HISTORICAL METALLURGY

ISSN 0142 3304

Journal of the Historical Metallurgy Society volume 15 number 2 1981

Journal of the Historical Metallurgy Society

JHMS 15/2 1981

Published by the **Historical Metallurgy Society Limited** and printed by the **Metals Society** to which the HMS is affiliated.

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The illustration on the Cover

From: Fleta Minor, or Laws of Art and Nature in Assaying, by Sir John Pettus, published in London, 1683

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Designed and produced by Roy Day FSIAD and IBM Composer set by Kathleen Taylor

Printed by the **Metals Society** at 1 Carlton House Terrace, London SW1Y 5DB

The production of wrought iron in Finery Hearths
Part 1: The Finery process and its development

Alex den Ouden

Introduction
When the bloomery was gradually superseded by the blast furnace, the iron produced could no longer be directly used in smithies. As this was at the time a very important application of iron, a solution had to be found.

The brittleness preventing the forging of blast furnace iron, called pig iron, is caused by its high carbon contents. This carbon has to be almost fully removed from pig iron to obtain wrought iron that is equivalent to the original bloomery iron. The process developed for this purpose, **fining**, was based on a mixture of a bloomery and the Catalan forge, already known at that time. In these iron ore was smelted to obtain a ball of almost pure iron, intermixed with slag. Charcoal here combined the roles of fuel – to obtain sufficient heat – and *reducing* agent – transforming the iron oxides of the ore to iron.

In the finery iron has to be stripped of surplus carbon, which is done by *oxidizing* the latter to carbon monoxide. Still, the same type of hearth could be used, by altering its mode of operation.

The fining process in a charcoal hearth[136]
The hearth proper of a charcoal fining hearth is formed by a well which is clad with cast iron plates. In and on top of the well a charcoal fire is built. At one side – in the Swedish Lancashire hearth at two sides – a tuyere, slightly down-tilted, is inserted directly above the iron side or tuyere plate.

Two zones can be distinguished in the hearth. Just in front of and above the tuyere lies the hottest zone; just below the tuyere a colder, oxidizing zone. Lower in the hearth the temperature decreases further.

At the beginning of the fining process pig iron is brought into the first, hottest, zone. It starts to melt, forming droplets of liquid pig iron. These fall through the charcoal and slag of the second, oxidizing zone. During this, the following processes take place:

- most of the Si present in the iron is oxidized into SiO_2;
- a part of Mn – if present – is oxidized into MnO;
- Fe is oxidized into FeO;
- a $FeO.MnO.SiO_2$ or $2FeO.SiO_2$ slag is formed;
- a small part of C is oxidized into CO;
- any graphitic C is transferred into combined C.

At the bottom of the hearth the iron droplets gather into lumps. These are semi-solid, since the temperature in that part of the hearth is lower and the melting point of the iron is increased by diminished C and Si. In the hearth the new-formed slag combines with slag intentionally left from previous fining. The described processes together form the so-called *Stage 1*, the refining or melting stage.

The finer now stirs and coalesces the lumps at the hearth bottom into a loup and lifts this in front of the tuyere. The combination of these two actions is called rabbling. In front of the tuyere the metal melts again and the droplets again fall through the slag in the oxidizing zone below the tuyere. Now the following processes take place:

$$C + MnO \longrightarrow CO\uparrow + Mn$$
$$C + FeO \longrightarrow CO\uparrow + Fe$$
$$Mn + O \longrightarrow MnO$$
$$Fe + O \longrightarrow FeO$$

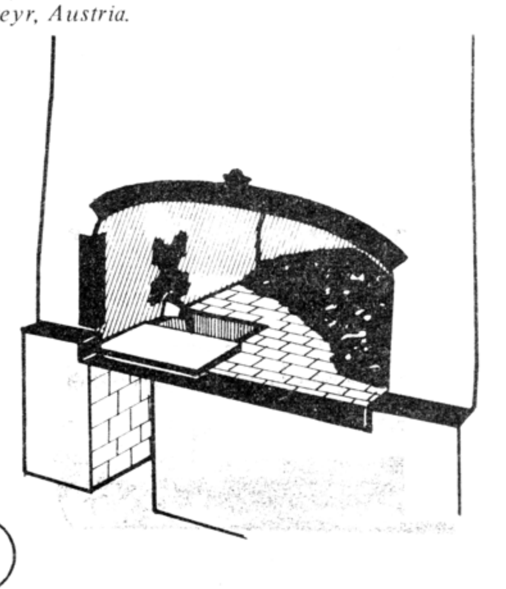
C is thus decreased with blast, via the slag. Rabbling is repeated a number of times. At each passage C is further decreased and the melting point accordingly rises. Finally the melting point becomes so high that melting down any part of the loup is no longer possible. Then blast is temporarily increased and a last melting and oxidation occurs. This, the repeated rabbling and melting, is the so-called *Stage 2*, the fining or rabbling stage.

Types of Finery Processes

The German forge

The construction of a German hearth resembles – in general terms – that of an ordinary blacksmith's hearth, see Figure 1. The sole is enclosed by three walls that carry the chimney. These parts are stone-or brick-built, usually with a cast iron lintel or with a brick vault. Thermal stresses are taken up by tie bars. The sole is covered in tiles. The hearth proper is let into the sole. It is a square well, covered on four sides and the bottom with cast iron plates. It lies adjacent to one of the side walls of the hearth. Through this wall, a tuyere is inserted. The fore (or front) plate of the hearth proper stands free from the sole. There are several holes in it[1], for slag tapping. On top of the front plate lies a work plate, also of cast iron.

German Hearth (Stuckofen-era) – General View, Steyr, Austria.



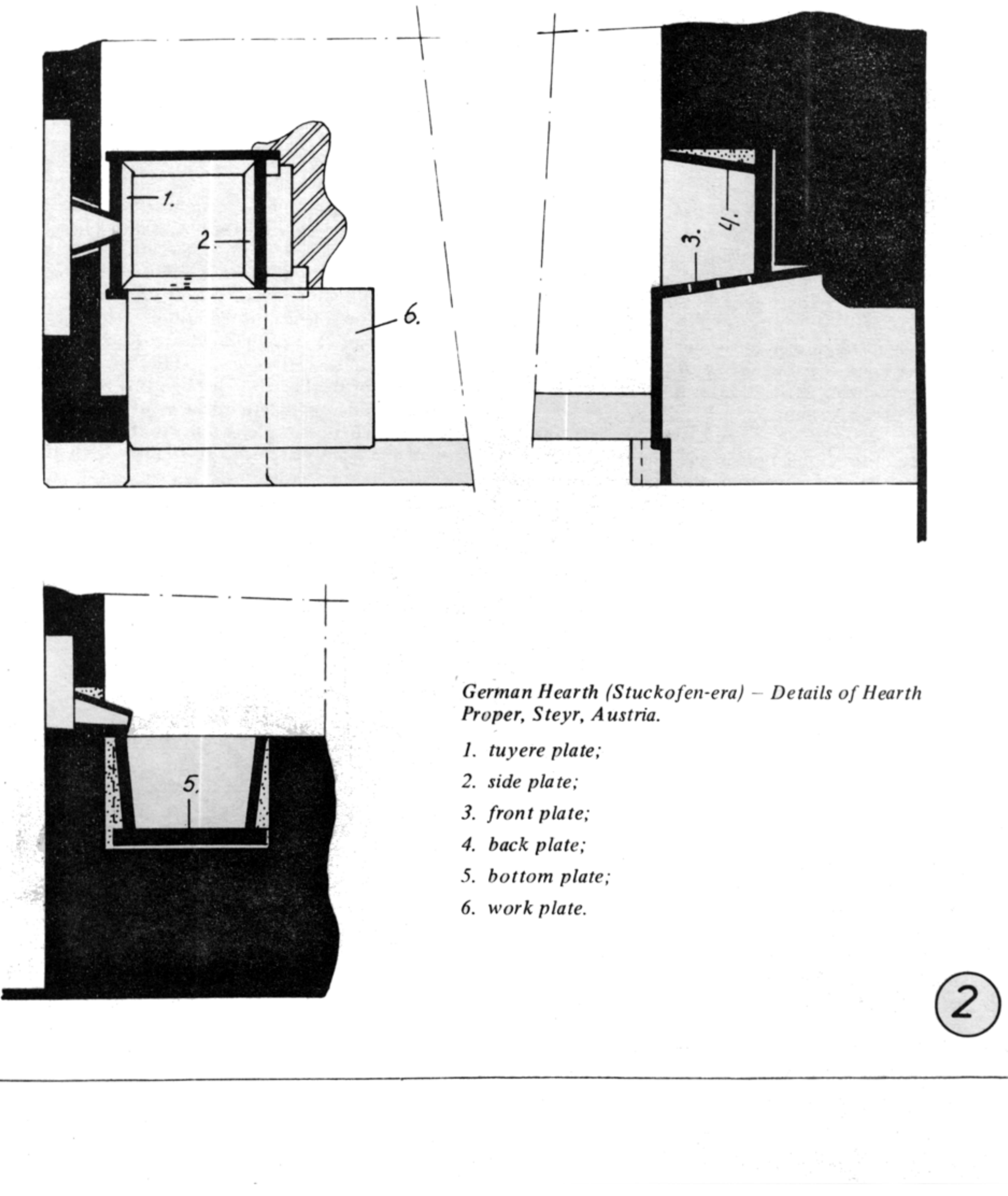
1

In the early German forges in Austria and Germany, 'Massl' and "Kraglach" from the "Stücköfen"[2] were used as raw material. The hearth proper used in fining and fagotting these, was quite deep, e.g. a depth of 0.3 m at a length and width of 0.4 m each, see Figure 2. The four side plates were set in loam, all tilted outwards. The bottom plate was not cooled. These early hearths were blown with two sets of single bellows. The mouth-pieces of these were inserted into a tuiron[3], set in loam. The fluctuations in air flow caused by the use of single bellows were considered to be advantageous to the iron quality[4]. The wall containing the tuiron was covered with – thinner – cast iron plates to protect the brick- or stone-work.

When the "Stücköfen" were replaced by blast furnaces around 1750, at first "Deutschhammer" were built[5]. These combined a blast furnace with two German hearths[6] side-to-side under one roof. From about 1775 however, blast furnaces and fineries generally were built as separate units, due to prevailing scarcity of charcoal.

The hearth of this independent finery – that was working pig iron exclusively – differs from the earlier German hearth in a number of ways, see Figure 3. The hearth sole is much lower, about 0.3m instead of 0.8m. The hearth has two walls, instead of three. The chimney is carried on two cast iron lintels resting at the open corner on a cast iron, brick or stone pillar. The hearth proper is larger with a length and a width of 0.5 m[7]. The work plate is much narrower, almost a sill.

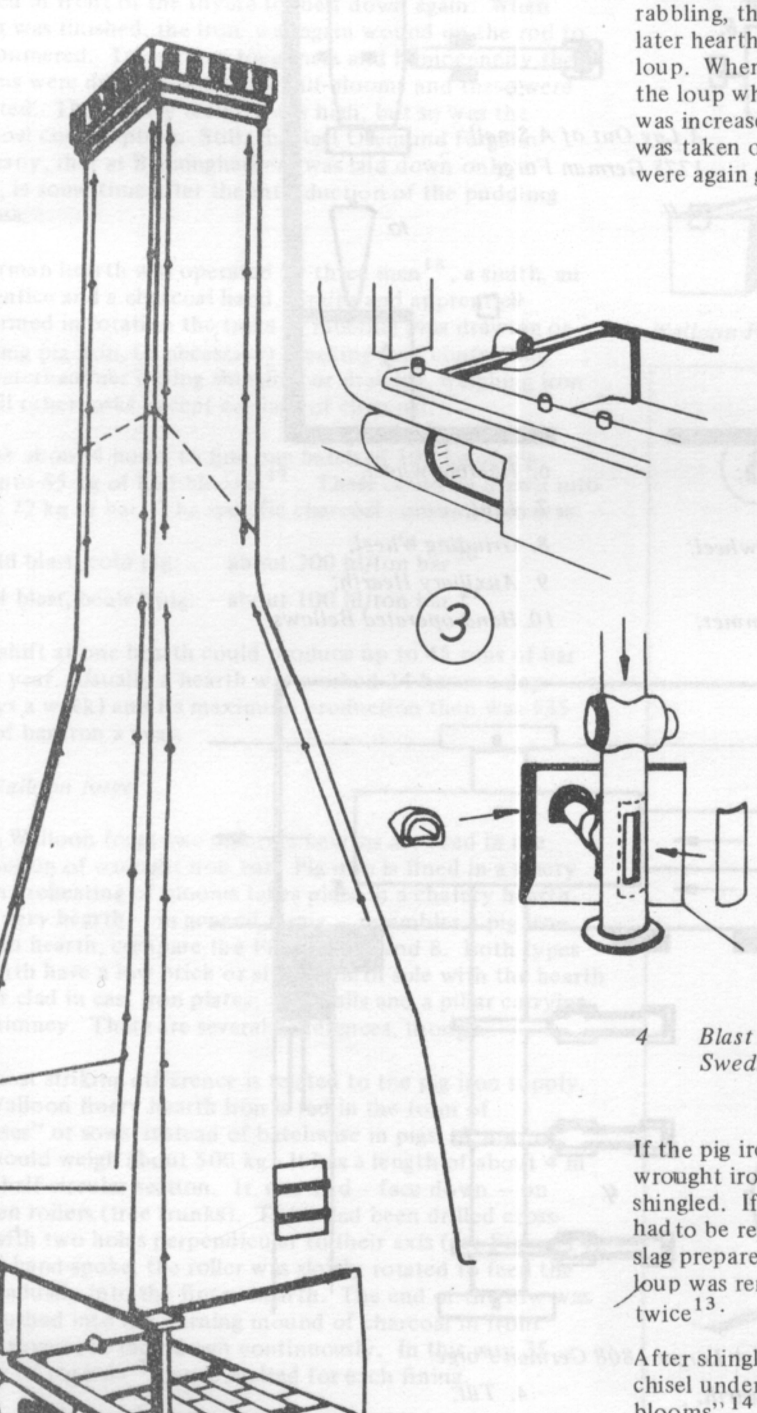
In Sweden, in the 1830s many improvements were made to the German hearth. In 1833 e.g., in Forsbacka, blast was heated in a separate wood fired stove[8]. Soon afterwards, waste gases from the German hearth itself were used for that purpose. A cast iron U-tube was laid across the chimney, see Figure 4[9]. Another improvement was to preheat pig iron before fining. In 1834, Morell used waste gases for this purpose, too[10]. The chimney was provided with a false bottom and a small door giving entrance to this (see Figure 4). Pigs of iron were piled on this bottom prior to fining.



German Hearth (Stuckofen-era) – Details of Hearth Proper, Steyr, Austria.

1. *tuyere plate;*
2. *side plate;*
3. *front plate;*
4. *back plate;*
5. *bottom plate;*
6. *work plate.*

Of course, the hearth is not the only object in a German forge. At least a hammer and a set of bellows or a blowing engine were needed . A very small scale German forge of 1775 is shown in Figure 5. It has one tail helve hammer and a grinding wheel, necessary for regular regrinding of the hammerhead. The German hearth is blown by bellows. A small hearth for general repair and forging work has hand operated bellows. The anvil in front of the German hearth was used to remove (with hand hammers) charcoal and slag from the finished loup prior to consolidating this under the waterhammer.

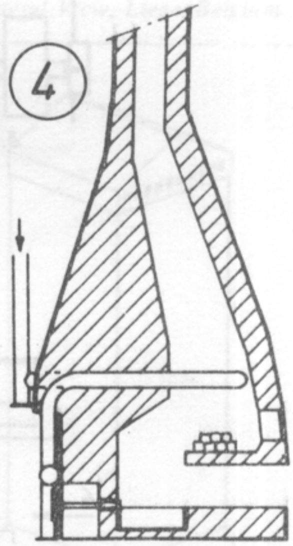


German Hearth (to fine pig iron) – General View, Hovla, Sweden.

A larger scale German forge of 1808 is shown in Figure 6. This has a tilt of three tail helves, a grinding wheel and a very peculiar semi-circular hearth with just one (back) wall containing the tuyere [11]. This hearth is blown with cold air by a Widholm blowing engine [12] with two bellows.

These two examples show tail helve hammers, but of course the more powerful, though less versatile, belly helve hammers were employed as well.

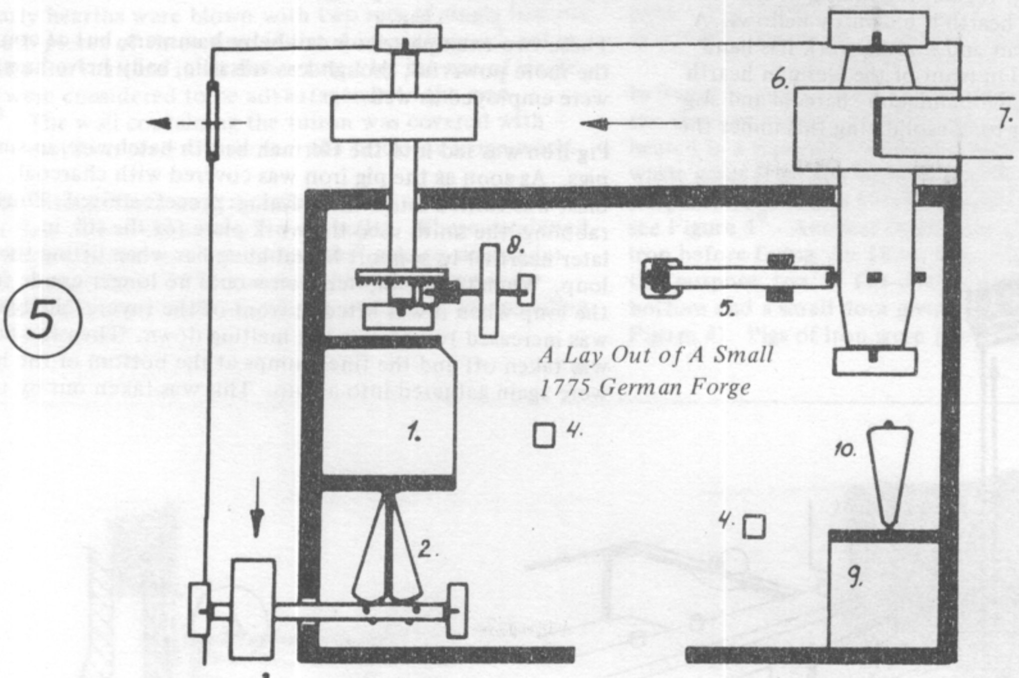
Pig iron was fed into the German hearth batchwise, in small pigs. As soon as the pig iron was covered with charcoal, blast was turned on, and the fining process started. During rabbling, the smith used the work plate (or the sill, in later hearths) to support his rabbling bar when lifting the loup. When finally molten iron would no longer exude from the loup when it was lifted in front of the tuyere, the blast was increased to obtain a last melting down. Then the blast was taken off and the fined lumps at the bottom of the hearth were again gathered into a loup. This was taken out by tongs.



4 *Blast Heating and Pig Preheating Arrangements in A Swedish German Hearth.*

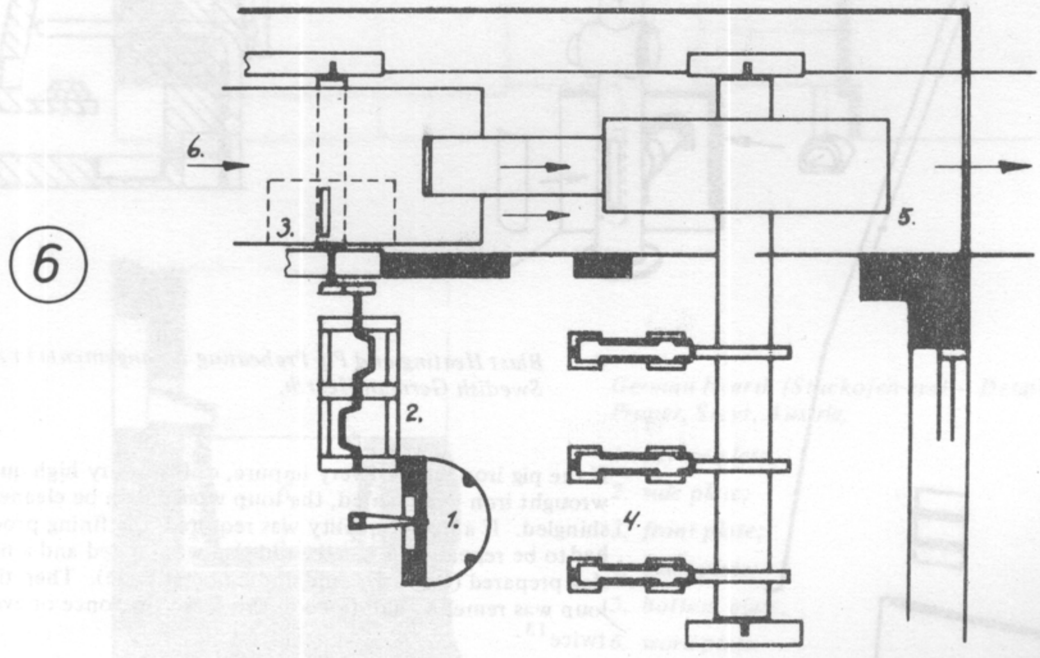
If the pig iron was not very impure, or if no very high quality wrought iron was wanted, the loup would then be cleaned and shingled. If a higher quality was required, the fining process had to be repeated. First the old slag was tapped and a new slag prepared (e.g. with sand and hammer scale). Then the loup was remelted and fined in this fresh fire, once or even twice [13].

After shingling the bloom was divided by means of a hand-held chisel under the shingling hammer, usually into 4 – 7 "half-blooms" [14]. These were reheated in the German hearth before being hammered out into bar. Since both fining, ie rabbling, and bar drawing were performed by the same smith(s), the division of the necessary tasks had to be strict. When a new batch of pig iron was melting down, no rabbling took place [15] and the smith could draw out half-blooms of



A Lay Out of A Small 1775 German Forge

1. *German Hearth;*
2. *Bellows;*
3. *Bellows Waterwheel;*
4. *Anvils;*
5. *Tail Helve Hammer;*
6. *Hammerwheel;*
7. *Leat;*
8. *Grinding Wheel;*
9. *Auxiliary Hearth;*
10. *Hand-operated Bellows.*



6 *A Lay Out of A Larger 1808 German Forge:*

1. *German Hearth;*
2. *Widholm Blowing Engine;*
3. *Blower Waterwheel;*
4. *Tilt;*
5. *Hammerwheel;*
6. *Leat.*

a previous batch. Drawing had to be in two passes. First a half bar with butt was made, and then, after a (second) reheating, now of the butt, the bar was finished [16]. During rabbling, no drawing could take place.

Many variations of this procedure were in existence. One was the "Osemund-Schmiede"[17]. In this forge very tough and homogeneous wrought iron was made, mainly for wire drawing. The hearth dimensions and the inclination of the tuyere slightly differed from those of an ordinary German hearth. The fined iron lumps were not gathered into a loup to be lifted in front of the tuyere, but wound on a rod and rotated in front of the tuyere to melt down again. When fining was finished, the iron was again wound on the rod to be hammered. To increase toughness and homogeneity the blooms were divided into small half-blooms and these were fagotted. The quality realised was high, but so was the charcoal consumption. Still, the last Osemund forge in Germany, that at Bruninghausen, was laid down only in 1858, ie some time after the introduction of the puddling process.

A German hearth was operated by three men[18], a smith, an apprentice and a charcoal hand. Smith and apprentice performed in rotation the tasks of rabbling plus drawing or fetching pig iron, (if necessary) breaking this, controlling the waterhammer during shingling or drawing, weighing iron and all other tasks except carriage of charcoal.

It took about 4 hours to fine one batch of 100 kg of pig iron into 85 kg of half-blooms [19]. These could be drawn into about 72 kg of bar. The specific charcoal consumption was:

cold blast, cold pig:	about 200 hl/ton bar [20]
hot blast, heated pig:	about 100 hl/ton bar [21]

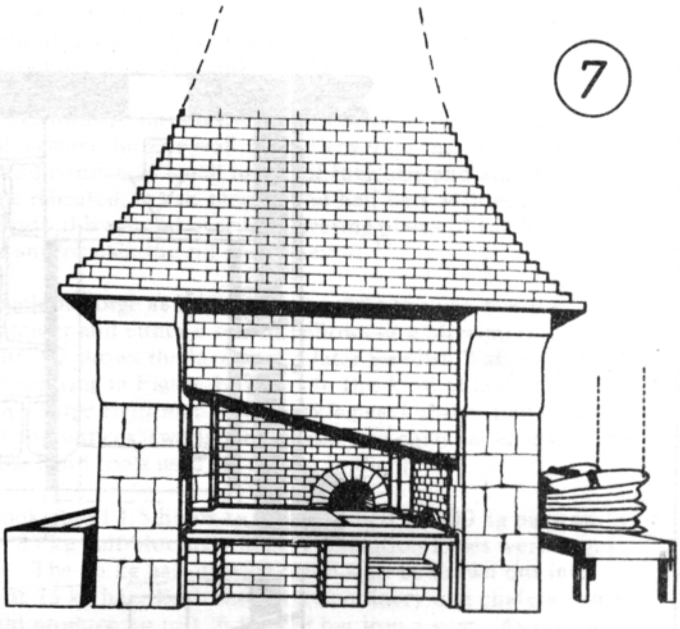
Each shift at one hearth could produce up to 45 tons of bar iron a year. Usually a hearth was worked 24 hours a day (6 days a week) and its maximum production then was 135 tons of bar iron a year.

The Walloon forge

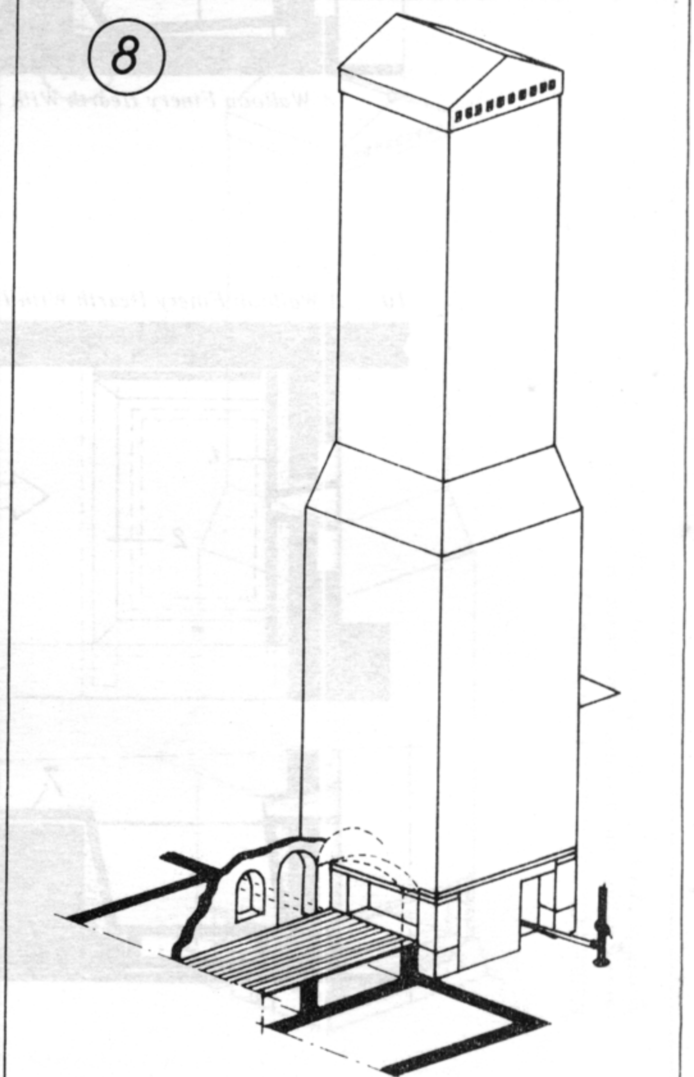
In the Walloon forge two separate hearths are used in the production of wrought iron bar. Pig iron is fined in a finery hearth; reheating of blooms takes place in a chafery hearth. The finery hearth – in general terms – resembles a pig iron German hearth, compare the Figures 3, 7 and 8. Both types of hearth have a low brick or stone hearth sole with the hearth proper clad in cast iron plates; two walls and a pillar carrying the chimney. There are several differences, though.

The most striking difference is related to the pig iron supply. In a Walloon finery hearth iron is fed in the form of "gueuses" or sows, instead of batchwise in pigs. A normal sow would weigh about 500 kg. It has a length of about 4 m and a half-circular section. It was laid – face down – on wooden rollers (tree trunks). These had been drilled cross-wise with two holes perpendicular to their axis (see Figure 14). With a hand-spoke, the roller was slowly rotated to feed the sow gradually into the finery hearth. The end of the sow was thus pushed into the burning mound of charcoal in front of the tuyere, to melt down continuously. In this way 35 – 100 kg of pig iron [22] were melted for each fining.

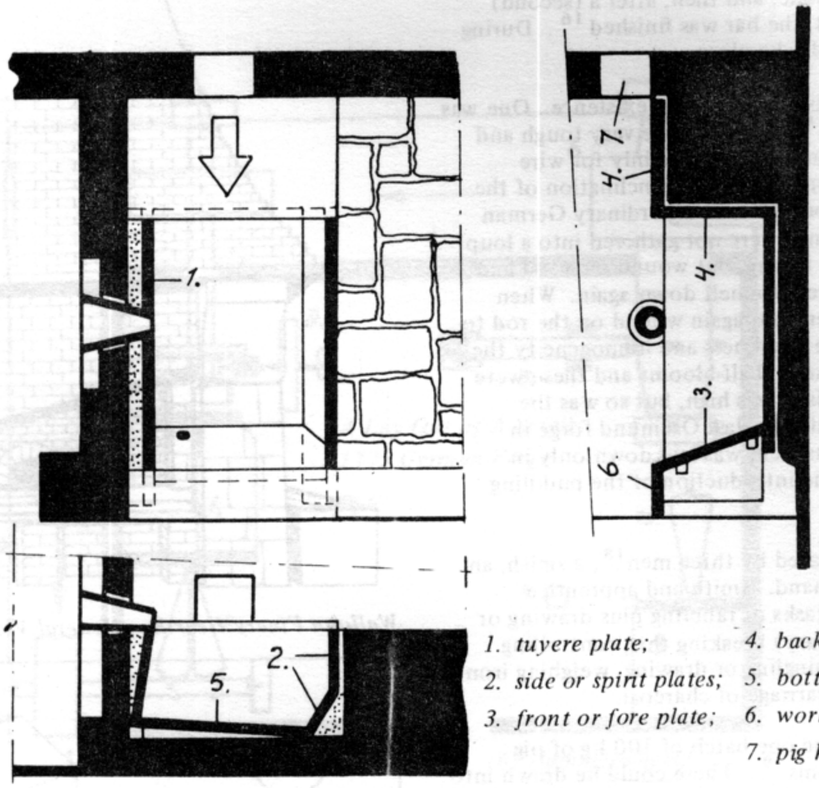
In most countries using the Walloon forge [23], the sow was fed from the rear of the finery hearth, necessitating a "pig hole" in the back wall, see the Figures 7-9. The hearth sole in front of the pig hole was covered with a cast iron hare or back plate. In some localities however the sow was fed –– on rollers – from the open side of the finery hearth [24] (see Figure 10).



Walloon Finery Hearth – General View, Liege, Belgium.



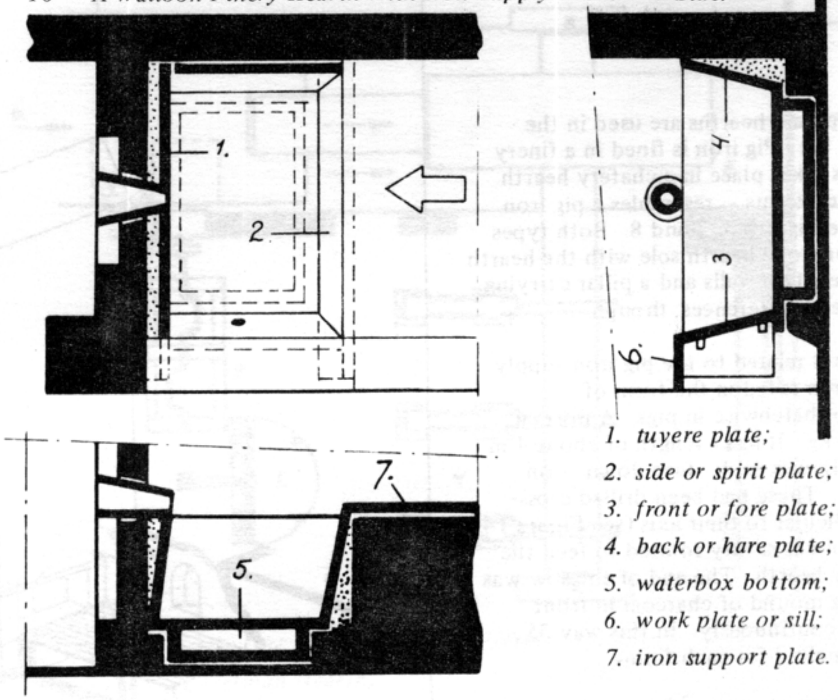
Walloon Finery Hearth and Iron Supply, Osterby, Sweden.



1. tuyere plate;
2. side or spirit plates;
3. front or fore plate;
4. back or hare plates;
5. bottom plate;
6. work plate or sill;
7. pig hole.

9 A Walloon Finery Hearth With Iron Supply From The Rear.

10 A Walloon Finery Hearth With Iron Supply From The Side.



1. tuyere plate;
2. side or spirit plate;
3. front or fore plate;
4. back or hare plate;
5. waterbox bottom;
6. work plate or sill;
7. iron support plate.

A second difference between a Walloon finery hearth and a German hearth is in the hearth proper. In a Walloon finery this is rectangular with a length of 0.65 m and a width of 0.45 m[7]. The hearth sole is also a bit higher than that of a German hearth, at 0.4-0.5 m. The cast iron plates covering the walls of the hearth proper were generally tilted slightly. In the German hearth all four plates leaned outwards. In a Swedish Walloon finery hearth this was also the case[25]. In other countries the Walloon tuyere plate, ie the plate standing just below the mouth of the tuyere, leaned inwards[26]. Comparison of the Figures 9 and 10 shows that further variations did occur in other side plates. These differences were related to the degree of impurity of pig iron, and they had a significant effect on the quality and quantity of fined iron. The correct setting of the hearth plates thus was an important task of the finer.

A third difference between a Walloon finery hearth and a German hearth is in the cooling of the bottom plate. In a Walloon finery hearth this is inclined slightly by inserting small pieces of iron under its corners. In the resulting interstice water was poured, to cool the bottom plate[25,27]. From some date in the 18th century, water-box bottoms were used[28] (see Figure 10).

At the start of a new fining the sow was pushed into the burning charcoal mound in the finery hearth and the blast was turned on. As soon as pig iron began to melt, the finer started rabbling[29] with a rabbling bar[30]. Thus, as opposed to German forge practice, the iron was worked not only during *Stage 2* of the fining process, but also during *Stage 1*[31]. To lift the loup in front of the tuyere, the finer used a second, lighter bar[32]. The hearth has a sill or workplate to lever this bar on. When sufficient iron was melted, the sow was pulled back but the finer proceeded with rabbling until his iron "had come to nature", ie was fully fined. As in German hearth practice, a final melting down of the loup with increased blast concluded the fining. One fining sufficed.

The loup was taken out with tongs. Adhering slag and charcoal were cleaned away with a hand hammer on an anvil or cast iron plate in front of the finery hearth. Then the loup was dragged with tongs towards the waterhammer. To this purpose the floor was covered with iron plates. A loup was first hammered into a bloom, this was divided with a chisel under the waterhammer and the parts were hammered into half-blooms, all without reheating. These half-blooms were about 0.4-0.6 m long and about 0.1 m square.

The further working of the half-blooms in Sweden was confined to the chafery. The half-blooms were reheated in this hearth, drawn out into a half bar with a butt, reheated again in the chafery hearth and finally drawn out into "råskenor", rough bars, eg of 70 mm width, 20 mm thickness and 3.6 m length.

In England a somewhat more complex process was used. The half-blooms were reheated in the *finery* hearth during the next fining. When the loup of this fining had been shingled and hammered into half-blooms the – now reheated – half-blooms of the prior fining were hammered into "anconies" ie their middle parts were drawn out to the dimensions of the bar to be produced. The length of an ancony would be about 0.9 m and the two knobs left at the ends had different dimensions. The small one was called "ancony end" and the large one "mocket head". These anconies were reheated in a chafery hearth, first the ancony end, which could be drawn out in one heat, and then the mocket head which needed an intermediate reheating.

