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Contents

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Hon. Editor
D. W. Crossley, Division of Adult Continuing Education,
University of Sheffield, 196-198 West Street, Sheffield S1 4ET

Hon. Secretary
Mrs S. Broomfield, 8 Woodview Crescent, Hildenborough,
Tonbridge TN11 9HD

Field Notes

compiled by J. S. Hodgkinson

The Domesday *ferraria*

The programme of field walking to locate the Domesday *ferraria* at Forest Row continued with fields immediately south and west of Emerson College. No significant evidence of specific sites of early ironworking has been found, although a general scatter of bloomery slag was noted in the field immediately south east of the College, with a slight concentration centred on TQ 4385 3515.

A Romano-British bloomery at Heathfield, Sussex

Trenches were dug through the slag heap of the bloomery noted at TQ 5763 2174, in Tilsmore Wood, and two sherds of East Sussex ware were recovered, both being parts of rims from cooking pots.[1] The smaller piece had a diameter of 190mm at the rim. The larger piece had a diameter of 170mm, and a piece of slag adhering to it. It had partial circumference of 40mm x 65mm, and bore a scribed pattern.

The previously noted site at TQ 5755 2184, which only has slag for 5 metres along the bottom of the stream, was investigated, but with no conclusion.[2] It might be the remains of a ford, although the stream can be stepped over. A rather large charcoal making site was noted, on the east side of the steam, 30 metres upstream from the slag.

A bloomery at Bletchingley, Surrey

The site noted by Straker at South Park Farm, Bletchingley, has been located at TQ 3320 4823.[3] A new site has been discovered at TQ 3385 4830, with both sites apparently getting their ore locally from a seam in the Weald Clay.

Notes and References
1. WIRG, *Wealden Iron*, 1st series **VI** (1973), 22.
2. WIRG, *Wealden Iron*, 2nd series **18** (1998), 6.
3. E. Straker, *Wealden Iron* (1931), 457.

The Wealden Iron Research Group Experimental Bloomery Furnace

B. K. Herbert

Introduction

This note records the setting-up and results of an experimental iron furnace on Ashdown Forest, Sussex. The Wealden Iron Research Group has been carrying out bloomery furnace experiments for about 25 years, initially under Roger Adams but now with a group of eight volunteers. It was one of the first Groups outside a university to study iron smelting under primitive conditions. Although several pieces of iron were produced, one an impressive 7lbs of high quality steel, it was impossible to make iron to order. The object of these experiments is to build on the knowledge already gained and try to consistently produce wrought iron and steel by the bloomery process.

It is assumed that readers are conversant with the bloomery furnace process, although many aspects are described as the note proceeds.[1]

A bloomery furnace produces iron by the direct process, the product is a solid piece of wrought iron or steel extracted straight from the furnace; this is an ancient process which produced iron suited to the blacksmith but is now only used by primitive people. This ancient furnace should be contrasted with the indirect process which produces a liquid cast iron that runs molten direct from the blast furnace into a mould; this process is suited to mass production techniques. Cast iron may be converted into a wrought iron by a secondary process called fining; this is carried out in a finery or conversion forge.

The earliest bloomery furnaces were circular depressions in the ground, around which a structure of clay was built, perhaps doming-in slightly, but having a definite hole at the top to vent the carbon dioxide and carbon monoxide gasses during smelting. A later bloomery furnace design, probably brought to England by the Romans, consists of a short chimney, 600 to 1000mm high and about 600 to 800mm in diameter, but still producing a solid piece of wrought iron. It is this latter type of bloomery furnace which the smelting team are experimenting with in Pippingford Park, not far from the blast furnace site of the same name, and where Roger Adams latterly chose to build his bloomery furnaces. As the site is ¼ mile from the nearest electrical supply, labour saving tools and normal laboratory apparatus cannot be used.

The complete apparatus, comprising the furnace, two bellows, gasometer, and air flow-rate meter was exhibited at the East Grinstead Library as a 'hands on' working display, although the furnace was made of corrugated cardboard.

Mostly metric dimensions are given in the text: for an adequate conversion to imperial

25mm = 1 inch
300mm = 1 foot
1 kilogram = 2 pounds
1 litre/second = 0.035 cubic feet/second or 2.12 cubic feet/minute

The Furnace

The new smelting group started in the autumn of 1995 by demolishing the original frost-damaged furnace and building a new one along similar lines, except that the walls were made thicker to improve the thermal insulation (Fig. 1).

A fine sand, from the Ashdown Sand geological stratum, was used to build the furnace structure between two sheets of mild steel rolled

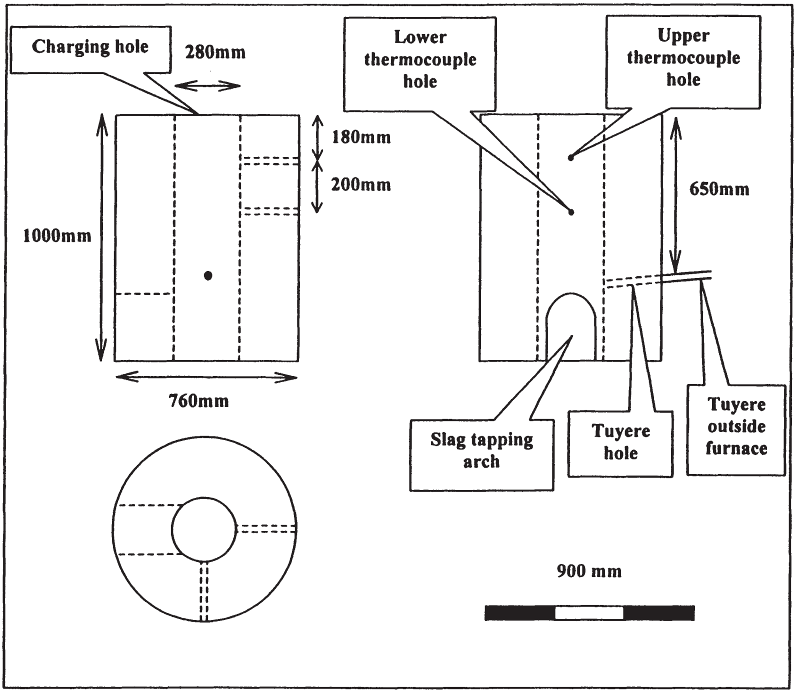


Fig 1: The bloomery furnace showing main features

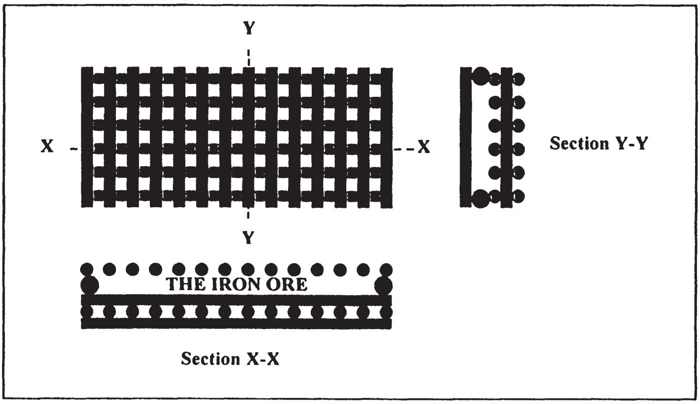


Fig 2: The layout of logs for roasting the ore

into cylindrical formers; the inner former 280mm diameter, the outer 760mm diameter and both 1000mm high. A log was placed where the tapping arch was required and later shaped to size. Unfortunately, an excessive amount of water was mixed with the sand to make it plastic. What with this water, the autumn weather and the formers acting as a seal to evaporation, the furnace did not dry out. On trying to speed up the drying process by removing the formers, the furnace slowly slumped to the ground. The furnace was rebuilt before Christmas using a drier mix: over winter the frost damaged the structure to such an extent that it partially collapsed.

Rebuilding for a third time, it was decided to compact the sand in a different, perhaps better manner; one person would tip the dryish sand between the formers whilst a second person walked round and round, inside the coaxial formers. As time passed, so this person stood higher (ziggurat-like), and required a pole, within the furnace, to steady himself. This construction method has withstood eight smelts with only minor repairs inside, caused by the bloom (slag) sticking to the furnace wall and frost damage.

The holes for both thermocouples and tuyère were drilled out when the furnace had dried; the former were lined with stainless steel tubes to allow just one thermocouple to be slid in and out for the two measurements.

The Ore

The Wadhurst Clay geological stratum is the most consistent seam of iron ore in the Weald, although there are not many surface exposures; the geological map might indicate where iron ore should be, but much of it has already been taken. The brickworks at Sharpthorne, Sussex, has always been the most convenient place to obtain iron ore, because it may be dug out of the working face of the clay pit; this is much safer and quicker than digging below ground. After an initial visit to the brickworks early in 1996, to make sure ore was available, a group of six later returned to find that the working face had been dug out to enable the clay to 'weather' for brick-making. Nevertheless, enough ore was recovered for many smelts. The new working face of the quarry, some 15m high, was of interest because it cut through several mine pits. The pits were visible because the back-fill was very loose and crumbly, and by the amount of water which was running through the normally impermeable Wadhurst Clay. No evidence of the bell pit shape was seen; it was perhaps, more of an inverted bell shape where it passed through three layers of iron ore. At the bottom of the pit, much of the lowest level of ore had been left, due to the tapering-in of the pit walls. It is this ore that was retrieved, with the knowledge that it had been used by the original ironworkers; although for bloomery or blast furnace we could not tell.

The literature tells us that it is advisable to roast the Wealden ore before smelting because it is an iron carbonate, $FeC0_3$, and it is preferable to convert it into the iron oxide form, ferrous oxide, Fe_2O_3. Also, water within the ore is driven off, whilst the removal of the carbonate makes the ore porous, allowing the hot carbon monoxide to permeate the ore and to improve reduction. Roasting is a simple process whereby the ore is heated in a wood fire and CO_2 is given off to produce the conversion. The excavated evidence points to roasting, as many rouge-red pieces of ore have been found, as well as roasted ore in trench-like features. Thus we have also roasted our ore, although it seems much harder than that found from antiquity, perhaps due to 1500 years of weathering.

The method used for roasting requires an open-ended trench, some 800mm by 1200mm and 500mm deep, lined on all four sides with sandstone blocks, or in our case fire-bricks. The open end enables the roasted ore to be removed with ease. These dimensions enable the trench to be covered by a sheet of corrugated iron because during roasting the hot ore will explode and travel at a dangerous speed.

The roasting process used consists of producing a very hot bed of wood ash, on to which well dried-out logs are placed side by side as follows (Fig.2):

1. Three criss-crossed layers of 75 to 100mm diameter logs at the bottom.
2. 150mm diameter logs all around the periphery, precluding ore from the colder areas.
3. Then the ore.
4. A final layer of 75 to 100mm diameter logs

The ore requires to be broken into approximately 40mm size pieces; the smaller the better, but breaking is quite difficult, and once again bits of ore fly all about, so protective goggles are necessary. This size of roasting hearth will take about a barrow load of ore; it is better to finish the day with this process as the noise is quite nerve wracking and it will take 24 hours for the ore to cool.

After roasting, the final ore-breaking takes place, along with a rejection process for pieces of partially roasted ore which are put aside until the next roasting session. It is difficult to describe the partially roasted ore, but it breaks with a ‘snap’ like the unroasted ore, the roasted being much softer. The final size of the ore should just pass through a 15mm sieve, not all ground into dust. The ore dust is not sieved out, because the small amount in each charge would not choke the furnace. After roasting, the ore is simply stored in a bucket, under cover, to keep it dry.

The Charcoal

Charcoal is required for two reasons:

1. to burn as a fuel to produce the desired temperature of approximately 1000°C at the tuyère,
2. to produce the gas CO, carbon monoxide. When hot, this gas combines with the oxygen in the iron ore to produce CO_2, leaving pure iron and slag; this is the reduction process. CO is produced in a fire when air is pumped in; however, an excessive amount of air re-oxidises the iron and it is lost. It is this fine balance of air flow which is likely to make or break the success of the smelt.

In the past, Roger Adams produced his own charcoal in a pit (i.e. underground). This is a time consuming and dirty process which requires a very dry site, high on the edge of a gill. Unfortunately, this situation is not available close by at the moment; however, we do intend to try this method soon, on the gently sloping land close to the furnace. Locally made charcoal was bought from Forest Row.

The size of the charcoal varies considerably and is generally too big. This has been overcome by using a heavy metal roller running on two wooden rails, which are as thick as the desired size of charcoal, 20mm at the moment. The cast iron roller is 80mm diameter and 610mm long but a garden roller would work. A few long pieces of charcoal remain, but these are quickly reduced in size with a sharp spade. The charcoal is sieved to remove the dust before being stored in large plastic sacks to reduce the absorption of moisture.

The Tuyère

Before discussing the bellows it seems reasonable to consider the tuyère. This is a special tube through which the air blast is taken to the inside of the furnace. One suspects that a well defined jet of air is required inside the furnace; this could not be guaranteed without a tuyère, because the inside wall of the furnace slowly crumbles away during smelting. The tuyère is fixed so that one end is flush with the inside surface of the furnace wall. To date, 25mm diameter ceramic tuyères have been used; however, they are very fragile and do not survive many smelts. A perfect solution would be a wrought iron tube (not to be confused with the modern mild steel) which has a melting temperature of 1550°C, well above the temperature inside the furnaces (glass blowers used wrought iron tubes when they picked up a gob of glass from their furnace). A more practical tuyère would be a thin-walled, stainless steel tube that protrudes some 200mm from the outside wall of the furnace, so that the plastic connecting tube (see next section) will not melt.

