from marl pits was a tiny fraction of the total.

Differentiation between grades of ore is limited in the descriptions of the loads being dug to three grades: mine (which was clearly also the general term), veins and bottom. In two instances a grade called '11 foot', in consignments dug and delivered by John Haffenden of Heathfield, is mentioned specifically because it was excluded from the loads carried to the furnace. In John Fuller's description of the seams of ore they are named by their depth measured from the bottom of a pit between 5m and 9m deep.[29] Bottom was a limestone, used as flux, veins was the best ore, and the 11 foot, or Greys, could evidently be used as a flux but was both thick and hard and "only good for paving".

When Sir James Hope visited Barden Furnace in 1646 he remarked upon the heaps of iron ore being burnt, and the accounts for Sir Henry Sidney's furnace in Glamorgan in 1568 make mention of "washers and burners of myne", though David Crossley noted that the practice was not employed at either Robertsbridge or Panningridge Furnace.[30] John Fuller implied that he burnt mine at Heathfield and a mine burner is mentioned in the accounts there in the 1750s,[31] but at Waldron, where payments for the smallest jobs

28. BL, Add Ms 33156, ff.4v & 62v.

29. B. Worssam, 'The geology of iron ore' in H. Cleere and D.Crossley, *The Iron Industry of the Weald* (2nd. ed. Cardiff, Merton Priory Press, 1995), 23-4.

30. P. Marshall, 'The Diary of Sir James Hope'. *Scottish History Soc., Miscellany IX. 3rd ser., vol. 50* (1958), 146; D. W. Crossley, *Sidney Ironworks Accounts 1541-1573*, Camden Fourth Series vol. **15** (London, Royal Historical Society, 1975), 13, 247.

31. Blackman, 'Gunfounding at Heathfield', 30; ESRO, SAS-RF/15/29, f.12, Thomas Harmer, mine burner.

were included in the accounts, there is only one reference to anyone being paid for work related to burning ore. In 1698-9 John Hylles was paid "to lay out of ye place to fire mine with".[32] The purpose of burning being to oxidize the ore, if unroasted ore was charged into the furnace it would oxidize anyway though probably at the expense of a greater amount of charcoal.

Charcoal

As with the procurement of iron ore the charcoal needed to smelt the iron was obtained by agreement with local landowners. However, while the cost of obtaining ore comprised three main charges, there were four, and sometimes five, cost elements in securing the charcoal. Firstly, the landowner or tenant was paid for the quantity of wood. This amount was usually about 4 shillings a cord but in some instances was as high as 8 shillings.[33] A considerable amount of the land on which the trees were cut evidently belonged to the Pelhams or to their tenants so this cost was often not included. The charge for cutting the wood varied between 1s 2d and 2s 6d a cord, each of which is assumed to have amounted to 128 cubic feet: 8ft. x 4ft. x 4ft. Cording, which involved stacking the wood into cords, was paid either by the score or by the individual cord, but averaged between 2 pence and 2¾d a cord. Coaling was paid by the load produced and cost between 2s 8d and 3 shillings. On average 1.75 cords of wood for Waldron Furnace produced a load of charcoal. The method used for making charcoal was not mentioned with one exception where reference is made in 1691 to "Coleing a pitt of cole", this evidently being regarded as unusual.[34] Finally, there was the cost of carriage of the charcoal to the furnace which, of course, varied according the distance from where coaling took place and could be as low as 6 pence a load but never exceeded 4s 6d. The average total cost of each load of charcoal delivered at the furnace was 9s 1¼d, and for each campaign between 1690 and 1716 (excluding the years for which no details were recorded), an average of 1,273 cords of wood were cut producing 751 loads of charcoal and costing £339.