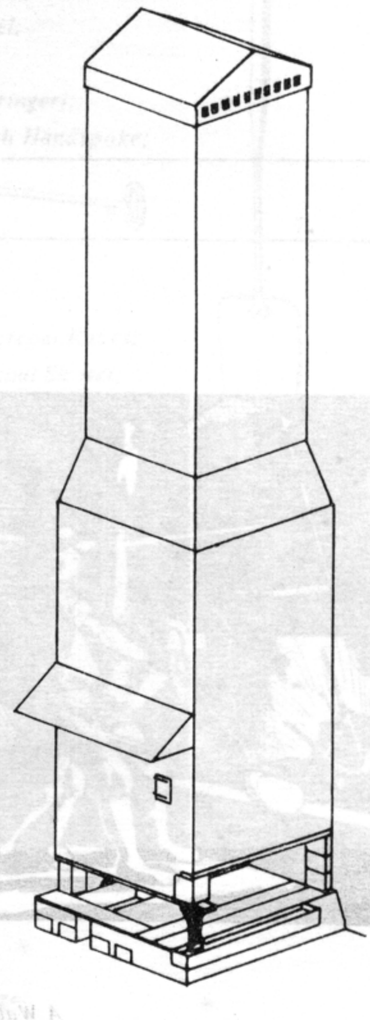
The chafery hearth, see Figure 11, in general construction resembled the finery hearth. The hearth proper is larger than that of a finery hearth, with a length of 0.9 m and a width of 0.6 m[7]. Also, the hearth sole of a chafery is fully covered in cast iron plates.

A large beehive shaped fire is built in and over the hearth well, against the side wall, amply covering the tuyere. The mound consists of small lumps of fuel, slag and ash. Pieces to be reheated, ie half-blooms and half bars with butts, are slid into this mound over the covering plates of the hearth sole and/or over the sill of the hearth[33].

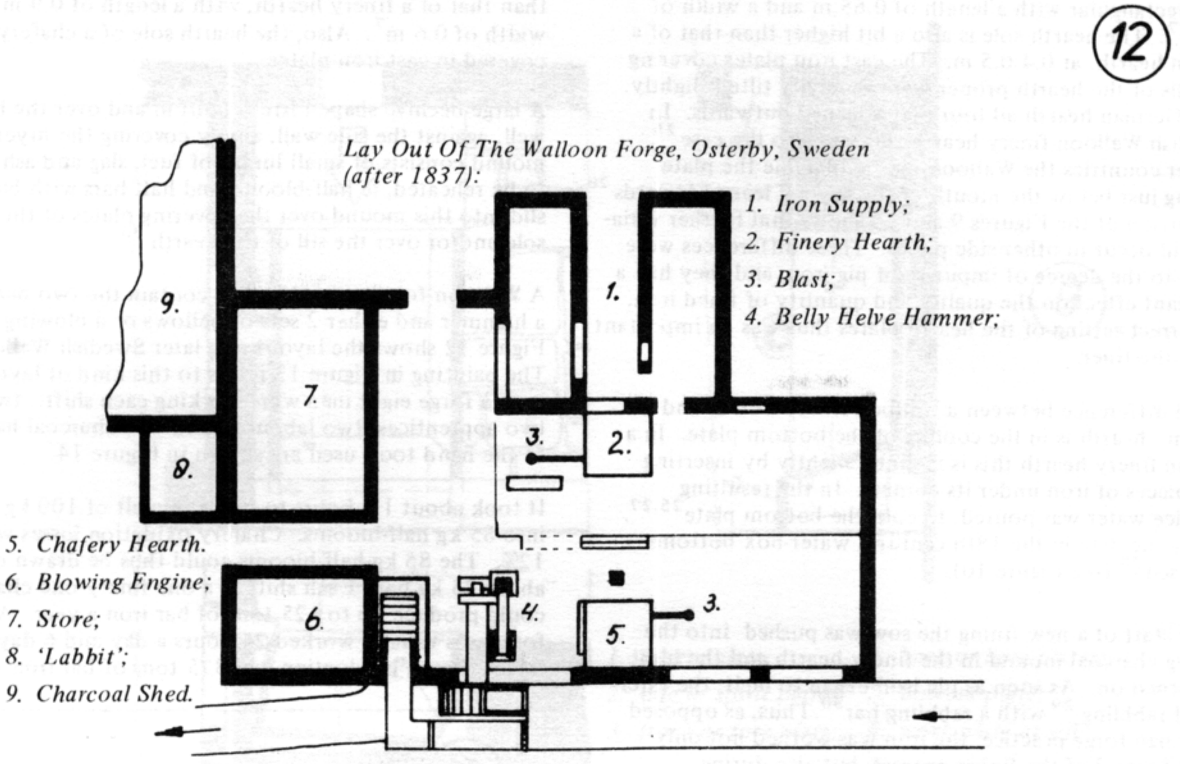
A Walloon forge at least had to contain the two hearths, a hammer and either 2 sets of bellows or a blowing engine. Figure 12 shows the layout of a later Swedish Walloon forge. The painting in Figure 13 refers to this kind of layout[34]. In such a forge eight men were working each shift: two smiths, two apprentices, two labourers and two charcoal hands. Some of the hand tools used are shown in Figure 14.

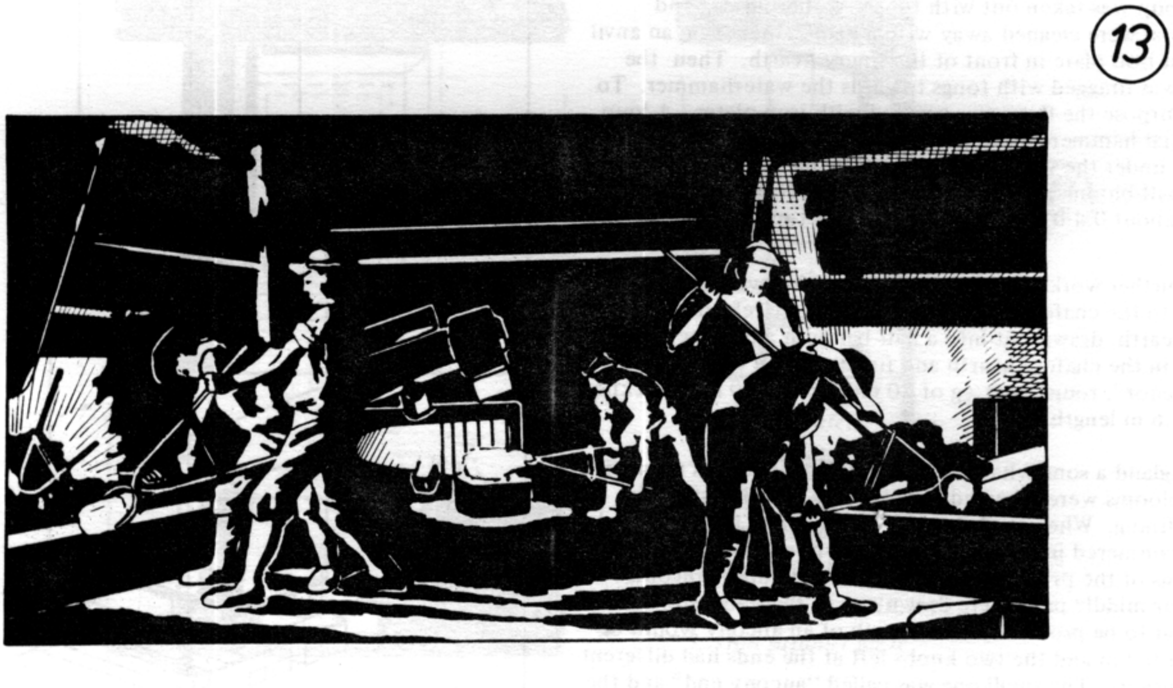
It took about 1.5 hours to fine one melt of 100 kg pig iron into 85 kg half-blooms. Chafery oxidation losses were about 12%. The 85 kg half-blooms could thus be drawn out into about 75 kg bar. Each shift at a one finery-one chafery forge could produce up to 125 tons of bar iron a year. As such a forge was usually worked 24 hours a day and 6 days a week, its maximum production was 375 tons of bar iron a year.

11

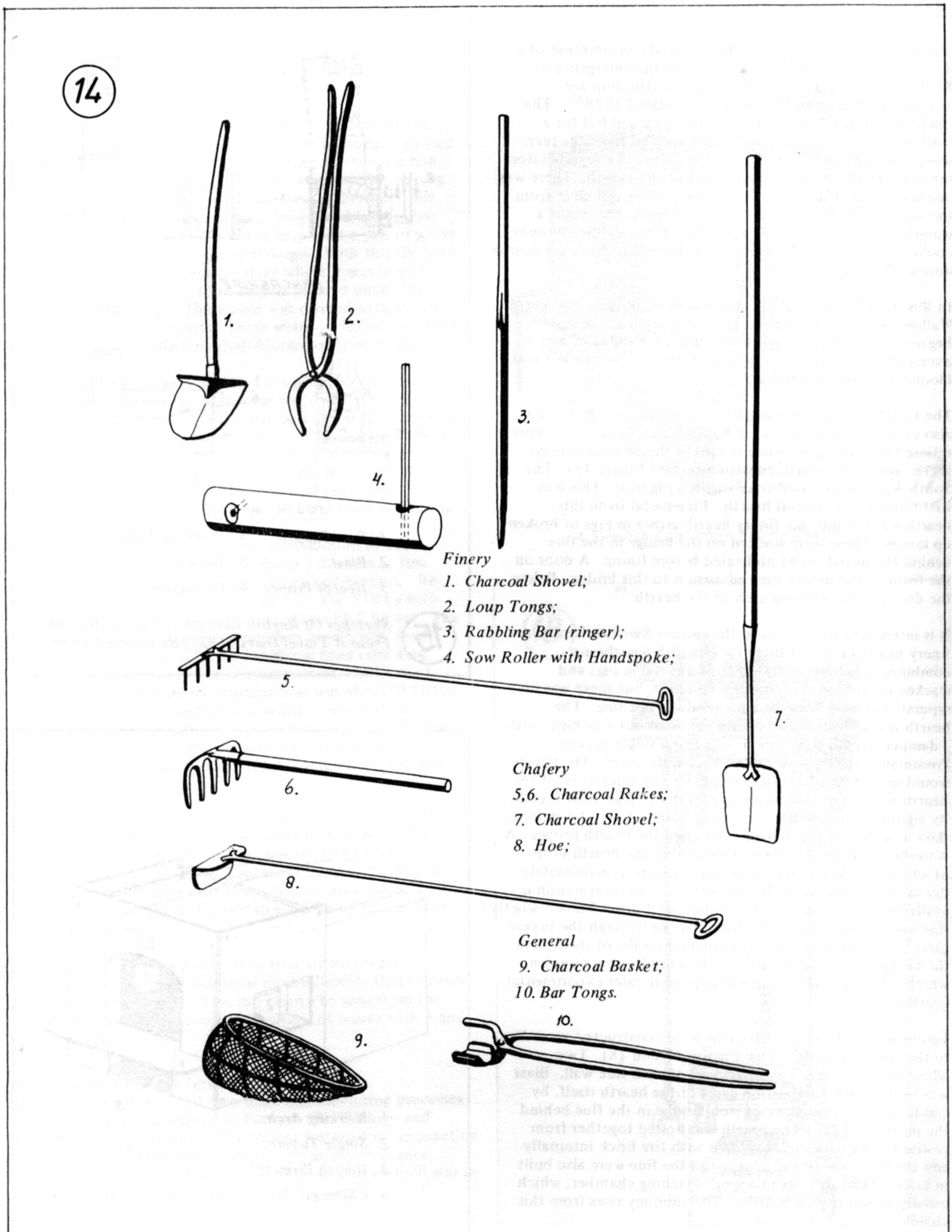


Walloon Chafery Hearth, Osterby, Sweden (drawn in the right position with regard to the finery hearth in figure 8, see also the lay out of figure 12).





A Walloon Forge (painting ca. 1800).



Tools, Used in A Walloon Forge:

The Lancashire forges

The general need to decrease the charcoal consumption of a Walloon finery hearth led in England to the emergence of the Lancashire hearth. Details of its construction are available from a Swedish travel report, dated 1828[35]. The finery hearth, see Figure 15, was fully enclosed but for a working arch. A sow of iron, which was fed from the rear, was pushed through a brick chamber acting as a reverberatory furnace heated by the exhaust gases of the hearth. There was one watercooled tuyere[36]. Although this is not clear from the sketches, the text of the report mentions the use of a waterbox bottom[37]. A damper flap on top of the chimney could reduce natural draught – and thus charcoal consumption during shingling, etc.

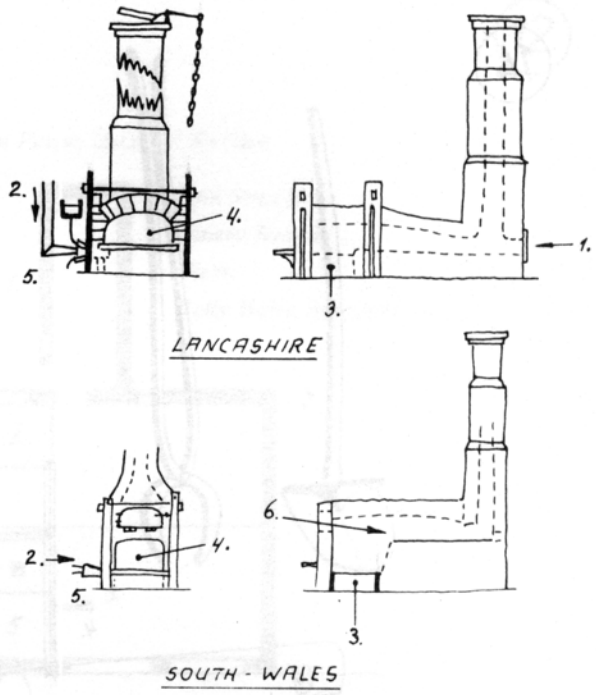
In this hearth, charcoal pig iron was fined in the customary Walloon way, ie rabbling was started as soon as the sow began to melt. Reheating of half-blooms was performed in a separate – coal-fired – reheating furnace[38]. The hot half-blooms were rolled into bars.

The Lancashire hearth was quite successful. In 1828 it was also used in tin-plate works in South Wales. The travel report referred to above gives some details of the process applied there, and of the hearth construction (see Figure 15). The South Wales works used coke-smelted pig iron. This was first refined in a run-out hearth. Fine-metal from this hearth was fed into the finery hearth either in pigs or broken-up lumps. These were stacked on the bridge in the flue behind the hearth to be preheated before fining. A door on the front of the hearth gave admission to this bridge. Below the door lay the working arch of the hearth[39].

It is interesting to see how in the earliest Swedish Lancashire finery hearths parts of these two English hearths are combined (see Figure 16)[40]. Iron was fed in pigs and stacked on an iron-clad bridge to preheat, but there was no separate charging door, just the working opening. The hearth was provided with a chimney of about 8 m high, with a damper flap on top. The hearth had a single tuyere. Presumably blast was heated in a separate stove. The tuyere would in that case be watercooled[41]. The brickwork of the hearth was enclosed in three large iron castings, held together by eight tie bars. In the brickwork a well of about 1 m long, 0.65 m wide and 0.4 m deep contained the hearth proper. A waterbox bottom was used. Presumably the hearth proper, of which details are lacking, would measure approximately 0.9 m by 0.55 m and be 0.3 m deep[41]. No information is available on the hearth plates, either, so it is not known whether slag was tapped through the fore plate or through the tuyere plate[42]. In the very first experimental model of the hearth the backplate leaned inwards[43]. It is not however known whether this special setting was applied in later experimental hearths.

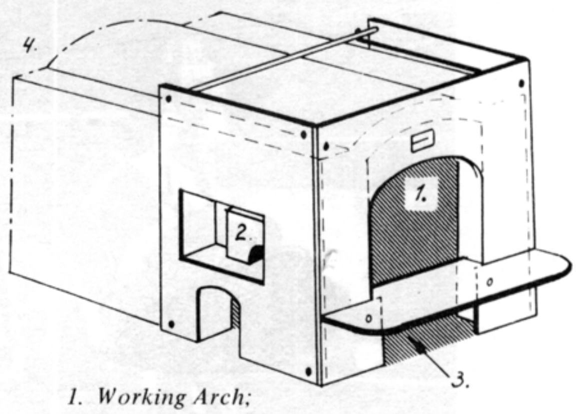
Later Swedish Lancashire hearths were constructed according to the same principle[44] (see Figures 17 and 18). Two – adjustable – tuyeres were used, one at each side wall. Blast was heated with combustion gases of the hearth itself, by conducting it through a cast iron U-tube in the flue behind the pig iron bridge. The hearth was bolted together from castings. The structure was lined with fire brick internally and the back side of the hearth and the flue were also built in brick. The flue ends in a spark-catching chamber, which usually served several hearths. The chimney rises from this chamber.

The hearth proper has four side plates and a watercooled bottom box. There is no slaghole. Part of the slag from fining was removed with a shovel after each fining. The



1. Sow Supply; 4. Working Arch;
2. Blast; 5. Tuyere;
3. Hearth Proper; 6. Pig Supply.

15 *Sketches Of English Lancashire Finery Hearths From A Travel Diary (1828) By Gustaf Ekman.*



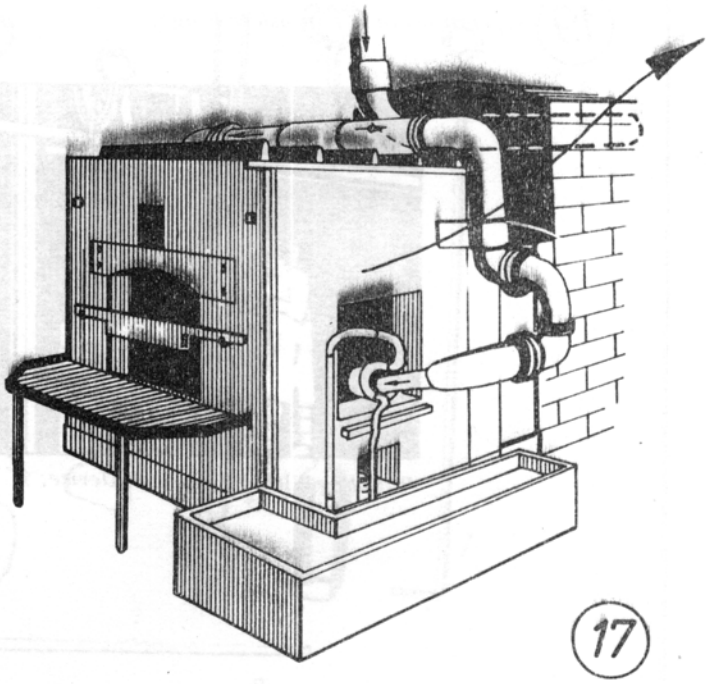
1. Working Arch;
2. Single Tuyere;
3. Hearth Proper;
4. Chimney.

16 *One Of The Earliest Swedish Lancashire Hearths (Furudal, 1831):*

remaining slag was used as a basis for the next fining. When a hearth had so been prepared, the pig iron stacked on the bridge was pulled into the hearth with a hook and buried in the charcoal. New charcoal was added with a shovel. Then the blast was turned on and fining began (see Figure 19).

Rabbling started – as in Walloon practice – as soon as the pigs began to melt. Two bars were used in rabbling, a stirring bar and a lifting bar[45]. From time to time the tuyeres had to be cleaned of adhering matter. This was done by tapping them with a third, lighter bar. In the final gathering of the loup prior to taking it out, a fourth, longer and heavier bar was used[46]. Two men took out the loup with a pair of tongs and a lifting bar and put it on a ball-bogie. With this the loup was brought to the shingling hammer where it was tipped off the bogie on to the anvil to be manoeuvred under the hammerhead by tongs. The bloom was divided with a very large chisel into 5 to 7 parts. These were – without reheating – hammered and/or rolled into half-blooms or even rough bar.

The number of men working in a Lancashire forge depended on the scale of operation. In a forge with 5 hearths and 2 reheating furnaces, a shift of 34 men was necessary, including the manager and two foremen. This shift further comprised five smiths, ten apprentices, four reheating furnace stokers and four bar drawers. The remaining eight men took care of the transport of pig iron, half-blooms, half bars, bars, charcoal etc. In Figure 20 some of the hand tools are shown.

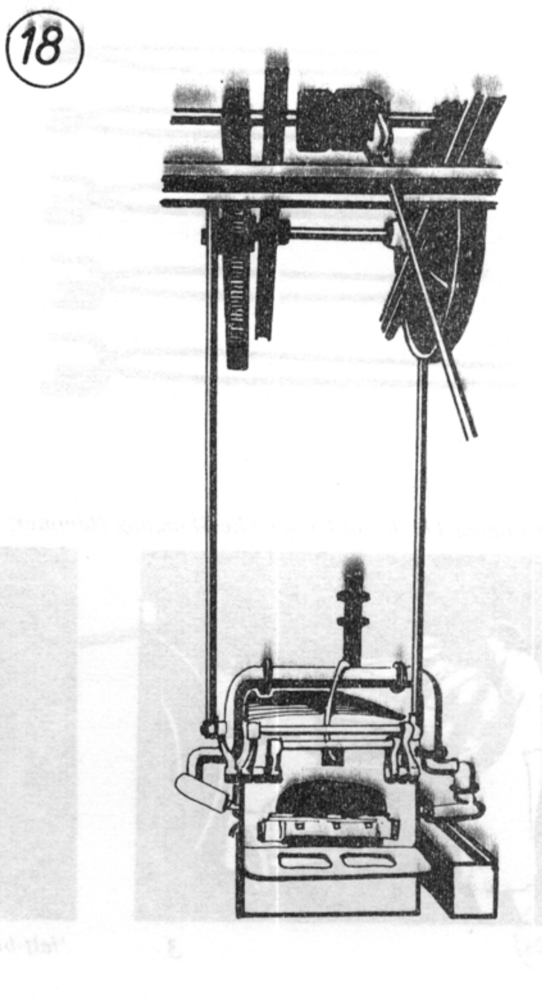


A Swedish Lancashire Finery Hearth.

In the early 1890s just prior to the introduction of the Lagerwall rabbling device, it took about 1.1 hours to fine one batch of 125 kg pig iron into 110 kg half-blooms. Reheating furnace losses were about 10.5%. The 110 kg half-blooms could thus be drawn out into about 98.5 kg bar. The charcoal consumption of the Lancashire hearth was about 38 hl/ton of half-blooms[47]. If a charcoal fired reheating furnace was used, this would consume about 40 hl/ton of bar iron[48]. Total charcoal consumption was about 83 hl/ton of bar iron[49]. Each shift at one hearth could make a sufficient number of half-blooms to produce up to 225 tons of bar iron a year. Usually a hearth was worked 24 hours a day (6 days a week) and its maximum production then was 675 tons of bar iron a year.

After the introduction of the Lagerwall rabbling device, in the late 1890s, these data were as follows: 1.08 hours for a batch of 135 kg pig iron, drawn out into 108 kg bar. Charcoal consumption of the Lancashire hearth: 35 hl/ton of half- blooms[47]. One shift at one hearth could make a sufficient number of half-blooms to produce up to 250 tons of bar iron a year.

Forges producing these amounts of iron are no longer comparable to the small industrial establishments that German and Walloon forges were. This can clearly be seen from the Figures 21 and 22, that show the lay-outs of works with 5 and 6 hearths, respectively.



A Swedish Lancashire Finery Hearth With Lagerwall Rabbling Device.

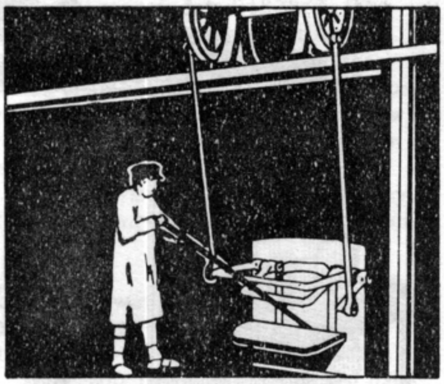
Development of hearth fining of wrought iron

In the period before 1750, two main manufacturing processes for wrought iron bar existed in Europe: the Walloon and the German forge method. The former was used in conjunction with charcoal[50] blast furnaces only; primarily in France, the Low Countries and England[51]. The second method was in use in Germany, Austria, Italy[52] and Sweden[51].

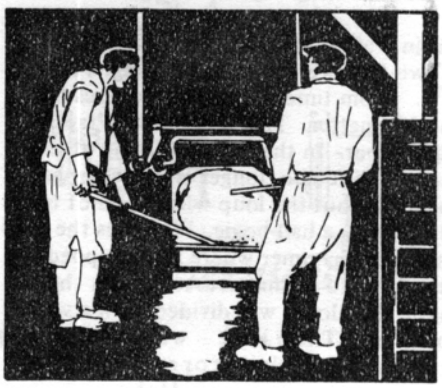
The German forge

It is important to realise that the German forge produced not only wrought iron but also steel – from several kinds of raw material.

(19) Operations In A Lancashire Forge;



Rabbling With A Lagerwall Device; 1.



Taking Out A Loup; 2.

20 *Tools, Used In A Lancashire Forge:*

Hearth Preparation

1. *Charcoal Shovel;*
2. *Charcoal Rake;*

3,4. *Slag Shovels;*

5. *Pig Tongs;*
6. *Pig Loading Shovel;*
7. *Pig Hook;*

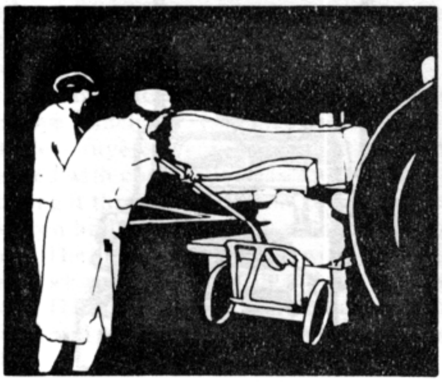
Fining

8. *Stirring Bar;*
9. *Lifting Bar;*
10. *Compacting Bar;*

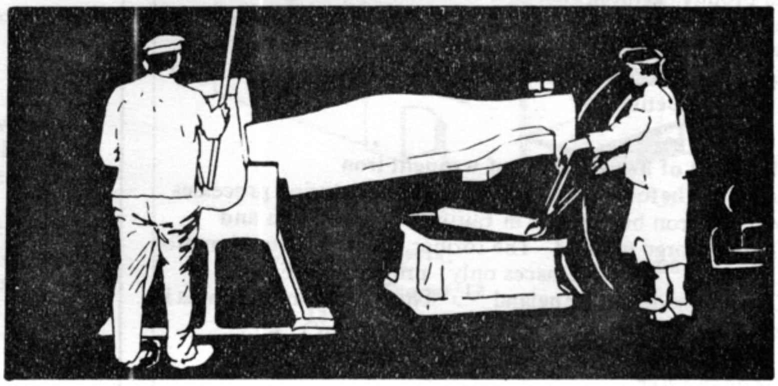
Shingling

11. *Ball Barrow;*
12. *Loup Tongs;*
13. *Bloom Tongs;*
14. *Half-bloom Tongs;*
15. *Half-bloom Lifting Tongs;*
16. *Half-bloom Barrow;*

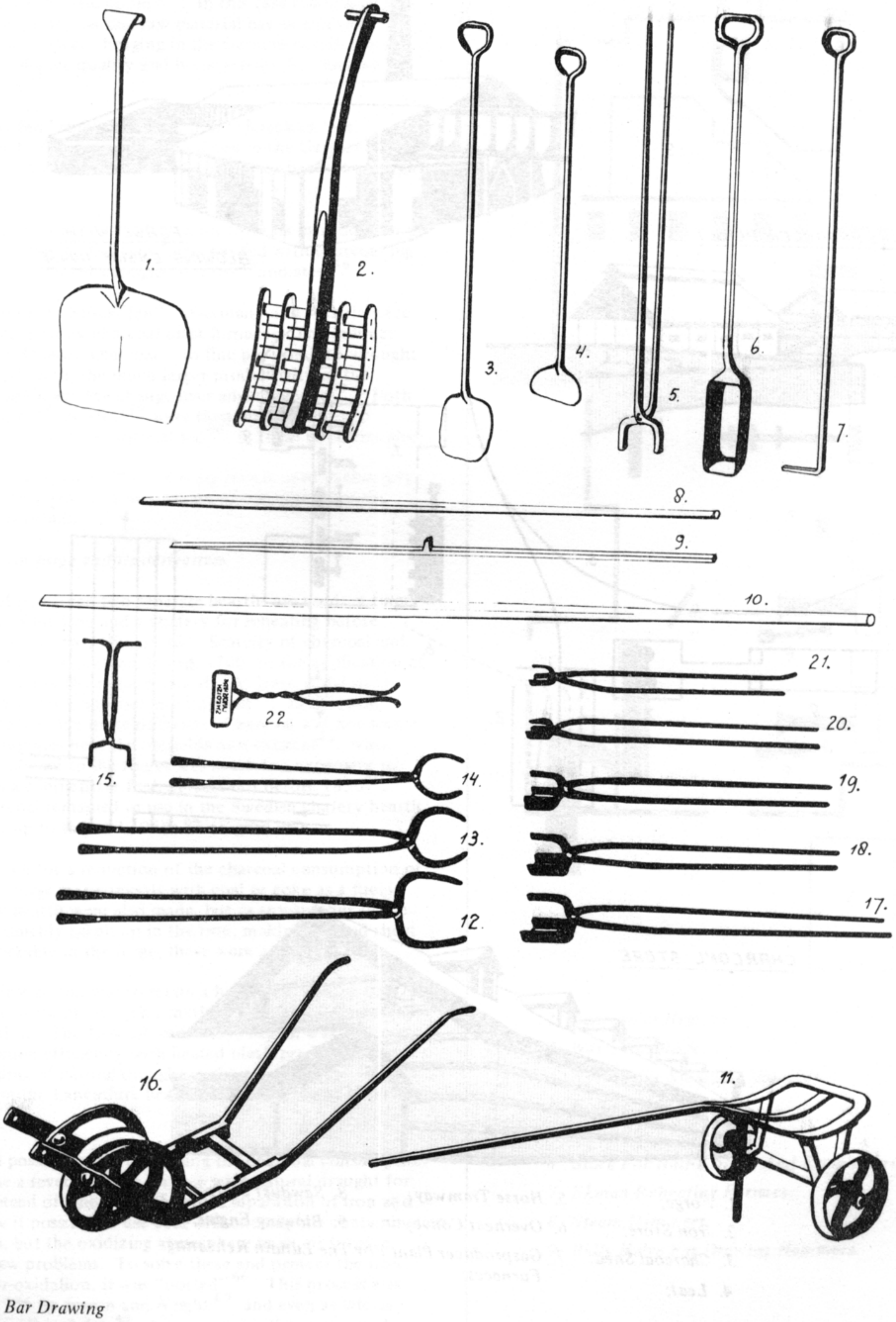
3. Bringing The Loup Under The Shingling Hammer;



3.

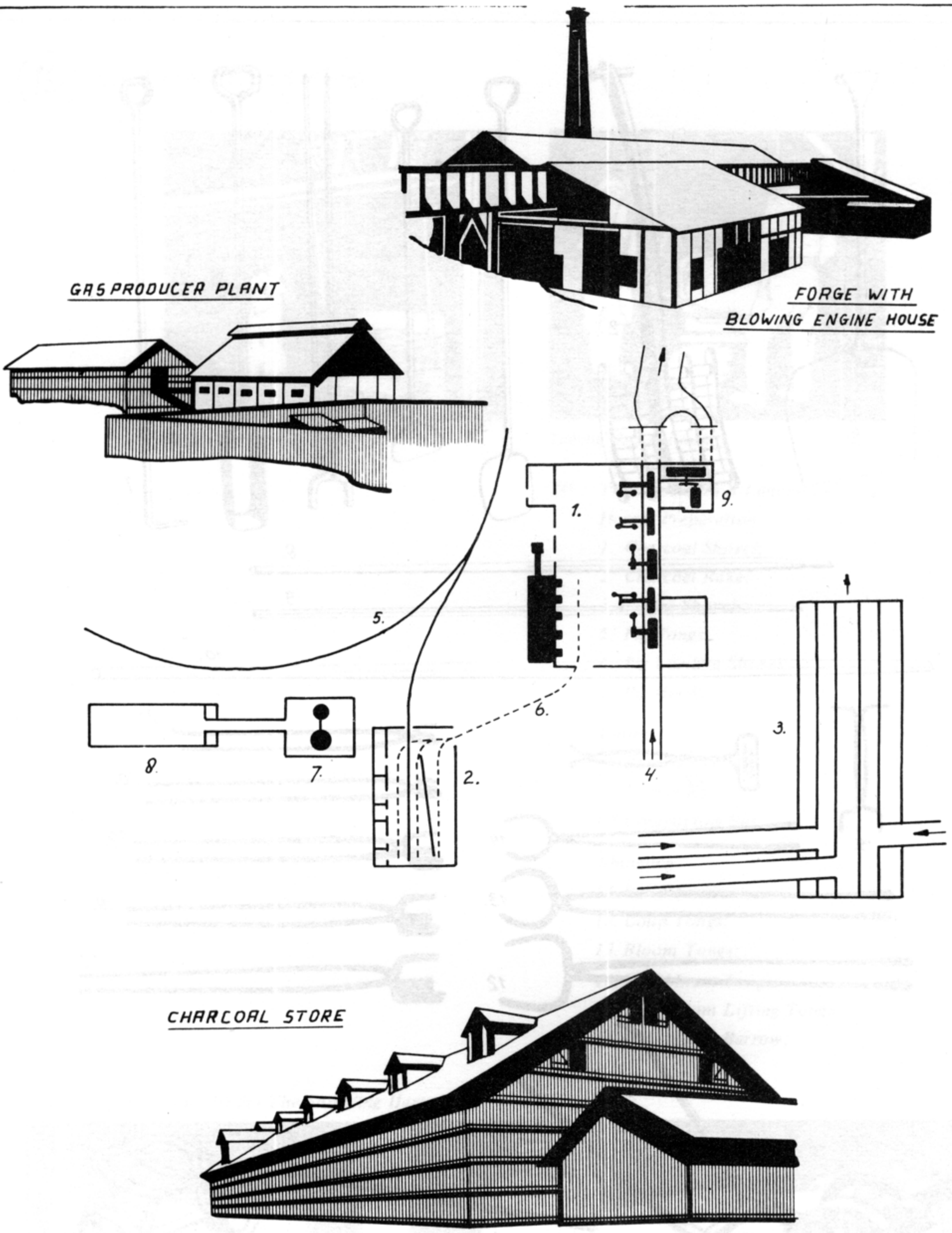


Half-bloom Hammering. 4.



Bar Drawing
17-21. Bar Tongs;
22. 'Stampel'.

20



1. Forge;
2. Iron Store;
3. Charcoal Shed;
4. Leat;
5. Horse Tramway;
6. Overheat Conveyor;
7. Gasproducer Plant For The Lundin Reheating Furnaces;
8. Sawdust Store;
9. Blowing Engine House.

21 Lay Out Of The Lancashire Forge (type 4), Korsa, Sweden:

Before 1750 in Austria and to some extent also in Germany, the raw material mainly consisted of parts of "Massl' or 'Stucke'[2] from 'Stuckofen'[2]. In this case relatively little fining is necessary, as this raw material has an analysis comparable to steel. Forging in the German hearth mainly served to enhance quality and homogeneity by "Garben" or fagotting[53].

In "Stücköfen" some liquid pig iron ("Kraglach") is also formed. This must truly be fined in the German hearth. "Kraglach" was usually fined down fully to become wrought iron[54].

In Sweden, on the contrary, straight from its introduction in the early 1600s the German forge was fed with charcoal pig iron and it produced wrought iron bar[55] and steel[56].

After 1750, the "Stücköfen" in Germany and Austria were quickly replaced by charcoal blast furnaces. The indirect process needs more charcoal – to fine pig iron into wrought iron or steel; still, the much larger productivity of the blast furnace made the change-over advantageous[57]. Both wrought iron[58] and steel[59] were then made directly in German hearths from charcoal pig[60] in these countries also.

But even after about 1750 when pig iron is used exclusively in the German hearth, many modes of operation remain, differing in details.

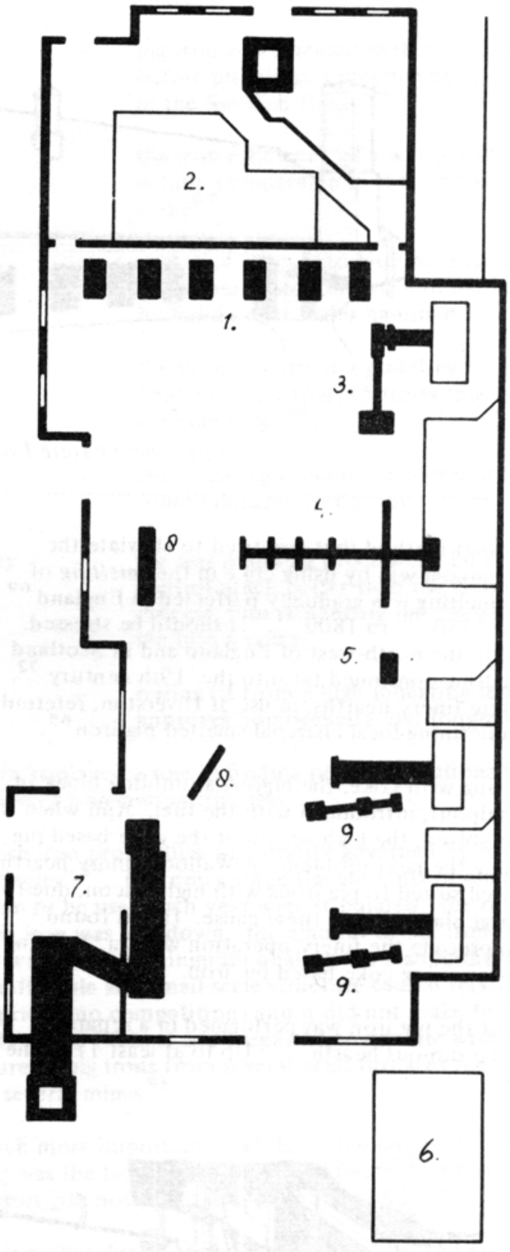
The Walloon forge and its derivatives

In the Walloon forge two separate hearths are used: a finery for fining of pig iron and a chafery for reheating before hammering into bars (Figure 13). Scarcity of charcoal and the availability of coal led, before 1700, to the application of the latter fuel in the *chafery* hearth. At least, it did so in France, the Low Countries and England[61]. In Sweden, circumstances were quite different. Charcoal was not scarce – and coal supplies near the orefields non-existent[62], while transport of coal to the forges was much too expensive to make this a competitive fuel, at least not before 1850[63]. Thus charcoal remained in use in the Swedish chafery hearth, even right up to the mid-1940s[64] (Figure 25).