It has been observed that an excessive back pressure is produced

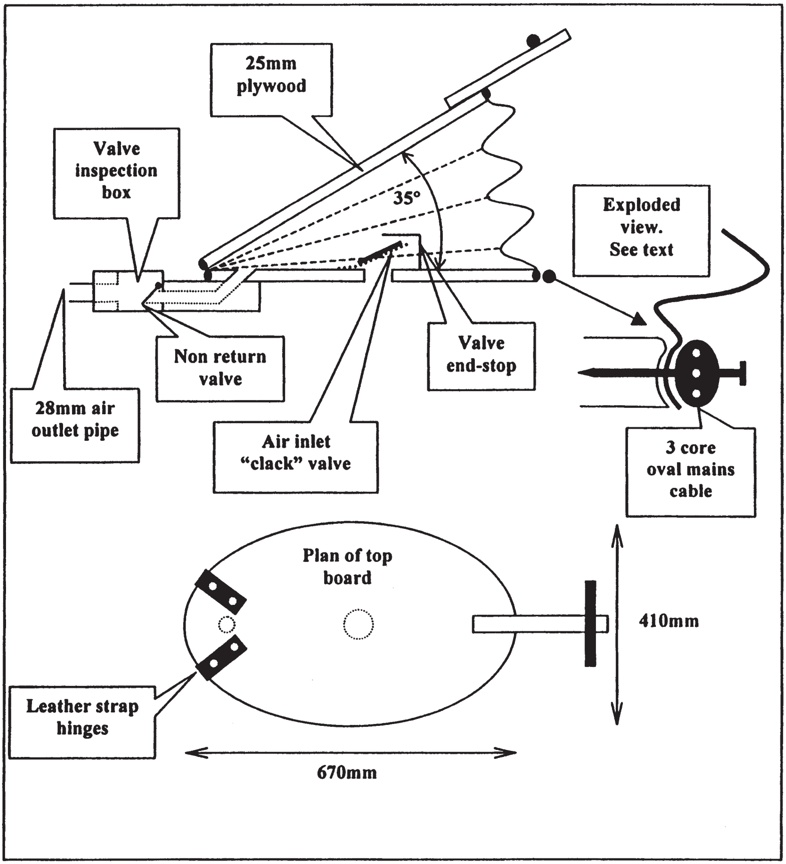


Fig 3: The bellows, two required for more than 4 litres per second

by small-diameter tuyères, 12-15mm, at high air flow rates, 3-4 litres per second. This is very important observation because it would place an excessive strain on the bellows' leather. Further study might show that multiple tuyères are better, each with a small air flow rate. The angle of the tuyère from the horizontal is another parameter; we have chosen a 10° down slope in all the experiments.

A standard size of air inlet/outlet pipe has been used on all the apparatus, namely 28mm copper water pipe, whilst vacuum cleaner hose is used for interconnecting between apparatus.

The Bellows

The most important piece of apparatus is the bellows, necessary for producing an adequate temperature inside the furnace. Unfortunately, none has been found from bloomery furnace excavations. Roger Adams built three pairs of traditional bellows at the start of his experiments, using 25mm plywood, with oval top and bottom boards, and Marley plastic sheeting as used for folding doors, instead of leather (Fig. 3). The air inlet clack valve and hinge is made of Marley plastic, with an aluminium plate on the top to keep it flat and give it weight, not forgetting a reliable end stop for the clack valve. The most important part of the bellows is the fixing of the leather to the boards (see exploded view Fig. 3); if there is any frictional movement between leather and wood, then it will wear out very quickly and usually at a critical moment. A groove is made all around the edge of both boards with a chamfer on the inside edge, into which the leather is stuck with silicone sealant. Before the sealant has set, a length of oval 30 amp mains cable is nailed over the leather to hold it in place, using large-headed felt nails. The two boards are held together with two sturdy leather hinges which are nailed to the boards.

A potentially explosive problem will occur if carbon monoxide, is drawn from the furnace into the bellows; this could happen if the clack valve is not 100% efficient. When the bellows contains an optimum air and carbon monoxide mixture, it is possible for an

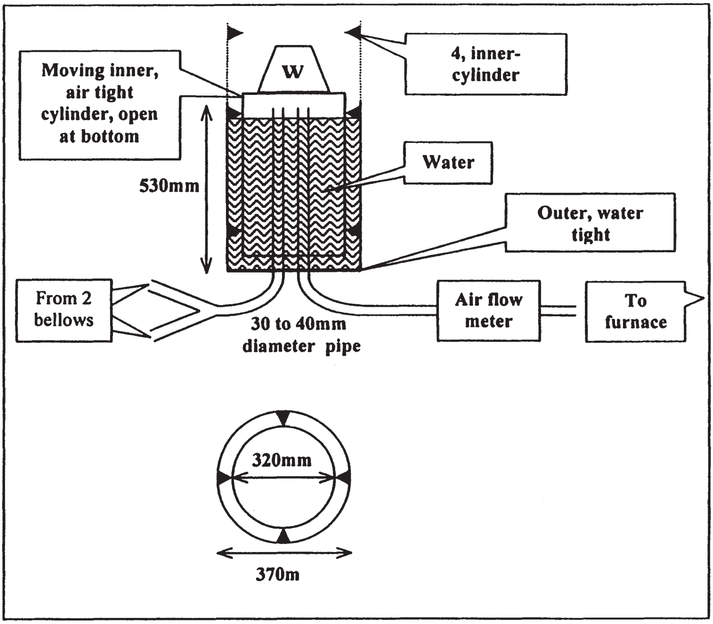


Fig 4: The gasometer using plastic containers

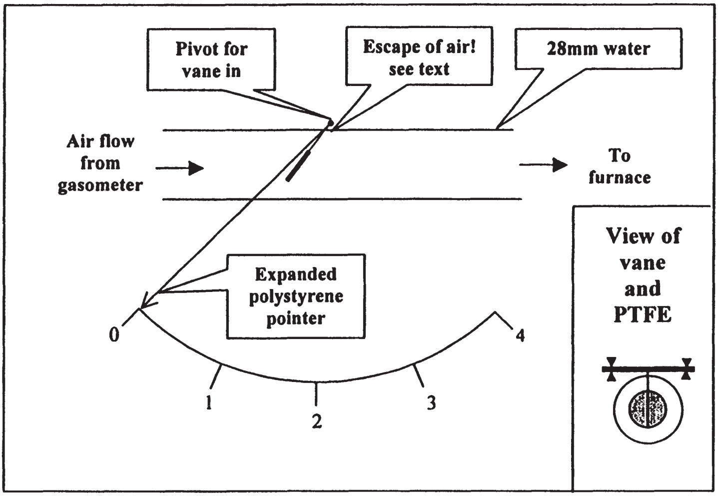


Fig 5: The moving vane air flow meter, litres per second (to be mounted in a sealed container)

ember, also drawn in from the furnace, to ignite the inside of the bellows. To overcome this problem, a non-return valve has been added to the output tube of the bellows. This is simply another flap valve, with gravity holding it closed; on pumping the bellows, the flap naturally opens. This non-return valve also resolves another problem when two bellows are used to pump into a common tuyère (or gasometer, see Fig. 4), whereby the pumping bellows would have pumped its air into the filling bellows.

Due to rough handling during an exhibition, the original Marley sheeting split and was replaced by an upholstery grade, heavy duty cotton canvas. To make it air-proof, a bathroom silicone sealant was watered down and painted on the inside surface; this has operated very satisfactorily.

The bellows has a capacity of 24.6 litres when opened 35°; this was measured using a gasometer (see next section), and could be pumped out in three seconds through a 25mm diameter pipe.

A hazardous condition occurs when smelting, for poisonous carbon monoxide gas is given off from the top of the furnace and seeps through cracks in the furnace wall. Although the danger can be minimised by igniting the carbon monoxide above the charcoal (it must be mixed with air/oxygen before it will burn), some CO will still waft about; it should be remembered that we cannot smell this gas. The danger can be further reduced by keeping the bellows (operator) well away from the furnace by using a long, 40mm to 50mm diameter vacuum cleaner hose to join the bellows to the tuyère.

There is much discussion about the type of bellows and how many should be used; without any evidence there is no clear answer. The argument goes that two bellows can give an almost constant flow of air, whilst one bellows will give a pulsating air flow; but which is the better? A pulsating air flow disturbs the charcoal, hopefully stopping voids being produced in the charge: a constant air flow ensures a constant source of CO for the reduction process.

Instrumentation

The object of the experiments is to produce wrought iron by the bloomery process, using traditional techniques. It might be argued that modern scientific tools and instruments should not be used to reach this objective. To counter this argument, it is suggested that by carefully studying the bloomery smelting process, which has been lost in the Weald for 400 to 500 years, it is necessary to carry out controlled experiments first, and when successful, revert to primitive methods.

The Gasometer

Due to our desire to measure as many parameters as possible, it soon became evident that measuring the average air flow from bellows would be difficult due to the pulsating nature of the air. To solve this problem, a gasometer was designed and constructed, operating much like those still in use for natural gas, although on a much smaller scale, the idea being to produce a constant air flow (Fig.4).

The dimensions of the gasometer are not too important, although the volume of the inner cylinder should be equal to or greater than the volume of the bellows. The air piping must be not be less than 25mm diameter, preferably larger, for air flow rates above 4 to 5 litres per second. The actual flow rate is set by trial and error and adjusted by a weight, ‘W’ (a suitable piece of ore) on the rising cylinder.

The Air Flow Rate Meter

The air flow rate is an important parameter for smelting. As already noted, a gasometer was built to produce a constant air flow, but no instrument could be found which was suitable for flow rate measurement; the so called ‘variable area flow rate indicator’ has too much resistance to the air flow, and was expensive.

Once again it was necessary to make a special instrument for the task; however, due to its complexity, only a simple sketch is shown in Fig. 5. The movement must be as light as possible with the circular vane about the half the diameter of the tube and with PTFE bearings to reduce friction. The pointer must be very light, due to its distance from the bearings, and damping is necessary to stop the pointer oscillating. These two problems were solved together, by using expanded polystyrene board which was filed and emery-papered down until it became paper thin. From the sketch it may be seen that air will escape where the vane exits the tube; for this reason the whole mechanism must be placed in a sealed box with a glass window, not a perspex window which produces an electrostatic charge that clamps the pointer.

Calibration was carried out using the afore-mentioned variable area flow rate indicator which was bartered for the design and construction of an electronic circuit. The calibrating air flow was provided from a vacuum cleaner, with an adjustable valve in the air flow.

Weighing Machine

A weighing machine is required to measure out the charge of charcoal and roasted iron ore. An imperial ‘Avery’ weighing machine, accurate to ¼oz, as used by butchers, was bought from work for a nominal sum. It was only after purchase that its weight was appreciated, being made wholly of cast iron, and has been an embarrassment ever since; it is a two-man task to set it in position and level it.

Thermocouple Temperature Meter

The other vital measurement is the temperature at the centre of the furnace. Due to the hot carbon monoxide gas being very aggressive, it attacks almost anything metallic. Thermocouples are the obvious choice for measuring temperature, with platinum-rhodium and tungsten-rhenium metals being the best, but far too expensive. Fortunately, a nickel-chromium (K type) thermocouple, operating up to 1100°C and having a stainless steel sheath for protection, is available for a reasonable price.[2] Only one thermocouple is required because it may be slid in and out of the two stainless tubes set into the furnace. The sheath is robust enough to be pushed between the charcoal to measure the temperature at the centre of the furnace.

A moving coil read-out meter has been used to date; this shows temperature trends much better than a digital meter and is adequately accurate. As a suitable moving coil meter may now be unobtainable, a digital meter is available.[3]

A 24 Volt Battery Operated Blower

During the most recent smelt a 24 volt battery-operated fan was, reluctantly, used. A great deal of time and energy is spent pumping two pairs of bellows and this time could be used more constructively around the bloomery site. It is hoped to devise a method of driving the fan in an on-off mode to simulate one pair of bellows,

A Typical Smelt

Since 1995 the team has carried out eight smelts, the last of which produced a 1.5kg bloom of wrought iron. When the Channel Four Time Team' produced iron during their visit to Sussex in June 1998, Jake Keen suggested that the initial temperature of the charcoal towards the top of the furnace was very important. With this in mind, the first charge was not added until the temperature of the pre-heating charcoal, 180mm down from the top, was about 800°C.

The following account shows, in listing form, the method used

Each charge weighs 3 lbs, and is made up by weight-ratio:

Roasted ore:charcoal = 1:2 = 1lb:2lb.

On mixing the charge the ore virtually disappears due to the vastly differing densities.