32. BL, Add Ms 33156, f.101.

33. Nowhere in the accounts is a cord defined but a widely-used measure was 128 cu ft (8ft x 4ft x 4ft).

34. BL, Add Ms 33156, f.8.

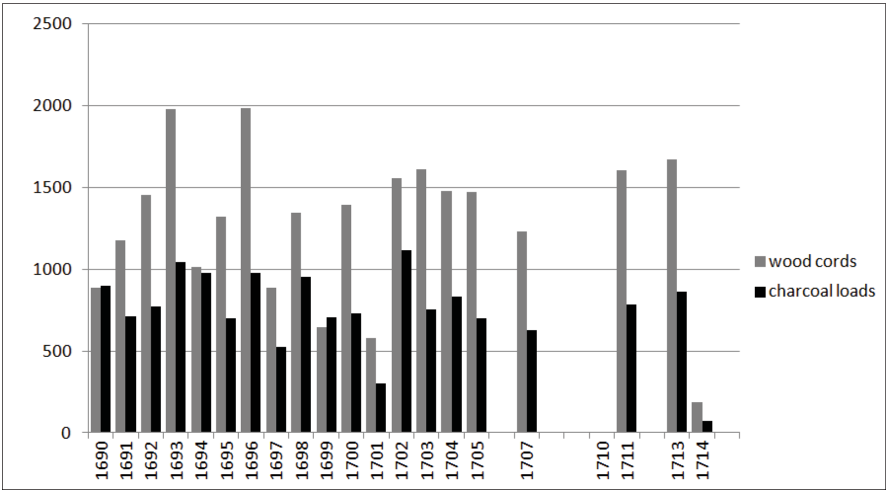


Figure 6: Waldron Furnace, Wood and charcoal supply 1690-1716

Actual quantities for each campaign varied considerably; for example, 1,985 cords of wood were purchased in 1696-7 but only 577 in 1701-2 (Fig. 6). Similarly, 813 loads of charcoal were bought in 1693-4 but only 186 in 1701-2. In some years not all the charcoal made for a campaign was used, the rest being either stored for use in the next one or sold, the most frequent buyer being the Pelhams' Halland estate. A frequently sold by-product of charcoal production was brayes, which was charcoal too small for inclusion in the charge of the furnace. This was used at the forges but also sold to blacksmiths and to other domestic users.

The accounts provide no information about the acreage of woodland required to produce the quantities of wood that were cut, nor for how long the wood had grown. However, a manuscript in the Cowdray archives that is believed to be from the late-17th century gives some insight to this.[35] It states that an acre produced about 10 cords of wood which equates to an average of about 127 acres of woodland being coppiced for each campaign at Waldron. The type of wood is also not mentioned with the exception of four cords of alder and willow noted in 1701-2, although this does not seem to have been

35. West Sussex Record Office, Cowdray 5128/11.

converted to charcoal.[36]

The parishes where woodland was exploited for charcoal were more widespread than for iron ore. As well as Waldron, Heathfield, Warbleton and Mayfield, wood was cut in Brightling, Hellingly, East Hoathly, Hailsham, Herstmonceux, Laughton, Burwash and Chiddingly. Several woods where charcoal was obtained are named in the accounts but it has only been possible to identify a few of them on large scale maps of the area, many of their names having changed and some of them cleared for agriculture.

Ambrose Galloway

Galloway, a Quaker, though not a particularly committed one, was a Lewes merchant who bought cast and bar iron from Waldron Furnace during the whole of the period covered by these accounts. He also bought the products, notably ordnance, of Maresfield and Pounsley furnaces, which were operated by John Newnham, and for a period ran Ardingly Forge for which he purchased sows and forge tackling from Waldron.[37] In the early 1690s he had acted as agent for Newnham in purchasing sows from Waldron, presumably for Maresfield Forge; 25 tons were paid for in December of 1692.[38] Although Ardingly Forge is only named twice, in 1696, as the destination of Galloway's purchases of anvils, hammers, hursts and other items of either forge equipment or of defective shells for working up in the forge, some of the other purchases of hammers and anvils and of sows from 1697 to 1706 may well have been intended for the forge too. However, from 1706 bar iron from the forges at Brightling and Bivelham accounted for the bulk of the deliveries from Waldron to his warehouse and wharf beside the River Ouse in Lewes. Receipts from Ambrose Galloway for the whole period amounted to nearly £4,060, nearly £650,000 in current money.[39]

Personnel

From 1634 until his death in 1671 the founder at Waldron Furnace had been

36. BL, Add Ms 33156, f.143v.
37. C. Brent, *Pre-Georgian Lewes* (Lewes, Colin Brent Books, 2004), 354.
38. BL, Add Ms 33156, f.16.
39. https://www.measuringworth.com/calculators/ppoweruk/ (accessed 7 Jul 2023).

James Wimble. It is probable that his son, also James, and described in his father's will as an iron founder, then took on the role.[40] However, he died in 1678 and, in the absence of either his will or records of the furnace at that time, it is not known who succeeded him. John Wimble, who was his son, was born in 1664 so would have only been 14 at the time and not old enough to take on the role of founder.[41] By 1690, though, he was in charge and continued in the role throughout the period under consideration. For the first year he was assisted by Joseph Mittell whose particular skill was in shot production. Other members of the Mittell family had been founders at Waldron and a hammerman at Brightling Forge earlier in the seventeenth century.