In the search for a reduction of the charcoal consumption of a Walloon forge, experiments with coal or coke as a fuel in the *finery* hearth were also made, but as any sulphur in the fuel was quickly taken up in the iron, making this red short and unworkable in the forge, these were not successful.

One possible action was to retain a hearth but reduce its charcoal consumption . This method was chosen for example in Lancashire. The Lancashire (finery) hearth was designed for maximum efficiency with heated blast, pre-heated pig and damping of natural draught in the chimney, etc. In this latter form the Lancashire hearth was still in use at Ulverston in 1828[65].

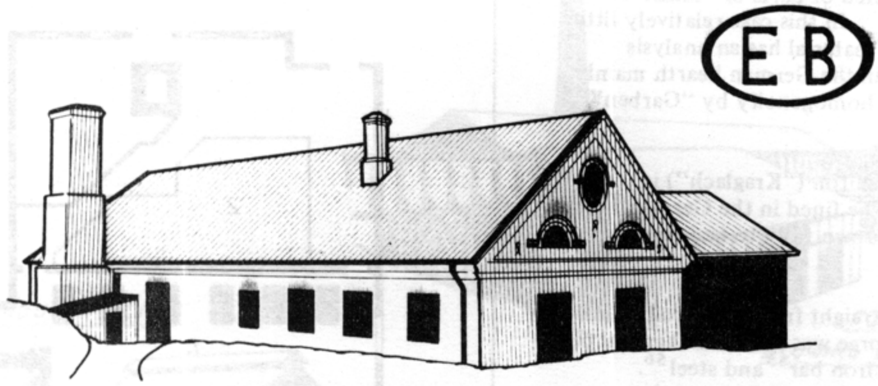
A second possibility for decreasing the charcoal consumption was to use a reverberatory furnace with natural draught for fining instead of a hearth. The strict separation of iron and fuel made it possible to use coal without sulphur contamination problems, but the oxidizing atmosphere in an air furnace caused new problems. To solve these and protect the iron from over-oxidation, it was "potted"[66]. This process was used in 1775 by Jesson and Wright[67] and even as late as 1796 at Coalbrookdale[68]. Of course this "stamping-and-potting" method culminated in Cort's puddling furnace, where strict control of the slag covering an iron bath made satisfactory metallurgical control of the fining process possible, without having to make recourse to pots.



1. *Lancashire Hearths;*
2. *Waste Gas Boilers;*
3. *Nose Helve Shingling Hammer;*
4. *Rolling Mill;*
5. *Shears;*
6. *Store For Half-blooms And Rough Bars;*
7. *Ekman Reheating Furnace;*
8. *Steam Hammers;*
9. *Belly Helve Bar Drawing Hammers.*

Lay Out Of The Lancashire Forge (type 5), Karlholm Sweden: 22

23



Engelsberg Estate Forge, Angelsberg, Sweden.

Further, another method that was tried to alleviate the scarcity of charcoal was by using coke in the *smelting* of iron. Coke smelting was gradually perfected in England [69] in the period 1750 [70] to 1800 [71]. It should be stressed, though, that in the north-west of England and in Scotland charcoal smelting continued far into the 19th century [72]. The Lancashire finery hearths, in use at Ulverston, referred to above, were fining local charcoal smelted pig iron [65].

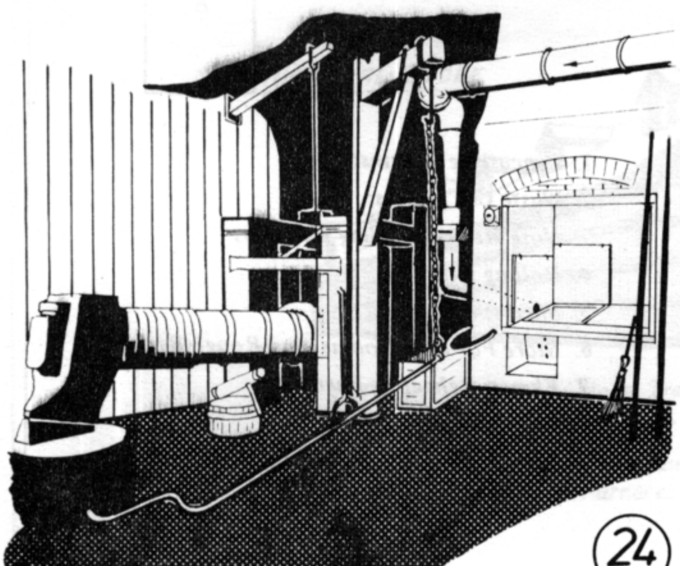
In iron smelting with coke, the biggest stumbling block of course was sulphur, introduced with the fuel. And when this problem was solved, the high silicon of the coke based pig iron [73] became the next problem. A Walloon finery hearth is not very well suited to pig irons with high silicon, due to the rather large slag volumes these cause. It was found necessary to precede the finery operation with a "refining" operation when using coke based pig iron.

"Refining" of the pig iron was performed in a separate hearth called a run-out hearth [74]. Up to at least 1770 the run-out hearth was charcoal fired, although the pig iron could be pre-heated in a (coal fired) reverberatory furnace [75]. In this way no charcoal was necessary for smelting . . . but extra charcoal was consumed in the forge. Later, very low sulphur coke was used in the run-out hearth, to bring the specific charcoal consumption in the forge back to the accustomed level [76].

This type of process:

coke smelted pig iron
↓
coke fired run-out hearth
↓
charcoal fired Lancashire finery hearth
↓
coke fired hollow fire chafery

did apparently work quite well, it was still in use at Pontymoils tin-plate works in South Wales in 1828 [77].



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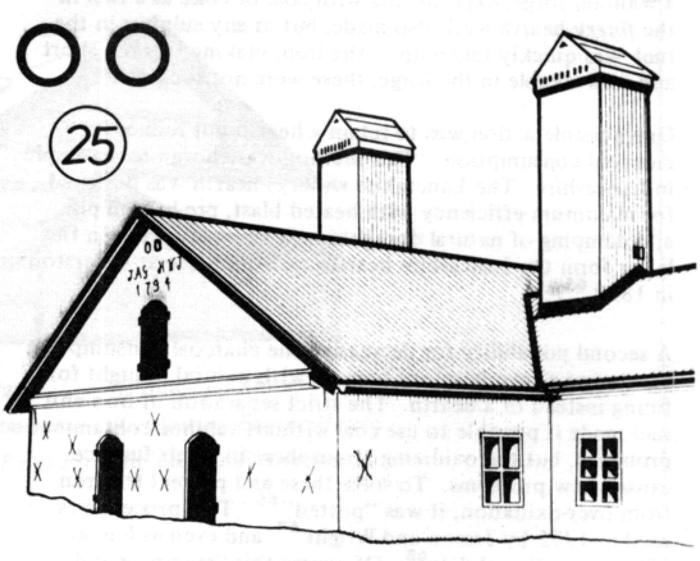
German Forge, Wien, Austria.

25



Double Bullet Walloon Forge, Osterby, Sweden.

Puddling

From the 1790s onwards, the Walloon process was replaced in England with one in which no finery hearth was used at all[78, 79].

coke smelted (white) pig iron (No 3)

coke smelted (grey or mottled) pig iron (Nos 1,2)

↓ coke fired run-out hearth

↓ coal fired puddling furnace

↓ coal or coke fired reheating furnace

↓ rolling for working into bars instead of shingling[80].

Due to the Napoleonic Wars and their blockades the puddling process was not introduced before the mid 1820s on the Continent. By then, wet puddling was available and between 1825 and 1840 this process quickly spread all over Europe, superseding the old German and Walloon methods.

The puddling process itself is outside the scope of this article as it uses no finery hearth, but its very quick adoption both in England and abroad caused some very special problems in Sweden. These could only be overcome by the development of a specific Swedish hearth fining process.

The Swedish situation up to the 1810s

Sweden has large amounts of iron ore – of high quality – and is quite rich in wood. In the 18th century these facts made for an advantageous position. The charcoal scarcity in other countries caused relatively high iron production costs. Swedish iron could thus – despite the sometimes very long transport route – very well compete with home-produced iron in most other countries, especially as its quality was relatively high.

During most of the 18th century the following rough statistics held:

- counted in money, half Sweden's export was bar iron[81].
- counted in iron 90% of Sweden's iron production was exported[82].
- of Sweden's iron export, 50% went to England[83].
- Swedish iron was made in German forges (90%) and in Walloon forges (10%).

The adoption of the puddling process in England caused a spectacular reduction in its iron imports. In the period 1815 – 25 only 15000 t/year were imported as compared with 45 – 50000 t/year around 1800[83]. This caused a decrease of some 20% in the Swedish export to England[83]. The emerging new markets of the USA quite easily took up this amount – and even more – but a *structural* problem remained:

English puddled iron was cheaper and of a better quality than Swedish German forge iron[84, 85].

A full analysis of this problem revealed several causes:

price – coke as a fuel in iron smelting is cheaper than Swedish charcoal;

– coal fired puddling and balling (-reheating[79]) furnaces produce more cheaply than a charcoal fired German hearth;

– pig iron is pre-heated with combustion gases before puddling, a practice not yet employed in the Swedish forges[86];

– the iron efficiency of a wet puddling furnace is fully comparable to that of a German forge[87].

– rolling of loups into blooms then into bars is cheaper than shingling and bar hammering by hand under water hammers.

– the productivity of a puddling forge (around 1830) is more than 15 times that of a German forge[88];

– the puddling process is adopted in many other countries in Europe.

quality – the wet puddling process can be kept under control much better than the German forge process, thus enhancing the consistency of the iron quality;

– rolling (if from a high reheating temperature) improves homogeneity and toughness.

Two facts played a role in finding possible solutions for this problem of non-competitiveness.

Swedish iron production was strictly governed by royal "privilegier"[89]. For every forge the amounts of charcoal and pig iron to be used each year were stipulated; the origin of the pig iron was laid down; the amount of bar iron to be made was fixed; a minimum quality was standardized[90]. This inflexible and small-scale structure caused relatively high prices (no competition) and it did not make for maximum quality either (almost any forge had to operate with a mixture of pig irons from several blast furnaces fed with ores from several mines[91].

A much more important – whilst at the moment unalterable – factor was the lack of coal in the orefields[62]. Cheap bulk transport was not possible, before the 1850s[63].

It is clear that due to the scarcity of coal for forges Sweden had to find its own unique answer to the standard puddling process.

Sweden's options

The *first* option was of course to find a fuel cheaper than meiler charcoal which was used exclusively at that time. Charcoal, made in retorts, costs less in labour than meiler charcoal[92], but the cost of transport of wood to the retorts is much higher than that of charcoal due to the much larger volume[93]. Experiments were technically successful[94], but over-all retort charcoal did not offer any cost reduction[95].

Wood and peat – in their natural form[96] - were the only available replacements for coal in reverberatory furnaces, ie in puddling furnaces.

The *second* option then, was a modified puddling furnace, suited to wood or peat as fuel.

The *third* option was to find a cheaper charcoal hearth fining method, by reducing the specific charcoal consumption and/or increasing the iron efficiency. This problem had been encountered before, in England. The Lancashire finery hearth, mentioned above, was developed for just this purpose.

The *fourth* option was to decrease bar iron costs or increase efficiency by better hammers and/or by rolling. Reheating in hearths is not feasible with rolling[97], so a reheating furnace suited to Swedish circumstances – again no coal – must be found before rolling can be advantageously introduced. Of course a reliable and not too precarious power source is necessary to realise all the benefits of rolling.

Swedish developments 1810-50

In 1812 at Klosters Bruk and in 1816 at Bispberg experimental puddling furnaces (wood fired?) were built[98]. In 1819, at Skebo Bruk, an experimental puddling furnace and reheating furnace, both wood fired, together with a rolling mill were constructed[98, 99]. This was the first attempt to introduce full puddling plant technology.

The wood fired reheating furnace does not reach sufficiently high pre-rolling temperatures without inadmissibly high oxidation losses, and the iron quality is disappointing[100]. That this was indeed caused by the use of wood as fuel in the reheating reverberatory furnace is adequately demonstrated in 1825 by rolling experiments in England with Swedish iron[98]: excellent bar was obtained after reheating with coal.

The wood-fired puddling furnace itself was satisfactory. High transport costs of wood however, together with the extra costs of having to hammer bar[101] – failing a reheating furnace suited to Swedish fuels and rolling – are the reasons why the puddling process never caught on very much in Sweden.

In 1829-30 the first charcoal fining hearths of an improved design were built. These were based on the Lancashire finery hearth.

Waern installed a South Wales forge in Backefors Bruk. As mentioned previously, South Wales tin plate works did use – at that time – a run-out hearth (on coke), a Lancashire finery (on charcoal) and a hollow fire chafery (on coke). As Waern was going to use charcoal-smelted pig iron, with an analysis comparable to that of refined metal emerging from the South Wales run-out hearth[103], he could dispense with the latter. As he had no coke, he could not use a hollow fire[104]. But the rest, hearths, blower, hammers, smiths, know-how: all were imported from South Wales[105]. Buying technology usually only works when the methods are further developed and adapted to local circumstances[106] and the Waern method never found widespread use, as this necessary evolution was neglected.

At the same time as – but independent of – Waern, Ekman built new finery hearths, at Dormsjö and Söderfors[107]. These were clearly copies from the Lancashire hearths that Ekman had seen 1828 at Ulverston[108], although some changes were made[109]. The results were encouraging:[110]

- the wrought iron was excellently suited to cementation and was of better quality than German forge iron;
- the specific charcoal consumption of the finery was low, even for very low carbon iron;
- the iron efficiency of the finery was high, unless very low carbon iron was made.

In the period up to 1834 the Lancashire finery hearth was introduced in several other works[111]. Of course some teething problems occurred. Pig iron quality varied considerably[112]; blowing engines could not meet the requirements of the new hearths[113]; smiths, accustomed to the slow German process only gradually picked up the required technology. But there were two much larger problems to overcome.

As could be expected, many experiments were done to increase the efficiency of the German forge, and this work, eg by Morell[114], comes to fruition in the early 1830s. In fact the improvements are similar to those of the Lancashire hearth: an enclosed hearth, use of combustion gases, etc. The resulting decrease in specific charcoal consumption is not as spectacular as that of the Lancashire hearth; but in the latter case reheating before hammering into bars needs extra fuel, something which in a German forge is unnecessary as reheating is done in the same hearth as fining. If a charcoal chafery hearth is used in conjunction with the Lancashire finery hearth, about 5% more charcoal is consumed than in the improved German forge. Both methods still cannot compete with the English puddling process. Clearly, rolling is necessary to come anywhere near competition with puddling plants. A reheating furnace, suitable for Swedish fuels, reaching a sufficiently high temperature was not yet available. Failing this, the Lancashire finery hearth could only be coupled with a chafery hearth and hammering of bars. The German process intrinsically could never be adapted to rolling[97]. Narrow thinking and the need for even small savings steered production towards improved German forges and thus hindered the evolution of the new process: in 1840 only 3-4 works really used their Lancashire hearths[115].

The second problem is one of scale. When combining the Lancashire finery hearth with a chafery hearth, two fineries were needed to keep the chafery fully occupied. Shifts of seven men then produced about 360 t/year[114]. Of the 510 iron-works registered in 1834, only 74 had "privilegier" exceeding that amount[116].

It is quite clear, that the original problem of non-competitiveness could not be solved before an efficient reheating furnace, suited to Swedish fuels, was developed.

In 1842–4 Ekman succeeded with the application of a new concept. He used a separate hearth as a gas producer in which, by means of hot blast and added water, carbon-monoxide and hydrogen are formed from charcoal. These are fired in the furnace chamber. The atmosphere there could at wish be made oxidizing, neutral or reducing by changing the blast and water supply. Combustion gases emerging from the furnace chamber were used to preheat the blooms and then to heat the blast[117] (see Figure 26).

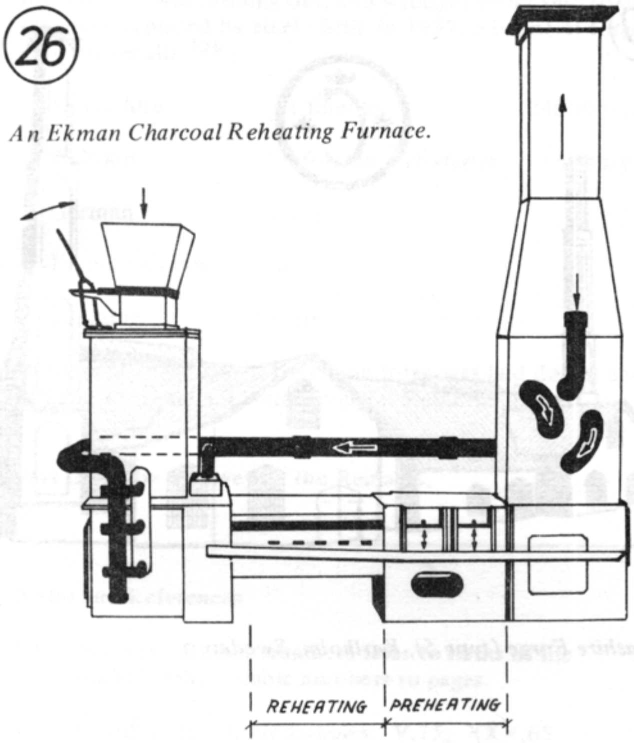
The concept proved very successful: within one year nine of these furnaces were in use[118] and on an average one furnace was fed by three Lancashire finery hearths.

Clearly, this development did not fit within the strict framework of the "privilegier", as the optimum use of a reheating furnace would mean:

- a large flow of uniform pig iron[112];
- several finery hearths;
- rolling of bar.

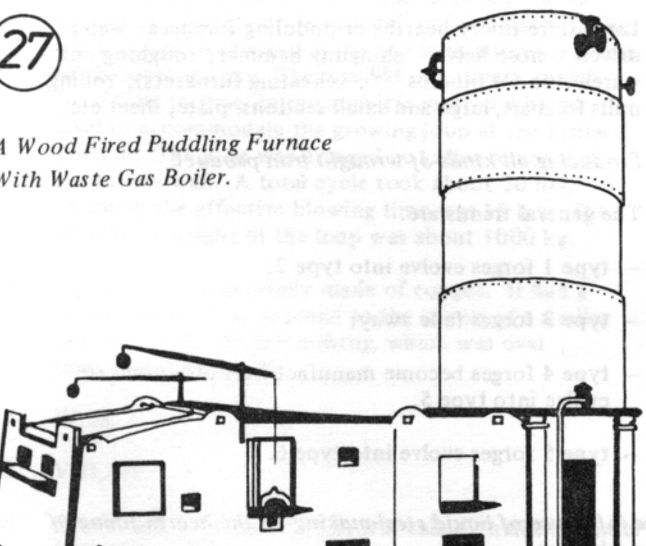
26

An Ekman Charcoal Reheating Furnace.



27

A Wood Fired Puddling Furnace With Waste Gas Boiler.



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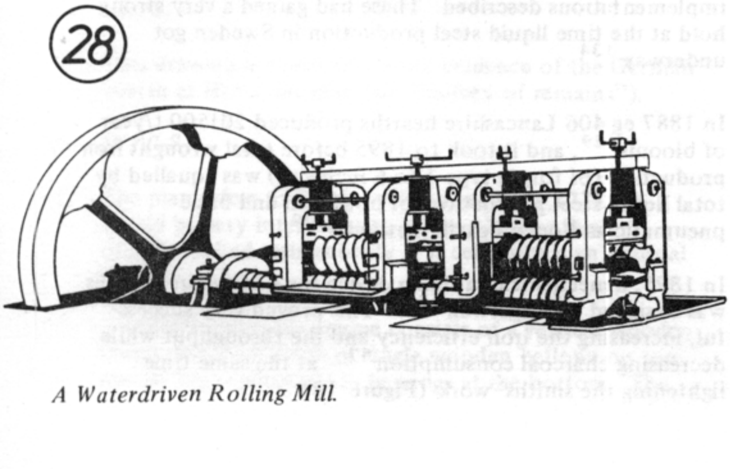


A Waterdriven Rolling Mill.

The large investment involved was really only justified in large scale works. The system of "privilegier" was abolished in 1846[119]. The first works using Lancashire finery hearths, an Ekman reheating furnace and a rolling mill was Lesjöfors – owned by Ekman[120] – in 1850[121] (see Figure 17). Of course, the reheating furnace could as well be used in conjunction with a wood fired puddling furnace (Figure 27). The first works to use this combination, ie a puddling furnace, an Ekman reheating furnace and a rolling mill was Surahammer – in 1851[122] (Figure 28).

In 1847 Ekman introduced a wood fired reheating furnace.[123] This is similar to the charcoal version, mainly with changes in the gas producer hearth. The wood has to be thoroughly dried in an oven to obtain a sufficiently high temperature in the furnace[124]. Usually combustion gases are used for this purpose. The consequent higher investment and – again – the higher wood transport costs however prevented a general adoption of this method.

Swedish wrought iron production after 1850

The Ekman reheating furnace finally made the application of rolling mills feasible, and Swedish bar iron prices again became competitive. In the mid-1850s the first Swedish railways were constructed[63], with home-produced rolled rails. The increased transport potential caused lower coal prices in the ore fields and higher charcoal prices, due to the now arising competition of other industries[125]. Furthermore, the demand for iron increased, due to lower transport costs. Gradually, coal became the main reheating furnace fuel. Only small changes to the gas producer hearth were necessary to adapt the existing furnaces to coal. The ironic fact remains that after a search of almost 30 years for a charcoal fired reheating furnace, this became obsolete in about the same time due to its own efficiency!

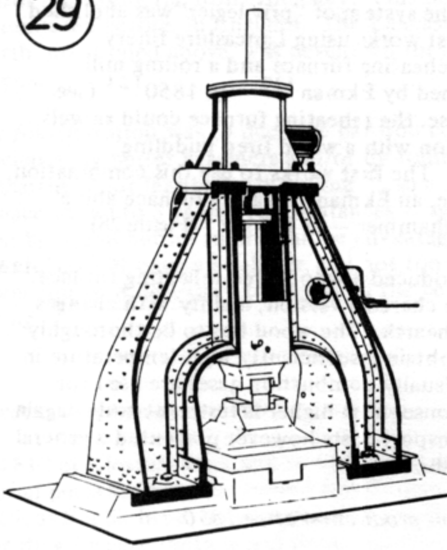
Lundin constructed in 1860-4 a furnace with a gas producer capable of burning sawdust, peat, splitwood, charcoal and mixtures of these. This furnace was the first to use the regenerative principle[126] and a condenser in the gas supply[127], but its main claim to fame is that it became – with minor alterations – the first Swedish open hearth furnace in 1867[128].

After the introduction of the tandem Lancashire finery hearth + Ekman reheating furnace, the German forge could no longer produce competitively. The former process however only works on a large scale. Many small forges had to look for a cheaper small scale process than the German method – or close. They found the Franche-Comté method. This is a mixture of the original Walloon and German methods, in that one hearth is used with two separate tuyeres, one for fining and one for reheating. There is no chafery so fuel for this is saved[129]. The fining operation in a Franche-Comté hearth is very similar to that in a Lancashire finery hearth.

Many small forges were reconstructed in the years 1845-50[130] simply by changing the German hearth to the new pattern. The last German forge in Sweden was presumably that of Rossberga, By, which was blown out in 1894. The Franche-Comté hearth remained in use until the 1880s, although the last one, at Woxna Bruk, was blown out only in 1920[129].

In 1851 the first steam hammer was bought from England (Figure 29). Increasing power demand on restricted sites, the logical effect of concentration, often led to water shortage[131] and difficulties in production. Steam, generated with waste heat gas cost little extra (apart from depreciation of the installations) and was a much more reliable power

29



A Bar Drawing Steam Hammer.

source. Steam hammers were considered unsuitable for shingling, though.

All these developments led to a gradually emerging pattern with six types of wrought iron production forges. These are:

1. Small scale forge – one hearth.

   Franche-Comté hearth; a water driven hammer, usually belly-helve.

   Producing bar for sale.

2. Small scale forge – one hearth.

   Lancashire finery hearth; a water-driven hammer, usually belly helve.

   Producing blooms for further working elsewhere.

3. Small scale forge – two hearths.

   Lancashire finery hearth; charcoal chafery hearth[132]; one or two water-driven hammer(s), usually belly helve.

   Producing bar for sale.

4. Medium scale forge.

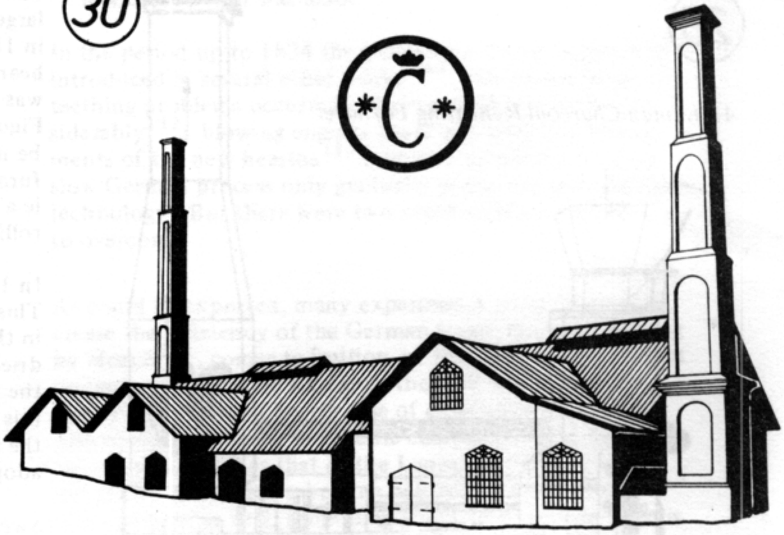
   Lancashire finery hearths; water-driven – nose helve – shingling hammer; warehouse for blooms[133]; reheating furnace(s); water-driven – occasionally nose helve, usually belly helve – bar drawing and finishing hammers.

   Producing bar for sale.

5. Large scale forge – bar exclusively.

   Lancashire finery hearths or puddling furnaces; water-driven – nose helve – shingling hammer; roughing mill; warehouse for blooms[133]; reheating furnace(s); steam hammers for bar drawing and finishing (Figure 30)

30



Lancashire Forge (type 5), Karlholm, Sweden.

   Producing bar for sale.

6. Large scale forge – universal.

   Lancashire finery hearths or puddling furnaces; water-driven – nose helve – shingling hammer; roughing mill; warehouse for blooms[133]; reheating furnace(s); rolling mills for bars, large and small sections, plate, sheet etc.

   Producing all kinds of wrought iron product.

The general trends are:

– type 1 forges evolve into type 2;

– type 3 forges fade away;

– type 4 forges become manufacturers of blooms or evolve into type 5;

– type 5 forges evolve into type 6.

The influence of liquid steel-making on the hearth fining of wrought iron

The puddling process had virtually wiped out all hearth-made wrought iron by 1850, except for the unique Swedish implementations described. These had gained a very strong hold at the time liquid steel production in Sweden got underway[134].

In 1887 eg 406 Lancashire hearths produced 201500 t/year of blooms[129], and it took to 1895 before total wrought iron production (of forges type 1 to 6 inclusive) was equalled by total liquid steel production (of both acid and basic pneumatic and open hearth methods)[129].

In 1895, a mechanical rabbling device for Lancashire hearths was designed by Lägerwall[135]. This proved very successful, increasing the iron efficiency and the throughput while decreasing charcoal consumption[47] – at the same time lightening the smiths' work (Figure 18)

But the tide was running out, and wrought iron came to be gradually replaced by steel. Still, in 1937, a count of forges gave the results [129]:

Lancashire	41 fineries	24800 t/year
Walloon	7 fineries + chaferies	1600 t/year
German	none	
Franche-Comté	none	
puddling	none	

In the mid 1940s the last Walloon forge was laid down, and in 1964 the last Lancashire forge, at Ramnäs[129].

Part II will be a Survey of the Remains.

Notes and References

NB Sources: Roman numbers refer to items in the bibliography; arabic numbers to pages.

1 "Kotlucken" or cinderholes: V,75; XXV,65.

2 In a "Stückofen", a loup of steely consistency – with carbon varying throughout the loup – and some liquid pig iron are produced. The former is called "Massl" or "Stück", the latter "Kraglach" or "Graglach". The "Stückofen" is charged at the top with alternate layers of charcoal and ore. There is just one tuyere, which from time to time during a melt is reset at a higher level to accommodate the growing loup at the furnace bottom. The loup was dragged out after removal of the tuyere wall. A total cycle took about 20 hrs, of which the effective blowing time was 15 hrs. The maximum weight of the loup was about 1000 kg.

3 The tuiron was generally made of copper. It had a circular section, as opposed to the tuiron of a similar hearth used for scythe making, which was oval (long axis horizontal).

4 IV,68.

5 VIII,148.

6 Occasionally one-such works was called "halbe Hammer"; VIII,149.

7 The depth of the hearth proper is about 0.3 m.

8 IV,73.

9 This drawing is based on on-site evidence of the German hearth at Hävla, Sweden (see "Survey of remains").

10 IV,47-8.

11 The plan refers to Storfors, Sweden (XXII,177). It would be very interesting to know whether this hearth worked satisfactorily – it certainly is an unusual design!

12 A Widholm blowing engine consists of a vertical wooden frame with 2 or 3 sets of single wooden bellows on top and an iron crankshaft in bearings at the bottom. The engine is powered by a waterwheel. There is no windchamber; the blast tube is square in section and made from wooden boards.
In the 1830s the wooden bellows were replaced with cylindrical cast iron pistons and cylindersby Ekman (see note 113). He used cast iron tubes; a very small windchamber(about ¼ of the stroke-volume of one cylinder for a 3-cylinder engine and a horizontal offset of the crankshaft of half a crankradius). This – in a single-acting engine – causes a decrease of the wear of the piston seals due to smaller lateral forces during the compression stroke of the cycle.
Fluctuations in flow and pressure of the blast were only partly eliminated by the small windchamber, but this was considered to be advantageous to the iron quality.
Still in the 1830s Bagge modified this engine by using a cast iron frame and – a more important distinction – a much larger windchamber, laid on top across the cylinders (over 7 times the stroke-volume of one cylinder for a 3-cylinder engine). In this form the engine has been used extensively for blast furnaces – and forges also.

13 VI,110.

14 After division the parts of the bloom were first hammered into uniform half-blooms without reheating: III,32.

15 This is generally held to be the cause of the superiority of Walloon iron, since in the Walloon method reheating and hammering was not done by the fining smith at all, so that he could give all his attention to rabbling during melting down: IV,36.

16 IV,33-7.

17 XXVI,19; XXVII,5-6.

18 XII,17; IV,48.

19 XII,17.

20 XI,849.

21 IV,109.

22 England: (1674) 35kg; (1760) 50 kg.
Sweden: (1800) 100 kg.

23 England, Sweden, France: XXV, 67.

24 Siegen in German Westfalen: XXV,67.
It is interesting to note that the restored finery hearth at Liège, Belgium, see Figure 7, has a pig hole, while in a book on the nearby Luxembourg Walloon forges, (XXVIII) a hearth with side supply is shown.

25 XXV,64.

26 XXV,66.

27 XIII,196.

28 XXV,69-70.

29 IV,34; XXV.67.

30 Called "ringer" or "ringard".

31 This is generally held to be the cause of the superiority of Walloon iron over German forge iron: IV,36.

32 Called "furgon" or "fourgeon".

33 Presumably half-blooms were entered from the front, being short; while half bars were entered from the side as they were over 1.5 m long.

34 Although the artist has taken some licence with the laws of perspective, especially in the case of the finery at the right side of the figure.

35 Cited in IV.

36 IV,42. This indicates hot blast, but the report does not make clear how blast was heated. The tuyere is cooled according to the method described in an English encyclopaedia in 1811: XIII,203.

37 IV,44.

38 IV,12.

39 The loups from this hearth were hammered into "stamped cakes". The cakes were divided by chisel and waterhammer into smaller parts that were fagotted after reheating in a coke fired hollow fire (IV,34:44). The billets obtained were drawn out by hammer into bar (30 x 13 mm section), cut into lengths of 28 cm), reheated and rolled into sheets. This process is described in an English encyclopaedia under the entry "Rolling Mill" (XV,328), published 1815. In the same encyclopaedia under the entry "Tin plate" (VII,266), published 1817, a different and rather faulty description is given!

40 IV,38-43.

41 Details of this part are lacking.

42 Though it would seem probable that slag was tapped through the fore plate, leaving the opening under the tuyere-hole free for the connections of the waterbox bottom. This would nicely combine the cooling implements of tuyere and bottom.

43 As opposed to both German and Walloon practice.

44 III,29-31.

45 In the Lagerwall rabbling device it is the latter bar which is moved mechanically.

46 No last melting down with increased blast was performed.

47

		by hand	mechanically
Iron efficiency of Lancashire hearth (no reheating)	%	88.1	89.2
Throughput	t/week	14.4	16
Specific charcoal consumption	hl/t bloom	38	35

48 IV,108-110.

49 With 11% oxidation losses at reheating.

50 Before 1750 only charcoal pig iron was fined in a forge: I,93.

51 II,86.

52 In this period about 90% of Swedish iron came as bar from German forges: 10% came as rough bar (raskenor) from Walloon forges: III,29; IV,35.

53 The fagotted steel is called "Raffinier-Stahl" in German. This term does slightly confuse the issue: no refining takes place!

NB Not only new "Massl" are used in the preparation of "Raffinier-Stahl". Steel scrap can be re-used too (Zerrennen von Schrott). Source: V,109; VI,112.

54 V,84.

55 IV,33.

56 An excellent description of steelmaking in a Swedish German hearth is given by Swedenborg. This is cited in VII,249-50.

57 Although strict regulation of charcoal production and allocation was necessary and forges and mines and blast furnaces had to be separated by rather long distances: VIII,148.

58 V,110.

59 The steel is known under the names of Natural or German Steel: VII,158,248.

NB Using the term German Steel also for Shear Steel (made by fagotting blister bars, ie without melting in crucibles), as in VII,159, is confusing.

60 This pig iron seems to have been grey – not white! : V,85.

61 I,93.

62 IX,76.

63 X,33.

64 This certainly was also partly caused by the facts that:

1 Almost all Swedish Walloon forges were working on pig iron smelted from Dannemora ore – this very high quality wrought iron remained in high demand for cementation kilns and/or crucible furnaces (mainly in England) for steel production far into the 19th century; XI,856,859; IV,33.

2 The Swedish Walloon forges produced mainly "råskenor", ie rough bar (IV,35) ...... thus the chafery charcoal consumption is low compared with bar producing chaferies.

65 IV,25.

66 On the analogy of the cementation kilns . . . although the pots were much smaller!

67 II,110.

68 I,94.

69 See II,105-7 for an excellent description.

70 About 1750 the first charcoal furnaces ceased production: I,93.

71 About 1800 only 10% of English pig iron was still charcoal-smelted: XII,18.

72 Eg Bonawe (Lorn) furnace 1874
Duddon Bridge furnace 1866-7.

73 Heated blast was not available before 1828.

74 In XIII,188 (1811) the hearth is called a run-out furnace; later (XIV,49), in 1873, the name is further corrupted to running-out fire.

75 II,111.

76 Ie to the level normal for fining of charcoal pig.

77 IV,24,44.

78 I,96.

79 XIII,188.

80 XV,328.

81 X,17.

82 XI,849.

83 X,25.

84 IV,10.

85 IV,24.

NB It is interesting to note that, although in the 1820s the Swedish Walloon forges are considered to be rather old-fashioned, the export of Walloon iron – mainly to England for use in cementation and/or crucible steel production – never dropped. The combination of the outstanding Dannemora ore, the French-type blast furnaces (geared specifically to the needs of the Walloon forges) and the long experience with Walloon forges made for highest quality iron, warranting prices almost twice as high as those of Best puddled iron: XVI,35.

86 IV,26.

87

	wrought/ pig iron	
German forge	0.71-0.77	VI,110,111.
Walloon forge	0.77	II,89; XVII,58; I,95.
Dry puddling	0.50-0.56	XVIII,12; I,95.
Wet puddling	0.77	XVIII,12.

88 VI,133.

89 IV,7-8.

90 The thought behind this restrictive policy was to maintain quality, to raise tax, to prevent over-consumption, to obtain well-spread employment and to prevent killing competition.