A log and rough graph of the basic parameters was made during the smelting, this was later transferred to Microsoft Excel, graph-making software:

1. Temperature at the upper thermocouple.
2. Temperature at the lower thermocouple.

3. The air flow-rate.
4. The time of each charge.
5. Any other important observations.

A condensed account of the furnace operation

Pre-heat the furnace, with wood, the previous evening, and leave burning overnight.
07:00 Pre-heat the furnace with wood again next morning.
09:20 With a few red embers at the bottom, half fill furnace with charcoal (any size).
09:20 Jam turf into the slag tapping arch to seal.
09:20 Start fan at 4 litres/second.
09:30 Lower thermocouple = 400°: Furnace filled with charcoal.
11:00 Upper thermocouple = 790°C: First charge introduced.
12:30 Tuyère becoming blocked: Tuyère rodded-out.
14:30 Tapping arch unblocked; no slag ran out; tapping arch re-blocked.

Whenever the charge had dropped about 25mm, the next charge was added. This was equivalent to one charge approximately every 14 minutes.

The temperature at the upper thermocouple was kept between 750°C and 850°C, by altering the fan speed, to give an air flow rate between 3 and 4 litres/second. During the smelt the lower thermocouple was reading about 900°C.

The air flow rate reduced on its own accord at times, because slag from the bloom flowed over the end of the tuyère hole; the slag was carefully rodded-out down the tuyère. A green stick, rather than an iron rod, was used to rod-out the tuyère and break any charcoal bridges within the furnace, so minimising any cooling effects.

Average furnace consumption

Total roasted ore 20 lbs in 4.75 hrs. Rate of ore consumption 4.21 lbs/hour. Total charcoal 40 lbs.

Comments

The bloom was well stuck to the side of the furnace just below the tuyère. It was felt that perhaps the furnace was too hot (900°C at the lower thermocouple), and that the temperature should be lowered to 800°C for the next smelt by suitably reducing the air flow rate.

Smithing

No attempt was made at smithing the bloom, and it has been kept as an example of a 1.5kg bloom.

Acknowledgements

The smelting group would like to thank the following for their help with these experiments.

Mr Wickham of Sharpthorne Brick Works, Sussex; Ibstock Building Products Ltd., for the iron ore.

Mr Billings, collier, of Forest Row, Sussex, for the charcoal and his delivery service.

Philips Research Laboratories, Redhill, for much of the materials and loan of instrumentation.

WIRG members with the funds for charcoal etc.

Mr and Mrs A. Morriss and family of Pippingford Park, Sussex, for letting us use their land (and timber).

The author would like to thank the smelting group; Dennis Beeney, Reg Houghton, Dot and Tony Meades, Tim Smith, Margaret Tebbutt and Bill Whiting, for their help over the years, with a special thanks to Bill Whiting for his comments after reading through the text.

Notes and References

1. For further reading on the subject see H. F. Cleere; 'Iron Making in a Roman Furnace', *Britannia*, **11** (1971); H. F. Cleere, 'Iron Smelting in a Reconstructed Roman Furnace', *Journal of the Iron and Steel Institute* (Feb. 1970); H. F. Cleere & D. W. Crossley, *The Iron Industry of the Weald*, 2nd ed. (1995).
2. Thermocouple Probe, K type, 0 to 1100°C, stainless steel sheath; R.S.

Catalogue No. (Nov 1998); 219-1647.

3. Digital thermocouple meter, K type; R.S. Catalogue No. (Nov 1998); 198-6488.

Vachery Forge and Furnace, Cranleigh, Surrey

Judie English

Documentary and field evidence for the forge and furnace sites at Vachery, Cranleigh, have been described previously (Straker, 1941) but whilst the location of the forge site is uncontroversial, field evidence for the furnace site is scant and it is thought that it was destroyed, or at least flooded, by the creation of Vachery Pond as the summit water for the Wey and Arun Junction Canal in 1814. Evidence will be given here for either an alternative, or possibly a second, furnace site. The identity and background of some of the people associated primarily with the forge site will also be discussed.

Vachery Furnace

A furnace pond is mentioned in several documents, but the site of the furnace itself has not been located and it has been assumed that the pond and works were submerged when Vachery Pond was created, or enlarged, for use as a reservoir for the Wey and Arun Junction Canal in 1814 (Smith, 1981). However, none of the maps available for this area of Surrey shows a pond in this position pre-dating 1814, and evidence will now be considered for either an alternative or additional furnace site.

Field evidence

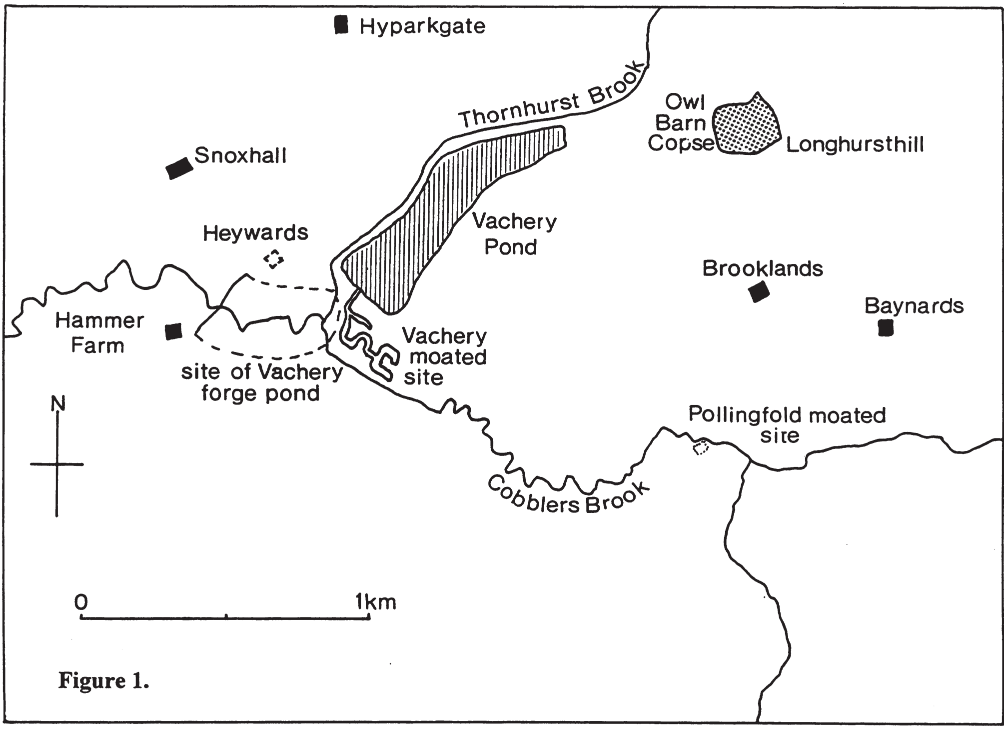
Field-walking the ploughed-out double moated site at TQ 079364, thought to be that of Pollingfold manor, in the mid-1980s, produced pottery dating from the 13th to the 18th centuries. This was a little surprising since the site was thought to have been abandoned by the mid-15th century when Baynards, built on better drained ground, became the capital messuage of this estate. More surprising was the massive amount of blast furnace slag concentrated in an area some 50m square close to the stream, Cobblers Brook, which fed the moats. Whilst the slag could have been brought in when the moats were infilled, the possibility that it is in situ and that this was the site of a furnace needed to be further investigated. Vachery and Baynards are adjoining estates, both of which were manorial centres and had parks, and were on occasion held by the same family.

Documentary evidence

The relative positions of the places under consideration are shown in Figure 1.

No documentary evidence has been found which relates directly to a furnace near Vachery, but the frequent references to a furnace pond make it clear that one existed. Of the two estates involved, Baynards was owned by the Bray family until 1580, when Edward Bray mortgaged it to John Reade and in 1587 John Reade released his rights to George More of Losely. Vachery was also owned by the Brays until the 1580s when it was sold first to John Reade and in 1605 to the Onslows. Despite the number of major families owning these properties, no early estate maps have survived, and none of the smaller-scale maps of Surrey add any useful information. By 1768, when Rocque's 1 inch/mile map was published, no pond is shown at Hammer Farm (the site of Vachery forge), Vachery or Baynards.

Nevertheless some documentary evidence exists. A lease of 1577 mentions a furnace pond and also the right to carry pig iron through Vachery Park to Vachery Hammer.[1] An old and heavily used hollow-way heads north east from the pond bay of the hammer pond in the direction of Vachery, but the Guildford to Horsham railway line of 1867 has destroyed it after a few hundred metres. In 1578 a lease


Hyparkgate
Thornhurst Brook
Owl
Barn
Copse
Longhursthill
Snoxhall
Vachery
Pond
Heywards
Brooklands
Baynards
Hammer
Farm
Vachery
moated
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site of Vachery
forge pond
N
Pollingfold moated
site
Cobblers Brook
0
1km
Figure 1.

seems to suggest the existence of three ponds, describing one as 'above the manor place of Vachery towards Baynards'.[2] This position would fit the present Vachery Pond – fishponds are mentioned at Vachery in 1297 and the site would always have been a convenient one in which to make a pond. The strongest evidence for this as the site of the furnace pond lies in the bounds of a lease of 1580 for a small piece of land which lay 'between Newpark Longhersthill the tail of the furnace pond the north end of the old park of Vachery and the highway at Hyparkgate'.[3] This 30a. holding, called in other documents Ebronde, has disappeared, but the name may be remembered in Owl Barn Copse. In 1576/7 Lady Jane Bray accused her son Edward of 'destroying the head of the great pond of Vachery'; this may have been the furnace pond but when later in the same year she gives permission to the ironmaster John Lambert als Gardner 'to dig new make and to raise the head of the said pond' she is clearly referring to the hammer pond powering Vachery forge.[4] It is worth noting that the footpath along the top of the eastern end of the bay exposes large pieces of slag and forge bottom which may relate to this permitted repair work.

However, there is also some evidence that there were ironworking interests within the Baynards estate. In 1589 Cuthbert Blackden leased to John Reade a holding called Brooklands which had once been held by John Lambert als Gardner.[5] The late 16th century house at Brooklands still stands and was, and is still, within Baynards Park, close to the moated site of Pollingfold (see Field Evidence).

No other documentation directly links the Pollingfold site with any other industrial processes, but a settlement of 1776 includes 'two corn mills within the Great Park erected'.[6] The location of these mills, later described as water mills, is unknown, but it is tempting to suggest that the leats of the moated site and possible ironworks may have been reused in this way.

The suitability of this area for the development of a large pond is illustrated by a map of 1811 showing two intended reservoirs for the Wey and Arun Junction Canal (Figure 2).[7] The western reservoir is Vachery Pond, but the eastern one is something of a mystery – either

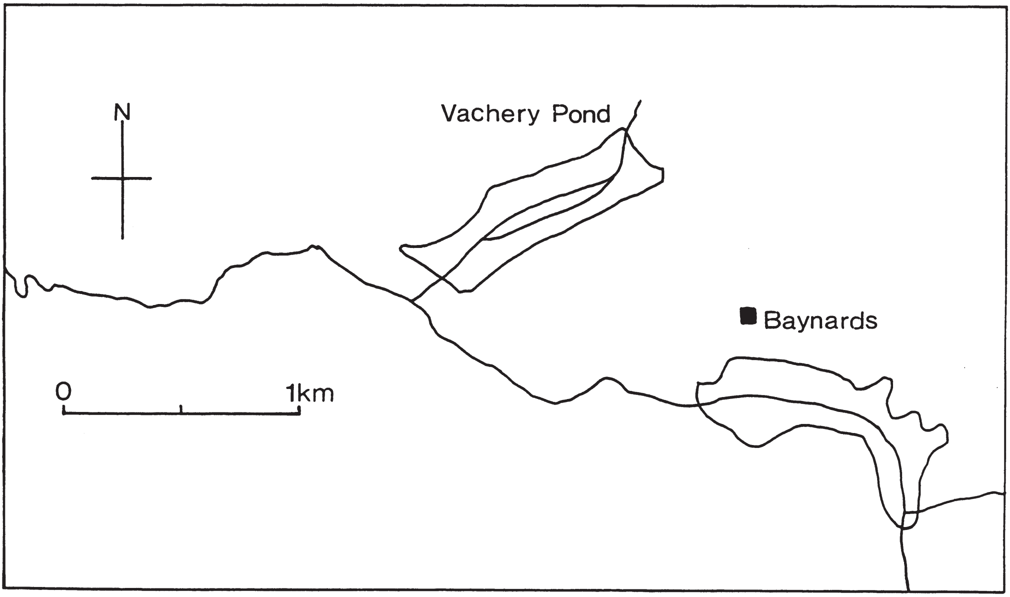

Figure 2

it was never built or it was thought feasible to use the pond referred to below.

According to Hone's Yearbook for 1831 a visitor to Baynards House was told 'that yonder great meadow down there, which we call the forty acres, was then first drained. Before that, it had been as fine a piece of water as ever you could see, with plenty of fish, and with boats and swans. You may yet see the old pond head – that high bank with trees upon it'. Vachery Pond would not have been visible from Baynards House but one in the position of the eastern reservoir would. It seems strange that a large pond existing within living memory in 1831 should have escaped direct cartographic record. However, some memory may be recorded in the fields named by the tithe map and award as Pond Field, Sluicegate and Floodgate Field.