Although other founders and fillers are referred to none is named. It was to John Wimble that payment for them was made, and from whom the unnamed individuals would have been recompensed. Wimble was paid at the rate of 27 shillings per founday – a six-day accounting period – essentially for keeping the furnace in blast and casting iron sows. Specific castings, which included hammers, anvils, hursts, forge hearth plates and hammer brasses for the forges, as well as firebacks, attracted an additional piece rate as did sifting ore and 'scoreing' (weighing) and 'pileing' (stacking) sows.[42] Most of the latter were annual payments.

Among the 'necessaries' expended annually at the furnace John Wimble was also paid for a variety of other services incidental to the operation of the ironworks. For example, in the 1693-4 campaign these were: digging and fetching clay and sand for the furnace; obtaining lath nails used at the furnace; and hiring a man to clean the top of the bridge. Effectively the founder would pay for jobs that needed doing and the clerk would repay him, or he or the clerk would obtain whatever services or supplies were needed and the clerk would pay the provider.

40. ESRO, PBT 1/1/32/27.

41. P. Collins, *The Wimble Family of East Sussex* (London, Dancing Elk Publications, 2003), 44.

42. Hammer *brasses* were not, in fact, made of brass but were cast-iron blocks. The hammer hurst pivoted within a pair of gudgeons, each of which was mounted on a brass.

Routine tasks and rebuilding

Regular maintenance was required to keep the furnace at Waldron operating efficiently. Some tasks were part of the cycle of annual campaigns such as breaking the old hearth and making the new one and re-building the furnace walls, which had to be undertaken before the furnace was blown in every Autumn, and the 'tunnel', which may mean the culvert through which the water flowed from the water-wheel, past the casting area and into the tailrace. Others, such as keeping the watercourses clear, might have to be done more or less frequently depending on their condition. Various individuals were paid sums periodically to keep parts of the furnace site clean. Charcoal baskets wore out and had to be replaced as did tools. Wheelbarrows regularly needed replacing.

The furnace was rebuilt in 1710-11 at a cost of £91 6s 9d, those responsible for the work being George Killner, the mason, and Richard Smith, the carpenter, who between them were paid £62 for pulling down the old structure and building the new one.[43] No detail of the work was recorded, although incidental piecework relating to this was accounted for among the 'necessaries'. These included moving the furnace tools to the iron house, carrying braids from the bridge house "before they pulled down ye furnace" and carrying to the furnace sand and lime for mortar.

Two ponds are mentioned in the accounts; the down pond was the principal source of water, with the upper pond holding the reserve supply. This latter pond appears to have been located at about TQ 5676 1875. Periodic maintenance was required for both, such as repairing or replacing floodgates.

Bellows

New bellows were made for the furnace and the two forges in 1690-1 at Simpson (i.e. Selmeston) in Sussex using two elm trees brought from Etchingham. A sawpit was dug for the purpose and the furnace bellows were made from two carfes or cuts, each 14½ feet (4.4m) in length. Presumably to weigh down the bellows boards, 3 lb (1.3kg) of lead was bought "to platte ye Bellowes". In a later campaign 52 tin plates, costing £1 14s 8d, were paid for

43. BL, Add Ms 33154, ff.107, 112v.

to use to plate the new bellows. Perhaps these were fixed to the part of the bellows where the cams on the axletree pressed against the bellows board. Lead would not have been an adequate substitute in that circumstance owing to its softness. New leather had to be purchased annually from Thomas, and later Nicholas, Venner, two bull hides being usually required although sometimes only one had to be re-leathered, with payment also being made for tanning them. Occasional replacement of the sheep skin 'vanters' suggests that these were the flaps that allowed air into the bellows but prevented its escape. "Meale for ye furnace bellowes" was another regular expense. A later entry refers to "one Tovett and a pottell of wheate for past for ye newe bellowes". A tovet was equivalent to two pecks or half a bushel, while a pottle was half a gallon, so 4½ gallons (20.5 litres) in all. Evidently the wheat was required to make a paste but how, why or where this was applied to new bellows this writer is at a loss to explain.

To ensure smooth running, the bellows mechanism also needed regular maintenance, grease being purchased to be "used about the cames". It was also used to lubricate the gudgeons within which the water wheel rotated.