91 IV,31.

92 About 1:3 : VI,98.

93 About 3:1 : VI,99.

94 IV,15.

95 XI,850.

96 Though dried, usually with the combustion gases of the fining and/or reheating hearths or furnaces: IV,89.

97 Due to insufficient homogeneity of temperature: IV,11.

98 XI,850-1.

99 IV,10.

100 IV,23.

101 Even the newly-introduced types of hammer from England could not compete with rolling; these are:

1830 The nose helve shingling hammer: formerly both shingling and bar drawing were performed under belly helve hammers;

1836 The belly or tail helve with a detachable T-piece: with this hammer both "räckning" or drawing and "slätning" or finishing could be performed from the same position without changing the hammer insert.

The latter hammer made a higher throughput possible, while the minimum bar dimensions that could be made in one heat became smaller: IV,70.

NB The T-insert for a hammer is already described in an English encyclopaedia, in 1811: XIII,197.

102 IV,11-2.

103 IV,46.

104 Waern first used a charcoal chafery, but afterwards discovered that his cost price was 25% higher than his selling price: IV,45. A suitable reheating furnace was not yet available, so rolling was impossible. Waern thus had to sell his iron as "råskenor", rough bars for cementation, to England, though its quality and in consequence, its proceeds were in no way comparable to those of Swedish Walloon iron. See note 85.

105 Waern's agents in England were Cowie and Brändström, Hull: IV,45,60.

Smiths: foreman Sam Houlder, with 3 sons and his son-in-law Whittington and their families came from Garnderis and Abergavenny, Monmouthshire: IV,45,50,60.

106 In the early 1600s the Walloon process was introduced in Sweden in a similar manner: both technique, gear and labour were imported. In this case a complete technology, from blast furnace to forge inclusive, was brought to the Uppland area around Dannemora. It is interesting to note, that this resulted in a more-or-less closed iron community, into this century, even, and that the technology did not spread to other places. In the case of Bäckefors, only part of the South-Wales process technology was used, thus making final success dependent on adaption.

107 IV,37-9.

108 IV,25.

109 In the Söderfors hearth, eg, pig iron was not – as in Ulverston(e) – fed a la Walloon in "gueuses" but in small pigs à la German: IV,39; XI,853.

110 IV,40-58.

111 1830 Dormsjö – drops the process very quickly again

Söderfors

1831 Ferna

Furudal

Dådran – drops the process very quickly again

Lesjöfors

1833 Mackmyra

1834 Liljendal

Fagersta

Hammarby

Forsbacka

Engelsfors

112 Better homogeneity and constant quality of pig iron are gradually obtained by:

– improved ore roasting techniques;

– higher blast pressure and larger blast flow;

– hot blast.

Significant improvements are not realised before the 1840s.

113 Ekman did design a new blowing engine for the new hearth in Ferna Bruk, which truly is a predecessor of the very well-known Bagge 3 cylinder blowing engine. The extra investment of a new blowing engine often was not authorized and the change-over to the Lancashire finery hearth then just consisted of a reconstruction of the existing German hearth.

114 IV,48.

115 Amongst others Lesjöfors and Munkfors: IV,58.

116 Amongst which 2 puddling works and 6 Walloon forges.

117 It is interesting to compare this description and the date – 1842 – with those of the Siemens patent for a gas producer!

118 Naes (N).

Horle Bruk

Finspång

Munkfors

Geijersholm

Gustafsfors

Uvanå

Likanå

Fentå

119 IV,112-8.

120 XIX,40-65.

121 IV,94.

122 XX,8.

123 IV,89.

124 The same type of wood fired furnace is also used to heat iron in the production of forgings. In this case a lower temperature suffices, and air-dried wood can be used.

125 Glass, eg.

126 Patented by Siemens, but according to Lundin he was mainly inspired by John Ericson's hot air engine of the 1830s: XXI,55.

127 Lundin's own invention.

128 It is claimed that the Martins in France were guided by Lundin's experiments of 1864 and that Lundin really was the first to successfully melt low carbon steel in an open hearth. As he had to replace the furnace lining after each melt, his hardly was a feasible furnace. The Lundin furnace was improved 1867-8, after his sudden death, by Rinman who had previously visited the Martins' works and obtained details of their furnace lining. The successful implementation of the open hearth furnace method thus seems to have been a case of interaction of French and Swedish developments, rather: XXII,216-23.

129 XI,856.

130 This method is certainly older, eg it was observed by Ekman in the Low Countries in 1828 (IV,35). The introduction in Sweden depended on two factors:

1 the economic need to replace the German hearth;
2 the creation of necessary technique.

It is interesting to see that only when the Lancashire hearth method had matured, smiths migrating from the larger forges to smaller ones spread the necessary (fining) technique – the small forges never could afford research of their own, or import technological knowledge.

131 It was quite usual that in a "bad" year a forge had to cope with serious water shortages for half the year; XXIII,3.

132 Usually the former German hearth, reconstructed.

133 In contrast with the forges type 1 and 3, the hammered blooms are kept in store – often to be supplemented by blooms from a forge type 2 – and pre- and reheated before further working. The loss of heat from the finery is amply compensated for by the much increased flexibility in production.

134 Bessemer blowing from 1858;

acid open hearth from 1867-8;

basic processes from 1890;

electric furnaces from 1900.

135 XXIII,11.

136 XXIX,25-8.

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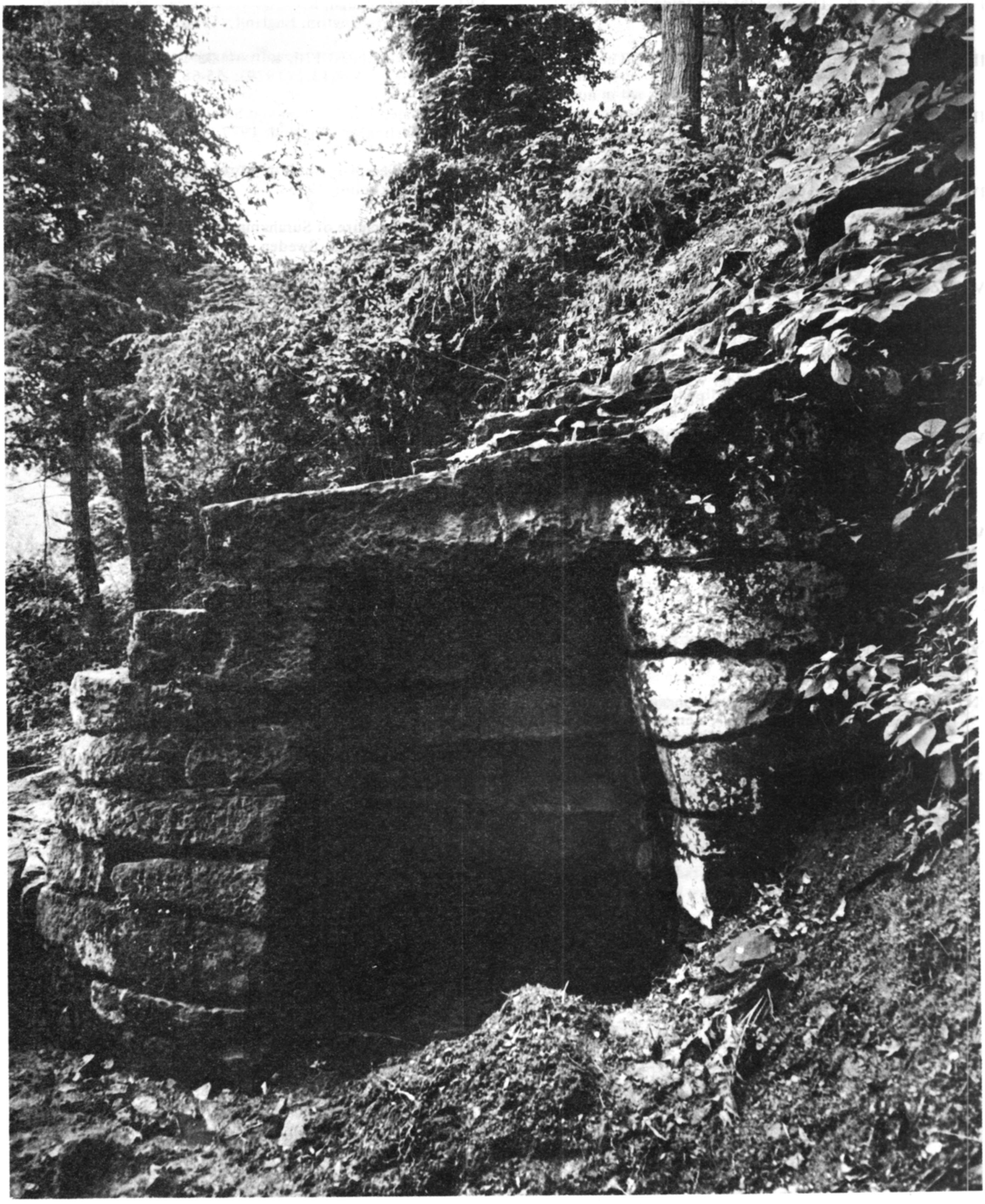
New light on early American ironmaking: The Eaton furnace

John R White,

Figure 1 *The Eaton tuyere opening. This was the only portion of the 1802 furnace still above ground at the commencement of excavations. The bottom-most visible course of sandstone blocks is approximately 1 m above the actual bottom of the furnace. The furnace itself was built into the steep gorgeside.*



Abstract

The Eaton (Hopewell) Furnace is one of the few early American blast furnaces that has been subjected to archaeological and metallurgical examination. The furnace was erected in 1802 and operated between 1803 and circa 1808 when, due to a combination of factors, it went out of blast. Three summers of excavations and the post-season analysis of the artifacts and raw materials has helped to piece together the activities taking place at the site and to evaluate the efficiency (or lack thereof) of the ironmaking operation. In the end, the findings indicate that a new chapter will have to be written on Ironmaking in the New World.

The Eaton-Hopewell Furnace (33MH9) is located in Yellow Creek Gorge just 200 m downstream from manmade Lake Hamilton in Mahoning County, between the cities of Struthers and Poland, two suburbs of Youngstown, Ohio. It lies midway up a steep slope with an incline in excess of 45 degrees.

The furnace, built in 1802-1803, was the earliest blast furnace west of the Alleghenies and the iron industry was the earliest of any kind in the Western Reserve. It operated with only one major interruption until about 1808, when, due to a combination of factors including an inefficient blast process, a shortage of readily available hardwood for charcoal, a concommitant and metallurgically 'lethal' innovation, and an accidental blow-out, it went out of blast[1]. Very little is known about the operation years. What few accounts have been found are written in local histories[2] and are somewhat repetitive (even in their errors), suggesting that they were gleaned from the same primary and insubstantial source. The Eaton was the earliest furnace of any kind in an area which, by the 1860s, was one of the largest iron-producing areas in the world.

Prior to excavation, very little of the furnace was observable and, like the remainder of the site, was either destroyed or buried under 175 years of erosional overburden. Only the blowing arch (Fig.1) and a small 1.75 m rim segment of the inner lining of refractory sandstone were visible. Evidence, including old photographs, indicated that little more of the furnace than this was exposed for at least the last 75 years. The cover vegetation was so dense with elm, sycamore, wild grape, sumac, and poison ivy that it took 4 full days just to clear the area for gridding.

Excavations[3] covering 3 seasons from 1975 through 1977 were carried out by a crew consisting of 30 Struther's High School seniors, 5 university archaeology students and recent graduates, and a more or less steady supply of university volunteers. The site was divided into 7 major excavation zones, 4 of which were of prime importance. This division served 2 purposes: it allowed for simultaneous sampling and investigation in different areas of the site, and it facilitated deployment of the field crew over the relatively restricted and precarious land area.

The Furnace

The Furnace zone consisted of the furnace structure itself and the fill within its perimeters. Overburden often reached a depth of more than 2 m. Excavation revealed the remains of the entire bosh area, and hearth (Fig.2, 3), measuring 180 cm in height from base to bosh and varying in width between 1.7 m and 1.9 m. The bosh, which is the widest point of the furnace and the structural feature that supports the charge, measured a maximum of 2.7 m in diameter. Based on these specifications, an estimated production rate of 2 tons of cast iron per day seems reasonable.

Table 1 includes a list of various furnace measurements.

TABLE 1 – EATON FURNACE DIMENSIONS

Feature	Dimensions
Furnace height (original)[1]	8.15 m
Height of total remains	4.50 m
Furnace shell (outer wall); thickest point (at base)	2.90 m
Furnace shell (outer wall); narrowest point (at base)	1.56 m
Insulation (middle) layer; thickest point	47 cm
Insulation (middle) layer; narrowest point	20 cm
Inwall, thickest	30 cm
Inwall, narrowest	21 cm
Bosh diameter; widest point	1.90 m
Bosh height[2]	1.10 m
Hearth (crucible) diameter at top	1.05 m
Hearth (crucible) diameter at bottom	95 cm
Hearth (crucible) height	1.87 m
Forehearth width at widest point	3.60 m
Tuyere height	2.85 m
Tuyere depth	2.64 m
Tuyere width; maximum at bottom	1.72 m
Tuyere width; minimum at top	1.23 m
Tap hole height	57 cm
Tap hole width	58 cm
Tymp stone height	52 cm
Tymp stone width	66 cm
Casting floor length[3]	16.5 m
Casting floor width[3]	14.0 m
Wheelhouse foundation floor; length	1.60 m
Wheelhouse foundation floor: width	1.53 m
Wheelhouse foundation floor; height	69 cm
Wheel pit width	2.12 m

1 Estimate based on the location of tipple area on adjacent slope in relation to the remaining furnace base.

2 Measured from the top of the hearth to the widest point (on top) of the bosh.

3 No structural remains were recovered. This measurement is based on stratigraphic and topographic considerations.

The inner stack lining was made from shaped blocks of sandstone ashlar that were cemented with a hard mortar coloured to a brick red. Examination of this mortar showed a consistency quite similar to that of the samples of sand and soil analyzed from the site. In a laboratory experiment red sand from the hearth opening was mixed with water and baked. This process resulted in the creation of a friable concretion not as hard as but not very different from the colour and texture of our mortar sample. This finding leads us to believe that the furnace builders expeditiously cemented their sandstone blocks together with mortar made from local sand or mud and water.[4] The intense heat and pressure produced by the furnace operation hardened and coloured the mortar.

The stack surface was patinated with a thick incrustation of slag, and the tap hole itself was closed with the remains of

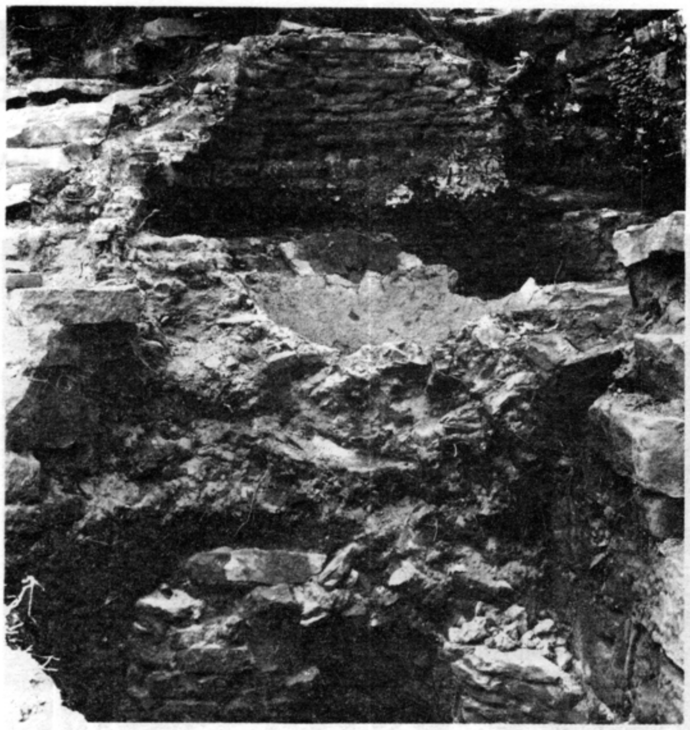


Figure 2 Bosh area of the Eaton Furnace showing inturned bosh and section of inner chimney lining of refractory sandstone. The debris in the centre is the collapsed insulating layer material. The top of the tap hole is visible in the middle foreground.

the furnace's last cast, a part of which upon cessation of the blast had been allowed to cool within the hearth. Remains of the cast, which consisted of a pudding-like conglomeration of charcoal, slag, ore, and iron, was discovered in the form of a long runner extending from the tap hole some 4 m out onto the casting floor. The runner was covered with 100+ cm of erosional soil. This finding suggests that incompletely reduced burden erupted onto the casting floor as a result of a furnace lining failure.

The outer furnace wall was composed of large hand-chiseled blocks of native sandstone, some weighing several hundred pounds. The furnace was built into the gorge slope with the natural sandstone cliff constituting an integral part of its construction. The insulating space between the heavy outer wall and the refractory inner lining was filled with sand that was subsequently oxidized to a bright red-orange by the intense heat generated by the furnace. When the furnace subsequently collapsed, the oxidized sand spilled out over the immediate casting floor area and served as a clear red demarcation between the lower cultural levels on which it sits and the post-1808 sandy loam overburden on top of it.

Figure 3 Plan view of the Eaton bosh. The crucible or firepot had a 2 ton per day maximum capacity.

The casting floor represented the area of maximum furnace activity. The area measured approximately 14 m x 18 m in area and was cleared to a depth of between 10 and 100 cm revealing a flat sandy floor. While no evidence was found of a casting floor shed in this area, such a structure would have been a necessity because even the smallest amount of precipitation coming into contact with the molten iron would cause a violent reaction.

Most of the artifacts that were found came from the casting floor. These included stove parts, fireback fragments, fragments of assorted heavy iron tools, spikes, heavy pins, staples, utensil pieces such as Dutch ovens, trivets and pans; and byproducts of the manufacturing process including sprues and scrap iron (Fig.4). Some artifacts were so encrusted with rust that identification was impossible. Several artifacts were made from wrought iron and must have been brought to the site from elsewhere because there is no evidence, historical or archaeological, of the Eaton's having a forge or facility for their production.

Below the sandy level constituting the casting floor was found an extremely rocky talus level composed of huge slabs and blocks of sandstone that had, through the centuries, detached themselves from the cliff side. Apparently, the furnace builders created the necessary flat casting floor by filling and covering the talus interstices with sand until a level working surface was achieved. Immediately southeast of the flat casting floor was a massive slag bank that sloped steeply from the perimeter of the casting floor to the creek level 11 m below. A cut made into this slag heap at its top revealed evidence that the furnace had undergone some major repair and relining during its use. Relining was done in a piecemeal or patchwork manner rather than by a complete overhauling . Fragments of discarded refractory sandstone were found sandwiched between layers of slag and cinder. The slag bank probably served as the general disposal area for all discarded material.

Zone B was the designation given to a small terrace roughly 6 m x 6 m in area located about 8 m downslope east from the furnace mouth. It was here that the original mechanism for supplying the blast was located. Excavations revealed a stone wall or footing and an almost square, flat sandstone slab floor measuring 160 cm x 158 cm along its sides. This structure was all that remained of the blowing shed or wheelhouse. The overshot wheel turned in the area between the walls and raised and lowered the bellows that rested atop the square slab floor (Fig.5).

The furnace charging area was located approximately 10 m up the cliff face from the bosh. Work was undertaken here to determine what we could about the charging process. We found more fragments of kidney ore, charcoal, and coal in this area than we had anywhere else on the site. This is as it should be, since it was from this spot that the charges of fuel, iron ore, and flux (limestone) were supplied to the furnace. The abundance of high quality bituminous coal in this zone led us to believe that the Eaton (Hopewell) used a combination of charcoal and raw coal as fuel. As the charging area would normally be expected to yield samples

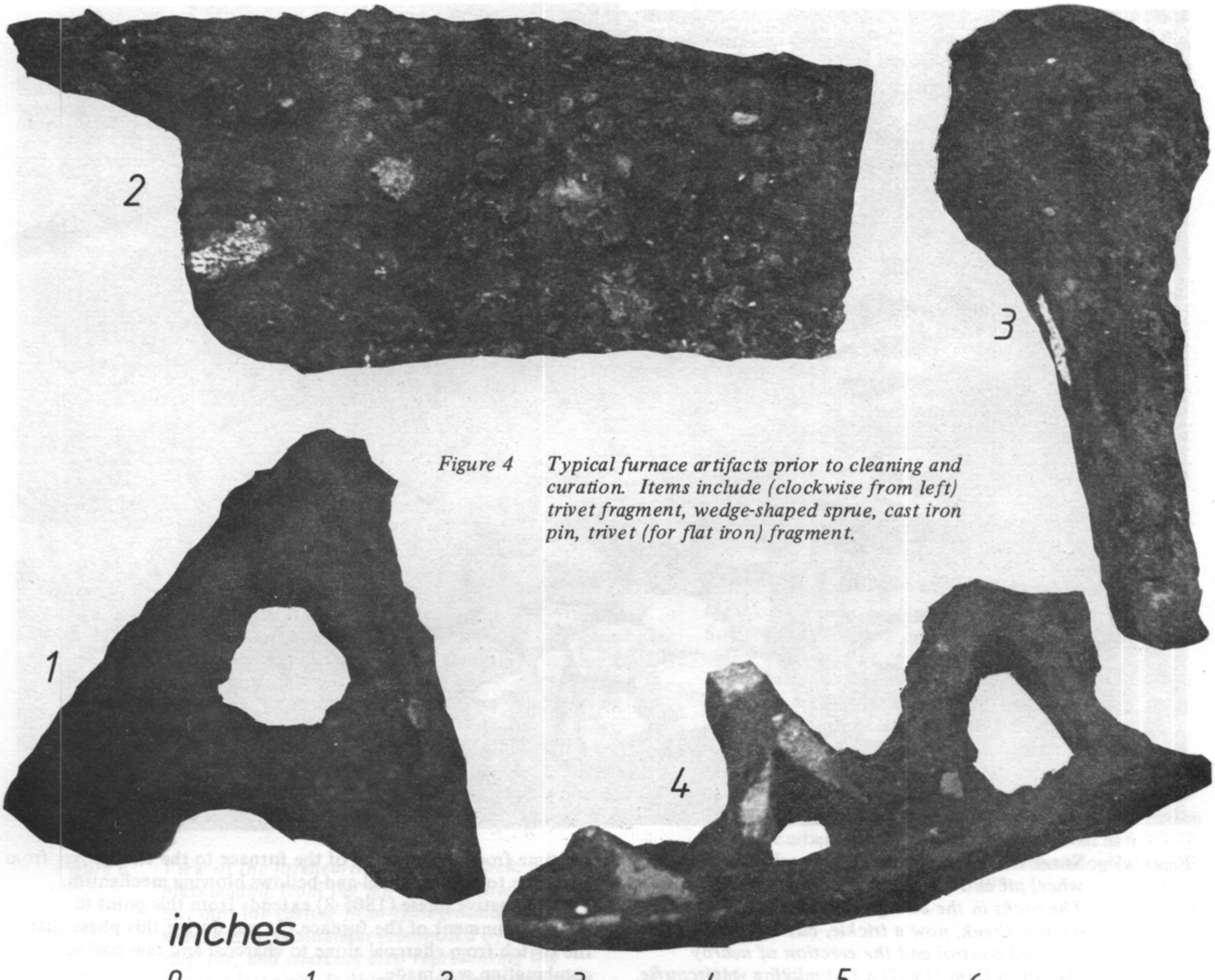


Figure 4 *Typical furnace artifacts prior to cleaning and curation. Items include (clockwise from left) trivet fragment, wedge-shaped sprue, cast iron pin, trivet (for flat iron) fragment.*

of the materials being introduced into the furnace, the recovery, in the upper levels of almost as many samples of coal as charcoal was considered a significant archaeological discovery. Normally such an occurrence would be sufficient support for the conclusion that both materials were used, in combination, as reducing agents. However, in order to provide independent non-archaeological support for this hypothesis, the various materials from the site were submitted to metallurgical and chemical analyses[5] with the following findings.

The Eaton Raw Materials

The ore used at the Eaton site is of the type referred to as nodular ore, a concretionary ore consisting of masses of impure carbonate of iron, often discoidal or ellipsoidal in form. The ore is generally composed of concentric layers or shells made distinct by weathering. The shape and deep red-brown colour is responsible for the name. The Fe_2O_3 content of the samples tested varied between 44.0% and 58.6%, with an average of 51.3%. Loss on ignition ranged between 25.0% and 32.5%. None of the specimens, chosen from various depths and areas of the site, contained measurable amounts of sulphur.[6]

The Eaton charcoal varied in ash content between 1.94% and 7.3%, with an average of 4.42%; and had a sulphur content which ranged between 0.01% and 0.02%, with an average of 0.015%.[7]

The native limestone used as a flux was of a very poor quality having a tolerable silica (SiO_2) content (as high as 33.8%) and a low calcium (CaO) content (27.5%). Premium blast furnace fluxes are usually selected for a low silica-high calcium ratio.[8] In none of the samples was a measurable amount of sulphur found.

When compared to slags from eight other historic furnaces, dating from 1650 to 1850 the Eaton material did not fare well as a desulphurizing slag, even for its time. The sulphur content of the tested samples varied between 0.23% and 0.55% with an average of 0.35%.[9]

Specimens of the Eaton cast iron were very much in abundance at the site where they occurred as fragments of finished (though usually flawed) products, casual droppings, or sprues. Spectrographic and titrimetric analyses established a range of sulphur between 0.055% and 0.17%. One specimen characterized as having 'poor reproducibility' had a sulphur content of 0.22%. The average for all samples was 0.086%.[10]

Figure 5 *Stone structural remains of the wheelhouse with wheel pit and bellows or blowing tub platform. The rocks in the background mark the bed of Yellow Creek, now a trickle, but before the era of flood control and the erection of nearby Hamilton Dam (1907) a fast-moving watercourse.*

It is evident that even the minimum sulphur containment (0.055%) in the finished iron plus the smallest sulphur content of the slag (0.23%) adds up to far more sulphur in the original mix than would be possible with the constituents generally conceded to have gone into the reduction process, i.e. minus the raw coal.

An analysis of the coal specimens taken from the charging area indicates a high quality bituminous coal with a relatively low ash and sulphur content. The sulphur content varied between 0.52% and 0.79% with an average of 0.63%.[11]

The only possible source for the sulphur found in such levels in the finished iron and the by-product slag is the bituminous coal. Archaeological findings and chemical analyses confirm that the Eaton (Hopewell) Furnace used a combination of charcoal and raw coal as the reducing medium.

Chronology of Site Use

Chronologically, the 173 years of site occupation or use were divided into two periods, the Furnace (1802-8) and the Post-Furnace (1808-1975). Each of these periods was subdivided into two phases.[12]

In the Furnace period, the Incipient phase (1802-5) covers the time from the erection of the furnace to the changeover from a trompe to a waterwheel-and-bellows blowing mechanism. The Innovative phase (1805-8) extends from this point to the abandonment of the furnace. It was during this phase that the switch from charcoal alone to charcoal and raw coal in combination was made.

Two important things took place during the Furnace Period: First, during the Incipient phase the furnace owner substituted a more efficient water-wheel-and-bellows system for the earlier and more primitive trompe as a means of supplying a steady air blast to the furnace. In order to accomplish this, the operation had to be shut down for a time, allowing the build-up of a sterile yellow layer which represents the hiatus and distinguishes the two phases of this period. Secondly, during the Innovative phase the entrepreneurs attempted to fore-stall the inevitable shortage of trees for charcoal by utilizing a fuel composed of a mixture of locally available bituminous coal and charcoal. Whereas the former innovation may have improved the efficiency of the furnace, the latter undoubtedly shortened its life. The sulfur introduced by the coal and the tarry residue left by its incomplete combustion were too much for the desulfurizing capacity of the slag and the relatively low temperature achieved in the furnace. When the furnace lining failed and the furnace contents poured out onto the casting floor, the owner did not bother to repair and relight but instead called an end to the entire operation. The critical aspects of this final senario (the lining failure and spillage) are directly evidenced; the furnace's last cast was found in situ as a huge salamander extending out onto the casting floor (Fig.6).

The faunal material (122 specimens) recovered from the structure identified as the ironmaster's house indicates that

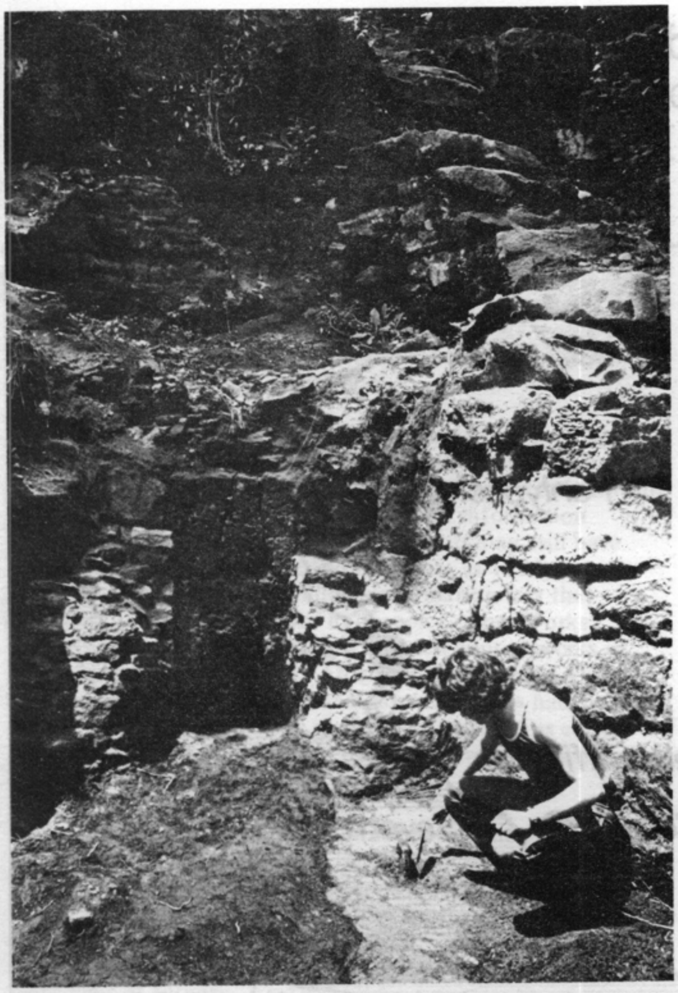


Figure 6 View of the forehearth area. The black, raised mass leading from the tap hole (middle ground) out into the casting floor (foreground) is a **shadrach** *or* **salamander** *(composed of cast iron, slag, ore, and charcoal bits) representing the Eaton's last cast. It plugs the tap hole and rises more than 60 cm into the crucible.*

the occupants relief heavily on Bos (beef) and Sus (mutton) for their meat supply. A large variety of pearlware and earthenware ceramics (2,336 specimens and 22 types), bone-handled pewter cutlery, clay pipes, and brass furniture fixtures attest to a life-style considerably more 'gracious' than might be expected.

In the Post-Furnace period, the Pre-Hamilton Dam phase (1808-1907) begins with the cessation of furnace operation and ends with the construction of nearby Hamilton Dam. During this time, the ironmaster's house continued to be occupied (perhaps by an employee of the Montgomery Furnace, which was established about 3/4 mile downstream at the cessation of the Eaton iron-making activities), and the zone south of the furnace headrace saw use as a staging area in the construction of the dam. The Modern phase (1907-75) extends from the completion of the dam to the excavation of the Eaton site. During this period the site saw only casual and intermittent use.

History credits the Pioneer blast furnace in Pottsville, Pennsylvania with being the earliest blast furnace in America to use anthracite successfully as a fuel in the smelting of iron. This occurred in 1839.[13,14] Prior to that time charcoal was the sole fuel used in American furnaces. Or, at least, this was thought to be the case. Evidence from the Eaton Furnace indicates that the texts will have to be corrected in this regard and the dates moved back to the midpoint of the first decade of the 19th century.

Acknowledgements. Thanks and appreciation must go to the Youngstown State University Research Council grant, support from which allowed for a good part of these excavations and analyses. Frank Galletta and Bob Pristera formerly of Youngstown Sheet and Tube Company did the extremely competent spectro- and wet chemical analyses. Dan Mamula and Dominic Russo and their Steep program supplied funds, equipment and the opportunity to dig the site. A full site report, replete with appendices covering analyses of various site materials, is completed and in search of a publisher.

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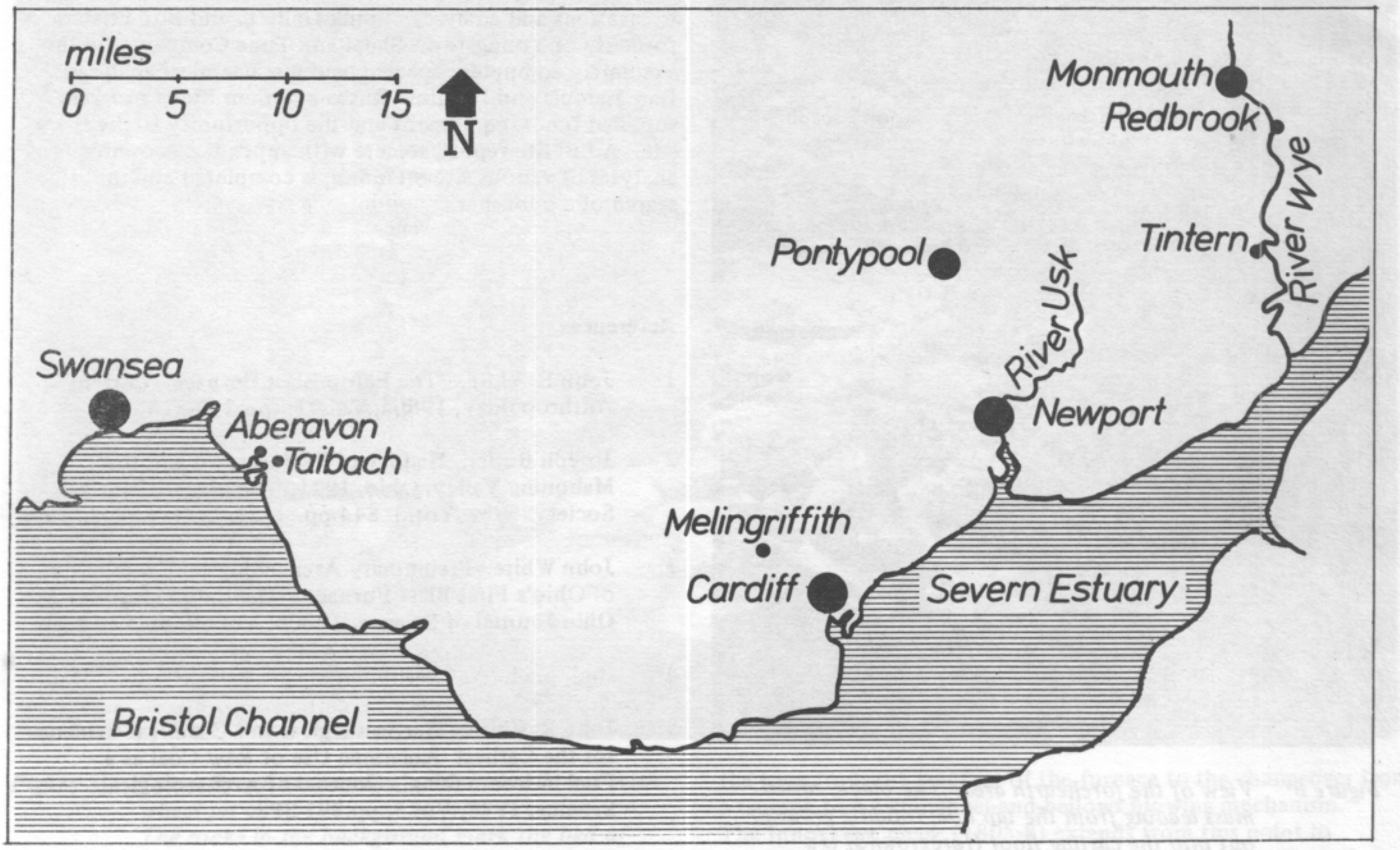
Metallurgy in the Wye Valley and South Wales in the late 18th century. New information about Redbrook, Tintern, Pontypool and Melingriffith

Gordon Tucker and Peter Wakelin



As part of a general investigation of manuscripts in the National Library of Wales describing tours in Wales during the early period of the Industrial Revolution, Peter Wakelin discovered the two manuscripts to be discussed here, and noting their significance, drew the attention of Gordon Tucker to them; the critical examination of the industrial parts of the narrative is due to the latter.

The more important manuscript is NLW MS 6497C[1], a handwritten book of 113 pages, the text being on the right-hand pages, while the left-hand pages contain inserted water-colour paintings, unfinished sketches or annotations, or are blank. Pages 1-97 contain the diary of a tour which starts at Clifton (Bristol) on Tuesday 16 July, and after visiting the Lower Wye Valley and parts of Monmouthshire and Glamorgan, returns to Clifton on Tuesday 20 August. The year is not stated in the MS, but we show below that it was 1782. Pages 99-113 appear to be a technical appendix which is reproduced in its entirety below.

The other document is NLW MS 2589B[2]. It is a printed book of 1775 with interleaves on which manuscript descriptions have been added; the date of these has not been precisely determined, but is undoubtedly in the last quarter of the 18th century.