In conclusion, there is ample documentary evidence to confirm the existence of a furnace pond beneath the present Vachery Pond. However there is also a strong suggestion of ironworking interests in Baynards Park. A furnace pond in the position indicated on the 1811 map could have supplied power to a site close to the moat of Pollingfold, where slag has been found, and would have been visible as described in Hone's Yearbook. Extensive landscaping within Baynards Estate, both during the creation of the Victorian Park and Home Farm after 1832 and in the later extension of the road network and digging of duck decoy ponds, destroyed much field evidence. Lack of documentary evidence may relate to the changes in land ownership – most of the documents relating to Vachery Forge are from the Bray family archives but they had sold their land during the 1580s; the Onslows, who owned both Vachery and Baynards in the early years of the 17th century were also involved in the iron industry elsewhere.

The people

A number of individuals involved in ironworking in Cranleigh came from families in the same trade, and several had worked at other sites within the Wealden industry. The majority of the evidence relates to the forge rather than the furnace; since most documents come from the Bray collection and the Bray family owned both Vachery and Baynards/Pollingfold manors at the relevant time, this bias may point to the furnace site having been short-lived.

The earliest evidence Straker was able to supply for ironworking at Vachery was from 1572 (Straker, 1941), but it is clear that the forge at least was in existence 20 years prior to that date. The first direct evidence for a forge in Cranleigh is a letter dated 1563 from Lady Jane Bray to William More of Losely, Sheriff of Surrey, complaining bitterly that her son, Edward, had caused two men who had been repairing the timberwork of her iron mill, and one of her miners, to be called to the Muster.[8] Owen Bray had sold the family's forge at Abinger in 1557, so this mill was probably Vachery Forge, and the repair suggests that the works had been built some time before 1563.

This suggestion is supported by the inclusion in the Subsidy Rolls (SR) for 1552 (Awty, 1984) of an alien called John Mocomber, living in Cranleigh. A John Makecownbull, described as a collier from France who had been in England for 34 years, occurs in the Denization Roll (DR) in 1544 (Awty, 1979) and members of the same family worked in the iron industry in Sussex from 1524. William Milkylbyll worked possibly at either Steel or Birchden works in Hartfield for Roger Machyn, one of his co-workers being Filpott Lambert, also an alien.

The ironmaster associated with the sites at Vachery was John Lambert als Gardner, who came from a family heavily represented in documentary sources relating to the iron industry in Sussex, and is first recorded in Cranleigh in 1573. In 1524 a John Lambert als Gardner was working at Hartfield (SR) and he was probably the 56-year-old from Normandy who, in 1543/4 had been in England for 34 years and worked at Parrock Forge. He may have been the Vachery ironmaster's father or, more likely, grandfather. John Lambert als Gardner was twice charged with illegally felling timber within the forbidden distance of a navigable waterway, once in 1573 and again in 1581 but on neither occasion was he convicted.[9]

As well as the Vachery site John Lambert als Gardner also worked a forge for Isabel Ashburnham, probably Kitchenham. Links with the industry in Sussex were not confined to the skilled French workers – the Vachery Rent Roll for 1571 also lists Richard Gratwicke and John Gardner as liable for 'the forge and the ground which they have by lease'. This Richard was the son of Roger Gratwicke deceased, who had held the underlease of St Leonard's Forest from the Duke of Norfolk, and the brother of Roger, who had extensive ironworking interests at St Leonard's, Cuckfield and Gosden (Cleere & Crossley, 1985). The 1581 charge against John Lambert als Gardner also named John Thorp, who had acquired the iron mill at Vachery and the adjoining property of Snoxhall from Edward Bray the previous year, after the latter had defaulted on a mortgage. John Thorp worked Woodcock Hammer Forge in Godstone and Warren Furnace in Worth in 1574, and his son, Richard, was also involved in the Vachery works.

John Lambert als Gardner made his will in 1593. Describing himself as an ironmaker, he left his house, Shurlocks (now Hammer Farm), to his wife Agnes and provided for his six sons, two of whom were called John, with financial bequests. He left the rental from his forge to repay a debt to his cousin John Gavis als Blackett and after the debt was repaid the forge was to revert, firstly to his wife and then to the elder John. The will was witnessed by, among others, Robert Heyward, the hammerman mentioned later. A John Blackett had been recorded in 1558 as holding an ironworks at Hodley, presumably Hoathly in Sussex.

No documentary evidence has been found of either John Gavis als Blackett or John Lambert als Gardner operating the Vachery works after 1593 but, as will be seen later, the Heyward family were still resident in Cranleigh with occupations related to ironworking in 1597. A John Lambert, collier, who made his will in 1608, lived in Dorking; he may have been the younger of the Cranleigh forgeman's two sons named John or, indeed, no relation.

In 1557 James Heyward, alien, resided in Cranleigh; he may have been related to Symon Heyward who was an alien working at Wadhurst – also at Wadhurst from 1543 was Maryon Lambert als Gardner who must have been related to John Lambert als Gardner, the ironmaster at Vachery. The Heyward family appear to have lived in a tied cottage close to the forge – in 1578 an extension of the lease of the forge by Lady Jane Bray to John Lambert als Gardner included two cottages, and in 1580 a house occupied by William Heyward, collier is noted in one of the closes north of the hammer pond – this house has long since disappeared.[10]

The Heyward family seem to have run foul of the law on several occasions. In 1574 William Heyward was the subject of a letter from Edward Bray to William More of Losely which is worth quoting at length:

> 'Further I am to request you to send for one William Heyward of Cranley who on one Thursday last as I went towards the church lay in my way with his gun charged to what end I know not but I doubt the worst. For when I had espied him and called him to me he ran away from me, wherefore I pray you send for the said Heyward. Also I pray you to send for one John Gardner of Cranley which by his own speech in a common ale house doth seem to be a maintainer of the said Heyward in his lewdness.'[11]

The consequences of this letter are not recorded, and it may be that the ironworkers had become embroiled in the long-standing dispute between Edward Bray and his mother. However, in 1597, after the death of John Lambert als Gardner, William Heyward senior and William Heyward junior, colliers, were both found guilty of burglary and Robert Heyward, hammerman, was later added to the indictment (Assize Records).

Another French family represented at Vachery was the Predoms. Listed in a Rent Roll for Vachery Manor dated 1571 is Maryon Predom, whose history is well documented.[12] In 1544 he was working as a finer for the Duke of Norfolk and had been in England for five years. In 1549 and 1551 he is to be found at Sheffield Danehill – a furnace and forge site owned by the Duke of Norfolk in the early

1540s, confiscated, but returned to the family in 1553. In 1557 and 1559 he was working for Christopher Dorrell at Leigh Hammer near Reigate, but by 1563 he had been replaced there by another finer previously in the employment of the Duke of Norfolk, John Gumrie. A probable relative, Pownsley Predom was still working at Leigh in 1576.

Maryon Predom also seems to have lived close to the forge site – possibly in the other cottage mentioned above. In 1574 the court of Shere Vachery and Cranley manor ordered Predom to scour ditches on his property, and both he and John Gardner were to make clear and bridge the lane leading to both their properties each on pain of 40d. – a considerable sum.

Several hints exist for the survival of ironworking at the Vachery site after the death of John Lambert als Gardner, most notably with the involvement of two individuals, John Shurley and William Sackville Crowe. Shurley, the owner of Cotchford Forge in Hartfield is mentioned in a covenant on Vachery in 1616.[13] Sackville Crowe leased land with William Gardner in 1619, including one 'parcel of land and pasture that the pond called the furnace pond overflows'.[14] William Gardner is likely to have been John Lambert als Gardiner's son, and Sackville Crowe was a courtier who held the monopoly of manufacture and supply of merchant guns from 1620-32 and was involved with ironworking at Freshfield and Maresfield amongst other places. It seems most unlikely that these people would have owned or leased small parcels of land in rural Surrey for any purpose other than ironworking.

The site was still remembered in later deeds; land sold in 1648 was bounded by 'the highway to the mill called the hammer', and the same description was still being used in 1735.[15]

The Vachery ironworking site was situated on the periphery of the main post-medieval Wealden industry, but clearly the people involved in its operation were part of a small and mobile community. Whether their brushes with the law resulted from an unruly nature or from a xenophobic reaction to their strange names and accents and their noisy, dirty industry with its reputation for destroying woodland we shall never know.

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Frith Furnace, Northchapel

Site Survey 1999

R. G. Houghton & J. S. Hodgkinson

This site was first surveyed for the Wealden Iron Research Group by Peter Ovenden in 1972, although the estimated length of the bay was later revised.[1] As part of a continuing programme to make measured survey drawings of water-powered furnaces and forges, the site was resurveyed in January and February 1999. Frith is an extensive site with large quantities of blast furnace slag confirming a working life in excess of a hundred years. The streams which fed the pond for the furnace, rise in springs at the foot of Blackdown, less than a mile to the west of the site, and downstream provided power for three other ironworks: Shillinglee Furnace, Mitchell Park Forge and Wassell Forge.

The earth bay, which curves slightly, shows evidence of stone revetment at its western end (A), where a spillway may formerly have allowed excess water to overflow, and where the present stream cuts through the bay. The channel through the bay, which is straight and appears to have been deliberately cut, has stonework along both of its sides at water level. A series of stone foundations across the stream may have been the remains of attempts to shore up this weak point in the bay (B). However, they may also be the remains of structures, the purpose of which is now unclear, related to either a spillway, or to an access on to the bay from the field to the west of the site. At the bay's eastern end a dry channel extends southward from an area where there is much evidence of burnt material, including brick (C). This is probably what remains of the tailrace of the furnace bellows waterwheel, and a roughly square mound close to the bay may indicate the base of the furnace stack (D). East of this, on the

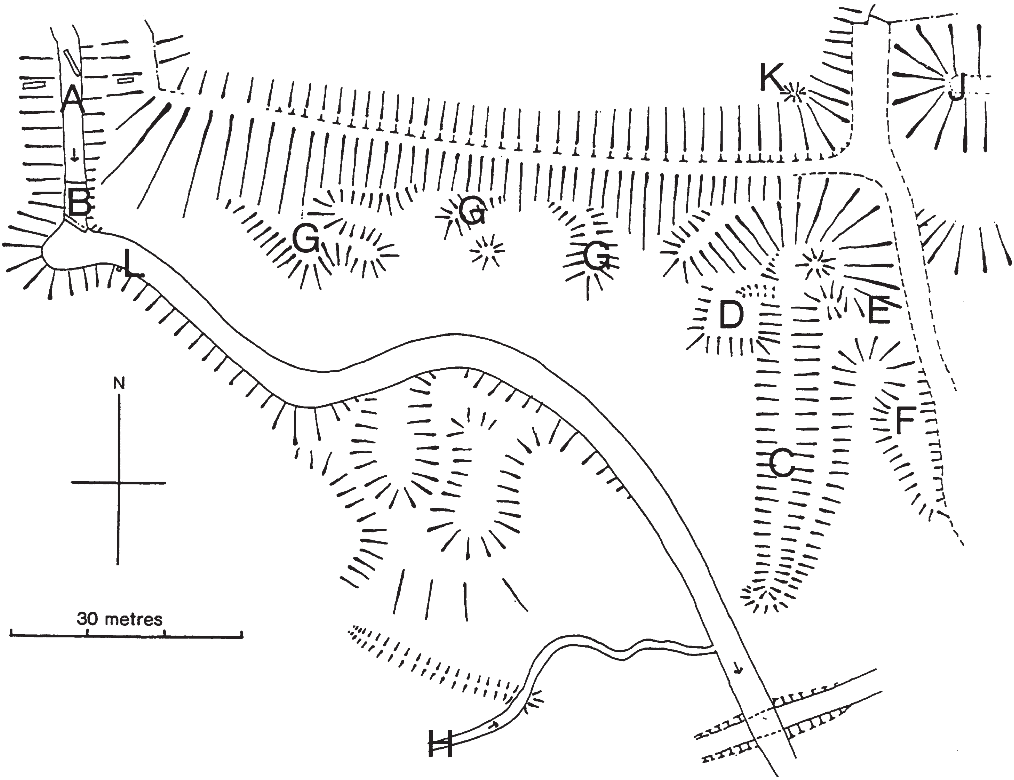

Fig 1: Frith Furnace, Sussex

natural bank of the side of the valley (E), there is an area of charcoal dust, suggesting the site of a storage shed which typically would be situated in a high position relative to the furnace, allowing easy access, via a charging bridge, to the throat of the furnace some six or seven metres above its base. To the south of this a large heap of slag, which includes at least one 'bear', has been dug into, presumably after the period of operation of the furnace, and removed for use as hardcore elsewhere (F). Although the top of the bay is relatively narrow, the heaps of slag which abut the bay along its length on the downstream side (G), and which have the appearance of having been tipped there from above, suggest that the top of the bay was formerly wide enough to carry a path or track.

Slag covers the site, in considerable heaps on the south side of the present stream, and from the evidence of a section formed by the bank of the stream which traverses the site, lies to a depth in excess of 1 metre in areas where there are no obvious heaps. The presence of such a section raises the question as to whether the present stream followed such a course during the working life of the furnace. A map drawn by Ralph Treswell in 1610 shows the furnace pond and a stream flowing across the site along a roughly similar course to the present stream, but issuing from a source in the corner of Frith Wood, which adjoins the furnace site on the south.[2] A small stream flowing on that side of the furnace site (H), which joins the main stream and divides the area covered with slag from the area where none is found, may be the residual of such a stream. To the east of the track which approaches the site from the north, lies a deep channel (J), which is clearly man-made as it is cut steeply into the land surface which otherwise slopes gently to the east. This follows a generally straight course in the same direction for a distance of about 225m until it reaches a confluence with the main stream. It is marked as a watercourse on the 1610 map, which suggests that its formation may have been significant in the laying out of the furnace site. A culvert in the corner of the former pond (K) was probably used to drain it when it was later used for fish.