Bridge and bridge house, furnace house and other buildings

A bridge connected the valley side adjacent to the furnace with the top of the stack to provide easy access for the charging of ore and charcoal, and this was covered to protect it, and those using it, from the weather. In 1691-2 a new bridge and bridge house were constructed at the furnace.[44] The old bridge was dragged out of the way and suitable timber was brought out of local woodland for the framework, which was underpinned. As with timber-framed houses the frame of the bridge house was assembled on the ground, a payment being recorded for the drink provided for the workmen on the day the structure was reared up. Evidently it was clad and roofed with tiles, 5000 plain tiles, 100 corner tiles and 12 ridge tiles being purchased, not to mention 2,500 lath nails. 2,088 feet of plank was cut for the flooring, with tiles seven square presumably around the furnace throat. The tiles were supplied by Thomas Pankhurst, who was probably a Heathfield brickmaker.[45] The total

44. BL, Add Ms 33156, f.19.

45. He is noted as a party to a lease of 1702; ESRO, SAS/RF 4/71.

cost was £20 10s 8d. Little has appeared about charging bridges and bridge houses in contemporary accounts of Wealden ironworks. The Panningridge Furnace accounts mention one and the need for it to be rebuilt on several occasions and some posthole evidence was found during excavation to suggest its position.[46] In 1726 the accounts for Robertsbridge Furnace briefly mention pulling down and setting up the bridge there, making it longer and making good the roof.[47] It appears that the furnace house was a separate building acting as an office and possibly a store. Repairs were carried out in 1691-2 involving tiling the walls and thatching the roof. In 1697-8 a payment was made for repairing the glass windows, a job that was repeated in 1701-2 when it was also re-thatched.

Another building in the furnace precincts was the wain house, where wagons were parked. In 1692-3 two of the works labourers, whose other jobs included digging minepits, re-thatched it with straw and withies. In 1698-9 a new workhouse was constructed, beer being paid for at the rearing of the frame.

Treading the wheel

Dry weather during a casting campaign could cause a furnace to be blown out prematurely for want of water, and John Fuller memorably wrote to Samuel Remnant in December 1743 that "they tread the wheele at 3 Furnaces vizt Robertsbridge, Waldron and Beckley".[48] This was not the first time that Waldron Furnace had been so affected. In late November 1695 payment was made to five men who had trod the water wheel for 12 days and 11 nights and for another man for 11 days and nights.[49] They received 2 shillings each for a day and a night, double the going rate for agricultural workers at the time.[50] The furnace was only six weeks into its campaign so to ensure that the correct temperature was maintained the rate at which the wheel was trodden

46. D. Crossley, 'A Sixteenth-Century Wealden Blast Furnace: A Report on Excavations at Panningridge, Sussex, 1964-1970', *Post-Medieval Archaeology*, **6** (1972), 58.

47. ESRO, HEH BA vol. 8, p. 15; microfilm XA3_13.

48. Crossley and Saville, *The Fuller Letters*, 187.

49. BL, Add Ms 33156, f.62.

50. G. Clark, 'Farm wages and living standards in the industrial revolution: England, 1670-1850', *Economic History Review*, **54**, *3* (August 2001), 485.

would have been carefully regulated for speed and consistency.

Conclusions

The late-Stuart period was a critical time for the Wealden iron industry. The region had ceased to be the principal source of iron for Great Britain with the number of active furnaces and forges considerably diminished since its peak at the end of the reign Queen Elizabeth, a century earlier. A workforce skilled in the production of guns and shot, however, and its proximity to the royal armoury in London and to the naval dockyards at Chatham and Portsmouth gave its ironworks a continuing role, the 1690s even seeing the construction of three new furnaces, at Heathfield, Lamberhurst and on Ashdown Forest. Waldron Furnace was not adapted for gun-casting until later in the eighteenth century, but it had been in operation since the 1570s or earlier and for much of that time in the direct control of its owners, the Pelhams. For the most part they relied on the survival of a market for bar iron and forgings for which Waldron Furnace contributed the raw cast iron sows.

The supervision by Sir John Pelham and later his son Sir Thomas has ensured that detailed accounts have survived, bequeathing a valuable insight into the minutiæ of the management of the ironworks. They may be deficient, in modern accounting terms, particularly in respect of details of income and in the inclusion of expenditure unconnected with iron production, but over a twenty-five-year period they illustrate the annual rhythm of the operation of the furnace, and of the associated forges (to be examined separately), that can stand as a typical example of the period in the Sussex Weald. They complement the contemporary accounts at Major John Fuller's furnace at Heathfield, then newly built.[51]

51. R. Saville, 'Income and production at Heathfield ironworks, 1693-1788, *Wealden Iron*, 2nd ser., **2** (1982), 36-63.

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