The more important matters which emerge from these sources are:

1. The Redbrook copper works were still operating in 1782.
2. Cannon were being cast and bored at Tintern in 1782.
3. Iron slag was crushed by wooden stamps at Tintern in 1782 for supply to the glass industry of Bristol, the heavier iron-rich components of the crushed slag being separated by gravity in running water for re(s)melting.
4. Cylinders replaced bellows for blowing at Tintern between 1782 and 1788.
5. In the late 18th century iron wire was still being drawn at Tintern and Pontypool by the intermittent 'tongs' method which had seemingly changed little over two centuries.
6. Reverberatory furnaces were apparently in use in iron-making at Pontypool in 1782.
7. Iron ore was won near Pontypool by hydraulic (scouring) methods as late as 1782.
8. The condition of the workers at Monmouth and Tintern in 1782 was very poor, but much better at Pontypool.
9. A detailed account is given of the process of making tinplate at Melingriffith in 1782.

A more detailed discussion of these matters, and their historical importance, will now be given. A critical examination of the dating and authenticity of MS 6497C then follows, with finally a transcription of the relevant parts of the MSS.

Redbrook Copper Works

There has hitherto been much uncertainty about the dates of closure of the copper-smelting works at Redbrook, near Monmouth. It seems generally agreed that the works at Upper Redbrook, which were associated with the Coster family[3] had ceased operations in the 1740s or perhaps early 1750s, although Jenkins[4] allowed more latitude: 'The last we hear of the Upper Redbrook works is in the year 1786 . . . Probably it was then idle and had been so for some years'. Certainly the Swedish traveller Angerstein, reporting on 28 June 1754, stated that the upper works were not then in operation[5] and Joan Day in her book[6] reaches this conclusion from other evidence.

The works at Lower Redbrook were operated by the English Copper Company. In one paper[7], Jenkins avoided making any statement on the date of closure, which may be significant since in the earlier paper cited he had used information given by Phillips[8] to suggest that operations may still have been carried on at Lower Redbrook as late as 1790, 'no doubt on a small scale'. (Phillips' information was that John Wright, 'who came from Redbrook Copper Works', took over the management of the Taibach copper works of the same company in 1790). Although Hart (see ref.4) seems to suggest that the Lower Redbrook works had closed in c1740, the date of closure could not have been as early as this because Angerstein reported these lower works as being in operation in 1754.

There is a suggestion of one of the copper works at Redbrook being still in operation in 1787 in the diary of Viscount Torrington[9]. During a boat trip down the Wye from Monmouth on 28 July 1787, he observes 'the Red Brook where are great copper works'; but this is only a casual reference with no evidence of the works actually producing smoke or other signs of activity. Certainly there seems to be no positive evidence hitherto of operation after 1754.

The information that copper works at Redbrook were still in operation in 1782 is thus a significant contribution. The MS does not indicate whether it was the Upper or Lower works which were active, but from the evidence cited above, it must clearly have been the Lower. Unfortunately no mention is made of the number of reverberatory furnaces used, and no estimate can be made of the scale of operation. There is, however, the statement on p.73 of the MS that the copper works at Aberavon were 'much inferior to those at Monmouth', and as the former were then in full swing, the inference is that the Redbrook works were fully active. There is, too, the reference on p.109 of the MS to a rolling mill in use at Redbrook; moreover, the long description of the water-powered rolling and processing of copper on pp.101-3 of the MS appears to pertain to Redbrook. Although there is ambiguity, it is unlikely to be the works at Aberavon which are being described, since Phillips[10] is emphatic that there was no rolling mill there before 1800.

Cannon at Tintern

There are two references in MS 6497C to cannon-making at Tintern; in the diary of the tour itself the travellers apparently saw the 'boring of Cannon', and in the technical appendix it is stated that the Tintern furnace was 'originally intended for casting of Cannon'.

There is other evidence of cannon-making at Tintern at this time. Viscount Torrington[11] in his diary of a tour in 1781, describes how on the 16 June he was travelling from 'Trelach Grange' (Trelech Grange) to Tintern, and passing the works in the wooded valley (of the Angidy), 'approach'd a noble foundery of cannon'.

In visiting Chepstow later the same day, Torrington saw on the quay 'incredible numbers of iron water pipes (like cannon) each 9 feet long and weighing about 800 weight, which are going to France . . . near 21 miles of them are sent'. Grey-Davies[12] infers they came from Tintern and says 'Some writers say that they were cannon being sold to the French . . .' but does not give a reference to such a writer. Obviously some confusion was possible, but Torrington seems to make a clear distinction between cannon at Tintern and water pipes at Chepstow. But in any case, it is more likely that the latter came from Bersham in Denbighshire than from Tintern[13].

As water pipes would hardly need to be bored, the reference to the boring of cannon in MS 6497C would appear to be positive evidence of cannon-making at Tintern, confirming Torrington's casual reference.

At what site in the Angidy Valley at Tintern the cannon were cast is not made clear; direct casting from the blast furnace would seem to be ruled out by the topography of its site, so that remelting of the pig iron in another furnace is probable.

Crushing of Iron Slag by Stamps at Tintern

There is ample evidence elsewhere[14,15] of the fact that slag was crushed and powdered by stamps at Tintern (and other places) in the 1780s, with the suitable components being sold to the Bristol glass works. There were certainly water-driven stamps at the furnace in 1821[16]. What appears to be new in the description in MS 6497C is that the stamps were wooden (seemingly also the heads, although we must assume they were shod with iron). One would have expected cast-iron heads by this period, as in Cornish stamps[17]. The expression 'the light part . . . is carried down the stream which turns the wheel' accords well with a sloping paved surface below the terminal stone structure of the leat at Tintern, which has been uncovered in the recent excavations; above this surface and linked to the leat is a channel which might have been the wheel-pit of a small undershot wheel coupled to the stamps.

The leat referred to was the main water channel providing power to the furnace site; from the terminal basin the main water flow was taken, by an aqueduct, itself carried on piers the plinths of which still remain, to the large overshot wheel which drove the bellows; the diameter of 30 ft given in the MS accords reasonably well with the archaeological evidence.

There is difficulty over the statement in the MS that the heavy part of the dross, after stamping and separation by washing, is carried to the furnace and re(s)melted. According to analyses tabulated by Tylecote[18], blast furnace slag contained very little iron; since, however, finery and chafery slag had a high iron content, it seems possible that the slag concerned was of the latter type. This view is strengthened by the fact that the subject is mentioned in the MS immediately after the statement that the metal from the blast furnace must be twice melted (finery + chafery ?) before it is pure enough to make bar-iron. On the other hand, Hart (ref.14) quotes George Wyrral as saying that the 'scruff' from the furnaces (which he clearly distinguishes from forges) contains 'considerable quantities of granulated iron, and also of ragged lumps . . .'; there is also little doubt that Shaw (ref.15) thought that the dross was from the furnace.

Replacement of Bellows by Cylinders for Blowing at Tintern

It is known that blowing cylinders were in use at Tintern furnace by 1788 because Shaw mentioned them in that year (see ref.15) and Mushet[19] makes it clear that the blowing cylinders at Tintern were of iron in c 1800 and that this use of cylinders was the first such use in a charcoal blast furnace in this country. The principle of iron cylinders replacing bellows at ~~blab~~ furnaces was, however, then over 30 years old, although not widely applied[20]. It is therefore of some interest that the MS of 1782 indicates that bellows were still in use then, thus dating the introduction of cylinders at Tintern to between 1782 and 1788. We feel justified in asserting that the MS description really does mean bellows and not cylinders because of the expression 'the mouths of two immense pairs of bellows'; cylinders do not have mouths, and two cylinders would not have invoked the term 'two pairs of bellows'. A 'pair of bellows' is, of course, a single piece of apparatus, and 'pair' would not be used in reference to something so essentially singular as a cylinder. That two pairs of cylinders (ie 4 in all) was not meant is supported by the fact that in 1821 a schedule of plant at the blast furnace included only 2 cylinders (see ref.16).

The description of the shape of the furnace in the MS is curious and hard to follow, but as visitors were unlikely to have seen the interior for themselves, this point is perhaps of little importance.

Wiredrawing at Tintern and Pontypool

The descriptions of the intermittent wiredrawing process and of the scouring process given in MS 2589B accord well with the postulations of Paar and Tucker[21], thus adding valuable support to their paper.

Reverberatory Furnaces and Slitting Mills at Pontypool

In the description of the ironworks at Pontypool (p 109 of MS 6497C) it is stated that 'the furnaces exactly resemble . . those made use of at the copper-works near Monmouth'. The latter were clearly stated to be reverberatory furnaces. In the description of iron-making it almost seems to be suggested that the reverberatory furnaces were used for smelting. Assuming this was not the case, it still leaves a puzzle, for Cort's reverberatory method of refining iron was not invented until 1784, Peter Onions experiments of 1783 at Coalbrookdale were in any case unsuccessful, and the reverberatory furnace of the Cranage brothers had been abandoned in 1767[22]. The 'potting' process, which also used reverberatory furnaces[23], does not seem indicated by the description, and in any case was little used until the 1780s. On the other hand, there may have been some confusion on the part of the observer; the furnaces may have been part of a foundry and could then have been 'air furnaces' of reverberatory type, used for re-melting pig iron[24]. Such furnaces were in use well before 1782.

On the same page of the MS is a detailed description of a slitting mill (the word 'slitting' being incorrectly written as 'tilling'). This accords exactly with the first recorded drawing of a slitting mill in England as given by Schubert[25], with date of 1758; the principle is different from that described by Plot in 1686[26].

Hydraulic Winning of Iron Ore near Pontypool

The graphic description of the methods of winning iron ore by crude rushes of water from upland reservoirs – variously known as scouring, patching, or hushing – is striking, particularly for the casual acceptance of the fatalities caused to the workers (a factor not noticed in other accounts), and also because one might have expected the practice to have ceased at Pontypool by 1782. Iron had been worked there for 200 years or so, and it would not have been surprising if the superficial ore (which alone could be obtained by scouring) had been exhausted.

Schubert[27] mentions that the practice of scouring persisted in places in South Wales until the early 19th century, and it was indeed quite usual then in the hills above Merthyr Tydfil and Ebbw Vale[28]; even as late as 1890 it was used at Maesteg in West Glamorgan[29]. At Pontypool it had certainly been practised in the mid-17th century[30] and extensively applied thereafter[31]. However, Coxe, only a few years after 1782, refers to true mining for iron ore near Blaenavon, only a few miles away[32]. Thus the description of scouring at Pontypool in 1782 in MS 6497C is important in establishing that the process was still in use there.

It was, of course, not only iron ore that was won by this method. Lead ore, in particular, was commonly obtained this way, and not only in Wales, but even more in the North of England.

It is fair to say that iron mining in South Wales is very poorly covered in the historical literature – in great contrast to coal mining.

The Condition of Labour

It is evident from MS 6497C that the condition of the workers in the Monmouth – Tintern area was very poor :

> 'At Tintern the misery and want endured . . . were extreme; at Pontypool, their situation was very different . . .' (pp 43-5).
>
> 'Labour is so cheap at Monmouth' (p 103).

This confirms what had been suspected before, that the industrial enterprises in the Lower Wye Valley had become severely run-down in the later parts of the 18th century. Yet the apparent prosperity of the workers at Pontypool is qualified by the description of the conditions of getting iron ore, already discussed above.

Tinplate Works at Melingriffith

In 1782 tinplate making was relatively new in Britain and the Melingriffith works were among the more important. They were first begun in about 1759, and in 1768 came into the hands of the firm which later became Harford, Partridge & Co. A history of the works has been given by Minchinton[33].

The description given in MS 6497C of the process of making tinplate, with all its complicated operations, is remarkably full, and much more detailed than any other account of that period known to us[34]. It is reasonable to believe it is accurate, as it accords reasonably well with descriptions of the process at a much later date.

The use of the term Block Tin is not understood. Since our transcription of the MS is correct, there must be an error in the MS itself.

Dating the Manuscript, No. 6497C

It seemed to us that the manuscript could not possibly be as late in origin as the 'circa 1809' quoted by the Department of Manuscripts at NLW. The copper works at Redbrook were in full swing according to the MS, yet we know from other sources that they must certainly have closed by 1790 at the very latest[35].

Reference is made in the MS to the sheathing of ships with copper, which, although known from the 17th century as discussed by Tylecote[36] in connection with Charles II's Dutch-built yacht Mary, nevertheless did not start on the widespread basis suggested in the MS until the 1760s [37]; to the tinplate works at Melingriffith, which did not start until 1759 [38], and above all, to the Aberavon copper works (presumably the works at Taibach) which did not start production until 1774 [39]. It is thus clear that the MS must refer to a tour made between 1774 and 1790.

In the year of the tour, 20 August (the day of return to Clifton) was a Tuesday, as clearly stated in the MS. This means that within the limits given above, the year of the tour could only have been 1776 or 1782. The activities at Aberavon seemed to be in such full swing that 1782 seems more likely than 1776.

Having reached this conclusion, from the internal evidence, we thought of consulting the Department of Maps and Prints at NLW in case they had any information on Rose Sotheby who had signed so many of the watercolours in the MS. Mr M Davies was able to turn up some typescripts in a file, which led us to two notes published by Jerman over 40 years ago [40]. These made it clear that the spine of the original binding of the MS had the lettering 'WELSH/TOUR/E.S./ 1782', making it quite certain that the date 1782 provisionally determined from internal evidence was indeed the correct one. It is interesting to note, however, that the Department of Maps and Prints considered that the pictures had been added to the script at a later date, within the range 1786 – 1799; and that the volume had been bound in 1799. The initials ES were considered to be those of Elizabeth Sotheby, sister of the Rose Sotheby who did the paintings and drawings. We could detect no difference in the writing between (a) the signatures on the pictures, (b) the main diary of the tour and (c) the industrial/technical appendix. It is therefore possible that the manuscript was written some years after the tour, and this, on its own, would leave the possibility that the appendix had been based on information of a later date than the tour itself. It is noteworthy that while the diary of the tour is written in the first person, the appendix is written impersonally, as though it had been copied from some other source. Nevertheless, the writer of the diary had actually visited the copper works at Aberavon and compared them with those near Monmouth (p73 of MS; see also p25), and on the whole it seems reasonable to give the date of 1782 to the whole of the contents of the MS. However, a later date, up to the limit of 1790, would not alter the significance of most of the matters discussed earlier in this paper.

That the technical appendix was, in fact, itself a transcription of some other document by someone not well versed in the technicalities, is attested by two transcription errors on p 109 of the MS: 'Tilling-mill' appears twice, but, as indicated in square brackets in our transcription below, the first time it clearly should be Slitting-mill, and the second time Tilting-mill. This then leaves the possibility that the appendix, although written into the MS in 1782, was based on an earlier document. We have shown above, however, that it could not have been earlier than 1774, and again, even this date would not seriously diminish the significance of the contents.

TRANSCRIPT OF PORTIONS OF MS 6497C, TAKEN FROM THE MAIN DIARY OF THE TOUR, RELATING TO METAL WORKS.

p19. From Tintern Abbey we proceeded to the Iron-works in the Neighbourhood, & to see the boring of Cannon; this last is well worth notice; but the Others are in much greater perfection at Pontypool.

p25. The 22nd. we saw the Copper-Works, w^{ch}. are three Miles from Monmouth, on the lower Road to Chepstow, and were much entertained with them.

pp43 & 45. The 29th., in our Way to the Iron-Works, belonging to Mr. Hanbury; they are chiefly situated in his fine Park, w^{ch}. is remarkably well wooded, & prettily water'd by the small River Byrthia –– Pontypool owes its very Existence to these Works, & may probably in the Course of a few years, become a Place of consequence, as the Mines in its Neighbourhood, contain a great Quantity of very good Ore, altho' not so rich as that w^{ch}. comes from Lancashire, with w^{ch}. the Tintern Forges are supplied –– At Tintern the Misery & Want endur'd by the Workmen & their Families were extreme; at Pontypool, their Situation was very different; th^{r}. constant Pay is 9 Shillings a Week, & they are allow'd a House, & as much Coal as they chuse; we saw one of these Families sitting down to Dinner, on a roasted Shoulder of Veal, & a Dish of Peas, by the cheerful Blaze of a Fire, that might be envied by many a reputable farmer.

p73. At Aberavon we stopp'd to see the Copper works, but found them much inferior to those at Monmouth – The Workmen's Houses are dispos'd in a very pretty Manner, in two strait Lines, at some distance from each other on the Declivity of a very steep Hill; the Works are on the other side of the Road, & as they are large & built of Brick, they mutually give & receive Ornament, from the Contrast of the small whiten'd Tenements opposite to them.

TRANSCRIPT OF INDUSTRIAL / TECHNICAL APPENDIX, PP99-113 OF MS 6497C.

p99] Some Account of the Copper Works near Monmouth &c:

All the Ore here us'd is brought from Cornwall; in the first Place it is calcin'd, that is put into a slow Heat, & continually stirr'd, till y^{e}. greatest part of the Sulphur & Arsenic, which originally bind it, are evaporated; & till it becomes a black Powder –– During this Operation, a thick yellow Smoke hangs over the Works, which is very unwholsome, as well as detrimental to Vegetation – The Ore is then put into a reverberatory Furnace, resembling an Oven; the Fuel, which is Pit-Coal, is put in at the Back of the Furnace, & there is a Grate under it, the Ore is put in at the Mouth; & when melted (which takes up 4 Hours to a Ton weight of it) the Furnace is tap'd, that is the Ore is let out thro' an Opening at the Side (which had been previously stop'd with Sand) on removing of this, & breaking a Passage in the coarser Ore, the purer Copper bursts out in a most beautiful Torrent of liquid Fire, runs into Moulds prepar'd for it in Sand, & is broken in pieces by throwing wet Sand upon it, where you wish to divide it –– At the Copper-works at Aberavon, the first tapping of the Ore, is run into cold Water, which not only breaks it into small Particles resembling Shot, & makes it fit for a second Melting, without their having the trouble of pounding

p101] it, but also clears it of all the remaining Sulphur, which is left swimming at the Top of the Water – This is an entire new Method –– The Ore is sometimes melted 8 or 10 Times, according to the different Purposes for which it is to [be] us'd –– The second Melting at Aberavon, is sent to Birmingham, & when a little qualified there, makes the white Metal Buckles &c &c –– The coarsest Copper is beat with an immense Hammer, upon an Anvil of cast Iron, to make Bottoms for Boilers &c –– That a little finer is roll'd into Plates, for sheathing of Ships, & for the better sort of brasiery Work: this is perform'd by means of Two small Iron Rollers fix'd one above another which turn inwards, & are brought closer & closer together by a Screw, according to the degree of thinness requir'd for the Plate; This is taken out of the Fire red-hot (in a pair of iron Pincers) & push'd between the Rollers; it is received in like Manner on the other Side, pass'd over them, & push'd thro' again & again, till it is arriv'd at the proper length, by which they judge of the thickness, as the Plate never increases in breadth –– The finest Copper of all, is ladled into Water, in order to mix with Bath Metal &c –– The Copper prepar'd for Brass, is poured into Water, thro' a Vessel with Holes in it, this they call Copper Shot –– They have

p103] within a few Years made a Discovery, of what is call'd Japan Copper, this is a secret only known here & at Swansea; it is form'd into small Bars, about 8 Inches long & 2 round, it is very highly varnish'd & of a most beautiful Colour –– The Chinese clip this Copper into small Pieces, stamp it with the Figure of one of their Pagods, & pass it as Money –– The Emporor of Japan us'd to carry on a great Trade with this in the East Indies, which we now begin to partake with him –– The Hammers, Rollers, & an immense p^{r}. of Shears made use of for cutting Copper of a great thickness, are all mov'd by Water-wheels –– The Copper-dross is run into various Moulds; these Bricks are sold for six-pence a Load, & could they be cheaply transported would be the best Materials possible for Building, as they become a fine vitrified black Stone, which nothing but the greatest Force can destroy; it is what all the Walls near Bristol are cop'd with – Notwithstanding the Copper passes thro' so many operations, yet Labour is so cheap at Monmouth, that it does not (even with the additional Expence of Fuel) bear the proportion of One Tenth to the Value of the Metal.

Some Account of the Iron-Works at Tintern & Pontypool.
The Blast, or Smelting Iron at Tintern is extremely curious. The Furnace is larger than those commonly us'd for this purpose, it being originally intended for casting.

p105] of Cannon; The Shape of it is a Cone revers'd, which from the lower End widens again, & forms a Square down to the Hearth; this Hearth has a very small opening behind, & a large One before; to that behind are directed the Mouths of Two immense p^{r}. of Bellows, that play alternately (by means of a Water Wheel 30 Feet in Diameter) & keep up a constant Blast, w^{ch}. acting on the melting Substance as it falls slowly thro' the narrow Part of the Cone, carries off the Dross at the opening before, while the purer Metal falls into a Channel in the Hearth, thro' w^{ch}. it is conducted into Moulds prepar'd for it in the Sand (these are call'd Sows, & from thence it derives the Appellation of Pig-Iron) & is broken in pieces in the same Manner as the Copper is –– The Furnace is charg'd (that is the Ore & Charcoal are put in) at the Top, where is a small opening; they are put in alternately; a Basket of Charcoal & 500 ℔ Weight of Ore, are half a Charge & in this charging the greatest Nicety is requir'd in regard to the Quantities –– As the power of the Blast is not sufficient to seperate at once all the Dross from the Metal, it must be twice melted before it is pure enough to make Bar-Iron: The Dross is also broken up, by means of several immense wooden Pestles, rais'd alternately by a Wheel: The light part of it (call'd the Cinder) is carried down the Stream which turns the Wheel, into a place appropriated for it, from whence it goes to Bristol, & serves as one of the Materials

p107] to make Glass of; the heavy part is carried to the Furnace & remelted –– All the Ore us'd at these Works comes from Lancashire –– At Pontypool the Iron Mine is about Two Miles & a half from the Works; it contains a great quantity of very good Ore, altho' not so rich as what comes from Lancashire; it is of two sorts which must be mixed together with an Addition of Lime-stone in order to make good Iron –– The Method by which they are procur'd is this –– The Ore is contain'd in a Rock, the upper part of w^{ch}. is of Lime-stone, & underneath is a Strata of Coal; when any of the Ore appears, a Torrent of Water is let down (from a Reservoir made at the top of the Mountain) upon it, to cleanse it from the Earth with which it is envelop'd; this Torrent also forces off large pieces of Rock, which falling into the Stream, the Water is stopp'd, & the Ore picked up by Women & Children, who gain a very good altho' a hazardous livelyhood by it; as the Reservoir sometimes gives way, & the Water rushing down with irresistable Fury, destroys in a few Minutes the Labour of Months, & put an instantaneous End to all the poor Wretches engag'd in this dangerous Employment –– This Method serves for the **Pin-Ore** –– The Other call'd **Vein-Ore**, runs in Veins in the Rock; it is no sooner discover'd, than the Earth is wash'd away in the Manner already describ'd, the Iron is then dug out, & when that Vein is lost, they proceed to wash away the Rock, until they find Another.

p109] The Furnaces exactly resemble both in Figure & Operation those made use of at the Copper-works near Monmouth –– The Ore is first calcin'd –– Then made into Pig-Iron –– When the Pig-Iron is taken out of the Troughs, it is heated again, till nearly in a state of melting, & then carried in Tongs, to receive the Stroke of a Hammer weighing 600 ℔, & w^{ch} repeats the Blow every Moment; the Pigs are sometimes heated 3 or 4 Times before the Bar-Iron is compleated – The Bar-Iron is then carried to the hammering Mill, where the Iron is brought to a greater degree of Density, by closing up the Pores of the Metal, thro' the means of Hammers, whose Strokes descend twice in a Moment altho' they weigh 704 ℔. This is in order to make the Iron fit for cutting Instruments, & for whatever requires particular Strength –– In the Cutting-mills, cold Iron Bars of the size of the small of the Leg, are divided into any given Length, (by a p^{r}. of Shears, whose Edge is an Inch wide) with as much Ease as Paper is cut with common Scissors –– The Bars are then made into Plates (These plates are y^{e} 3rd. of an inch in thickness.) in the same manner as the Copper is roll'd at Monmouth –– They are next carried to the Tilling-mills [Slitting-mills] where they are sever'd lengthways, to make Wire-rods, Nails &c &c; this is done by means of Two Iron-rollers with Grooves in them, betwixt w^{ch}. they are plac'd red-hot, & One Turn thro. these Grooves compleats the Work – These Iron-rods are then carried to the Tilling-mill [Tilting-mill], where they are again made red-hot, & plac'd under a Hammer of 56 ℔ Weight, w^{ch}. gives 286 strokes in a Minute; a Man turning them

p111] about very fast, that no two Strokes may light on the same Place, his Seat is plac'd in a Groove, that he may retire as the Rod lengthens, & is drawn out into a coarse rough sort of Wire –– These jagged Rods are then carried to the Wire-works, where they are first temper'd, & afterwards plac'd in Troughs for 6 Weeks, with Water constantly dripping on them; they are then pull'd with Violence thro' an Engine in w^{ch}. there are Holes successively smaller & smaller, till y^{e}. Wire arrives at the required Fineness –– It is impossible to describe the Nauseousness of the Smell occasion'd by what is call'd the tempering Pickle –– In these Works all the Instruments that act upon the Metal to mould it into such a variety of Shapes are of Cast-Iron, & are mov'd by immense Water-wheels of the same Materials.

Some Account of making Block Tin at Melin Griffith

The Iron is at first made into Bars of 10 Inches & ½ in length, 3 in breadth, & 2 in thickness; after having been 3 Times heated, doubled, & pass'd thro' Rollers, it is converted into 8 Plates, each 14 Inches in length, great care having been taken every Time they pass'd thro' the Rollers to seperate the Folds; the Edges are then cut smooth, & the Sheets reduc'd to the proper Size; these are successively laid in 3 different kinds of Pickle; & after has been bent in such a Manner, that a

Man can take up a Dozen at a time, they are again heated; when taken out of the Furnace, they are slightly struck against the Ground, in order to beat off those Scales w^ch^. they

p113] have contracted from the Pickle being hardned in the Fire; & when cold they are again pass'd thro' the Rollers, to smooth them entirely; they are afterwards put into 2 other sorts of Pickle: & 3 Times scowered with Hemp & Bran: The Iron Plates are now fit to be put into the first Pot of Block Tin (on the surface of which is a Coat of Tallow an Inch thick to make the Tin adhere to the Iron) where they lay half an Hour; they are then carried to the last Pot, where having been only dipp'd in, they are brush'd over to make the Tin lye smooth & equal, thrown into hot Grease to take off any superfluous spots, & scower'd 3 Times more; they are then pack'd up 150 together, in Boxes, which compleats the whole of the Business.

TRANSCRIPT OF NOTES ON IRON AND WIRE WORKS AT PONTYPOOL AND TINTERN IN MS 2589B.

There are two Forges for converting Pig-Iron prepared from the Ore dug in the Neighbouring Hills behind the Town into Bars & Plates for every Use. The Ore is smelted at a Furnace near the Mines about two Miles from Pontypool, & cast into Pigs. The Refiners mixt two Sorts of Ore together for smelting both w'ch are found in the Neighbourhood contained in a Sort of Peables; The Ore is of a rusty Color, w'ch is dug in large Pieces, but seperates into smaller Portions on being exposed to the Air. This is the richest Ore. The other is of a much lighter & whiter Color, not so rich; & helps the former in fusing w'ch would not so easily seperate from the Stone without it. However the Dross that comes from the Ore in Smelting is very serviceable to the Wyre-Drawers, who use it in polishing the Wyre, breaking & putting it with the Wyre into Cylindrical Trunks fastened to the Axle of a Water-Wheel; w'ch turning the Cylinders, the Dross by Friction assisted by Water polishes the Wyre, wearing off the Rough Particles of the Wyre by its superior Hardness. The Iron Forges are the same as that at Tintern, & the Wyre-Drawing Machine is the same likewise with that at Tintern. The Latter Machine is very simple, & worked by a Water-Wheel, w'ch turns a long Cylinder of Wood, on w'ch at distinct Distances are fixed iron Cylindical Rowlers fastened to two Pieces of Wood let into the large Cylinder. These Rolers as the Cylinder turns round strike the lower End of a beam w'ch by its middle is fixed in the Floor above, being half above, half below the Floor; This Beam plays on y^e^. pin it is fastened by, backwards & forwards as the Rolers strike it. And as soon as the Roler has passed under it a Chain fastened by one End to the Beam at the Bottom pulls it back with a Spring occasioned by a flexible Stick to w'ch the Chain at the other End is fastened. By this Motion the Beam pulls backwards & thrusts forwards an Iron Rod about 2 Foot long fixed to its upper End. And at the End of the Rod is fastened a Pair of Pincers made in this Form [a space is here left for a diagram, but none is included]. These Pincers are fixed to a Piece of Wood w'ch moves on an inclined Plane whose greatest perpendicular Height is next to the Beam aforementioned. The Thrusting of the Rod opens the Pincers w'ch close on being pulled back, so that when a Bit of Wyer is applied to the End of the Inclined Plane, the Pincers, w'ch descend to the Point of it, catch the Wyer & draw it towards the Beam before mentioned. It is a Man's Business to apply the Wyer thro an Iron Gauge, w'ch is bored with Holes of the several proper Sizes for the Wyer; The Pincers dragg the Wyer thro' these Holes w'ch transmit it of the requisite Size.

Acknowledgements

Many people have helped greatly with advice and information. Thanks are due to Mr Stephen R Hughes for suggesting the study of the MS accounts of tours in Wales held at the National Library of Wales, and to the staff of the Library for their co-operation. Mrs Joan Day suggested the equation of Aberavon with the Taibach copper works, and supplied the paper by Phillips, together with some other useful ideas. Mr R O Roberts kindly answered questions about Taibach. Professor J R Harris drew our attention to the potting process and to the paper by Chaloner. Mr David Bick gave a useful perspective on scouring or hushing, and Mr Reg Nichols supplied much useful information and some references on the application of the process at Pontypool. Miss Amina Chatwin and Mr S D Coates read the paper in draft and made constructive suggestions which have much improved the commentary.

References

1 Mr Dafydd Ifans of the Department of Manuscripts and Records at N L W has given the following information:-

The official description of N L W MS 6497C reads:

'A TOUR IN MONMOUTHSHIRE AND GLAMORGAN. A journal of a tour through parts of Monmouthshire and Glamorgan during the early part of the nineteenth century [circa 1809]. The volume is illustrated by over thirty water-colour drawings and unfinished pencil sketches by Rose Sotheby, some of them being original drawings by her and others being after Gilpin, Grimm, and J Smith. One original water-colour drawing, dated 1809, is by Maria E Sotheby, **English,** XIX cent.' This manuscript was purchased by the Library from Messrs Hodgson & Co., 115 Chancery Lane, London WC2 on the 24 October 1929, and was repaired and bound at this Library in 1964.

2 Mr Ifans has given the following information:-

The official description of NLW MS 2589B reads as follows:

'A TOUR IN WALES. An interleaved copy of Henry P Wyndham: **A Gentleman's Tour through Monmouthshire and Wales** . . . 1774 (London, 1775), with comments and notes by another traveller. **English.** XVIII cent.' The manuscript contains the following note: 'Bought from Mr F Crowe, Wrexham 21/10/1914 £1.1.0. The MS notes are in the autograph of Thomas Pennant.' Our accession register confirms this information. The volume was repaired and bound at our Bindery in 1963.

3 Joan Day, 'The Costers: Copper smelters and manufacturers', **Trans Newc Soc, 47,** 1974-6, pp 47-58.
C Hart, 'The Industrial History of Dean', David and Charles, Newton Abbot, 1971, pp 108-111.

4 Rhys Jenkins, 'The copper works at Redbrook and at Bristol', **Trans. Bristol & Glos Archaeol Soc, 63,** 1942-3, pp 145-167.

5 R R Angerstein, 'A Journey through England in the years of 1753, 1754 and 1755', from archives of Jernkontoret, Stockholm. English translation in the Library of the University of Liverpool; copy of relevant portion kindly supplied by Mrs J Day.

6 Joan Day, 'Bristol Brass', David & Charles, Newton Abbot, 1973, pp 70-71.

7 Rhys Jenkins, 'Copper smelting in England: Revival at the end of the seventeenth century', **Trans Newc Soc, 25**, 1943-4, pp 73-80.

8 M Phillips, 'The Copper Industry in the Port Talbot District', **Trans Aberafan and Margam Historical Soc, 6**, 1933-34, pp 91-113.

9 'The Torrington Diaries' ed C B Andrews, Eyre & Spottiswoode, London, 1934, Vol.1, p 270. The diarist was the Hon John Byng, who only later became Viscount Torrington, but we use the latter name to avoid confusion.

10 M Phillips, op cit; and A L Evans, 'The Story of Taibach and District', Port Talbot, 1963.

11 'The Torrington Diaries', op cit, p 23.

12 T G Grey-Davies, 'A metallurgical history of the valley of the Wye', **Metallurgia, 72**, 1965, pp 153-8.

13 W H Chaloner, 'Hazards of trade with France in time of war, 1776-1783', **Business History, 6**, 1963, pp 79-92.

14 C Hart, op cit, pp 157-160.

15 S Shaw, 'A Tour to the West of England in 1788', London, 1789, p 205.

16 H W Paar and D G Tucker, 'The old wire and iron works at Tintern, Mon.', **J Hist Met Soc, 9**, No 1, pp 1-12.

17 B Earl, 'Cornish Mining', Barton, Truro, 1968, p 83.

18 R F Tylecote, 'A History of Metallurgy', The Metals Soc, 1976, pp 82 and 88-9.

19 D Mushet, 'Papers on Iron and Steel', John Weale, London, 1840, pp 314-5.

20 A T Arnott and M Sayer, 'Beam engines in blast-furnace blowing', **Indust Archaeol Rev., 3**, 1978, pp 29-44.

21 H W Paar and D G Tucker, 'The technology of wire-making at Tintern, Gwent, 1566-c1880',**J Hist Met Soc, 11**, 1977, pp 15-24.

22 W K V Gale, 'The British Iron and Steel Industry', David & Charles, Newton Abbot, 1967, p 43.

B Trinder, 'The Industrial Revolution in Shropshire', Phillimore, Chichester, 1973, p 57.

23 C K Hyde, 'Technological Change and the British Iron Industry 1700 - 1870', Princeton, 1977, pp 83-88. The potting process seems to have been first brought to attention by G R Morton and N Mutton, 'The transition to Cort's puddling process', **J Iron & Steel Inst, 205**, 1967, pp 722-8.

24 R F Tylecote, op cit, pp 121-2.

25 H R Schubert, 'History of the British Iron & Steel Industry', Routledge & Kegan Paul, London, 1957, p 309.

26 R Plot, 'The Natural History of Staffordshire', Oxford, 1686.

27 Schubert, op cit, pp 209-210.

28 B S Osborne, 'Patching, Scouring and Commoners : The development of an early industrial landscape', **Indust Archaeol Rev, 1**, 1976, pp 37-42.

29 D E Bick, personal communication.

30 Doc.Man/D/133/000, Gwent C R O. This document of the Manor of Wentsland and Bryngwyn complains of the damage done by scouring to the lands of the manor.

31 Notes by James Bladon, and Additions and Corrections thereto, in 'The Local Register or Chronology of Pontypool and the Neighbourhood', Pontypool, 1869.

32 W Coxe, 'An Historical Tour through Monmouthshire', London, 1801, Vol 2, p 228.

33 W E Minchinton, 'The British Tinplate Industry', Oxford, 1957, pp 20-24.

34 For example, A Rees, 'Cyclopaedia', 1819-20, quotes a description by a Mr Donovan, dated 1805, which omits several of the stages described in our MS.

35 C E Hart, op cit, p 108.

36 R F Tylecote, 'Copper ingots and marine copper', **Int J Nautical Archaeol, 9**, 1980, pp 67-68.

37 J R Harris, 'Copper and shipping in the eighteenth century', **Econ Hist Rev, 19**, 1966, pp 550-568.

J H Harland, 'Piet Heyn and the early use of copper sheathing', **Mariner's Mirror, 62**, 1976, pp 1-2.

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39 M Phillips; A L Evans, op cit. It is only fair to point out that the date of 1774 is not very well substantiated, although it is accepted not only by Phillips and Evans, but also by Mr R O Roberts of University College, Swansea (Private communication). The claim by G Grant-Francis ('The Smelting of Copper in the Swansea District', London,1881, pp 96 and 103) that the Taibach works started in 1727 certainly does not seem to be soundly based and is categorically denied by later researchers.

40 H N Jerman, 'John Warwick Smith and the Sothebys', **Nat Lib Wales J, 1**, 1939-40, p 150; and 'On the dating of a volume of drawings', ibid, p 156-7.

Gordon Tucker is Senior Fellow in the History of Technology and Honorary Professor in the University of Birmingham. He has written on a number of aspects of the history of technology including molinology and the slate industry. His contributions to this Journal include lead smelter flue systems and the history of the Tintern wire industry.

Chancery Masters' Exhibits in the PRO

This list has been compiled by Sybil Jack of the University of Sydney as a result of her researches in the Public Record Office, London. We are grateful to her for allowing us to reproduce it. (Editor).