Access, both in 1610 and in the present day, was along a track from Eastland Farm, entering the site at the north-east corner. Stonework in the high bank of the stream (L) hints at the possibility that some sort of a bridge may have existed there to allow material to be carried across the stream to the west.

The 1610 map bears the representation of a building, which may have been intended to show the position of the furnace. The first edition of the Ordnance Survey 6-inch map shows a building in a close on land to the east of the site, and a scatter of brick of an early type identifies the site. When William Yaldwin occupied the furnace in 1641, the terms of the lease refer to a tenement for the founder or filler of the furnace.[3] This building was demolished within living memory.

The survey was carried out in collaboration with the West Sussex Sites and Monuments Record, and the authors acknowledge, with thanks, the assistance of John Mills and Pamela Bruce, and the Sussex Archaeological Society for the loan of surveying equipment.

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Notes from the Board of Ordnance Papers 1705-20

Ruth Rhynas Brown

The Board of Ordnance papers for the period 1700-1750 are much less informative than the others dealt with in my previous articles, since there are gaps of many years in the series of surviving Minute Books until 1749. I have chosen a series of extracts which show relations between the Board and the gunfounders; first, the Board's attempts to control the weights of guns and then how they introduced a new gun pattern while attempting to reduce the price of iron. Inevitably the records dwell on times when matters go wrong rather than well, so that these details may be misleading about successful gunfounding business. However they do reflect the growing pattern of control which the Board would increasingly pursue during the 18th century.

At the beginning of this period, there were only a handful of gunfounders, the Gotts, the Fullers, the Westerns and William Benge, all of whom had long careers, and Thomas James and Charles Manning who only supplied guns for a short time. Within a few years new founders came in, notably William Harrison, Richard Jones and William Jukes. Stephen Peters, a London ironmonger, also acted as agent for the Fullers and the Board's blacksmith at Woolwich, both of which positions would be inherited by his partner, Samuel Remnant. All these gunfounders were involved in a complicated web of formal and informal partnerships, both sharing contracts and loaning guns for their completion. There were also family relationships; Peter Gott was both cousin and brother-in-law to Maximilian Western. Family relations need not necessarily work happily since people can fall out as easily with their kin as with business partners. Shot was provided by a larger group of founders, including workers outside the Weald.

1. 1705-1708

A short run of Minute Books in this period show that one of the Board's main preoccupations was the weight of guns. At first founders were casting guns which were too heavy, as they were paid by weight and could maximise the profits of the casting. Moreover, they believed a heavy gun had a better chance of passing the strict proofs of the Board. Meanwhile, the Board disliked paying for useless weight while the Navy complained of overloading their ships with too-heavy guns. The Board decided to keep a stricter note of the weights of guns; there was supposed to be a strict refusal to pay for guns over the limit of an extra hundredweight per ton. In trying to right this position, Peter Gott began to cast guns too light, an equal problem as these were prone to cracking and unpredictable recoiling. He was also having difficulties in finishing his and his partner William Benge's contracts in time.

> 'That a Letter be writt. to Mr Gott to acquaint him wee have had under our consideracon his Contracts in behalf of himself and Mr. Benge and find he is in Arrear according to the enclosed Accot. and also that if the Guns undelivered upon Mr. Benges Contract are not yet cast, that he must make them of the Lengths and Natures markt against them in the enclosed Account and in the Answer to let us know what time wee may expect them at Woolwich.'

A few days later the Board were forced to write again to Gott:

12 May 1705 WO 47/22, 152

> 'That ye 7. 24 Pounders of Mr Gotts proved the 25th April last be refused upon the account of their being heavier considerably than they shou'd by their Contract and ye Weight of the 2. 6 Pounders of ye same Proofe be examined whether they are agreeable to their Contract, and that the Bill for ye Gunns of the said Proofe be bro'tt into March Quarter.'

The following month the Board and Gott came to an arrangement:

14 June 1705 WO 47/22, 190

'That ye 7. 24 Pounders Iron Ordnance of Mr. Gotts ordered not to be rece'd proved ye 26th of April past being over weight be now rece'd, he having made application to us and being willing to lose wts. over as specified in his Contract.

And also that Mr Mannings Guns proved ye 24th February 1704/5 upon the like Accot be rece'd except 2. 3 Pounders wch. he is to take to himself.'

The Board allowed a hundredweight per ton in the guns in the contracts with its founders. Here the Board agreed with Gott to accept the heavy guns but refused to pay for weight over the agreed allowance. Interestingly the Bills for these guns mistakenly call them 12 Pounders although the weights show clearly that they were the 24 pounders in question (WO 51/70, 50v). The weights recorded range from 48-1-12 to 49-2-12. But more worryingly the Bill Books record that the Board paid the price of the true weights of the guns and not the lower price agreed, although it is possible the money was recovered at a later date from Gott. The Board kept a watch on the problem, when the following year another proof of Gott's guns was held.

12 March 1705/6 WO 47/23, 190

'That a Letter be writ to Mr. Felton and therin send him inclosed the Weight of Mr. Gott's Gunns proved ye 7th Inst, that the Board approves of their Weights, And that he makes out a Bill for them same accordingly.'

After this a number of proofs passed without incident. On 3rd October the founders were asked:

WO 47/24, 148

'That Letters be writ to the Gunfoundrs. to give them notice what warrants are order'd for their casting Guns, and Shot for next Years Service, And to send to them an Acct. what Guns and Shot they are in Arrears wch. the Board expect with the utmost Dispatch'.

In the meantime Peter Gott's problems continued when his shot was closely examined at Woolwich:

7 November 1706 WO 47/24, 174v

'That a Letter be writ to Mr. Felton, that as soon as the shot belonging to Mr. Got & Founders wch. were some refused for being hollow'd, others for being fill'd up with lead.'

7 December 1706 WO 47/24, 201

'That a proper Clerk go down to survey and receive the Round Shot refused for being hollow, now fill'd with lead wch belong'd to Mr. Got and other of the Founders.'

However even this was not an end to Gott's problems.

3 May 1707 WO 47/24, 311v

'That the Guns belonging to Mr Got prov'd on the 21st March 1706/7 bee returned by reason of their being too light (vizt) DiCulvering of 9 Ft 15 and 6 pounders of 8½ Ft. 4 And that the Guns undermencioned be reced. in
DiCulvering of 9 fot ... 28. 0. 24

These guns were paid for in a bill of 17 March 1706/7. Surprisingly a few even lighter guns were also accepted, including 6 pounders which should not have been less than 2 cwt underweight i.e. they should have been 22 cwt and would not be accepted under 20 cwt; the weights are written in the margin for the guidance of the clerk both for what to pay and what was acceptable. This can be seen in the next extract:

28 June 1707 WO 47/24, 354v

'That a Letter be writt to Mr Felton Storekeper at Woolwich to make out Bills for Guns belonging to Mr Gott the 28th May last and for Guns belonging to Mr. Western wch. were prov'd ye 19th and 23rd Instant except one 6 Pounder of 8½ fot.poiz 19-3-20 – being

> 2-0-8 underweight...
>
> That it be a Standing Order to all the Gunfounders in Gen. that for the future they will have no more allowed them of weight over or under what their Contracts mention than 1 cwt in a Ton.'

Although the founders were reminded of this the following July, in October 1707 Peter Gott had one gun refused for being too light while Major Fuller had 12 guns refused – two for being too heavy, 10 for being too light (WO 47/25, 97v, f178). Following the earlier example, several of these disputed payments to Gott, Manning and Fuller are singled out in the Bill Books by having the correct weights in the margins.

The Board now took a new tack to prevent further abuses, ordering on 30 October 1707 a 'Warrant to Mr. Ogbourne to fix at such a proper place near the Crane at Woolwich a Standing Gibbet to weigh the Artificers Ordnance before they are proved, takeing the Surveyer Gen'ls directions where the same must stand and how made.' (WO 47/25, 179).

2. 1715-1720: The New Pattern

There follows a long gap in the Minute Books until 1715. The long wars against Louis XIV had finally come to an end, and a new dynasty was on the throne of Britain, bringing many changes. The Board of Ordnance was not immune; the Royal Regiment of Artillery had been set up on a permanent basis, providing a corps of officers whose influence would grow with the years, shifting the balance from naval to field experience. A survey of existing guns was undertaken, and a new gun design was to be introduced for both land and sea service in both brass and iron. This would be facilitated by the destruction of the Moorfields bronze foundry in London and the building of the Royal Arsenal at Woolwich, directly under the Board's control.

By now the unfortunate Peter Gott had died suddenly in mysterious circumstances, following the sudden collapse of his family's finances and there were rumours of suicide. His son, Samuel, now took his place as a gunfounder along with his uncle and cousin, Maximilian Western and the Fullers. Western, as the senior founder of the Board's contacts, took a leading role in negotiations, but his nephew would not allow any family feeling to interfere with business.

First on the 26th April 1715, the Board ordered:

> 'Referr'd to the Survey'r Gen'l a Letter of the 14 Instant from Mr. Felton touching the low state of 12 Pounders and 6 Pounders Gunns at Woolwich to Consider what Gunns will be proper to Contract for.'

A few days later the Board wrote:

WO 47/28, 144v

> 'Letters to ye respective Gunfounders to send in their Propasals for casting iron Ordnce. – Mr Western, Mr. Gott, Majr. Fuller & Mr Jones.'

27 May 1715 WO 47/28, 157v

> 'That ye Gunfounders have notice to attend the Board on Tuesday next, & Letters write to them Accordingly – Mr. Western, Majr. Fuller, Mr. Gott, Mr. Jones.'

31 May 1715 WO 47/28, 159v

> 'The gunfounders attend abt their proposals for Casting of Guns & Mr Western being out of Town, the Board put off ye Determination of that affair, til Friday Sevennight.'

10 June 1715 WO 47/28, 162

> ‹The Gunfounders called in, & agreed to furnish the Office with 610 tons of ordne. at 16 £ pr. Ton the higher natures, & 14 £ per Ton for the lower natures Vizt.
> Maxn. Western

Saml. Gott
John Fuller
Richard Jones
Stephen Peters.

That Contracts & Warrants be made with them Accordingly.

And that so many of the Guns lying in Woolwich Warren which Maj. Fuller provided for the Service as will answer the present £14 a Ton as well as the Lower, if he had the whole Quantity yt. is contracted for, but ye Contracts being already settled, ye Board do not think proper to alter ye same. Mr Samll. Gott, attended also and desired a greater proportion of Guns, but was refused for the same reason.'

Jones had an iron foundry at the Falcon Inn, Southwark and he and Peter Gott had worked together on projects such as providing iron work for the St Paul's Cathedral. He was also involved in the financial dealings of the Gott family and it will become clear that the casting would actually be undertaken by Samuel Gott.

5 July 1715 WO 47/28, 177v

'That the Draughts for casting the Iron Ordnance last Contracted for, be sent to Mr. Stephen Peters for himself and Maj. Fuller.'

23 August 1715 WO 47/28, 204

'Letters to the Gunfounders to return the Draughts delivered them for casting the 6 Pounders by, upon their last Contract.'

22 Nov 1715 WO 47/28, 250

'Ltr. to Mr Richard Jones Security to know if he is about casting the Gunns According to Contract, as he alledges in his Ltr of the 25th Inst.'

16 December 1715 WO 47/28, 260

'A ltr to Mr Jones' security about performing his contracts for Delivering Iron Ordnance.'

Jones' securities – Messrs. Harrison, Ludgate and Whistler – were ordered to appear before the Board. This is one of the earliest references to William Harrison, who was to become one of the most important gun suppliers. He was a London ironmonger at this period.

20 December 1715 WO 47/27, 171

'Mr Harrison one of Mr. Jones's security acquainted the Board that Mr. Got undertakes the casting & delivering the Gunns for Jones According to Contract, whereupon he was told that it is incumbant upon him To be well satisfied of their being at work.'

31 January 1715/6 WO 47/29, 77v

'… to Mr. Saml. Got Gunfounder, in answer to his of 31st Decem, last that Mr. Jones security's have given such Satisfaction that his Contracts shall be Comply'd wth. that the Board depend upon thre performance.'

24 May 1716 WO 47/29, 136

'Orders to Capt Richards & Smith to go to Woolwich & Examine the Guns brought in by Mr. Western & Mr Gott, with the Draughts.'

12 June 1716 WO 47/29, 142

'Mr Western & Gott, Gunfounders, attended the Board about the making the iron Ord'nce contrary to the Draughts given them & were desired to go to Woolwich to examine the same if they were not as represented by Capt. Smith and Richard; the 4 Capts. of the Train, & the Capts to go wth. them if they desire it.'

The new note that has crept in is that previously the Board had been concerned whether the new guns were within the acceptable weight limits; now the new guns were also compared to the draughts; that is, they now had to conform to the new patterns dictated by the Board.