Mining and quarrying

C103	82	Accounts & papers relating to Wheel Ruby Iron Mine, St Austell, Cornw. 1843-52.
	89	Lease of coal mines, Northop. Flint, 1822.
	97	Leases of coal mines, Cheshire & Lancs. 1814 & 1822.
	149	Lease of coal mines, Walsall, Staffs. 1838.
	[16]	Coal merchants' partnership agreement, dissolution of partnership & accounts. Lond., [770-3].
	167	Lease of quarry, Eccleston, Lancs. 1820.
C104	1	Leases of coalmines & lands, Silkstone, Yorks, 1810-30.
C105	38/39	Lease of coal mines Eglwysilan, Glam. 1733.
C107	55	Papers concerning a colliery, Staffs. 1813-40.
	61,62	Leases etc of lands in Lancs. including coal, slate, lead & iron mines.
	73	Deeds & papers relating to tin mines & other property, Cornwall, 1737-89.
	74	Deeds etc of collieries in Staffs. & colliery accounts. 1775-1812.
	85	Deeds etc relating to tin & copper-mines in Redruth & St Agnes, Cornwall, 1817-31.
	98	Book of 'a survey of tin bounds', Cornwall, 1784.
	99,100	Tin-mining accounts etc.
	147	Mines, mills and other property in Westmorland & Devon, 1758-1810.
	148	Deed of a mine etc in Hennock, Devon, 1812.
	160	Account-books of collieries at Coseley, Staffs. 1802-11.
	161	Papers relating to copper-mines in Middleton-Iyas(?), Yorks, 1745-50.
	163	Deeds etc relating to lordships, manors, mines etc belonging to Sarah Middleton, a lunatic Westmorland, Lancs, Durham, Devon, 1506-1821.
	179	Papers relating to Flack lead-mines in Cumberland & lead & copper mines at Alverton, Staffs. 1747-1838.
	188	Documents in a suit relating to the coal trade, Middlesex 1697-99.
C108	3	Welsh Copper Co. 1726-72.
	13	Papers relating to Alum works at Kettleness, Yorks. 1729-50.
	47	Deeds of lead mines at Wirksworth Derbys. 18th century.
	62	Accounts, rentals & deeds of lead mines at Wirksworth, 1565-1692.
	82	Coal merchant's day book, London, 1734.
	111,112	Accounts, correspondence & inventory ref. Roghills Colliery & Furnace, 1804-35.
	145	Taft-moor Colliery, Durham Account books. 1769-79,
	147	Festiniog slate quarries, Caernarfon. Accounts correspondence c.1812.
	184	Title deeds – lead mines & collieries in Flint, Halleyn, Tanfield, 1718-30.
	360	Accounts, Danen Vawr lead-mine 1740-3.
	394	Deeds of collieries in Durham & Northumberland, 1673 & 1723.
C109	77a	Title Deeds (Ryton) with maps of Ketley colliery etc. Salop, 1737-58.
	88	Weigh bills at Golden Hill Colliery, Burslem, 1815-21.
	121	2 account books of working expenses of colliery, Birch Hill, 1840-46.
	125	Colliery accounts, leases etc. East Lanes, 1846-51.
	198	Affidavits, mining accounts, Burslem, Staffs, 1740-79.

	240	Colliery wage bills, Staffs. 1778-89.
	272	Leases, rentals, colliery accounts, Staffs. 1733-52.
	274	Colliery Accounts, Lancs, 1726-9.
C110	47-49/13	Coal merchants, indenture of partnership, 1770.
	84	Coal merchant's books. Surrey, 1821-34.
	93	Leases of coal mines & colliery accounts.
	119,120	Accounts of lead & calamine mines – Shipham, Som. 1723-61.
	146	Report on mines, Cardigan, 1701.
	170	Agreement & reports on coalmines, correspondence. Dudley, Staffs. 1796-8.
	171	Articles of partnership (coal, iron, corn & malt merchants) Norwich, 1795 & 1796.
	172	Partnership agreement (coal merchants) Westminster, 1776.
	187	Lease of estates & lead mines, mining & smelting accounts & letters. Denbigh, 1785-94.
C111	107-110	Order book, day book & letter-book of Ornamental Stone Works, Lambeth Abstracts of Title to Saltworks etc.
C114	32	Pantyglien slate quarry - account book? Carmarthen, 1821-5.
	60	Coal merchants – account books 1703-5.
	115	Accounts, papers & correspondence relating to copper & tin mines. 1809, 1813. Devon & Cornwall.
	120	West Cork Mining Co – accounts, wages lists & correspondence. 1834-6.
	145	Colliery accounts, Durham.
	149	West Cork Mining Co. – correspondence & papers, 1834-7.
	185	Colliery accounts, Pontyfelin, Mon. 1760, Kenton & Doxledge collieries – correspondence, valuations. Northumb. 1811-13.

Foundries etc.

C103	68	Winter & Co, founders, coppersmiths & worm-makers; wages books. Battersea 1800-3.
	181	Iron refiner, indenture of apprenticeship. Glamorgan, 1756.
C104	29	Lead-smelting accounts. Bagillt, Flint, 1782-99.
C105	24	Furnace accounts, St Leonards, Heref. 1717-25.
	33/10	Patents for inventions in ironwork. Crayford, Kent, 1682.
C107	84	Law papers, sale bills, accounts etc. relating to ironworks & other property in Monmouth, Brecon, Glam. 1818-30.
	148	Deeds of property in London, including Welsh Copper Cos. office 1667-1743.
	172	Deeds & prints concords relating to ironworks. Surrey, 1677.
C108	84	Boyd River furnace, accounts 1777.
	135	Dowlais Iron works – correspondence Glamorgan, 1777-84.
	323	Inventory an ironmonger's stock, 1777.
C109	25-9	Day books of Court Ironmonger, with details of iron-work in palaces etc. 1727-48.
C110	133	Draft contract for ironwork Birmingham, 1833.
C114	124-127	Ebbw Vale & Sirhowy (?) Iron Works (?) 1805-1828.
	182	Ironmongers' account book 1684-6.

Evidence of copper smelting in Bronze Age Jericho

Lutfi A Khalil and Hans-Gert Bachmann

Introduction

During the excavation of Jericho from 1952 to 1958 by the late Dame Kathleen Kenyon[1] numerous metal artefacts and associated finds were salvaged from the tell and the many tombs. Minute pieces removed from the metallic objects were submitted to various analytical techniques, ie x-ray fluorescence (XRF), polished section microscopy and atomic absorption spectroscopy (AAS). These artefacts essentially tools, weapons and various implements together with a number of metallic waste and byproducts like runners etc. are fully described morphologically and analytically by Khalil[2].

Among the metal finds a number of ill-defined objects are included which were first inspected by the authors in 1979. According to the stratigraphy, this material is of Early Bronze (EB) or Middle Bronze (MB) Age (2900 – 1550 BC)[3]. It consists of minerals and mineralised or partly decomposed fragments in the form of irregularly shaped lumps and nodules, varying in diameter from 1 to 5 centimeters and weighing from 1 to 20 grams.

After cutting, these samples revealed their inhomogeneity, clearly visible by optical inspection under low magnification. In order to leave the specimens intact as much as possible for any future investigations, minute amounts of powdered material (from a few milligrams to less than 0.5 gram, depending on the size of the sample in question) were submitted to XRF and x-ray diffraction (XRD). Disposable plastic beakers with Mylar-foil bottoms were filled with the ground specimens. Analyses for elements with atomic numbers above 12 were carried out with an energy-dispersive XRF spectrometer. The instrument is equipped with a molybdenum x-ray tube. As the primary radiation coincides with the sulphur fluorescence radiation (Mo $L\alpha_1$ = 2.293 keV, S $K\alpha_1$ = 2.308 keV), analyses for sulphur had to be made on another instrument with a chromium tube. For phase analyses by XRD, the Guinier-film technique was employed (with Cu or Co $K\alpha_1$ - radiation resp.). The diffraction patterns were identified by comparison with published data from the JCPDS-file with the aid of a computer program as well as by visual inspection. The characterisation of all the samples investigated is summarised in Table 1.

Results and Discussion

Most of the samples included in this report were discovered in rooms facing a street on the site. The excavator's notebook also mentions a fire pit nearby. Only samples nos 13 and 14 were found in a rubble pit. Unfortunately, nothing is reported about material, like crucible sherds, tuyeres, etc. which – if they had been associated with the metallurgical relics – could have shed some light on the activities that once took place in these habitation layers and sites. Therefore, we have to rely entirely on the selection of specimens included in Table 1 and which – based on chemical and phase analyses – can tentatively be placed in the following groups:

1 Ores (Samples nos 4, 5, 13 and 14).

They are of similar composition. Malachite and paratacamite as secondary copper minerals are present in all specimens. In all but sample no 13 they are associated with copper oxides (cuprite and tenorite). In sample no 5, which is of red-brown colour, the cuprite content exceeds that of the green minerals by far. Paratacamite may be a constituent of the ores as found in the mine, but it may also be a weathering product formed after the pieces of ore were subjected to influences of a saline surrounding. This is to be expected in a settlement in an arid climate near the Dead Sea[4]. Cuprite, the oxide of monovalent copper, is known as a rich copper ore as well as the decomposition product of green copper minerals that have been heat-treated. Thus, it is possible the specimens in question have seen higher temperatures. However, they are distinguished from the following group in so far as they are compact nodules without cracks, fissures and vesicles, ie they lack signs indicating heat treatment. Samples nos 4 and 5 are rich ores of high specific gravity, while samples nos 13 and 14 – both found in a rubble pit – have to be taken as lean ores, which may have been the reason for discarding them.

2 Partly decomposed ores (Samples nos 1, 2, 3, 9, 11 and 12).

On the basis of their mineral content (cuprite, malachite and paratacamite) samples nos 9, 11 and 12 could equally well be added to the first group. However, they show strong indicationg of heating, like internal cellular structure, degassing holes, cored appearance (rim of cuprite surrounding a core of still unaltered green minerals) which is lacking in all the samples of the first group. The remaining specimens nos 1, 2 and 3 contain additional minerals typical of melting and/or smelting slags, like delafossite, spinels and fayalite, though only in minor amounts. The sulphur content, present in samples nos 2 and 3 may point to small admixtures of sulphides (eg chalcocite, chalcopyrite). Iron sulphide was identified as a decomposition product in the outer zone of sample no 2. In all the specimens of this group, heating has resulted only in partial decomposition of the original lumps of ore, hence the heading 'partly decomposed ores'.

3 Partly smelted and slagged ores (samples nos 7 and 10).

Specimen no 7, schematically illustrated in Fig 1a, is a globular piece of partly reduced ore which shows cuprite as a major constituent and also considerable amounts of metallic copper in form of filaments and concretions surrounding a large central hole. Weathering is negligible. This piece of rich ore has undergone reduction to a certain extent. The cross-section of a somewhat similar sample (no 10) is given in Fig 1b. It has the characteristics of a slagged ore fragment, ie vesicles of varying size and shape, droplets of copper metal (some of these may be matte on account of the noticeable sulphur content of the specimen) plus oxides (cuprite and spinels). In many ways this fragment resembles a crucible slag, but as its main constituent is copper in metallic and oxidic form, we rather prefer to label it: slagged ore.

4 **Decomposed crucible fill (Sample no 6).**

Apart from cuprite and paratacamite this specimen contains iron hydroxide as a weathering product, mainly contained in a reddish-brown outer zone surrounding a core of greenish colour. XRF reveals a noticeable amount of tin (order of magnitude: a few percent). We have tentatively classified this sample as decomposed crucible fill. Originally, it could have been a mixture of copper-tin-iron ores or a slag-metal runner from bronze melting. This is the only sample containing tin among the whole assemblage of finds. Perhaps this sample has to be seen in the same light as the following:

5 **Roasted arsenopyrite (Sample no 8).**

The only mineral phase identified with certainty in this sample is goethite, an iron hydroxide. The faint green spots on the outside of the apparently roasted and weathered piece indicate the presence of malachite, ie minor amounts of copper compounds. The most striking peculiarity, however, is the presence of arsenic as major constituent next to iron. On the freshly cut surface of the specimen streaks of metallic appearance are clearly visible. These are interpreted as traces of the original, unaltered mineral. All findings point to a material which originally must have been

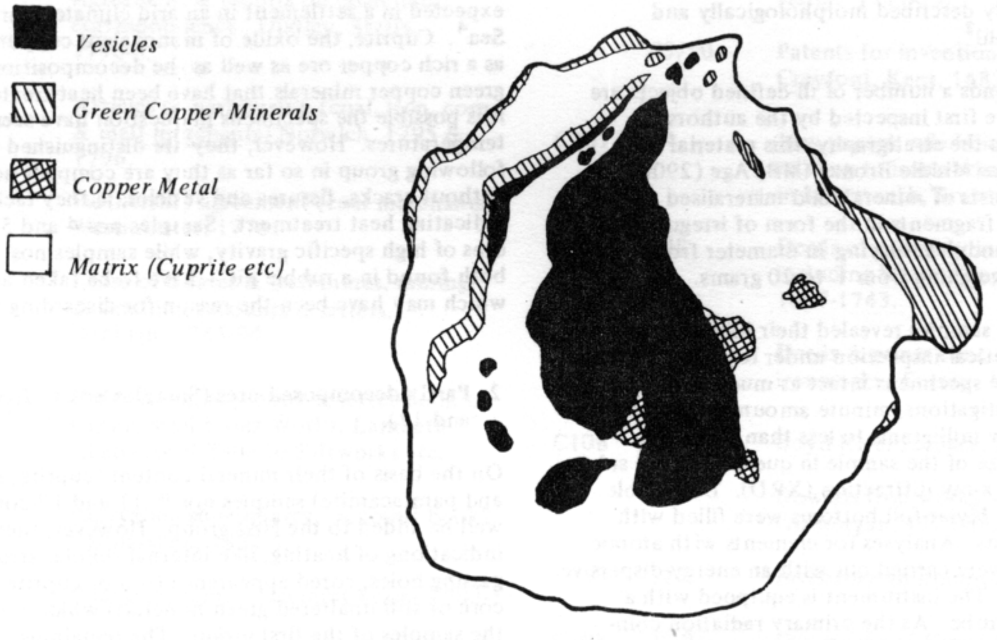


Fig 1a (above): Sample no 7; scale 1:4.
Fig 1b (below): Sample no 10; scale 1:4.

an iron-arsenic mineral, most likely arsenopyrite, FeAsS (sulphur is present in amounts of a few percent). The sample is not just an odd piece of weathered mineral. Heat treatment has not only left a roasted crust but also cracks and vesicles left by evolving gases.

Summarising the analytical results as evident from Table 1 and the descriptions above, we assume that we are dealing with debris from a metal worker's workshop. Though we lack the evidence of associated finds, notably of crucibles or their sherds, the small scale operations making use of specially selected pieces of ore required some sort of refractory containers, ie crucibles, as reaction vessels.

Tylecote[5] has shown that the smelting of rich secondary copper ores in crucibles presents no difficulties. We have carried out similar experiments. A ceramic crucible with a capacity of about 200 ccm was preheated with glowing charcoal. Over a period of 15 minutes, alternative charges of crushed malachite and charcoal – each amounting to about 20 grams – were placed on top of the glowing charcoal bed at the bottom of the crucible, thereby filling the crucible to half its height. A ceramic tube, connected to a flask of compressed air, acted as blowpipe through which a constant stream of air was passed into the crucible. It was not difficult to maintain a temperature of about 1200°C in the reaction bed. At the end of the experimental run (30 to 40 minutes after the last charge had been added), the crucible's content showed – beside ashes and unburnt charcoal relics – a yield of metallic copper in the form of prills, globules and distorted wires. As we used very rich ore, there was no slag formation. These experiments are additional proof that with a relatively simple set-up, ie crucible, charcoal, crushed secondary rich copper ore and a blowpipe inserted into the charge, copper metal can be smelted. The yield and the

Sample No	Locality: Trench	Locality: Square	Locality: Stratum	Period[1]	Colour of Powdered Sample	X-Ray Fluorescence[2]	X-ray Diffraction[3]	Description
1	II	II, III + VI	xxxii - xxxiii	MB	Red-Brown	Cu, Fe, (Pb, Si, Ci, Ca, Ti); S:-	Dela, Mala + Un	Ore, partly decomposed
2	II	II, III + VI	Li	MB	Rim: Red-Brown Core: Light Green	Cu, Fe, (As, Pb, Ci, K, Ca); S: -2%	Rim: Isu, Para, Sp ? Core: Para.	Ore, partly decomposed
3	III	———	Lxxxv	MB	Red-Brown-Grey	Cu, Fe, (Pb, Ca, Si, Ci): S: 2%	Cup, Sp, Ten, Fay, Mala	Ore, partly decomposed
4	III	———	Lxxxi	MB	Dark Grey-Green	Cu, Fe, (As, Pb, Ni, Ca, Ci); S: -	Cup, Mala, Para	Ore
5	II	II, III + VI	Vi	EB	Dark Red-Brown	Cu, (Fe, Ci, K): S:-	Cup, Para, Mala	Ore
6	II	II, III + VI	L-Li	MB	Medium Brown	Cu, Sh, Fe, (As, Pb, Ci): S: 0.5%	Cup, Para, Goe	Crucible fill, decomposed
7	II	———	Lviii	EB	Deep Purple Red	Cu, (Fe, Ca): S:-	Cup, Cu	Ore, partly smelted
8	II	II, III + VI	xLiva	MB	Medium Brown	Fe, As, Ni, Cu, (Cr, K, Ca); S: 2%	Goe, Mala ?	Arsenopyrite? roasted
9	I	———	xLix-L	EB	Deep Purple Red	Cu, Fe (As, Pb, Ca); S:-	Cup	Ore, partly decomposed
10	II	II, III + VI	vi	EB	Greyish Green	Cu, Fe, Ca (As, Mn, K,Si, Ci, Ti?, Sr?); S: 2%	Cup, Chal[2], Para, Cu, Sp ?	Ore, partly slagged
11	III-IV	———	c	EB	Purple Red	Cu, (Fe, Pb, Ca, Ci); S:-	Cup, Mala, Para	Ore, partly decomposed
12	II	II, III + VI	x	EB	Greyish Green	Cu, (Fe, As, Ci, Ca, K, Si, Sr?); S:-	Para, Cup	Ore, partly decomposed
13	I	Rubble Pit	———	EB	Light Green	Cu, (Fe, Pb, Mu, Ca, K, Ci, Si); S:-	Mala + Un	Ore + Gangue
14	I	Rubble Pit	———	EB	Light Green	Cu, (Fe, Pb, Mn, Ca, K, Si); S:-	Mala, Ten, Cup	Ore

Table 1: Metallurgical finds from Bronze Age Jericho

[1]Abbreviations: EB = Early Bronze Age (2900 – 2300 BC)
MB = Middle Bronze Age (1900 – 1550 BC)

[2]Explanations: Major constituents underlined
Minor constituents Normal script
Traces in brackets

[3]Code for Identified Phases

Chal	Chalcocite	Cu_2S
Cu	Metallic copper	Cu
Cup	Cuprite	Cu_2O
Dela	Delafossite	$CuFeO_2$
Fay	Fayalite	Fe_2SiO_4
Goe	Goethite	FeOOH
Isu	Iron sulphide	FeS
Mala	Malachite	$Cu_2(OH)_2CO_3$
Para	Paratacamite	$Cu_2(OH)_3Ci$
Sp	Spinels	Fe_3O_4 etc
Ten	Tenorite	CuO
Un	Unknown(s)	

efficiency being dependant on the skill of the operator and the duration of the process.

The finds we investigated are from EB or MB layers, ie periods in which tin bronzes were generally known and widely distributed. The Jericho smelters made use of tin bronzes as well as of arsenical copper. Arsenical copper, antedating the use of tin bronzes, apparently still had some importance even after the introduction of tin bronzes, perhaps due to scarcity of tin. The Jericho metals workers made use of and experimented with copper ores, arsenical minerals and tin-containing material, either as mineral, metal or tin-bronze scrap. They knew that by joint smelting and/or melting of selected and suitably prepared charges either in crucibles or small hearths arsenical copper as well as tin bronzes could be made and that they were aware of the special properties of various types of alloys. The finds investigated are probably only a fraction of what was left behind in one of the local workshops.

The raw material, ie hand-picked, high-quality ores, was imported. The odd lean pieces contained in a 'shipment' were obviously thrown away (viz samples nos 13 and 14 from the rubble pit). When speaking of import, it is not our intention to enter the controversial field of provenance discussion. There are deposits of rich secondary copper ores near the East and West bank of the Wadi Arabah (Timna, Feinan etc), about 200 kilometers to the South of Jericho. They could have supplied some of the material found, but probably not the specimens containing arsenic, and a fair number of our samples contain this element[6]. Much as the knowledge of trade routes would add to our picture of life in Bronze Age Jericho, the evidence is still far too scanty. It is merely our aim to show that metal smelting and alloying were not limited to large production centres, but were common practice also within communities and settlements, thereby adding to the diversification of trades and crafts so essential to the transition from village to city.

Notes and References

1 Kathleen Kenyon: Digging up Jericho, Ernest Benn Ltd. London, 1957; preliminary reports of the Jericho excavations have appeared in various issues of the Palestine Exploration Quarterly, 1952-1957 and 1960.

2 Lutfi A H Khalil: The composition and technology of copper artefacts from Jericho and some related sites. Thesis (unpublished), University of London, 1980.

3 The chronology of Jericho introduced by Kathleen Kenyon is divided into the following periods:

Chalcolithic	3300 – 2900 BC
Early Bronze Age	2900 – 2300 BC
Intermediate (Early-Middle Bronze Period)	2300 – 1900 BC
Middle Bronze Age	1900 – 1550 BC

The stratigraphy of the finds analysed is quoted from the late Dame Kathleen Kenyon's field books, by kind permission of T Holland, editor of the forthcoming Jericho publications. It is hoped that further explanations of the somewhat puzzling stratigraphic labelling will be given in the final excavation reports.

4 The severe influence of saline soils on a silver object found in the same stratum resulted in total conversion of the artefact to silver chloride and bromide.

5 R F Tylecote: Can copper be smelted in a crucible? JHMS, 1974, 8, 54.

6 In a recent summary of the Timna area – H G Conrad and B Rothenberg (ed): Antikes Kupfer im Timna-Tal, Bochum 1980, p 4 and 216-217 – the As-content of the many ore samples analysed varies from nil to 500 ppm. The same is true of copper ores from the east bank of the Wadi Arabah – F W Prokop and W F Schmidt-Eisenlohr: Erfahrungen bei der Untersuchung von Kupfervorkommen im Wadi Araba, Jordanien. Erzmetall, 1966, 19, 111-120. The As-contents of samples from Wadi Abu Khuscheiba range from 50 to 80 ppm.

Lutfi Khalil is a graduate of the London Institute of Archaeology where he took the Archaeometallurgy course under Prof Bachmann. His subject was the composition and technology of copper artifacts from Jericho. He is now with the Department of Archaeology in the University of Jordan at Amman.

H-G Bachmann is an industrial chemist with Degussa in Frankfurt. He has taken a keen interest in archaeometallurgical excavations in the Near East and has been contributing to the Archaometallurgy Course at the Institute of Archaeology, London. His main speciality is slags.

The remains of an iron smelting furnace near Woodbridge, Suffolk

Michael L Weight

Introduction
The furnace to be described in this paper was discovered in November 1978 on the so-called 'Rookery Mount' site near Bealings House, Woodbridge, Suffolk. The site is registered at Ipswich Museum and is located at TM 24354875.

It was found amongst trees, above ground, and was filled with earth. Its close proximity to some dog graves (undated) suggests that it may have been exposed during the digging of the graves, but that the significance of the find was not realised at the time.

Description
The furnace consists of a slightly tapered, cylindrical shaft, 90 cm in height. The maximum outside diameter is 52 cm and the walls are 7 cm thick at the top of the furnace.

The present height of the furnace is probably less than the original height. This is indicated by the jagged nature of the inner wall at the top of the furnace, which suggests that the upper portion has been broken off at some time. This can be clearly seen in Figs 1 and 2.

The inner wall is solid and dense and was probably formed when the furnace was worked. The outer wall is composed of dried earth/clay which is extensively cracked and in some places has crumbled away completely, exposing the inner wall of the furnace. This is clearly seen in Fig 1. Fig 3 shows the top of the furnace and the nature of the inner and outer walls.

As well as the open top of the furnace, there are two other openings present. The slag tapping hole, situated at the base of the furnace, is 15 cm in diameter and has an appearance consistent with liquid material being run off through the hole.

The air inlet (shown in Fig 1) is located 25 cm up from the base of the furnace and is 6 cm in diameter. It is on the opposite side to the slag tapping hole. There is also evidence of a second air inlet (now blocked by the inner wall) located 28 cm above the existing inlet, suggesting that the furnace has been used more than once. It is possible that this inlet was found to be too high for an efficient smelt to be achieved.

The Smelting Process
During operation, the furnace would be charged with a mixture of iron ore and charcoal from the top and air would be forced through the air inlet via a tuyere and bellows of some description. The iron ore would be reduced to the raw iron by carbon monoxide, produced by the incomplete oxidation of the charcoal.

Liquid slag would be tapped via the slag tapping hole and the iron bloom would be removed, probably from the top in this furnace, owing to the relatively small size of the slag tapping hole.

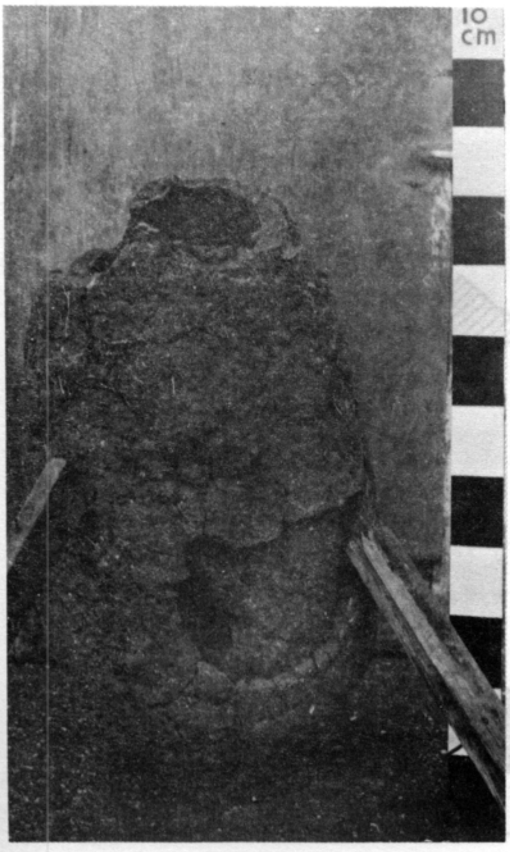


Fig 1

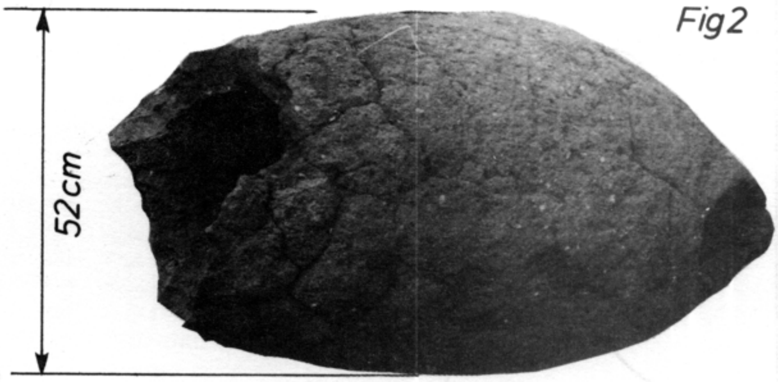


Fig 2

Fig 3

A detailed account of the principles involved in the reduction of iron ores by the direct method is outside the scope of this paper. For further details, attention is drawn to the references given at the end of this paper.

Analysis

As a result of the limited analytical facilities available to the author, a full and detailed analysis of the furnace could not be carried out. It was possible, however, to analyse the furnace for iron and manganese content.

Samples from the inner wall of the furnace were prepared for analysis using the sodium carbonate fusion method and then assayed for iron and manganese content by atomic absorption spectrophotometry. Results are given in Table 1.

Sample	Iron	Manganese
Tapping Hole	16.1%	2.6%
Inside, opposite the air-inlet	19.4%	0.4%

Table 1: Results of Iron and Manganese Analyses

The iron levels found, whilst being lower than might have been expected in primitive slags produced by the direct method, indicate that the furnace was used to smelt iron ores. These low levels may be due to contamination of the sample by the furnace lining.

The level of manganese suggests that 'bog iron' ore may have been smelted in this furnace, although it is not possible to be very precise, regarding the types of ores smelted, especially from the results of this limited analysis.

Discussion

According to the Ipswich Museum Record Office, the Rookery Mount site was excavated in 1885 by Major Moore. The finds were entirely prehistoric in date and seem to have been mainly Neolithic and Early Bronze Age.

The furnace described in this paper however, is certainly not of this period, and must have been worked during a much later occupation of the site. Dating the furnace to a precise period is very difficult, if not impossible. However, a number of conclusions may be drawn from the furnace type.

The furnace itself is almost certainly a shaft furnace used for smelting iron ores. Coghlan[1] states that the use of such furnaces in pre-Roman times was unlikely, but allows the possibility of their use in the "less backward provinces".

Aitchison[2] states that shaft furnaces were not used *at all* before the Roman Period, a view which is supported by Tylecote[3]. Indeed, Tylecote[3] states that a distinguishing feature of the Roman technique was the removal of slag from the furnace in a semi-liquid state.

Coghlan[1], drawing from work by Weierschausen[4], describes Roman shaft furnaces found on the continent which are very similar to the furnace described in this paper. Davies[5] notes that such furnaces were very common in

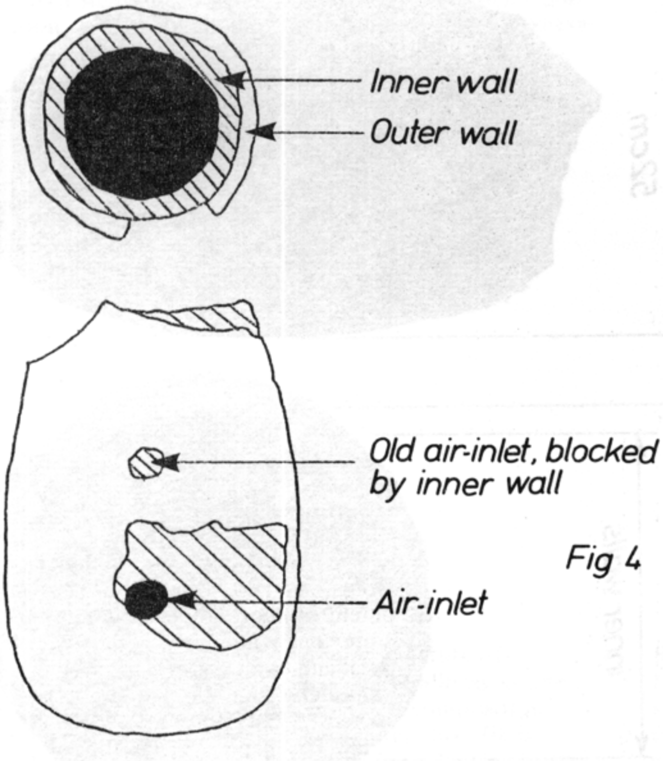


Fig 4

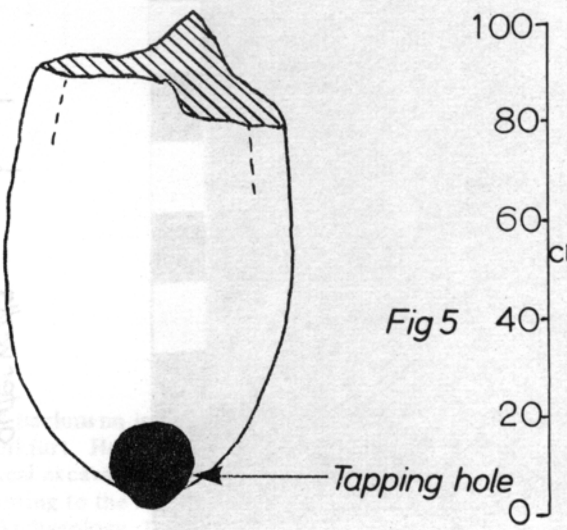


Fig 5

Roman times, their distribution was widespread and they had a long life.

It would seem therefore, that the earliest reasonable date of the furnace might be sometime during the Roman period in Britain (AD 43-450).

However, as Aitchison[2] and Tylecote[3] have pointed out, there were no major changes in the basic iron smelting technique until water power was harnessed some time near the beginning of the 15th century. During this period, therefore, shaft furnaces may have been widely used.

Forbes[6] states that the Romans increased the number and size of iron smelting furnaces but did not develop new types, and goes on to state that shaft furnaces were in use until the 13th and 14th century AD.

One fact which perhaps points to the furnace belonging to the post-Roman period is its size. It is relatively small and obviously free standing, features which one might not expect given the scale of Roman iron smelting operations (Tylecote & Owles[7]).

Tylecote[3] notes that after the Roman withdrawal, there is no evidence of new techniques taught, but that there is much evidence to support the continuation of the early, small scale, Iron Age tradition. One possible reason for this apparent 'regression', proposed by Tylecote[3] is that when the Romans left, the prevailing economic conditions did not favour large scale smelting operations, since the military need no longer existed.

It is quite possible, therefore, that the furnace described is post-Roman, indeed it may have been used up to the 13th or 14th century AD, as described by Forbes[6].

Conclusion
The structure described in this paper is undoubtedly a shaft furnace, once used for smelting iron ores.

Although it was found on a prehistoric site, the furnace type suggests that it dates from a later, but undetermined period. This suggests at least two occupations of the site, widely spaced in time.

A more detailed analysis of the slag, especially the phosphorus content, may be helpful in determining the type of ores smelted and might perhaps help to narrow the possible period of use of the furnace.

Whilst such analyses were outside the scope of the facilities available, small samples may be obtained for further analysis from the author.

Acknowledgements
Thanks are due to my colleague, Mr D H Willey, with whom the furnace was found, to Col S Gulyas for permission to investigate his estate, and to Mr L Pole of the Saffron Walden Museum for his help and advice concerning the furnace.

References

1 H H Coghlan, Notes on Prehistoric and Early Iron in the Old World, Oxford, 1956.

2 L Aitchison, A History of Metals, London, 1960.

3 R F Tylecote, Metallurgy in Archaeology, London, 1962.

4 P Weierschausen, Vorgeschichtliche Eisenhutten Deutschlands, Leipzig, 1939.

5 O Davies, Roman Mines in Europe, Oxford, 1935.

6 R J Forbes, Metallurgy in Antiquity, Leiden, 1950.

7 R F Tylecote & E Owles, A Second Century Iron Smelting Site at Ashwicken, Norfolk, Norfolk Archaeology, 1960, 32 (3), 142-162.

Michael Weight. Although currently involved in hardware and software development of microprocessor computer systems, the author's previously published papers have been in the fields of biological and clinical research. It is the author's contention that many finds by amateur archaeologists are inadequately documented and consequently remain effectively undiscovered. This paper is the author's attempt to avoid this pitfall.

Botanical mineralogy

Richard Doncaster

In 1977 The Historical Metallurgy Society had its Annual Conference in Aberystwyth. In our traditional tour of old metalworking sites we visited Fron Gogh, an old lead smelt. There I found Sea Campion (Silene maritima). I had always been told that Sea Campion was only to be found on the coast of Britain or over 2000 feet above sea level on mountains, as it is on the Brecon Beacons and in the Lake District. Yet here it was at Fron Gogh at 900 feet and 10 miles from the sea. So why? Was it by chance? Or was it from some special preference for a metal.

There has been work on the relationship of plants and metals but it is not easy to come by and is highly specialised, both minerally and botanically. But there is a lot of folk lore. Most of us have heard of gardeners' ideas about hydrangeas and copper; or is it iron? The dieticians tell us to eat nettles (Urtica dioica) for the iron in them. Popeye the Sailorman recommended Spinach (Spinacea oleracea). Nettles and spinach are said to contain more iron than other plants. Bracken (Pteridum aquilinum) and seaweeds were burnt into a product called kelp for the potash that was in them.

At the end of the nineteenth century mines were dug in Cornwall in the belief that the presence of metal, probably tin or copper, beneath the surface could be detected by the deflection of a hazel twig, a process called dowsing when applied to water divining.

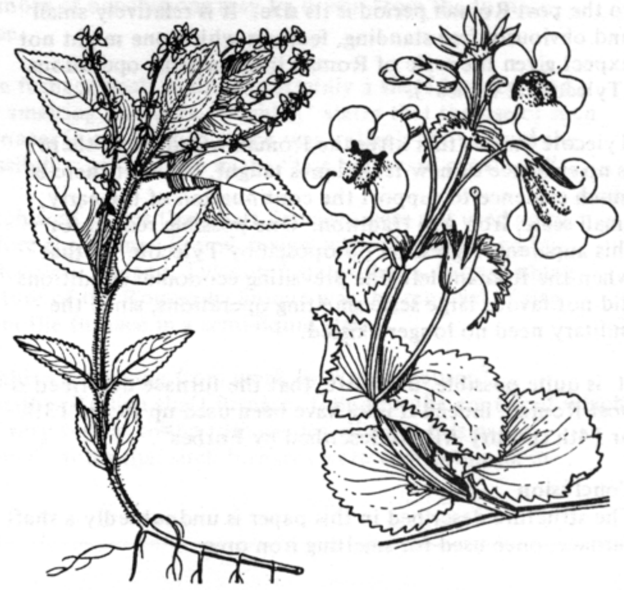
It is said that John di Castro, an Italian chemist circa 1450, observed Holly (Ilex aquifolium) growing plentifully in the district of Tolsa, near Rome. This discovery led to the first alum works in modern Europe being established there by Pope Pious II.

Anne Pratt, a botanist of the nineteenth century, makes some interesting comments. Cotoneaster is only found wild in one place in the British Isles, on Great Ormes Head in North Wales. She recalls a Mr Christy saying 'We reached some copper mines in Gt Ormes Head, overhung by a range of limestone precipices. On these rocks cotoneaster (Cotoneaster integerrimus, Gt. Orme Berry) grows abundantly'. Today in Cornwall cotoneaster grows wild on copper mine spoil tips but is said to be a garden escape.

There is a plant called Weld (Reseda luteola) which is remarkable as being the first to appear on rubbish thrown out from coal mines, as those of you in North Derbyshire and South Yorkshire will well know. You can find Bladder Campion (Silene vulgaris) on the spoil tips of Snailbeach lead mines in Shropshire. Campions and Catchflies, both of the Pink (Caryophyllacaea) family are recorded as indicators of copper and some heavy metals, although what heavy metals I do not know. Nor do I really know what a heavy metal is.

As a reminder to HMS members, Davies-Sheil, who guided us at our Annual Conference walks in the Lake District in 1968, told us that he could almost identify iron working sites from the groups of Ash (Fraxinus excelsior) trees and the nettles that grew on them. Dog's Mercury (Mercurialis perennis) abounds on ironstone workings in South Yorkshire and Reg Morton, our Chairman in the early years of the Society, used it as an indicator of iron working.

We all know Monkey Flower (Mimulus guttatus) an import from the USA. Was it by chance that it was growing in the tail goit of Bryntail lead smelt? Or so profusely along the rivers amongst the lead spoil tips of Wanlockhead?



Mercurialis perennis *Mimulus guttatus*

On our Annual Conference at Teesdale in 1978 Jake Almond took some of us up Wensleydale to lead mine sites. We saw the bare patches where the crushing gins had worked and nothing seems to grow. But we never studied the lichens and mosses on the stones, many of which are said to be indicators of various metals, like the primitive stoneworts (Characeae) which are to be found in strontia pits in Gloucestershire. Anyone who knows lead in Derbyshire knows Spring Sandwort (Minuartia verna) which almost only grows on lead spoil tips.

I have read of a so called Spanish Moss which lives on copper wire. And there is a bacteria which lives on iron oxides and performs a process called chemosynthesis, converting soluble ferrous iron from plant decay to ferric salts which might have been a source of some of the leaner iron deposits around the world.

All of which is very interesting and brings me to Edward Carpenter and his book The Art of Creation. In this book he came to the conclusion that all natural things, organic and inorganic, were alive. And should be treated so.

Which really brings to life our visits to metal working sites.

Notes and News

The recovery of Ore Cars lost in the Trent River, Peterborough, Ontario, circa 1880.

Some two years ago in our investigation of the Ironworks Site in Marmora, Ontario, Canada, we came across some typewritten information relating to an accident that happened at a later stage of the ironworks operations that was worth pursuing, or so we thought.

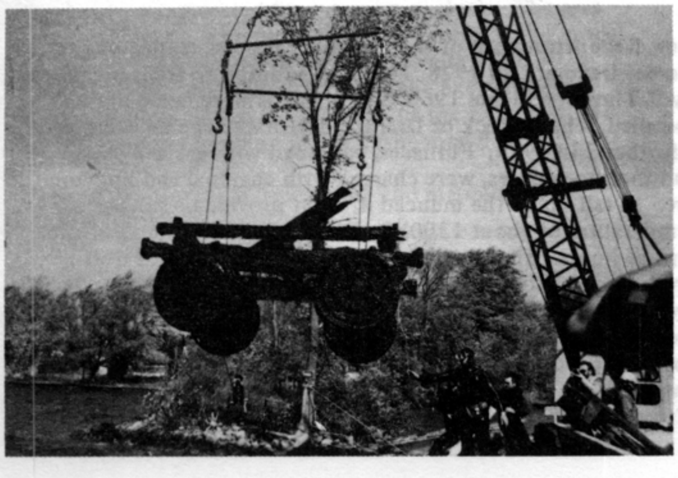
It seems that sometime around 1880, the date has yet to be determined accurately, due to the negligence of the driver of the shunting locomotive, some five ore cars had been accidentally pushed into the River Trent killing one of the workers, stated to be a Samuel Bray, a Crimean veteran.

In discussing the matter we found that some of our volunteers were divers and with a little instruction as to how they were to proceed they commenced to work every weekend during the Winter, the only time when it is possible to see more than about 6 inches into the murky water, cutting through up to 24 inches of ice to do s o During this time they managed to photograph all the five vehicles and to plot their various positions, as well as recovering samples of the wooden portions of the cars, and free metallic items, for analysis.

We were most concerned about the wooden parts because we had hoped to try to conserve at least one of the cars complete, so the timbers were carefully accessed in the laboratories of Parks Canada and were pronounced capable of conservation. During the year we hoped to obtain the use of the Floating Crane used to maintain the locks on the Trent Canal and on the 8th October we were able with the co-operation of the staff of the canal to lift four of the five vehicles from the bed of the river and take them to Peterborough, in preparation. At a recent meeting we have agreed that we shall try to conserve one of these vehicles, and reconstruct the others with modern timbers and during the coming year will hope to produce drawings of the construction of these vehicles.

At the time of writing it is believed that these may well be the oldest vehicles of this type in Canada, and so it is our intention to examine at the metallic parts for information that they might be able to reveal to us.

Arthur D Dunn



Conferences and Reports

Internationales Symposion Zur Vor - Und Fruhgeschichtlichen Eisengewinnung, Akademie Sankelmark near Flensburg, Federal Germany.

This conference was sponsored by the Landesamt fur Vor- und Fruhgeschichte von Schleswig-Holstein (Dr J Reichstein) with a subvention from the Volkswagenwerk-Fonds. It took place on 10th-14th November 1980. The majority of participants were members of the Comite pour la siderurgie ancienne. The programme consisted of the following constributions:- R Pleiner (Prague): Neue Entdeckungen der romerzeitlichen Eisenhutten in den bohmisch-mahrischen Siedlungsraumen; A Hauptmann-G Weisgerber (Bochum): Eisen in Siegerland; J A Brongers (Amersfoort): Historical Survey of Iron Production from Local Ore in the Netherlands; G Magnusson (Stockholm): Some Iron Production Sites and their Localisation; P Galliou (Brest): Iron and Iron Age and Roman America; B G Scott (Belfast): Some Problems in the Reconstruction and Interpretation of Indo-European Metallurgical Vocabularies; K Beilenin (Krakow): Der Rennfeuerofen mit eingetieftem Herd und seine Abarten in Polen; Mrs I Martens (Oslo): The Norwegian Bloomery Furnaces and their Relations to the European Finds; H Barbre-R Thomsen (Varde): Rekonstruktionsversuche zur fruhgeschichtlichen Eisengewinnung; J Alexander (Cambridge): New Models for the Spread of Iron-Using in Europe; Z Bukowski (Warszawa): Zum Problem der altesten Eisenbearbeitung und Eisengewinnung im Gebiet der Lausitzer Kultur. Neue Ergebnisse; H Vierck: Berufsbild und sozialer Rang des Schmiedehandwerks; G Sperl (Leoben): Untersuchungen an eisenzeitlichen Schlacken aus dem Burgenland; R F Tylecote (London): Recent British Ore Analysis and the Smelting of Pyrite Nodules; J Piaskowski (Krakow): Charakteristik des in Schleswig-Holstein geschmolzenen Rennfeuereisens; Mrs A M Rosenqvist (Oslo): Report on Chemical and Mineralogical Analyses of Norwegian Ores, Slags and Iron; J Keesmann (Mainz): Eisengewinnung im Rennfeuerver fahren, Erz und Produkte; Mrs I Serning (Grangesberg): Archaeological Reflections on Metallurgical Analyses; M Mangin (Dijon): Le travail du fer et son role dans la naissance et le developpement d'Alesia; H Cleere (London): The Organisation of the Iron Industry in the Western Roman Provinces in the Early Empire, with Special Reference to Britain; A B Johansen (Goteberg): Problems on Origin and Cultural Affiliation in Early Iron Production along the Timber-Line in South-Norway; M Muller-Wille (Mainz): Ein Barrenhort aus Haithabu; H Hingst (Schleswig): Eisenverhuttung and Siedlung in Schleswig-Holstein; H Stumpel-T Utecht (Kiel): Magnetische Sondierungen im Eisenverhuttungsfeld von Joldelund; G Bauhoff (Dusseldorf): Zur Geschichte gusseiserner Ofenplatten. — The last day was devoted to an interesting excursion to the Carls-Hutte Foundry at Rendsburg, and to the visit of the Giessereimuseum: a trip to the excavation of H Hingst at Joldelund in the afternoon, where slag-pit furnaces and auxiliary features were found at more than 1 m depth with the aid of magnetometric prospection (H Stumpel, T Utecht).

The symposium offered a magnificent survey of the recent activity in the ancient and early research of the bloomery iron making and working in most of the European countries. The organisation was excellent (with simultaneous translations of papers and discussions in German, French and English) and the whole enterprise was most successful.

R Pleiner, Prague

Mines et Fonderies Antiques de la Gaule: Table Ronde. This conference has been organised by the Centre de Recherche Archeologique de l'Universite de Toulouse-Le Mirail on 21st-22nd of November 1980. Apart from important papers on ancient mining and metallurgy in general, contributions dealing explicitly with the early metallurgy of iron were: M Mangin (Dijon): Caracteres et fonctions de la metallurgie du fer a Alesia; J C Blanchet (Compiegne): Four a fer primitif sur le site du premier Age de Fer de Choisy-le Bac (Oise): Ch. Peyre (Paris): Mines et ferriers de la commune de Minot (Cote-d'Or); A Bouthier (Cosne-Loire): Donnees nouvelles sur l'utilisation du minerai de fer dans le Nord-Ouest de la Nievre a l'epoque gallo-romaine; P L Pelet (Lausanne): Recherches sur la metallurgie du fer dans le Jura vaudois; R Sablayrolles)Toulouse): Interet et problemes de l'etude des ferriers antiques: l'examples de la Montagne Noire; C Domergue - F Tonnon (Toulouse): Les problemes des fours et de la production de fer dans les centres metallurgiques gallo-romaines de la Montagne-Noire. Other papers of a more general nature were: J M Pailler (Toulouse): Les mines et la metallurgie antiques dans la litterature scientifique de langue francais: R Halleux (Liege), Nouveaux textes sur la metallurgie romaine: J N Barradon (Orleans), Methodes de measures utilisables dans l'etude des mines et des fonderies antiques: R F Tylecote (London); Metallurgy in Punic and Roman Carthage: K Gruel (Orsay) and N H Gale (Oxford), Quelques constatations sur l'origine de l'argent des monnaies coriosolites: J R Marechal (Pont l'Eveque), Thermodynamique des scories gallo-romaines: L Tixier (Auvergne); L'exploitation miniere gallo-romaine des Anglais a Dahu (Cantal): G Barruol (Languedoc), Les mines qntiques de la Haute Vallee de l'Orb: D Ratz (Paris-Sud), Les aurieres de l'Ouest du Massif Central dans leur contexte geologique: C Dubois, Mines de cuivre antiques dans le Seronais: H Cuppers (Treves), Mines, fours, metaux et scories antique de la region de Treves: P Gaillou (Brest), Mines et metaux de l'Ouest de la Gaule: A trip to metallurgical sites of the Montagne Noire took place in the afternoon of the last day of the conference. *CPSA and RFT*

Research of Ancient and Early Medieval Iron of the DNEPR River-Basin, USSR, resulted in the manuscript of a book by M F Gurin entitled 'Metallurgy and blacksmith's work in the Belorussian Dnepr Area (1st millennium AD)' 1979. It was the first time that metallography of ancient blooms, bars and ready-made iron artifacts had been applied to the study of the technological level of blacksmith's work in the territory of the Belorussian Republic. In addition, the relevant ore resources are discussed.

After A K Anteins, Riga (CBSA)

Excavation Reports and Smelting experiments

Characteristics and Role of the Metallurgy of Iron at Alesia. The metalworkers' craft constituted a major role in the economic life of the oppidum of Alesia, situated on the Mont-Auxois near Alise-Sainte-Reine, France, during the period between the 1st century BC and the 4th century AD. As to the iron making and working, more detailed evidence has only been discovered recently, during field excavations by the Universite de Dijon. Traces of metallurgical and auxiliary installations and features have been observed within areas of commerical and artisan's urban quarters, both concerning the iron work and bronze foundry. The production was carried out on a small scale. Analyses of slags, iron bars and artifacts point to a certain primitivity of metallurgical installations on one hand (simple bloomeries with open reduction hearths in houses), and on the relatively good quality of products on the other. What is extremely interesting is the continuity of that type of craft which survived in the same site without any important change from the beginning of the Gallic oppidum until the decline of the Roman Empire. This indicates the existence of a traditional pattern among the native population in some parts of the Gaul, based on small-scale production of local indigenous centres with their agricultural environment which stood still aside the large-scale production of the Roman or Gallo-Roman industrial centers.

After M Mangin, Dijon (CPSA)

Olomucany, Moravia – New Bloomeries of the Early Middle Ages. During 1980 there were discovered a further two bloomery sites in the valley near Olumacany, in Blansko district. According to the characteristic pottery they are dated to the period about 800 AD, ie to the period when the Greater Moravian Empire developed. Both workshops are situated on an adapted river terrace and they consist of two batteries of 7 and 8 furnaces. This built-in furnace type is in both cases identical, and very close to that one known from Zelechovice. Northern Moravia (1950/51). These are noteworthy due to long induced draught tunnels serving during initial stages of smelting and to short shaft lined with refractory clays and especially to oblique tuyeres, pointing into furnace hearths from the rear of furnaces. Throat and tuyere blocks could have been modelled as pre-fabricated parts separately and then installed in the furnace hollows. Average size of furnaces in bloomeries nos 2 and 3: tunnel length 70 cms, total furnace length ca. 100 cms, shaft height 50 cms, hearth diam 28 x 36 cms, throat diam 15 cms.

After V Souchopova, Blansko (CPSA)

Tin dressing mill at Colliford Reservoir, Bodmin, Cornwall.. Further work was done on this site in the summer of 1980. (For previous report see JHMS 1980, 4 (2), p 104). Another possible wheel pit and mill were found about 300 m to the south of the first mill. Further leats and buddles were uncovered. More pottery was found which dates the mill to the 15th and 16th centuries.

It is now believed that there were 3 or 4 basic phases of mill construction and use, the last of which may belong to the early 17th century and not be industrial. *T Greeves*

New Reconstructions of the Bloomery Process carried out at Varde, Denmark, in 1978, 1979. In addition to trials organised by R Thomsen in late 1960, 3 new smelts were made in the so-called Scharmblock or Drengsted furnace type in 1978, and a further 2 in 1979. Furnaces, equipped with gas analysers and thermo-couples, were charged with charcoal and bog iron ore. In tall shafts the induced draught provided a suitable temperature of about 1300^{o}C. Time required was considerable: tens of hours. The smelts were successful in terms of iron production – about 3-4 kgs of forgeable spongy iron was the average yield per furnace-and-smelt. But no typical heavy slag block, well-known from many furnaces of the mentioned type, could be produced. The mystery of their creation remains unsolved.

After H Barbre and R Thomsen, Varde (CPSA)

New Trial Smelts at Blansko, Czechoslovakia. Discoveries of early medieval bloomeries at Olomuoany invited the organising of new experimental smelts on furnaces modelled on those which appeared in the field. In June 1980 there had been installed a well equipped bloomery in the park of Blansko Castle, where the Museum – the sponsor of excavations and smelts, is housed. The furnace type tested was that with a thin front wall and tuyere panel (9th century AD). Beech charcoal and Indian hematite ore with ca 60% of Fe_2O_3 was charged in various proportions. Temperatures oscillated between 1200 - 1250°C (forced draught by a compressor). Individual smelts lasted 4-5 hours. Iron sponge conglomerates embedded in slags have been obtained. Analyses are in progress. The work was assisted by Prof B A Kolcin, Inst of Archaeology at Moscow, a well-known archaeometallurgist. All furnaces are well preserved and ready for another set of smelts planned for 1981.

R Pleiner, Prague – V Souchopova, Blansko (CPSA)

Book reviews

ANCIENT COPPER IN THE TIMNA VALLEY. H G Conrad and B Rothenberg (eds), (in German). 'Der Anschnitt' Deutschen Bergbau-Museum, Bochum, 1980, 236 pp, 266 illustrations, 12 tables, 34 folding maps and plans, 78 DM.

This publication describes the results of continuing research at Timna (Israel) from 1974 to 1976 conducted by the Deutschen Bergbau-Museum and the Arabah-Expedition. Separate excavations of ancient copper mines and a large smelting site are reported. The range of related topics includes cartography, geology, mineralogy, geomorphology, and of course, archaeo-metallurgy. There are ten papers by specialist members of the project. The multidisciplinary approach of this new Timna Project presents a foundation for the resolution of many controversies.

The introductory paper by B Rothenberg reviews the development of archaeological and metallurgical research at Timna, discussing the sources of previous misunderstandings. The organization of the cooperative teams, as well as the goals for both excavations are presented. Due to the large quantity of remains at Timna, a single 4 km² model area was selected for intensive analysis. The area was chosen to be representative. The centre of the model area is about 2 km away from the excavated Site 30, a major wall-enclosed industrial site. The excavation of Site 30 was conducted to complement the related studies and excavation of copper mines in the model area.

W Lieder reports on the surveying and mapping of the model area.

Y Bartura, A Hauptmann and G Schone-Warnefeld present the geology and mineralogy of the Timna Copper Deposit. Much of the general information is available elsewhere. However, there are improved sections and new ore analyses.

A most significant related study is by A Hauptmann and A Horowitz on the geomorphology and paleomorphology of the model area. Their work identifies five erosional terraces. Ancient mine shafts are located only on the older terraces (II-V), with the present Wadi system cutting down and exposing connecting mining galleries. This clarifies many of the odd mine locations evident in the earlier Timna publications.

The next two papers, each by the same team of H G Conrad, L Fober, A Hauptmann, W Lieder, I Ordentlich and G Weisgerber, describe the ancient mining systems and their interpretation of mining techniques.

I Ordentlich and B Rothenberg present another paper on the finds from the excavation of the mines.

In the final paper on the model area, B Rothenberg summarizes and proposes a chronology for the ancient mining technology. According to Rothenberg, the Early Chalcolithic Elat Culture utilized pits dug into the alluvial terraces to collect complex copper nodules. If this date is also accepted for Site F2, then the Elatian Culture at Timna represents the very beginning of copper smelting. Irregular shafts and galleries cut with stone tools are attributed to the Late Chalcolithic Timna Culture, possibly equivalent to Sites 39a and b. The most common regular shafts and galleries cut with metal tools belong to the Late Bronze-Early Iron Age, Egyptian New Kingdom. What were once called 'plates' or ore-dressing sites are actually debris filled mine shafts. No Roman mines are reported in the model area.

The excavation of smelting Site 30 is described by B Rothenberg, with the final paper on copper smelting remains co-authored by H G Bachmann and B Rothenberg. Archaeologically, three phases are recognised. The second and most important phase being contemporary with Site 2 and Site 200 (the Timna Temple, XIX and XX Dynasties). Metallurgically, just two different technologies are present. Stratum II and Stratum III represent the same smelting process using iron oxide flux in small furnaces with a reconstructed internal diameter of 0.24 m and two tuyeres. Four loci are reported as copper smelting furnaces. This process is in contrast to the later technology of Stratum I, which used manganese flux in much larger furnaces. The proposed furnace for Stratum I was reconstructed from loosely fitting furnace lining fragments and had an internal diameter of 0.54 m and six tuyeres! However, since large furnaces were not actually found in situ, the size and number of tuyeres is highly questionable. Twenty new slag analyses are included. A single heating experiment was conducted on site with natural draught.

The fragmentation of evidence between specialist papers is regrettable. The various presentations on mine description and interpretation could have been more usefully synthesised with actual finds and proposed dates. Cross reference between papers is difficult. There is no index.

Another criticism concerns order of magnitude calculations. For example, the proposed average production value of 30 kg per mine is too low. It was based incorrectly upon the copper analysis of disseminated ore remaining in the ancient mines instead of a quantity estimate of the complex nodules containing considerably more copper.

The standard of illustrations and photographs is very good. The folding maps and plans allow a good scale of reproduction, especially for the mining systems. Printing errors are few.

This volume of 'Der Anschnitt' devoted to recent multidisciplinary research at Timna presents much new descriptive information. It is a valuable addition to the study of ancient extractive metallurgy.

John F Merkel

SOUTHWESTERN COLONIAL IRONWORK. Marc Simmons and Frank Farley. Museum of New Mexico Press, Santa Fe, 1980. 216 pages. Illustrated. $ 25.95 hard cover, $14.95 soft cover.

This is a substantial work illustrated with nearly 200 photographs and 42 line drawings. It covers a period of about 300 years from 1519 to 1821 AD. As the authors state, the object of the study is to show the nature and scope of the Hispanic blacksmithing craft, and to describe the kinds of ironware used in what is today the southwestern United States.

The book is conveniently divided into two sections. Part I deals with Ironworking in Spain, ironworking in Colonial Mexico, ironworking in the Spanish Southwest, and iron and the Indian trade. Part II gives a comprehensive treatment of the Smithy, Farriery, Tool forging, Ironware on the farm, ranch and trail. Horsemen's hardware, Iron in the home, Builders hardware, Mission iron and conclusions. Part I of the book traces the story of smithcraft from Spain to the American Southwest, while Part II deals with the work of the Colonial smith, his methods, equipment and products turned out. This section covers a great variety of work, from simple mining and other tools to complex and ornate examples of the smith's art.

Clearly this work will be of interest to European archaeologists and technologists who will find a wealth of comparative material in Part II. Some confusion could arise from the statement on page 4 that the Moors also introduced a technique of inlaying, called damascening, that involved chiseling a linear design on iron. Damascening is of course quite different from inlaying and the true damascene process was the result of a skilful metallurgical and forging process probably associated with the high carbon Indian steel known as Wootz. To those interested in the Spanish Espada Falcata (page 3) we may mentioned that an examination of one of these swords was published in Sibrium, Vol 3, 1956-57, Etruscan and Spanish Swords of Iron.

The production of the soft cover book reviewed is very good, and the photographs and line drawings well reproduced. The book is very good value at the price of $ 14.95. The work is certainly to be recommended.

H H Coghlan

LEAD IN HISTORY AND ART/BLEI IN GESCHICHTE UND KUNST. Wladimir W Krysko. Published by Dr Riederer – Verlag GmbH, Stuttgart 1979? 244pp + 233 ill.

This book is divided into two parts: the first part occupies about 60 pages and 82 illustrations and in it the author traces the history of the production and uses of lead from its first appearance in about 7000 BC at Catal Huyuk in Anatolia to the present day. The second part, taking about 22 pages and 150 illustrations, deals with the use of lead in art from about 3800 BC in Egypt to modern times. The text throughout the book is presented in alternating columns of English and German (which nicely reveals the relative economy of the English language), and the illustrations similarly have captions in both languages. The book is very well presented and attractively bound, but an unfortunate omission is the absence of any kind of index.

It is the first part of this book which will probably most excite the interest of readers of this journal. In the first five or six pages of text the author traces the early history of metallurgy and makes a good case that lead may have been the first metal to have been smelted from its ores and that this discovery may have led to experimentation with other ores, leading to the important discovery of the smelting of copper about 3800 – 3500 BC and then to the relatively rapid mastery of other types of pyro-metallurgy. Krysko emphasizes the opinion that the extraction of lead-silver alloys from silver bearing lead ores, followed by the separation by cuppelation of the lead/silver alloy into litharge and metallic silver, became the chief object of early metallurgy; though this may well be true, proof of the author's assertion, in support of his case, that litharge was used in glazing ceramics dating from 5000 BC is not known to the reviewer. Far more perusasive evidence of the seminal importance of early lead/silver metallurgy seems to the reviewer to come from Kay Prag's description of the relatively large amounts of silver which appear in the Levant in the fourth millennium (1), contemporaneous with or somewhat preceding the appearance of relatively large amounts of copper artefacts.

The author then treats briefly of the ores, ore-processing and extractive and refining metallurgy of lead, the emphasis being chiefly on more modern methods. Though some mention is made of the ingenious helicoidal washeries used in the Laurion for ore beneficiation in the 5th - 4th centuries BC the reader is given no indication how rare these were in comparison with the ubiquitous plane washeries. No account whatsoever is given of ancient, medieval or 19th century smelting or refining methods, but in describing modern methods of lead refining the author comments wryly that the silver and gold, when separated at last from the lead and each other, are then returned again to the earth for storage in subterranean vaults.

Krysko proceeds to a brief description of the phenomenon of creep in lead and the necessity of overcoming this effect in large structures of lead both by incorporating alloying elements and by iron or steel supports cast into the structure, following this by a discussion of lead production and prices through the ages. His discussion of the many uses of lead in antiquity-metrological, fishing net and loom weights, sling bullets, solder, foundation plaques, as a bronze deoxidant, in building construction, to sheath the hulls of ships, in Roman civil engineering, as a medium of exchange etc. – is slightly flawed by unfounded assertions of the use of lead glazes in the Nile Badarian culture and from 3800 BC at Egyptian Abydos, and by a claim that clear and red glass and artificial lapis lazuli, all containing many tens of per cent of lead, were common from 2000 BC onwards. In fact Caley (2) has shown that the Nimrud red glass (containing $\sim$20% PbO) dates from the 8th to 6th centuries BC, not 2000 BC, that lead glasses (in Egypt, Rome and China) are otherwise known only from about 200 BC to 200 AD. In later times an account is given of the wide variety of uses of lead in printing type, the coming of stained glass windows, glass making, as a roofing material, in lead-acid accumulators, electric cable sheaths, radiation protection, in petrol, paints, vinyl polymer stabilisers, solder etc.

The section on the use of lead in art is beautifully illustrated and covers the period 3800 BC to 1977 AD, showing uses in making figurines, medallions, pilgrims signs, sarcophagi, monumental sculptures and fountains, lead crystal glass and non-representational art of the most modern kind by artists such as Sabatier, Raftopoulou and Rigot. This section is unfortunately also marred by faulty archaeology, such as the statement on p 108 that Schliemann found very little gold and no silver at Mycenae. The least observant tourist visiting the National Museum in Athens could give the lie to this statement, and the considerable amounts of silver from Mycenae listed by Karo (3) suggest that, contrary to Krysko's view, cupellation of lead-silver alloys was known and practised by the Mycenaeans of Shaft Grave times. Further there is as yet no support, beyond an unfounded and worthless statement by Landerer, that lead glazes were used by the Mycenaeans. Xavier Landerer, Professor of Chemistry at Athens in Schliemann's day, is responsible for many unfounded and misleading statements about the artefacts excavated at Mycenae and the geology of the Cycladic Islands, statements which have been too readily accepted by many subsequent scholars.

All-in-all, however, this is a useful book which does much to redress the unfortunate neglect by many archaeologists of lead, a metal which is in fact very important in the history of the development of mining and metallurgy not least because of its close association with silver. The section on the use of lead in art is fascinating, and will certainly introduce most readers to novel and beautiful uses of this apparently dull and unprepossessing metal.

Noël Gale

References

1 K Prag, 'Silver in the Levant in the Fourth Millennium BC', in Archaeology in the Levant, ed P R S Moorey and P J Parr, Aris and Phillips (1978), 36-45.

2 E R Caley, 'Analyses of Ancient Glasses', Corning Glass Centre, New York (1962), 85.

3 G Karo, 'Die Schachtgraber von Mykenai', (1930), Munchen.

ENTRATSELTE GEHEIMNISSE DER ALTEN BRONZEN (The Solution to the Problem of Early Bronzes). I R Selimchanow. Veb Deutscher Verlag der Wissenschaften. Berlin. 1974. 14 x 21 cm. 93 pages. Figs and eight pages of coloured plates.

As the title indicates, this book by the well-known authority, Professor IR Selimchanow, is directed towards the solution of the various problems in connection with the ancient bronzes which are still not completely solved. Although much has recently been written about ancient bronzes it is true to say that a number of problems remain for consideration. The book is not a large one only containing some 93 pages but, helped by the use of somewhat small print, it is remarkable how much information and detail the author has managed to include.

Selimchanow has not confined himself to a limited discussion but covers quite a wide field, chapters being given on: How people learnt of metals. What sort of metals. Chemical aids. Development of systematic examination of ancient metals in the USSR. The metals as a basis for Historical Age. A whole chapter is devoted to arsenical bronzes and also to the tin-bronzes including some discussion of 'where did the tin come from'. The Sumerian bronzes. Smelting of ancient metals and the technology of bronze production.

Throughout his text the author has naturally had to give an indication of the age of the various metallurgical stages. Archaeologists have always been much concerned with dating evidence for cultures in the various countries, but for metallurgical history undue weight really need not be given to exact dating. Very recent discoveries, carbon 14 dating, etc. have suggested changes to the previously accepted chronologies for the Near East and in Europe. However, for metallurgical studies this is not of first importance – for the history of bronze and other metals it is the sequence of evolutionary stages which matter, and not a fixed and narrow chronology.

Of particular interest is Selimchanow's discussion of the numerous and highly important arsenical bronzes to which he devotes a whole chapter. The composition and origins of this series of bronzes is a complex matter. As well as the straight copper-base arsenical alloys the author distinguishes other groups with impurities such as nickel, antimony, and lead. In his table 5, page 89, in which the convention of a pre-tin and a tin-stage is introduced, the various alloys are listed. As more work is done, and analyses available, concerning the so-called arsenical bronzes perhaps we shall have to a 'four period' system.

In conclusion it may be said that this is a good book and should certainly be given serious study by those interested in this particular field of non-ferrous technology. Much of the text is technical and will be of value to the metallurgist, but archaeologists should not have undue difficulty in following the general theme, and they would benefit by reading much of the text.

H H Coghlan

David E Bick: The Old Industries of Dean.
The Pound House, Newent, Glos, £4.50, 1980, 80pp.

A pictorial survey of old industries in the Forest of Dean; largely based on early photographs, most of which are published for the first time. Maps and prints are also included. It is a good deal more than a picture book as the captions are copious and give a considerable amount of information. Almost half the book is devoted to coal mining, and there are other sections on Stone, Lime and miscellaneous industries. In this respect the book is of more general than metallurgical interest, but it does contain sixteen pages devoted to iron mining and smelting in the area. There are old photographs of Wigpool and Shakemantle mines, and Cinderford and Parkend furnaces. The pumping engine at Shakemantle, made by the Neath Abbey Ironworks, and a lithograph from a patent specification, granted to Moses Teague of Park End Ironworks, showing a system of economising on fuel, by applying blast furnace heat to act upon the ores about to be smelted: also one of David Mushet's drawings of a furnace similar to that at Whitecliff are included.

Amina Chatwin

MINING IN CORNWALL 1850-1960. J H Trounson, on behalf of the Trevithick Society, Moorland Publishing Co, Ashbourne, Derbyshire.
Vol 1, Camborne – Redruth area (1980).
Vol 2, The rest of Cornwall (1981), each volume £3.50.

The pioneer photographer Henry Fox Talbot visited his uncle Sir Charles Lemon in 1841. What a shame, what a loss that the shy Henry did not point the lens of his new invention at one of the mines which brought his uncle such wealth. Had he done so, you could be sure that the results of his efforts would now be preserved in the collection of J H (Jack) Trounson, whose portfolio of pictures treating all aspects of Cornish mining and its related industries must be the most extensive anywhere. Mix this prime ingredient with Jack's encyclopaedic knowledge of his subject ever at his finger-tips, then add to that a silver tongue which, once set in motion, it is impossible to stop pouring forth anecdotes about the mines, the engines which pumped them and the miners who laboured under difficulties scarcely imaginable today, and you end up with a man who can with justification be called a living legend. For years friends have pestered this extremely busy man to launch himself into print. At last he has done so. Both author and the Trevithick Society are to be congratulated on packing into two small volumes a rich collection of prints, with as lucidly informative an accompanying text as has appeared on this subject since 1893. No one has better qualifications to do this than Jack Trounson, to whom everyone with an interest in Cornish mining, past, present, and future, eventually turns for advice and guidance.

Photography of Cornish mines was rather slow in getting off the ground – if you'll forgive the rather inappropriate phrase. Harding, in the 1850s, did not venture out of Polperro, and while Capt Harry Roberts claimed in his Reminiscences of Perranporth that the view of Wheal Leisure was taken in 1840, it is at the very least a decade later, as Jack Trounson realises (vol 2, pl 96) and is rather uninteresting in showing only abandoned mine buildings. Not until the 1860s do we find photographs of active mines and miners, as at St Just United, and Botallack (vol 2), and then the dates are disputed, except for the photograph taken during the Royal visit to Botallack on 24 July 1865 (pl 8). Many early photographs are of West Penwith mines, doubtless in part because of the Royal visit and the inspiration of such books as Wilkie Collins' **Rambles beyond Railways** (1852) which described so graphically the underground dangers at Botallack.

No book of Cornish mining photographs is complete without a selection of the impressive exposures underground by John Charles Burrow which he began late in 1891 largely at the suggestion of his friend William Thomas at Camborne School of Mines. Many of the original glass plates survive at the Royal Institution of Cornwall's museum at Truro. Some of these pictures are used by Jack Trounson, including the one of the miners riding on the Man Engine at the 234fm level at Dolcoath in 1893, and what is perhaps the most famous of all underground scenes, the massive timbering, or 'stull', at the 412 in the same mine; an eerie view when it is realised that a matter of weeks after Burrow's visit in 1893, a heavy fall of rock claimed seven lives, an eighth man escaping unhurt after thirty-seven hours' entombment. The sole omission from these volumes, and it is not a serious one, is that the authorship of the photographs is not given in those cases where it is known. It would have added interest if the work of Burrow, Jordan, Bragg or Govier, had been distinguished by the use of initials.

All aspects of mining are covered in the two volumes, from the labour of the face workers, to that odd moment of leisure when a miner at Phoenix is having a trim by the mine barber, an ancient custom revived when the Phoenix Mines were last worked before World War 1. Ore dressing receives a good quota of plates, from the building of Botallack's new crushing and concentrating mill in 1908, to the concentrating tables working at East Pool & Agar, and delightful shots of 'bal maidens', usually posing in their best white aprons which would be replaced with rough hessian as soon as the photographer had finished.

Arsenic, an important by-product of a number of mines late in the last century, also receives attention. The intricate maze of arsenic flues is seen under construction at Botallack about 1908. From South Crofty comes a series of plates showing the operation from roasting to produce an arsenic 'soot', to its conversion into snow-white arsenious oxide which was ground into a fine powder.

Wolfram, an important by-product especially in war time, was once a troublesome mineral in tin ores. Its removal became easy with the use of a magnetic separator, like the one pictured at Tincroft. I had seen this photograph before, unlabelled, and wondered what on earth it was. Now I know. That is one of the beauties of these books. However extensive one's knowledge of Cornish mining, everyone will find here something that is new to him.

Between them the volumes contain 268 photographs covering the whole of Cornwall. Let us hope that at least one more volume will be forthcoming. Many more rarely seen photographs merit circulation to a wider public, at the same time needing the expert interpretation of Jack Trounson. The oldest method of tin mining, tin-streaming, together with the smelting of tin, and all the other ancillary industries which depend on those who work the mineral lodes, are all subjects worthy of the same treatment.

It is a shame to have to pass any adverse comment on these books, and what is written next should not deter anyone from buying them, for they are very good value for money. Even allowing for the very variable quality of photographs, it is obvious that a number reproduced here fall far short of the originals' quality. For many people this will not be apparent, but for those who know the original Victorian and Edwardian prints, it is most regrettable. Plate 72 in Vol 2, for example, is arguably the best surface view ever taken of Blue Hills Mine, St Agnes, a splendid composition by Govier sometime in the 1890s. The original is as sharp as crystal, with that rich velvety sepia one can only dream of nowadays. But here the picture is diminished to a drab grey. To make matters worse it is extended across the centre of the double-page spread. Designers really must be kept on a tight leash. Their picture juggling may be all right in theory, but in practice it would have been better, in this instance, to have rotated the picture through 90^{o} and put it on one page. The same is true, among others, of Burrow's famous picture of the bridge at the 170fm level at East Pool, here enlarged to a pale shadow of the original; far better if it covered one page allowing another whole page for the view of Wheal Agar which really needs that size, instead of cramming its mass of detail into a space only 4 x 3½ inches.

The best photographers, and J C Burrow can certainly be counted amongst them, are true artists. Books like Jack Trounson's deserve the same respect and treatment as books dealing with fine art subjects. Surely this is not too much to ask in the late 20th century. Nevertheless, these two books merit high praise and they should be on the shelves of everyone who has or pretends an interest in Cornwall and its mining history.

R D Penhallurick

Erratum

In Tom Greeves's review of Chernykh's book on p 47 of the last issue (Vol 15 (1)) line 18 of the first column should read 'Group I copper predominates' and not Group II.