19 June 1716 WO 47/29, 144v

'… that Mr. Blake Proof Master, & Capt. Smith, Richards, go & view Mr. Westerns Guns & mark them according to the report made by the said Capt against the Officers coming down to Woolwich.'

While Western and Gott were dealing with complaints that they had not cast the guns accurately to the draughts, Richard Jones was failing to cast any guns at all, despite frequent complaints and letters. William Harrison took over the contracts himself.

18 Sept 1716 WO 47/29, 191v

'A Ltr. to Mr Wm Harrison (Mr. Rich. Jones Security) wth. the Draughts of an Iron 24 Pounder Gun of 10 Foot long.'

11 January 1716/7 WO 47/30, 85

'And Mr Wm. Harrison desiring leave to take back 30-12 Pounders delivered at Woolwich upon Mr Jones's Contract, dated ye 10th of June 1715 wch he would make good wth. others, as soon as the Roads wou'd permitt their Carriage to the Warrt (Rejected).'

However a week later the request was accepted when Harrison added bills to the amount of £1000 as security.

21 May 1717 WO 47/30, 144v

'Mr Gott attended, & desired a Greater Number than is now Proposed for him, in regard he hath a Signification from the Mr. Genl. for casting Ordnance for His Majty. Service, wth. ye rest have not, & that Maj. Fuller has 2 shares by having Mr. Peters as well as his own to cast.

Ord. that Contracts be made as fol:

Saml Gott	- 60
Max. Western	- 40
John Fuller	- 30
Stephen Peters	- 10

- 6 pounders of 9 foot at £14p Ton

And Letters to acqt them therewith.'

The following month, new contracts were let on very similar basis to the same founders, who tried various ways to increase their allowance.

5 July 1717 WO 47/30, 167v

'Mr Western Gunfounder this day represented by his letr. that he was ready to Contract for 300 or 400 Tons of Iron Ordce. beyond his late agreement for 119 Guns & that he wou'd Stay 12 Months after the Course of the Office for paymt. of the Money – The Board cal'd him in & told him, they could not tell what money might be allowed this Office by Parliament for ye next year, therefore could not come under any such Contracts.'

However when its financial position was at last clarified, the Board agreed to Western's terms in December, circulating the other founders of the new terms offered. On 9 May 1718 they were written to, asking formally if they would agree to the same terms as Western.

28 May 1718 WO 47/31, 176v

'A Lr. to Maj. Fuller Gunfounder, that if he'l furnish Iron Ordnce. at £13-6-0 pr. Ton (To be paid according to the Course of this Office) Contract will be Ord. to be made out wth. him.'

This was agreed by the Board on 18 June, confirming that the proposal was made by Fuller himself.

28 August 1718 WO 47/31, 218

'Mr Western, having requested a Survey to be made of sevll. of his Iron Ordnce & Coll. Borgard having reported Yt he found but 7½ Pounders of 9½ foot, agreeable to ye New Regulation. Ord'd That the said 7½ Pounders (after Proof) be rec'd.'

In fact Fuller's contract was cancelled when the Board was forced to terminate most of its contracts because of financial deficiency in the following October. A new contract was issued on 31 October 1718 for the most needed iron ordnance and 'Coll. Borgard be desired to make draughts for them accordingly' (WO 47/31, 255v).

On the 16 December 1718, the Board decided to write to Messrs Western, Fuller, Gott, Peters, and Harrison 'That if any part of whats due on former contracts & wants be not moulded they are not to proceed therin till further Order, his Maj. present Service requiring Ordnance of Particular Natures for wch. they'll have proper directions' (WO 47/31, 291).

The founders hastened to complete contracts before the deadlines. However now they were asked to take unwanted iron ordnance no longer fit for service. Both Fuller and Western refused to take any, although Peters was prepared to buy old armour (WO 47/32, 116 and 118).

In March 1719 the Board knew which guns were wanted for service and were able to issue new contracts and orders for 80 12 Pounders were split equally between Western, Gott, Fuller and Peters (WO 47/32, 157v). However there were still problems and the Board recorded on the 3 April: 'A Letter to Mr Westerne acquainting him that if he will not accept of the last prices, his proportion will be disposed off among the rest of the Gunfounders.' (WO 47/32, 171v).

23 June 1719 WO 47/32, 232v

'… to Col. Borgard to examine the 15 6 Pounder Iron Ordnance belonging to Mr. Western, to know if they answer the new regulacon that if so they may be proved with Mr. Gotts next Saturday.'

14 September 1719 WO 47/32, 276

'A Letter to the Gunfounders mentioned in the Margin (Messers Westerne, Gott, Fuller, Peters) to loose no time upon casting - 24 Pounder Iron Ordnance of 9½ Ft ... 20 each That as soon as there is a full Board, consideration will be had of giving further warrants but that probably (for the present) there will be no Small Guns, and as these 24 Pounders are much wanted, Those that have any Objection are desired to give timely notice that the Board may take their Measures accordingly.

That if any of the Founders refused their Proportion that the Guns he was to Cast are to be divided amongst the rest, or to those that are willing to take them.

That Mr Wm Harrison (if under no agreement) may Contract for 24 Poun' of Iron Ordnance of 9½ Ft ... 20 and for the future may have an equall Dividend with the rest. And a Letter to Mr Wm Harrison accordingly.'

18 December 1719 WO 47/32, 310

'Mr Fuller the Gunfounder attended in relacon to casting the Iron Ordnance. Order›d that his Letter be lookt out & laid before the Board Tuesday next And that all the Gunfounders have notice to attend.'

23 December 1719 WO 47/32, 312v

'Mr Western's Clerk attended the Board & said he had received no further Proposall from his Master about casting of Iron Ordnance than what is mentioned in his Letter of 16 September last. Was answered they could say nothing to him.

But order'd Circular Letters to the Gunfounders to put in their Propasalls if they designed to have a proportion of the following Natures of Ordnance to be cast for the next Year for sea service … 192 (guns).'

8 January 1719/20 WO 47/33, 70v

'Mr Westerne Gunfounder attended & was called in & asked if he would take less that £18 for 24 Pounders downwards to 12 Pounders inclusive and £16 for 9 Pounders & downwards, he anwered he could not, and the rest of the Gunfounders having alledged the same;
The Board agreed to make Contracts & warrants for the foll'wing

natures vizt.

Mr Western for	24	Pounders	of 9½	…	24
	12	Do	of 9½	…	24
Major Fuller for		Do	of 9	…	60
MrGottfor	24	Do	of 10	…	24
Mr Peters for	24	Do	of 9½	…	24
Mr Harrison for	24	Do	of 10	…	32
		Do	of 9½	…	4

And if they have not Draughts of these severll Natures of Guns that Col. Borgard should supply them. And Letters to acquaint them with the above written Order and that they are to be delivered at Woolwich for Proof before the 31 December next.'

This is the last surviving complete set of Minutes until 1749. Although the Bill Books fill in some of the picture, the details of the relations between the Board of Ordnance and the Founders has to be drawn from the letter books of the Fullers and of the Harrison partnership.

Swedenborg's Description of English Iron-Making

Jeremy Hodgkinson & Anne Dalton

In *Wealden Iron*, Ernest Straker made use of an illustration of the Gloucester Furnace, Lamberhurst, from an 18th century treatise on iron entitled *De Ferro*, written by Emanuel Swedenborg, which had been published in 1734.[1] In the original treatise the illustration accompanied a chapter on iron-making in England which included a description of the furnace, as well as of Wealden gun production, and blast furnaces and forges in general. No complete translation of the treatise into English is known to the editors.

Swedenborg was born in 1688. His father, Jesper Swedberg, was a Lutheran cleric and academic, but both his mother's and his stepmother's sides of the family had interests in the iron industry, owning ironworks in Vastragard and Bergsman, as well as at Starbo in Norrbarke, and a share in the furnaces at Axmar in Gastrickland.[2] Swedenborg was educated at the University of Uppsala, where his father was on the staff, and graduated in 1709. The following year, he embarked on an extended tour of Europe, visiting England, France, Germany and the Netherlands, and on his return in 1715 was appointed an Assessor in the *Bergskollegium*, the Royal Swedish College of Mines. Swedenborg began writing on mining and ironworking, establishing Sweden's first scientific journal, the *Daedalus Hyperboreus*. In 1722 he visited Germany and the Netherlands again. His *Opera Philosophica et Mineralia*, of which *De Ferro* formed a part, and which also contained a treatise on copper, *De Cupro*, was published in 1734. It was published in Saxony because of the greater freedom there than with Swedish presses, which were subject to ecclesiastical censorship, and also because of the quality of the German printing. Publication was in Latin because it was the internationally accepted academic language. *The Opera*, and in particular the first of its three volumes, known as the *Principia*, brought Swedenborg international respect. The examples used in *De Ferro* were drawn from throughout Europe and Russia. Subsequently he began to consider themes which explored the link between the worlds of science and spirituality. During a visit to England in 1745 Swedenborg received a vision which convinced him that his course lay in revealing the inner meaning of the Bible, and he abandoned the material concerns that had occupied him until then and, for the rest of his long life devoted his energies to propounding a Christian theology. He died in London in 1772.[3]

Sweden had abundant resources of timber, water and high quality iron ore, and by the end of the Middle Ages, together with Spain, was exporting iron to other European countries. Swedish iron at that time was the product of a largely peasant economy, but this situation was radically altered in the early part of the 17th century when Dutch entrepreneurs, spurred on by their country's isolation from its traditional sources of supply of iron, began to develop iron production in Sweden.[4] The establishment, in 1637, of the *Bergskollegium* introduced a greater regulation of all the stages of iron production and marketing, and initiated a degree of organisation in the Swedish iron industry that was largely absent in its competitors. The state-inspired recognition of the importance of iron to the nation's economy stimulated visits to other iron-producing areas of Europe by a number of individuals involved in the iron industry in Sweden, who reported to their colleagues on their observations. Swedenborg numbers among these.[5]

In the first instance the translation below was made from the text which is printed in the *Descriptions des Arts et Metiers*, published in Paris in 1762.[6] Subsequently, it has been possible to compare Bouchu's version with a fairly literal translation into English from Swedenborg's original Latin text. The translation which follows, therefore, is an attempt to render Swedenborg's narrative in a modern idiomatic English, using the translations both from the Latin and the French as a guide. Specific terms which he used have been preserved, where appropriate, and names and measurements have been shown in both their original and modern forms. In translating *De Ferro* from Latin into French, the translator, Monsieur Bouchu, must have encountered the problem of rendering measurements in the text meaningfully, and this problem remains. Swedenborg used a variety of units of measurement, and in some instances, such as in the use of the Swedish ship pound, it is clear what he meant, and modern sources can provide the necessary conversion (see note 11 below). However, with other units, such as the ell, foot, inch or pound, although these measures were used internationally, their meanings differ from one country to another, and it is not always clear whether Swedenborg was using English measurements or Swedish ones. In these instances a common sense approach has been adopted and the context has been taken as a guide to what was originally intended. Similar problems have been encountered with a small number of words italicised in the Latin text. These have been left in their original form, with the modern version following, either in square brackets or as an endnote.[7]

The Text

The method of smelting ore and of re-melting raw iron in England

The veins of iron ore mined in England are usually explored and investigated in galleries which are sunk in the countryside, often to a great depth.[8] Sometimes they find a vein about ten or twenty feet [3.05m-6.1m] below the ground, after they have first dug through layers of sand and clay. The ore is also found at a still greater depth under red clay which is rich and can fertilise the soil. Just above the ore, in some places, there is a rocky layer which is often mixed with the ore as a flux in place of limestone in the proportion $^{1}/_{14}$ part of the rock with ¼ part of limestone. This type of ore, when burnt, takes on a purple colour, and it can be used, instead of emery, to polish glass.

In some parts of the country the land appears rich in iron ore, but it is of variable quality, poorer in one place, but richer in another.

In England iron ore is also frequently found in marshy places, and in layers of as much as one foot or more in thickness, and this ore is quite rich. When it is melted it is mixed with another type of more solid ore, in case the stack of the furnace is obstructed by it, and blocked. This type of ore, when it is first dug up, is of a yellow colour and greasy, but when it has been exposed to the air it becomes dry and disintegrates into black dust.

Ore is also quarried in the mountains, in the harder rocks of England, but this sort of ore can have a low yield, and consequently is mixed with the former sort. There is another type of iron ore of a grey colour, which is usually found near the surface of the mountains, about ½ ell [0.27m] thick, or less, and this ore is called *Pinmine*.[9] It is not hard, but is like chalk or hardened clay, which enables it to be extracted in pieces, and when these fragments are split a nodule of mineral can be seen inside.

Also, ore of a pale blue colour is mined in *Dean Forest*. It is heavy, with white, shining flakes, as a result of which the iron from it becomes brittle, unless it is mixed with old slag or cinders of mineral coal.

Iron ore is also found mixed with stones of various sorts. Some, like copper ore, are found between layers of slate or mineral coal, especially in *Staffordshire*, taking its name from its colour.

Blast Furnaces in England

The smelting of iron from ore and the forging of it in workshops flourishes in England, and in the past few years the number, both of furnaces and forges, has increased considerably, with an improvement in working methods. Several blast furnaces and forges are in the county of Lancashire, particularly at Lichtonbeck, Cunscy and Backbarrow.[10] Mines are at Henningwood, in Lowsoness, and Adgarley, near the town of Ullversson [Ulverston], The ore from the mines is rich, and impregnated with a red colouring, but the ore mined around Whithavers [Whitehaven] is richest, for out of 5 tons, or 37½ skeppund [5625kg], of ore 3 tons, or 22½ skeppund [3375kg], of iron can be made, so the proportion of this ore to raw iron is 100:60, or 60%, and so that the ore melts better, old slag, or what has previously been removed from furnace hearths, is mixed with it, producing abundant iron.[11]

In Lancashire they use charcoal to smelt the ore, but if this is not available they use a combustible earth or ‘heavy clayey soil’; but it has been discovered that the iron then becomes sulphurous and difficult to work, and when hot, it breaks up, and bar forged from it contains holes and cracks, so it is of little use unless mixed with better quality iron.[12]

Iron smelting flourishes particularly around Starbridge [Stourbridge]. The blast furnaces there are tall; as much as 26 Swedish feet [7.72m] to the top.[13] However, they are not built in the same way as in Sweden.[14] The exterior of the furnaces, as well as the interior, differ from the furnaces of other regions. Outside they are square, each side being 12 ells [6.4m] long,[15] for the exterior of the furnace is built with parallel walls to a third of its height, from whence they slope towards the top, where the inside walls are square and measure 20 to 22 in [0.51m-0.56m]. The hearth is oblong in plan, in the upper part 2 ft 4 in [0.71m] long, from the front part to the opposite dividing wall or to the back, and 18 in [0.46m] wide, but lower down, next to the foundation stone, it is 2 ft [0.61m] long and 17 in [0.43m] wide. It is 5 ft [1.52m] high to the point where the walls slope. Inside the furnace is built of bricks or heat-resistant stone, and externally from other types of stone. The hearth itself is made of four hard stones each weighing 1 to 1½ tons [1016kg -1524kg]. The largest stone makes up the base of the hearth, and the other three its walls. A fifth one is placed over the tapping hole. It often happens that the stones are eroded, to such an extent that a hearth that was 17 in [0.43m] wide originally, is increased to a width of 3 ft [0.91m]. The tuyère hole is also stone, and the lower part of the opening is reinforced with an iron plate, above which rests the nozzle of the bellows. The bellows are usually wood, but in some places are still made of leather. The leather ones are 18 ft [5.49m] long and 4 ft 2 in [1.27m] wide. The nozzles of the bellows are 1 ft 4 in [0.41m] long. The wooden bellows are made from oak planks 5 in [0.13m] thick at the widest point, and elsewhere 6½ in [0.17m]. At the head of the bellows, where they are narrowest and where the hinge is, they are 7 in [0.18m] thick and 8 in [0.2m] wide. The length of the wooden bellows is 18ft [5.49m], and their breadth 4 ft [1.22m] or more. The air valves are 17 in [0.43m] long and 16 in [0.41m] wide. The nozzles of the bellows are 4 ft 6 in [1.37m] long, and they project 3 ft 3 in [0.99m] outside the bellows. The diameter of the opening of the nozzles is 2 in [0.05m]. The inside of the bellows is lined with tin for a depth of 7 ft [2.13m] from the nozzles, allowing the air to pass more freely, and extinguishing the fire should it be drawn through the nozzles into the interior. The water wheel measures 22 ft [6.71m] in diameter, the depth of the paddles being 23 in [0.58m], and the distance between them is 6 in [0.15m]. The shaft is 2 ft 9 in [0.84m] in diameter, and 24 ft [7.32m] long.

The calcining of the ore is not carried out in a specially constructed hearth, but on the bare ground and in the open air. Firstly, a bed of charcoal is laid down, using the smaller pieces which cannot be used in the blast furnace, or which have been raked out of the furnace when smelting has finished.[16] Above this layer of charcoal is placed the ore, then charcoal again, and then ore, continuing layer upon layer to the required height. Then, when the charcoal which is underneath has been set alight, the whole pile catches fire, and it burns for a week or longer. However, care must be taken that the heat does not become too great, to the extent that the ore nearest the flame melts.

Different sorts of ore are mixed, such as *Ironstone* and *Iron-ore*, in a fixed ratio. Around the furnaces in *Starbridge* [Stourbridge] are two sorts of ore. The first, called *Ironstone*, is dug from soft soil or clay, and is found in pieces not far from the surface. It is quite dry and low-yielding. The other sort is richer, two parts of it producing one part of iron. This type is divided into two species, one rich in sulphur, the other sulphur-free.

For smelting, moderately large oak charcoal is used, but the larger pieces are kept to be used in the forge. For melting 1 skeppund [143kg], not more than ½ läst [858kg] or 6 or 7 tons of charcoal is burnt.[17] In *Lancashire* peat is mixed with charcoal, but the iron is then impregnated with sulphur and become brittle when hot. In some places they use mineral coal, but that is first burned or calcined into ashes, or *Cindres* as they are called. It has been discovered that a smaller quantity of iron is obtained in this way, than if charcoal is used, for from pure charcoal 15 or 16 tons [15,242kg-16,258kg] of iron could be obtained in a week, but if cinders of mineral coal were mixed with them, only 5 or 6 tons [5,081kg-6,097kg] could be made, and the resulting iron is brittle when warm, and is cheaper and hardly suitable for making tools.[18]

The furnace is filled first with charcoal. When it has sunk to a depth of 5 ft [1.52m], three more baskets of charcoal are added, and then 10 containers of ore, and again when it has settled 5 ft [1.52m] in the furnace, three more baskets of charcoal with 10 containers of ore.[19] In some places 20 containers are filled with types of ore; for example, 18 from the ore which is called *Ironstone*, and two from the mineral powdered into sand after calcining. In 12 hours there are six charges. The iron is tapped twice, but sometimes only once, in 24 hours. At each tapping they usually obtain 7½ skeppund [1,463kg] of iron, which they divide into 23 pigs. The slag is green and glassy, and is taken to the glass-makers' furnace, but the glass obtained

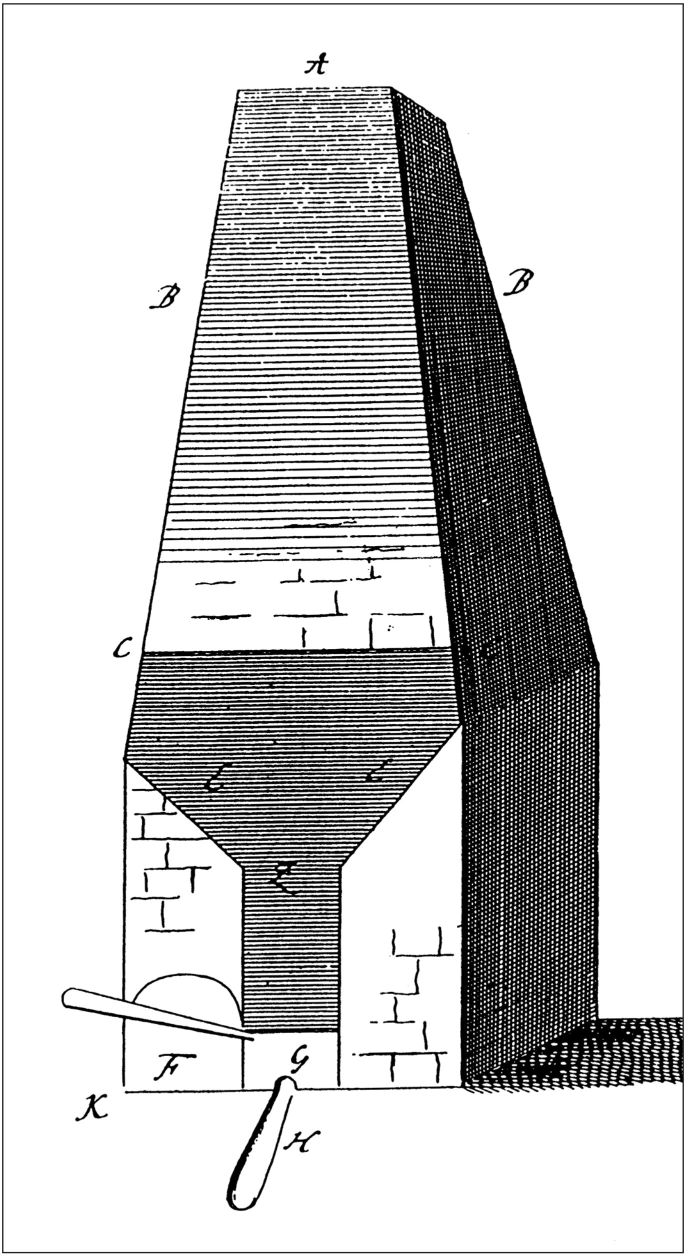

Fig 1: Gloucester Furnace, Lamberhurst

from it is fragile, and to prevent this from happening, slag without iron must be chosen.

On each occasion four or five baskets of charcoal are placed in the furnace, then ore on the top, charcoal on top of that, and another layer of ore, and at the same time ½ or ⅓ of a bushel of the stone mentioned above. However, care must be taken not to put too much in.

If the furnaces are quite large, the iron is tapped through the usual opening into prepared moulds or beds, but if they are quite small the volume of liquid iron is collected in a vessel, and is poured from there in the necessary quantities. The iron is usually tapped twice in the space of 24 hours and at each tapping 12 or 13 cwt, or 4 skeppund [780kg], is cast. If large guns are to be cast, the volume of iron is kept in the furnace for the space of about two days, depending on the quality of the ore and of the furnace itself.

As far as the construction of the furnaces is concerned, it is possible to see how they are made, from the attached drawing. Plate XV [Fig. 1] depicts the furnace at *Glocester* in Sussex, which is the tallest and most famous of that region;[20] its height is 28 ft [8.53m], where elsewhere they are 24 ft [7.32m]. **A**, on Plate XV, shows the upper part of the furnace, where it is charged. There the furnace is 22 in [0.56m] square.

BB are the walls of the furnace, which have a height of 28 ft [8.53m]. At CC the height is 20 ft [6.1m]; in other places it is 15 or 16 ft [4.57m -4.88m], where the furnace is only 24 or 25 ft [7.32m-7.62m] high.

CC is the largest part of the furnace, that is 1 or 1½ ft [0.3m-0.46m] above **DD**. The internal size of the furnace there is 7½ ft by 8 ft [2.29m by 2.44m], though others describe it as 8 ft square. At **DD** the slope or Boshes begin, made so that the ore and the charcoal does not fall immediately into the hearth, preventing smelting. The Boshes are widest at the top, but next to the hearth they are only ½ ft [0.15m] wide.

EE are the sloping walls, which are 18 in [0.46m] long, and if one adds the height of the hearth, also 18 in, together they make 3 ft [0.91m]. This is the height of these walls from **Z** to **G**, or the top part of the hearth. The height **DD** to **KK** is 7 ft [2.13m]. This ratio is observed if the height of the furnace is 24 or 25 ft [7.32m-7.62m], but if it is still higher, then what are called the Boshes must be still higher and longer in the given ratio. **FFF** is the thickness of these walls, which also vary according to the greater or lesser breadth of the hearth.

When the smelting is finished these walls are demolished, but the foundation stones are kept for a long time before they are removed.

G is the hearth, which is 5 ft [1.52m] long from the opening in front to the opposite side, and is 2 ft 2 in [0.66m] wide and 1 ft 6 in [0.46m] high. The molten iron rises to this height, right up to the tuyère opening. But the hearth is only this size if large guns are to be cast. If only utensils, small grates, pots and other items of that sort are to be cast, the hearth will be 4 ft [1.21m] long, 18 in [0.46m] wide and 10 or 12 in [0.25m-0.3m] high.

H is the front opening through which the iron is tapped. **I** is the tuyère opening, which lies nearer to the wall facing the tapping arch, but at a distance of only 8 in [0.2m] from the front wall. It is thus positioned so that the blast can reach the opposite wall when the hearth is full. It should be noted that the ore does not melt until it comes to the tuyère. **K** shows the bottom of the furnace. For the foregoing description we are indebted to the most illustrious Swedish Lord Commissioner Kahlmeter.[21]

Iron Blast Furnaces for casting guns in England

Most of the furnaces for casting guns for use in war are in the counties of Sussex and Kent. The counties are not far from the sea, and the ore found there is of a rich quality.

The furnaces are constructed as described above, but in some places two are joined together between the same walls. Nowadays blast furnaces for guns always have one chimney, one vault and one hearth, for one furnace performs the same function as a double one once did, provided that the hearth is made broader and the furnace capacity greater. Otherwise the ore is put in and tapped in the same way as in the ordinary furnace, as already described. Guns are cast in winter, but in summer raw iron. The furnaces in Sussex are somewhat larger than in Kent. Around *Tunbridge* [Tonbridge] it is reported that two guns can be cast in 16 hours, each weighing 1500 *Weight* [762kg]. Following the usual method the moulds are made out of clay, with hair and dung added, and they are set vertically beside one another in the ground.

Prince Robert carried out many experiments here in smelting iron with coal, especially with what is called *Pickkohl,* and the work is said to have lasted for several weeks, but the hearth had been filled with slag and obstructed with a viscous substance; besides which the iron became too sulphurous.[22]

The same Prince Robert, an expert in this field and in chemistry, is said to have undertaken other experiments concerning iron, whereby he mixed salts of different kinds, and other substances, with the molten iron to preserve the guns against rust, for the inside of the barrel and the vents are susceptible to corrosion by rust, and become uneven and scaly. I think that he succeeded to the extent that they were made rust-free for between 9 and 7 years. He also tried to cast lighter guns, which nevertheless performed as well as the heavier ones.

The ore which is obtained here [in Sussex and Kent] is softer than in the other parts of England. Therefore, it is mainly used for the casting of guns, for which a fairly fluid ore is needed, and one that does not contain much sulphur, which blisters the guns. Nevertheless the ore should not be completely lacking in sulphur, for otherwise the guns can easily split from frequent firing, which is avoided if the ore has a share of each quality.

Forges in England

The iron forges are either compound and double, or they are single. In the double forges there are three hearths and only one hammer. Two of the hearths are called *Fineries* and the third is a *Chaferie*. The finery hearths are of oblong shape, constructed of iron plates, which are about 2 ft 3 in [0.69m] high and 18 in [0.46m] wide. The bottom plate has a thickness of 2 in [0.05m], and lies freely on a base of charcoal dust. At the front of the hearth, where the smiths stand and carry on their work, lies a square mass of iron, as wide as the hearth, in the middle of which is an opening so that the slag can be let through it. So that the hearth may be contained and the walls are not displaced, it is supported with pieces of iron. They say that not all hearths are the same depth, but vary according to the nature of the ore. Near *Milliron* [Millom] a hearth is said to be constructed to a depth of 9 in [0.23m]. The sheets of iron which form the sides are fixed to the wall, and the rear wall is covered with a sort of plate, on which are placed the lumps of raw iron which are to be melted in the hearth. When the slag has been removed, and the iron is now dense and viscous, it is then taken out under the hammer. There it is stretched out to a considerable length, with cast iron left at one end, and called *Anconies* or *Blooms*. Later the iron is thinned down into bars.[23]

The chafery hearth is made like the first two, with this difference only, that it is made somewhat larger and deeper, with a length of 3 ft [0.91m], a breadth of 2 ft [0.61m] and a depth of 1 ft 4 in [0.41m]. The bellows of this hearth are longer, but the blast blows more slowly from them than in the finery hearths. The anvil and the hammer are made of cast iron. The weight of the hammer is usually 600 to 660 lbs. [272kg-299kg]. Out of 8000 lbs. [3,629kg] of raw iron, 6000 lbs. [2,722kg] can usually be obtained when refined and drawn out into rods.

The so called lumps or masses, which are called *Piggar*, are sent to the melting hearth or *Finery*, and from there the amount that can be melted in an hour is what is required for 1 *Weight*, which is called a *Loop*.[24] The glowing lump is struck by hand hammers in case, I suppose, it should be broken into pieces by the big hammer. It is then beaten under the big hammer into a piece in the shape of a cube, of which the side is ½ ell [0.26m]. Then this cube is carried to the same hearth, and for one hour it is held in a hot sweat, then it is drawn out under the hammer to a length of 3 ft [0.91m], starting at the middle, rough iron being left at each end, and then after being heated in the second [chafery] hearth is forged into a complete bar.

Three Loads of charcoal are consumed in the *Finery* hearth for 1 ton [1,016kg] of iron, and one Load in the *Chafery* hearth. In one finery hearth 2 tons [2,032kg] can be melted and purified in a week, but in a *Chafery* this increases to about 5 or 6 tons [5,080kg-6,097kg].

A new attempt in England to smelt iron in reverberatory furnaces using stone coal or mineral coal

It is said that in the year 1729 an attempt was made in England, three miles from Whithavers [Whitehaven], to smelt iron ore with burnt mineral coal;[25] the story circulating long after. It was said that ore for this experiment was brought from Cumberland and that it was crushed to small pieces under a hammer tipped with iron, and that the coal was pulverised by a millstone. 8 measures or 172 lbs. [78kg] of ground ore were first put into an air, or reverberatory, furnace, built and vaulted for the purpose, and in 8 or 10 minutes it was burnt and calcined. It was discovered that out of 8 measures, 6½ or 143 lbs. [64kg] remained behind. A half-measure of another ore was mixed with this residue, so that the total weight was 154 lbs. [70kg], each being ground to a thin dust under a millstone. To this mineral dust was added 5 measures or 35 lbs. [16kg] of coal, also one measure of potter's clay, and it was mixed together with two bucketfuls of water. Finally the mixture was placed in the furnace, and laid over the whole area of it, and when the air was introduced through the open vents it was left for about 1 hour and 40 minutes, with the throat of the furnace opened only once during the prescribed time. Meanwhile the ore, melted by this hidden fire, flowed into the shape of a lump or confused mass, and then when it was removed it was beaten and worked with wooden hammers to expel the slag and superfluous matter. When this was done it was put into the furnace for half an hour more so that, in exposing it several times to heat, the impurities were burned out more effectively, and then it was beaten by a 35 lb. [16kg] hammer and broken into pieces. It is said that the glowing iron appeared soft and was marked quite deeply by the blows of the hammer. Meanwhile 286 lbs. [130kg] or 6½ measures of coal had been consumed. So it can be seen that iron ore can be melted and reduced to a flux by the drier heat of a reverberatory furnace, but it cannot be purged of its impurities without a blast of hot air, nor are the impurities within burnt out, but rather burnt in. The sulphur in the coal remains in it and so spoils the iron, so that what was soft and ductile in it is made refractory and harsh, or that the better part of it, especially when it driven from the ore, is turned into slag, or it is burnt away as smoke (for the sulphurous vapour causes the iron to evaporate), or it enters the iron and corrupts its structure, so that it cracks whether hot or cold. For Mars is not mollified by this pyritic fire, but is rather made ill-tempered by it. The Cyclops, who make the sulphurous thunderbolts of Jupiter, make their iron not with wood, but with this coal.

The English method of burning coal, and of removing the sulphur through calcining

Since coal is full of sulphur, it is not suitable for smelting certain metals, especially iron, unless it is first deprived of sulphur; hence it is first converted into *Charcoales* by burning it. They construct a pyramid of pure coal, but around the bottom they put the largest pieces, in the middle they leave a cavity, which is almost the size of a hat. On top and around they pile coal, until the pyre is the required height. The cavity they fill with straw, twigs or other tinder, which easily catches fire and spreads it. Because it is lit from the top, the fire spreads little by little towards the lower and surrounding parts, from which it follows that the force of the fire first catches the inside and burns it, and then follows its path to the outside. If the fire is stronger than it should be in one place, to the extent that the coal seems to reduce to ash or cinders, the heap is immediately covered in that place with earth or other dusty matter, cutting the fire off, and preventing it from taking hold on the whole pile with complete force and freedom, and turning the whole pile into cinders and useless soil. At last when the flames have been extinguished and the fire quietened down, the coal appears equally burned, but to ensure that the fire is fully extinguished, dust is put on top and all openings closed. By this method, in England, coal is deprived of its sulphur and turned into a sort of ash but still a burnable material, which is called *Cendres,* and when the whole pile has obviously become cold, the dust is removed. The coal, which is now called *Charcoal*, deprived of the rest of its residual heavy sulphur, is said to be suitable for smelting the metals copper and iron, but as far as iron is concerned, it has been discovered that it is rendered useless by this process.

Notes and References

1. E. Straker, *Wealden Iron* (London 1931), 78; Straker erroneously states that *De Ferro* was published in 1724. E. Swedenborg, *Opera Philosophica et Mineralia*, vol. 2, *De Ferro* (F. Hekel, Dresden & Leipzig, 1734).
2. The family's name was changed from Swedberg to Swedenborg when it was ennobled in 1719.
3. H. Carlborg, 'Swedenborg's work on iron,' *The New Philosophy*, Journal of the Swedenborg Scientific Association (April 1926), 36-59;
4. M. Fritz at al, *Iron and Steel on the European market in the 17th century* (Stockholm 1982), 18-19.
5. Ibid., 11-12.
6. *Descriptions of the Arts and Trades, made or approved by the Gentlemen of the Royal Academy of Sciences; Paris 1761-82. Vol.3, The art of Iron Forges and Furnaces, by Monsieur the Marquis de Courtivron and by Monsieur Bouchu.*

Section 4. treatise on Iron, by Monsieur Swedenborg, translated from the Latin by Monsieur Bouchu. 1762. The translation is of the twelfth chapter of Section 4, corresponding with the twelfth 'paragraph' of the Latin original.

7. The editors are particularly grateful to Peter Dalton for his assistance with the translation of Bouchu's French, and to Tom King, formerly of Ardingly College, for translating Swedenborg's original Latin. Decisions on the final version have been the editors' own.
8. At this point Swedenborg inserted, 'and so they construct an entrance, the construction of which I have decided to discuss in dealing with common salt.'
9. The Latin text uses the word *ulna* for this unit; a footnote in the French text gives this as *dix pouces* ½, or 10½ inches; this version of the *ell* is therefore somewhat smaller than other national versions of the same unit, which ranged from the Swedish ell of 0.594m and the English ell of 1.143m. *Pin-mine* was a term used in South Wales for the sideritic concretionary ironstones of the Carboniferous coal measures. It was used particularly in the context of the name of particular nodular horizons, or nodule-bearing horizons, within the succession; T. Young, pers. comm.
10. Leighton Beck, Cunsey and Backbarrow, formerly in north Lancashire; P. Riden, *A Gazetteer of Charcoal-fired Blast Furnaces in Great Britain in use since 1660* (2nd edn 1993), 107-8, 109, 114.
11. The Swedish nautical pound, or *skeppund*, was the Swedish measure used for iron. The *skeppund* existed in four forms: *skeppund bergsvikt*, 'mountain (rock) weight', equivalent to 150kg, and used to weigh bar iron; *skeppund upplandsvikt,* 'inland weight', equivalent to 143kg; *skeppund stapelstadsvikt* or *stockholmsvikt*, 'staple town (export) weight', equivalent to 136kg. The differences between these three recognise the addition of a proportion of the transport costs between ironworks, inland market and export port. There also existed the *skeppund tackjarnsvikt*, 'pig iron weight', equivalent to 195kg. K-G. Hildebrand, *Swedish Iron in the Seventeenth and Eighteenth Centuries* (Stockholm 1992), 175; Fritz, 243-4.
12. *Terra pinguis*, literally fat, rich or fertile earth, ground or soil, was translated by Bouchu as *terre grasse* or ‹heavy clayey soil›; E. Roubaud (ed.), *A French and English Dictionary* (London 1881), 276. *Terre Grasse* is compact, very clayey and waterproof, also called green clay, which was used at a coking plant, in order to seal the furnace doors in early furnaces; J. Corbion, *Le Savoir ... Fer. Glossaire du Haut Fourneau*, 3rd. ed. 1989/1991. We are grateful to Cornel Doswald for this reference.
13. A Swedish foot was 297mm, compared to the English foot of 305mm, thus 26 Swedish feet were equivalent to 25 ft 3¾ in
14. Illustrations of 17th and 18th century Swedish furnaces make it unclear in what way the furnaces in the English Midlands differed from them in size.

However, the smooth profile of the internal stack section and circular plan hearths shown in Swedish furnaces of the period contrast with the more abrupt internal changes of shape of the boshes and square hearths of many English furnaces; Hildebrand, 48-9; D. W. Crossley, *Post-Medieval Archaeology in Britain* (Leicester 1990), 160-3.

15. A footnote in the French text gives this as 21 feet.
16. This charcoal was known as braize; H. R. Schubert, *History of the Britsh Iron and Steel Industry* (1957), 216, 284 n.2.
17. The Swedish *läst* was equivalent to 12 skeppund, which was the weight of a Swedish *tunna*, a capacity measure used for various substances including charcoal; so ½ läst appears to equate to 6 skeppund, thus giving an ore to charcoal ratio of 1:6 or 7; Fritz, 253. The comparison with 6 or 7 tons seems erroneous.
18. Presumably these are English tons; 15 or 16 tons a week equating to just over 2 tons, or 2,032kg, a day.
19. The word used for these containers in the Latin text is *vasculum*, a small dish. At Heathfield Furnace, containers called boshes were used to load ore into a furnace, the name perhaps being derived from the bosh or trough used in mining and metal-working as a water container.
20. Gloucester Furnace, Lamberhurst, which in 1734 was in Sussex.
21. Henrik Kahlmeter, or Kalmeter, toured Germany, Holland, France and Britain between 1718 and 1730, visiting southern England in 1720. He kept a journal of his travels as well as submitting a series of official reports to the Bergskollegium; M. W. Flinn, 'The Travel Diaries of Swedish Engineers of the Eighteenth Century as Sources of Technological History', *Transactions of the Newcomen Society,* **31** (1961), 99-100.
22. Prince Rupert (1619-82), nephew of Charles I, was granted a patent in 1671, which encompassed a number of ironworking processes; Schubert, 270, 325-6. It has been suggested that *pickkohl* is a corruption of pit-coal, a term sometimes used to distinguish mineral coal from charcoal.
23. Schubert, 279, n.6.
24. *Piggar* is probably a corruption of pig-iron.
25. This is presumably Little Clifton Furnace, which was built in 1723; Riden, 114-6.