Abstracts

GENERAL

Anon: Hydrogen reduction of archaeological iron. *Conservation News, June 1979,* **9**, *2-3.*

An interim policy statement on the use of hydrogen reduction for the treatment of archaeological iron, made by the area museum service for South East England, is reported. Following criticism of the use of a hydrogen reduction furnace, the museum service formulated guidelines for its use. The method could destroy metallurgical evidence of archaeological significance in wrought iron. Procedures for safeguarding such evidence were recommended. PJW

Anon: Touching gold; touching silver. *Engelhard Europe, Winter 1978,* **12**, *4-7.*

This is a review of an exhibition held in London in late 1978 to celebrate 500 years of hallmarking gold and silver objects by the Worshipful Company of Goldsmiths. The paper deals with the history of assaying and hallmarking in the UK. WAO

T C Champion: The early development of iron working. *Nature, 1980,* **284**, *513-14.*

Brings together some scattered references which indicate that the discovery of iron did not diffuse from one single centre, that early iron was not superior to bronze, and that it was not immediately adopted by bronze-users. Early iron finds have been reported from Thailand (1600 BC), China (1200 BC), Netherlands (12the century BC), Romania (1200 BC) etc. Attention is now focusing on the social and economic conditions which encouraged the development of iron technologies. BAA

Alan D Franklin, Jacqueline S Olin and T A Wertime, Eds: The search for ancient tin. *Book, Smithsonian Institution Press, Washington D C, 1978.*

This volume includes nine symposium papers covering a range of topics on ancient tin. The geological environments in which tin is found are described together with accounts of geological and archaeological surveys particularly in the Near East and South Asia. The importance of arsenical copper is discussed and questions are raised about the sequence leading to tin bronze production and trade. Included is a paper on the trace element analysis of tin sources worldwide. AA

W A Oddy. Editor: Scientific studies in numismatics. *Book, British Museum Occasional Paper No. 18, British Museum, London, 1980.*

Text contains the papers of numismatic interest which were presented at the 19th International Symposium on Archaeometry and Archaeological Prospection held in London in 1979. The papers include analysis results on Roman copper coins and modern silver tokens together with papers on the metallurgy of Celtic coins, the application of computers to die study, and the manufacture of medieval forgeries. The paper by Craddock et al contains important new evidence on the origins of brass. WAO (AA)

W A Oddy and M M Archibald: The technique of some forged medieval silver pennies. *In Book. Scientific Studies in Numismatics, 1980, 81-90.*

This paper describes the method of making one type of forged coin for contemporary use which consists of a core of lead and/or tin sandwiched between two embossed precious metal foils. A survey of known examples of this type of forgery is followed by a discussion of the numismatic and scientific evidence which led to a hypothesis explaining how they were made. WAO (AA)

P M Roberts: Brazing in antiquity. *Engelhard Europe, Winter 1978,* **12**, *8-11.*

A very brief review of the history of hard soldering from c 4000 BC. Examples are drawn from the Egyptian collections in the British Museum. WAO

R F Tylecote: Copper ingots and marine copper. *Int J Naut Archaeol Underwater Explor, 1980,* **9**, *67-8.*

Metallurgical analysis of plano-convex ingots from Plymouth and Looe Bar are compared with data for copper sheeting from the post-medieval yacht *Mary*. The Plymouth ingot is attributable to LBA by its weight; its 0.4% tin content, high for British finds as a whole, could suggest an ore source in Cornwall-Devon. The Looe Bar ingot, from a post-medieval wreck site, has an analysis comparable with that of the *Mary* sheeting. More analyses of unalloyed coppers of AD 1000 to 1700 are needed. BAA

R F Tylecote: The effect of soil conditions on the long-term corrosion of buried tin-bronzes and copper. *J Archaeol Sci, 1979,* **6**, *345-58.*

Thirteen hoards selected from *Inventaria Archaeologica* were examined in relation to the chemical condition of the soil in which they had been buried. Even though the soil samples had to come from sites which yielded their hoards up to a century ago, a reasonable relationship was found between the pH of the soil and the state of the metal. High tin bronze was found exceedingly resistant to a wide range of corrosion conditions. Acid soils are aggressive to metals, alkaline soils benign; peat and peaty soils were mainly benign although acid. BAA

R F Tylecote and J W B Black: The effect of hydrogen reduction on the properties of ferrous materials. *Stud Conserv, 1980,* **25**, *87-96.*

Heating ferrous artefacts (wrought iron, steel, or cast iron) can cause changes in their metallurgical structures. The effects of heating and cooling ferrous material in different atmospheres are studied and recommendations made concerning types of ferrous artefact which should never be subjected to elevated temperatures. *Authors (abridged)*

O Werner: From where the lead content of the old brasses? *Mineralische Rohstoffe als kulturhistorische Informationsquelle, 1978, 118-132.*

The source of lead in early brasses is claimed to be the calamine of the zinc ores. The zinc/lead ratio is not claimed to be changed during melting processes. RACR

Frank D Woodall: Early smelt mill bellows. *Industrial Archaeology, Winter 1980,* **15**, *(4), 291-294.*

The author concludes that early smelt mill bellows were worked by cams and weights, but when they came to be driven both ways then storage compartments and relief valves became an essential part. (Author)

Ulrich Zwicker, Karl Nigge and Benno Urbon: Distribution of metallic elements in patina layers. *Mikrochim. Acta Suppl, 1979,* **8,** *393-419. (German).*

Patina layers on copper alloy archaeological artifacts were investigated. Alloying elements were generally enriched in the patina layers. The behaviour was observed especially for As, Pb, Sn and Sb. In the case of brazed joints composition of the patina was sometimes different in each piece due to electrochemical action. AATA

BRITISH ISLES

J K Almond: A century of basic steel: Cleveland's place in successful removal of phosphorus from liquid iron in 1879, and development of basic converting in the ensuing 100 years.

Ironmaking and Steelmaking, 1981, 8, *(1) 1-10.*

Growing international interest in removing phosphorus from the liquid iron during the 1870s is outlined, and Thomas and Gilchrist's involvement with the phosphorus problem is described, including the two men's crucial work in Cleveland in 1978-79. The difficulties that had to be overcome are itemized, and the ways in which they were dealt with are briefly discussed. Adoption of Thomas and Gilchrist's technique in different countries is then considered including reasons for the spectacular growth on the Continent but slower development in the USA and the UK: application of basic conditions to open-hearth processing is mentioned. Re-introduction of basic converting into the UK during the 1930s is traced, including measures to minimize nitrogen. The advent of top-blown oxygen converting and the development of bottom-blown converters using oxygen plus hydrocarbons is summarized. (Author, adapted)

Anon: Steel Group checks Ancient Cannon. *Foundry Trade Journal, 1981,* **150,** *(3207), 243.*

Mons Meg was made in Mons in 1449 by the Duke of Burgundy's gunmaker, Jehan Cambier, and sent in 1457 as a present to the King of the Scots. The hoop-and-stave structure of the barrel fractured during celebrations for the birthday of Charles II's brother, James. Now at Edinburgh Castle, this news item describes the problems encountered when the gun weighing 8.5 tonnes was moved to a foundry at Armadale to be radiographed to detect any cracks in the barrel or general deterioration. APG

Leslie A Armstrong: Analyses of bronze implements and foundry metal. *Man, Sept.1926,* **XXVI,** *164-167.*

Six bronze prehistoric implements and three fragments of founders' metal, Irish or English, were analyzed quantitatively for six to eight elements plus silica. B Ap

T Blagg and S Read: The Roman pewter-moulds from Silchester. *The Antiquaries Journal, 1977,* **57,** *270-276.*

Pieces of six limestone moulds for the casing of pewter vessels, found on the Forum at Silchester, are described and illustrated. Five were used for casting three types of dish or plate. Two were moulded on both sides to form part of nests of moulds. The sixth piece was the inner mould for a cup or flagon. The techniques of manufacture are considered. The grooves for casting the rims and feet appear to be compass-drawn, but there appears to be no evidence that the moulds were lathe turned. AA

G C Boon: A Greco-Roman (lead) anchor-stock from North Wales. *Ant. J. 1977,* **57,** *(1), 10-30.*

A very useful and comprehensive paper on the subject giving structure and dimensions based upon a unique specimen in British Waters dated to the 2nd cent BC. RFT

Colin Brewer: Anglo-Saxon weapons. *Metals Australasia, 1979,***11,** *7, 4-6, 7 refs.*

An account of the legendary Weyland the Smith's method of manufacturing a sword is provided; his unusual method has a scientific basis. The results of metallographic examinations on the Saxon scramasax and the sword found at Sutton Hoo are presented. Saxon armour and the course of the Battle of Hastings are also discussed. KJ

D C Cox: A currency bar hoard from Harrow Hill, Middle Littleton. *Vale Evesham Hist Soc Res Pap, 1979, 7, 31-8.*

A spit-shaped currency-bar recorded in D F Allen's 1967 catalogue was the sole survivor of an apparent hoard mentioned in an 1822 diary entry recently discovered. The entry records 104 pieces, making this the third largest such hoard in Britain. The find-spot lay somewhere in the suggestively-named Harrow Hill field which also has RB remains, a medicinal well, and some circumstantial evidence for a hillfort.

D W Crossley: A gun-casting furnace at Scarlets, Cowden, Kent. *Post-Med Arch. 1979,* **13,** *239-249.*

A timber-lined casting pit was installed between 1590 and 1664 at this blast furnace site. The methods of construction are similar to those used at Pippingford and Maynard's Gate Sussex. The adjacent floor is a feature paralleled at Pippingford and at Rockley, Yorks. The furnace has been thoroughly robbed of its stone, but its position and orientation can be satisfactorily established; evidence was found for refurbishing at the end of the 17th century, yet it seems likely that abandonment came before 1717. Author

G R Gilmore: Chemical analysis of the silver token coinage of 1811-1812. *In Book. Scientific Studies in Numismatics, 1980, 91-97.*

This paper describes the neutron activation analysis of a number of English silver tokens of 1811-1812. The silver contents were mostly between 80 and 90%. WAO

R J Harrison and P Craddock: The rediscovery of the lost hoard of LBA axes from Roxby, Lincs. *Ant J 1979,* **59,***(2) 231-244.*

Analyses of 18 bronze socketed axes found with 3 pieces of nearly pure copper ingot. It also includes scrap axes and fairly complete examples of the Heathery Burn tradition (8th-6th cent BC).

Some axes have a high concentration of lead and tin due to inverse segregation. All are leaded tin-bronzes with low As and Sb but relatively high nickel for the British Isles. The Sb is higher than the As.

RFT

D A Jackson: Roman iron working at Bulwick and Gretton. *Northamptonshire Archaeol, 1979,* **14**, *31-7.*

SP 929939 etc. Furnaces, channel hearths, and quarry pits have been examined in two ironstone quarries. What little survived of the furnace structures suggested similarity to Wakerley Type 3. The channel hearths lay parallel in groups and contained no ore or slag. BAA

D M Metcalf: Chemical analysis of English sceattas. *Brit Numis J, 1978,* **48**, *12-19.*

Reports results of analyses using the Isoprobe spectrometer: silver fineness ranged from c 98% to c 20%, but coins of the same variety tend to have similar compositions, and a progressive debasement beginning about the 730s is likely. BAA

J Musty and Leo Biek: Celtic coin moulds from Old Sleaford, Lincs. *Ant. J. 1976,* **56** *(2), 238-241.*

Gives results of examination of a pellet fragment found in one of these clay-sand 'moulds'. The mould had been heated from above and the pellet melted within was a hyper-eutectic Cu-Ag alloy containing about 65-70% Ag and 30-35% Cu with a hardness of 75 HV1. RFT

S Needham: An assemblage of LBA metalworking debris from Dainton, Devon. *Proc Prehist Soc, 1980,* **46**,*177-215.*

The assemblage consists of clay-sand mould for making swords, spearheads and ferrules. These have been made in two parts with a removable pattern and closed by means of an outer wrap or investment. No wooden or other reinforcement was used. Crucible sherds were also found on the basis of which a 3-legged crucible with a lip has been reconstructed. It is not certain how this was poured.

A mineralogical fabric analysis has been carried out. RFT

Richard and Edward Knight: Ironmasters of Bringewood and Wolverley. *Trans Woolhope Nats Fld Club, 1979,* **43**, *7-17.*

The widespread operations of the Knight family as iron-masters began during the civil war and continued without a break to the present century. Willey Furnace, Shropshire seems to have been the first furnace to have associations with the Knights, prior to 1730. By 1695 Richard Knight was leasing the Flaxley Furnace, Glos. By 1725 he was operating ironworks at Morton, Bringewood and Charlcotte. Various Shropshire partnerships followed. In 1751 Edward Knight in partnership with Baron Foley was operating Elmbridge Furnace, Newent. The family played a unifying role between the ironworks of the Forest of Dean and the forges and other works of the Stour Valley. IJS

Francis Pryor: A catalogue of British and Irish prehistoric bronzes in the Royal Ontario Museum, *Toronto, Roy Ontario Mus, 1980.*

The ROM collection was mostly acquired by C T Currelly up to 1930, with an eye on quality and range. Items are fully described (including notes on their surface condition, colour, patination, etc) and metallurgical analyses were performed by Paul Craddock (British Museum) on all 184 pieces. Included are axes (flat, flanged, palstaves, winged, socketed), spears, knives, dirks and rapiers, swords and ornaments. Most important items are the LBA shield of Harlech type from the River Lea near Ponders End, and three items of the Harrogate hoard. BAA

A Rodell: New Rails for Old (Illustrated). *Railway Magazine, March 1981,* **127**, *(959), 140-142.*

Cast iron rails were used on the horse-drawn wagonways, however the Stockton & Darlington railway was largely laid with rolled wrought iron rails in 15 ft lengths weighing 25 lbs to the yard, but these were soon found to be too light for the loads they had to carry, and the Liverpool and Manchester was first laid with wrought iron rails weighing 25 lbs to the yard. Later the weight of the rails used increased to 75 and even 86 lbs per yard. However no additional weight of iron rail would enable them to resist crushing at the small points of contact between wheels and rail. The Midland Railway experimented with steel rails at Derby in 1857. The development of the Bessemer process greatly reduced the cost of steel, and the London and North Western Railway ordered 500 tons of Bessemer steel rails which were laid down where greatest wear was experienced. One steel rail was still giving satisfactory service under conditions which had worn out completely eight iron rails. APG

EUROPE

Toscano y Barba, Alonso Alvaro: Metal craft: In which the real benefits of gold and silver amalgams are discussed. *Book. Imprenta del Reyno, Madrid, 16th-19th Century Imprints. Libros Latinos. Redlands, CA, 1979, In Sp.*

This is the first detailed study of the amalgam process of silver and gold production and was therefore considered very important throughout the 17th and 18th centuries. MdIA

T B Bartseva: On the chemical composition of Scythian period standard heads. *Sov Ark 1980 (3), 77-91. In Russian.*

Sums up the results of spectro-analysis of 58 objects dated to the 6th to 3rd cent BC. These were all tin bronzes some containing as much as 33% Sn. The lead varied from 0 to 12%. 12 elements were determined. These objects came from the Sula region on the left bank of the Dniepr. RFT

D Bernard, A Roux, J Barralis, K Gruel and F Widemann: Experimental study of tin distribution in Coriosolite coins. *In Book. Scientific Studies in Numismatics, 1980, 41-52.*

A metallurgical study of three Coriosolite coins of the Trebry hoard has shown that the copper-silver alloy contained some tin concentrated primarily near the surface of the coin. This led to hypotheses about methods of surface enrichment of tin. Several alloys were prepared with the compositions derived from the analyzed coins and the structural variations in these alloys were observed for different simulated methods of melting and coining. From the results of the experiments an attempt is made to explain thesmechanism of the introduction of tin into the alloy. AA& WAO

P Betancourt, T S Wheeler, R Maddin and J D Muhly: Metallurgy at Gournia. *MASCA Journal, Dec 1978,* **1**, *7-8.*

Elemental and metallographic analysis of fragmentary ingots and copper artifacts from Gournia, in eastern Crete, has confirmed that metalworking was probably practiced on this site in Minoan times. Scrap metal was evidently used and recycled many times. JW

T F C Blagg and S J Fleming: Casting a bell for the abbey of San Paolo di Valdiponte. *MASCA Journal, Dec 1978*, 1, *14-15.*

Excavation of the abbey in the title (in the province of Perugia) revealed a series of pits used to cast bronze bells. Thermoluminescent dating of the fired remains gave AD 1510 + 40. A brief interpretation of the result is presented. JW

Jean Bourhis and Jacques Briard: Chemical composition of Armorican socketed axes: methods, data, interpretation. *Rev Archeom, 1977*, 1, *3-14 (in French).*

Thousands of bronze axes with a high lead content were produced in Armorica in about 700 BC. Spectrographic analysis of large typological groups has been performed, and the principal constituents verified by electrolysis and gravimetry. The high lead content and the heterogeneous nature of the axes confirms their use as a form of currency. BAA

T Capelle: Notes on Celtic handicraft. *Boreas. Munstersche Beitrage zur Archaölogie, 1979, 2, 62-75. In German.*

A survey of the best known facts illustrating the high level of Celtic handicraft in the Late La Tène period including the bloomery and blacksmith's work. CPSA

E N Chernykh: The chemical composition of the Tamanian Metal hoard.. *Sov Ark 1980, (2), 150-154 (in Russian).*

33 objects from this hoard comprising pieces of ingot, sickles, knives and adzes were analysed. None were tin bronzes; most contained arsenic in the range 1-6%. The Sb content was low but there was a direct correlation between Sb and Ni, and between Sb and Ag.

The Taman peninsula lies in the Krasnodar region. The hoard was placed in a big clay vessel and contained nearly 50 objects. The combination of North Caucasian and North Pontic types dates it to the 13th-12th centuries BC of the late Bronze Age. RFT

E N Chernykh: The Constanta hoard and the problems of the Balkan-Caucasian links in the Late Bronze Age. *Sov Ark, 1981 (1), 19-26 (in Russian).*

This Romanian hoard contained two sickles of Kuban type which were chemically different from the rest of the hoard (ie they were impure coppers rather than tin bronzes). The rest of the artifacts, comprising socketed axes, sickles, a knife and some plano-convex ingots were made of typical Balkan metal. The Kuban-type sickles are clearly imported. Links between Balkans and North Caucasus are at this time (15th-13th cent BC) extremely rare. RFT

B Chropovsky ed: Important Slav sites in Slovakia. *Bratislava, 1978 (in Slovakian).*

From the metallurgical point of view, the following sites deserve special attention in this catalogue: From Hradok, a hoard of 247 iron axe shaped bars (p 84): From Komjatice, another small hoard of the 9th century AD discovered in a sunken-floored hut (p 102): From Moravsky Jan, a hoard of iron implements dated to the 8th century (p 130-131): From Pobedim, another hoard of axe shaped bars, one of 13 similar hoards from that fortified site (ca 850 AD) and from Vrsatske Podhradie, a big hoard of 21 iron implements including long blacksmith's tongs, anvils and sledge-hammers (p 239). CPSA

G A Dzis-Rayko and I T Chernyakov: A golden bowl of the Vylchetryn type from the North-Western Pontic area. *Sov. Ark 1981 (1), 151-162 (in Russian).*

A two-handled bowl from the Odessa region, 74.72% gold with rivets and restoration of 60-65% gold. Dated to the 15th-13th centuries BC. RFT

Cynthia Jones Eiseman: The Porticello shipwreck: lead isotope data. *MASCA Journal, Dec 1979*, 1, *18.*

Lead isotope ratios have been obtained on five samples excavated from the Porticello shipwreck, in the Straits of Messina, which dates from the 5th century BC. All except one fall into the isotope ratio ranges of the 'Laurion field' suggesting that the lead may have originated in the galena mines near Athens. The remaining ratio was typical of lead from a group of sources including Italy, Syria and Turkey. JW

H Frei: Funnel-shaped pits – evidence of early ore mining. *Archaologische Wanderungen um Augsburg (Otto Schneider et al ed). Stuttgart – Aalen, 1977, 40-45 (in German).*

About 8000 funnel-shaped pits have been registered in the environs of Augsburg, Federal Germany: the most important areas are situated near Dachsberg, Aichach etc. These features are remains of buried mine shafts ca 3-5 m depth which were exploiting limonite ore in tertiary sands. Radiocarbon dates (Aichach) show the mining to be between 750-1000 AD. CPSA

H Frei: The valley in the Rauher Forest. *Ottmarshausen - Von den Anfangen der Siedlung bis zur Gegenwart. Ottmarshausen 1978, 23-24 (in German).*

There are numerous groups of funnel-shaped pits (medieval mines near Ottmarshausen, Federal Germany (Aystetter Berg, Eisental, Vogelberg etc). They are dated to the 9th - 10th centuries AD. Investigations have shown that limonite in form of goods was mined. Iron bloomery slags were found at the site called Aystetter Muhle. CPSA

V D Gopak and F M Zavernyaev: Iron artifacts from the Pochep settlement. *Sov Ark, 1981 (1), 181-191 (in Russian).*

A metallographic analysis of mainly sickles and knives from the 1st-2nd centuries AD and the Bryansk region. They are mostly iron and steel is rare and heat-treatment only used occasionally. It is claimed that iron was smelted on the site but that non-ferrous metal was traded. Some of the blades are clearly welded iron-to-steel, and the maximum hardness of 464 HV has been achieved in one of these. These are of the iron-cored steel-encased type. The authors claim that the level of technique was comparatively low. RFT

M J Hughes and J A Hall: X-ray fluorescence analvsis of Late Roman and Sassanian silver plate. *J Archaeol Sci, 1979*, 6, *321-44.*

About 200 analyses have been made on Late Roman and Sassanian silver objects using energy-dispersive X-ray fluorescence. Much of the material analysed came from hoards (eg Mildenhall, Water Newton, Sutton Hoo) of the period AD 300-700. The analyses showed that throughout the period and across the geographical area silver fineness was high (average 95% silver); and discriminant analysis revealed some broad compositional differences between hoards. Authors (abridged)

M F Gurin: Metallographic investigation of iron artifacts from Abidnya (Byelo-russia). *Sov Ark 1980 (4), 251-259 (in Russian).*

Knives and sickles. Contains a table of structures and hardnesses. The usual iron-steel welded and carburized structures are represented and hardnesses reach 600-700 HV in a few cases. The objects belong to the 2nd-5th cent AD. RFT

G Heckenast: Production of iron in medieval Hungary. *Studia Historica Academiae Scientiarum Hungariae 142. Budapest 1980, 22 pp (in German).*

The author summarizes the present knowledge on early bloomery process and iron production as reflected in written sources of the 13th-17th centuries. A great deal of attention is devoted to the historical terminology concerning iron, bloomeries, iron mines, hammer-mills etc. Surprisingly in many documents written in Latin, German or Hungarian there is a confusion of terms used for different production plants. The medieval hammer-mill represents, in early Hungary, a small-scale capitalistic element placed in the feudal system. CPSA

E Klein: Investigation of old Greek lead slags. *Mineralische Rohstoffe als kulturhistorische Informationsquelle, 1978, 104-108 (in German).*

Chemical analysis of old Athenian coinage and ores from the Laurion district, Greece. Methods used include x-ray fluorescence, and phase analysis of the old ores and slags. Single phases were investigated by electron microprobe. RCAR

I Martens: Iron smelting in Upper Telemark in the early Times. *Fortiden i Sokelyset. Datering med 14-C metoden. Trondheim 1979, 121-129 (in Norwegian).*

The book marks the 25th anniversary of the Laboratoriet for Radiologisk Datering. This paper by Mrs Martens deals with the excavation of bloomery sites in the area of the Mosvatn Lake in Vinje, Telemark. Bloomery furnaces of simple bowl or open hearth types (ca 550-800 AD) and more developed shaft furnaces from the 11th century were found at Hovden, Erlandsgard, Nystaul etc. Later clay shaft installations with an outer stone wall were used in the Middle Ages. CPSA

O Mueller and W Gentner: Investigations on archaic Greek silver coinage particular on the turtle coins of Aegina. *Mineralische Rohstoffe als kulturhistorische Informationsquelle, 1978, 109-113 (in German).*

Progress report on the chemical and lead isotope analysis of coins of the Asyut hoard – (900 coins total, 140 for scientific investigation). Laurion and Siphnos are among the source localities of the ores. It is considered that the silver of the coins of Aegina, due to their high content of tin and gold, might be of alluvial ores of rivers. RCAR

S Ya Olgovski: The bronze artifacts from Berezan. *Sov Ark 1980 (4), 190-201 (in Russian).*

These cover the 7th - 5th centuries BC and show Scythian and Greek influence in the North Pontic area. They include arrow-heads, fish hooks and needles. In the early period tin and lead-tin bronzes were both used. Later, quite high antimony contents appear (0.01-1.0%). RFT

E Pernicka and O Mueller: Ore investigations for source determination of antique Greek silver. *Mineralische Rohstoffe als Kulturhistorische Informationsquelle, 1978, 114-117 (in German).*

Provenance tracking was tried by lead isotope analysis of 14 ores of the Laurion district. It was supported by neutron activation analysis of twelve elements. RCAR

H Mommsen, M Befort, Q Fazley, T Schmittinger and A B Follmann-Schulz: Analysis of a silver statuette of Mercury from Bonn. *Archaeometry, 1980, 22 (1), 87-92.*

A roman silver statuette of the first century AD and found in Bonn 1896 has been nondestructively analysed with the PIXE (particle induced X-ray emission) method. The advantages of this method especially for the quantitative analysis of metal objects are summarized. They are mainly based on the use of high energy projectiles (eg α-particles of 30 MeV). Different parts of the statuette – Mercury, the ram and the plinth are found to consist of different alloys. This supports the stylistic argument that they may not originally have belonged together. Author

A Pietzsch: Reitersporen und deren Rekonstruktion. Technological observations on the manufacture of early spurs and their reconstruction. *Arbeits - und Forschungsberichte zur sachsischen Bodenkmalpflege, 1979, 23, 83-206 (In German).*

Twelve practical reconstructions of making different types of iron spurs from the Late La Tene period until the 14th century AD, based on individual finds from Central Europe. Phases of forging, techniques of nonferrous inlays, time consumption. Rich documentation. One of the very useful contributions to the understanding of early metal work. CPSA

V I Raspopova: Metal artifact of the Early Medieval Sogd. *Leningrad, 1980 (in Russian).*

Results of excavations carried out in the town of Pendjikent, one of the centres of the 8th century AD Sogdiana in Central Asia. In three excavated quarters with streets and individual sites there was a number of indications of blacksmith's activity. Some of them were definitely smithies, equipped with hearths and domed furnaces, containing smithing slags and scales, or semiproducts (especially features nos 58/XVI, 36/XVI, 42/III, 1/XXI etc.) In an isolated position traces of a smelting furnace (0 30 cms). Twin tuyere nozzles, iron bars, hammers and anvils were found in different areas of the excavation. An important iconographic plaque with a carved blacksmith and monkey was also found (Fig 37). CPSA.

N V Ryndina: Metal of Cord Ceramic Cultures of the Ukrainian pre-Carpathian region (Podolia and Volyn). *Sov Ark, 1980 (3), 24-42 (in Russian).*

A comprehensive paper giving the results of analysis and metallography on 77 objects. These fell into two groups: pure coppers and tin bronzes. Three sources of ore were singled out:- one was used by the population of all the cultures and was local; another is connected with Caucasian copper deposits and the third is from the Carpathians. The metallurgical traditions were essentially those of the Tripolye culture (Early Bronze Age). RFT

E Roesdahl (Mrs): Fyrkat. A Viking fortress in Jutland II. The Finds and the Cemetery. *Kobenhavn, 1977 (in Danish).*

Two of the long boat shaped houses from the fort contained accumulations of blacksmith's debris including: cinder, slags, whetstones and soapstone or clay protective shields for the forge. The material was dated to the 10th century AD. CPSA

Anna M Rosequist, D O J Christie and B E Alfsen: Provenance of nails and rivets from boats dating from the 9th and 10th centuries found in South Norway. *Universitetets Oldsaksamlings Arbok, 1979, 181-189. (In Norwegian with English summary).*

Trace elements (P, Mn, Co, Cu, Zn and As) in iron nails and rivets from the Gokstad ship and other locations around the Oslo fjord and from West Norway were determined by spark source mass spectrometry. During the comparative data analysis, five elements turned out to show characteristic patterns in the composition of the iron. The study concludes that the rivets from the Gokstad ship had probably been manufactured in the area around the Oslo fjord and that their composition is significantly different from rivets found in West Norway. ESS

V D Rusanov: On the metalwork of the tribes of the Chust culture. *Sov Ark, 1980 (4), 55-64 (in Russian).*

119 objects were analysed from this find of the 2nd-1st millennium BC (LBA). The bulk were tin bronzes with relatively low tin contents and some lead. Nine elements were determined altogether and an attempt was made to determine the sources of metal. RFT

N V Ryndina, A D Degtyareva and V C Rusanov: The results of chemical and metallographic analysis of the artifacts from the Shamshi hoard. *Sov Ark, 1980 (4), 154-172 (in Russian).*

27 objects of the LBA were examined and 25 of these were tin bronzes. One was arsenical copper. The contents of the trace elements, Pb, Bi, Ag and Ni were high and bear similarity with the Volga-Urals group of the Andronovo culture. The structures indicated hot working, homogenisation and cold work. The objects examined include shaft hole axes, palstaves, knives and a dagger. RFT

E Tholander: Some dating problems in the history of iron metallurgy in Sweden. Proceedings of the Nordic Conference on Thermoluminiscent Dating and other Archaeometric Methods. *Uppsala University 25th-26th Nov 1976, 94-102.*

Four stages in the development of the early Swedish metallurgy of iron are presented: the period of the hearth, the period of the shaft furnace of the Classical Antiquity, the period of the Stuckofen, and the period of the blast furnace. The small bloomeries of Smaland differ from the high scale production bloomeries in the Svealand. CPSA

G Tonceva: The Chronology of the Early Hallstatt period in Northeast Bulgaria. *Studia Thracica 5. Sofia, 1980 (in French).*

Several iron artifacts (iron flange-hilted swords from Alexandrove and Topcii, knife from Sava Conevo, etc.) can be dated to the period about 1000 BC, at least to the 10th century. It should be mentioned that at the same time the bronze industry was flourishing and flint and bone industry were also surviving. CPSA

E Tholander: The History of Mining and Metallurgy – Goals, Means and Methods for Studies and Research Work. Stockholm papers in History of Technology. *Rapport Trits-Hit 1001, Stockholm 1979.*

After presenting his methodical approach the author discusses various methods and means applied to the study of early metallurgy of iron in Sweden: oral tradition, terminology, written sources, investigations of artifacts and archaeological excavations of different installations, analyses of raw materials and waste products. CPSA

E Schuldt: Handicrafts and Trade of the 8th to 12th centuries AD in Mecklenburg. *Schwerin, 1980 (in German).*

A curious variant of a blacksmith's hammer with a twin-eye (Dargun, 10th-11th century) tongs from Menzlin, chisel from Gross Raden. CPSA

C Veny: New Materials from Moro Boti. *Trabajes de prehistoria, 1979, 36, 465-479 (in Spanish).*

Two iron anchors from a Roman barque, dating from the very beginning of the present era (0-25 AD). One is 3.25 m long, the other 1.71 m. CPSA

ASIA

H G Bachmann: Slags as indicators of archaeometallurgical processes. *Mineralische Rohstoffe als kulturhistorische Informationsquelle, 1978, 66-103 (in German). 11 figs, 3 tables.*

Phase diagrams and analysis of chemical composition of slags can determine the smelting process originally used. Slags of five sites in Timna/Israel were investigated ranging from the 14th century BC to the 1st century AD. A computer program was employed in data analysis. RCAR

H C Bhardwaj: Aspects of ancient Indian technology. *Book. Motilal Barnardsidass, Delhi, India 100 007, 1979, 212.*

Monograph based on doctoral thesis discusses the technology of early India. Information provided on dates of objects and materials author has examined; sites from which artifacts have come are also described. Special interest of research is applying chemical analysis to ancient objects and materials. The composition and technology of ancient Indian glassware are described. The technical examination of Black Polished Ware is given. Also treated are copper, silver, gold and iron: composition, physical structure and metallurgy. The experimental procedures are delineated. ERC

P T Craddock, A M Burnett and K Preston: Hellenistic copper-base coinage and the origins of brass. *In Book. Scientific Studies in Numismatics, 1980, 53-64.*

The systematic analysis of large numbers of Hellenistic coins from around the Eastern Mediterranean has revealed the use of brass back to the beginning of the first century BC. in the region of Phrygia and Bithynia and for the coinage of Mithradates of Pontus. Greek authors speak of brass production in Asia Minor from the fourth century BC.

The composition of these coins suggests that they were made by the cementation process and, as such, they are probably the earliest artifacts of cementation brass yet discovered. However, it seems likely that they were made using a zinc sulphide ore, rather than the carbonate ores used from Roman times onwards. This and other evidence suggests that brass may have originated as a by-product of lead and silver production. PTC (AA)

L A Cammiade: Iron smelting by Kois, a jungle tribe in the eastern Ghats of India. *Man, April 1931,* **XXXI,** *66-67.*

The Kois smelt iron from a local ore in small clay flues. The flues are about 30 in high and 4-5 in in diameter, with two holes in the base for ventilation and letting out the slag. A wicker stage at the top holds the mixture of ore and charcoal to feed in during the smelting process. Bellows and procedure are described. B Ap

G F Carter and E S Theodory: Chemical compositions of copper--based Roman coins. VI. Colonial coins of Caesarea Cappadocia. *In Book. Scientific Studies in Numismatics, 1980, 65-80.*

Twenty-eight copper-based coins from Caesarea Cappadocia, minted between 180 and 244 AD were analyzed for Fe, Ni, Cu, Zn, Ag, As, Sn, Sb and Pb using x-ray fluorescence. Compositions were compared with contemporaneous coins minted in Rome. The Commodus coins of 180-192 AD contain 13.5 ± 4.5% Zn compared with about 4 ± 3% Zn in several coins minted in Rome, showing that orichalcum coins in Rome were debased sooner than coins at Caesarea. AA

G J Fabris and F E Treloar: X-ray fluorescence and atomic absorption analysis of Sarawak gold artifacts. *Archaeometry, 1980,* **22,** *(1), 93-98.*

A number of pieces of gold foil and scrap from a Sarawak iron-working site and small shrine were analyzed by an X-ray fluorescence method using milligram samples only. The method is described and the results compared with those obtained by atomic absorption spectroscopy. Only one sample indicates the deliberate addition of copper and this can be related to its function. All other samples seem to have been made from alluvial gold without further treatment. Author

R M Farquhar and I R Fletcher: Lead isotope identification of sources of galena from some prehistoric Indian sites in Ontario, Canada. *Science, Feb 8, 1980,* **207,** *4431, 64-643.*

Lead isotopic compositions were determined of specimens of mineral galena (PbS) found at late Archaic and initial Woodland sites in southern Ontario. These made it possible to determine the 'most likely' source areas for these galenas, from lead-zinc mineral deposits in the Upper Mississippi valley and in the S E Ontario – N New York State region. EWF

Wladimir K Krysko: The Birth of Metallurgy. *J of Metals, July 1980,* **32** *(7), 43-45.*

This article is based on the author's illustrated book, Lead in History and Art, published in English and German. The claim that lead was the first metal to be extracted from its ores is based on the finding of lead beads at Catal, Huyuk, Anatolia, Turkey, in layer X, the carbon 14 dating for which is not later than 7000 - 6500 BC. Lead does not occur naturally to any significant extent in the metallic state. Hence the beads of this metal must have derived from metal extracted from ore. APG

You Sun Kim: Analysis of major chemical components of cultural samples excavated at the Hwang Ryong-Sa Temple site. *Sci Papers on Japanese Antiques and Art Crafts, Dec 1979,* **24,***44-50. (In Japanese).*

Cultural samples such as bronze objects and glass beads excavated at the Hwang Ryong-SA Temple site (6th century, Silla Dynasty) were analyzed for their major chemical components by means of atomic absorption spectrometry. Bronze samples contained trace amounts of zinc; whereas, appreciable amounts of zinc were found in the contemporary Korean bronze samples excavated at nearby King's tombs. TK

D M Metcalf: The survival of mercury coating on Byzantine miliaresia restruck on Arabic dirhams. *MASCA Journal, June 1979,* **1** *(2), 42-43.*

Mercury to silver ratios were measured using the 'Isoprobe' (an x-ray fluorescence instrument) for Arabic dirhams and Byzantine miliaresia from the 8th century AD. Arabic silver dirhams from the 8-10th centuries have detectable amounts of mercury on the surface, for reasons still unknown; such coins were sometimes restruck into miliaresia by the Byzantine emperors. The objective was to see if the mercury survived the restriking. The results were inconclusive. JW

AFRICA

N H Gale and S Stos-Fertner: Lead isotope composition of Egyptian artifacts. *MASCA Journal, 1979,* **1,** *(1).*

Lead isotope ratio results are summarized for galena samples from Egypt (both ancient excavated samples and modern ones) and from Arabia. Similar results are summarized for silver and lead artifacts. There is no evidence of the silver in ancient Egypt coming from an internal source, though a foreign alternative cannot yet be identified. Lead was apparently sought from far afield, and a trade link to Laurion, in Greece, is especially convincing. JW

B Fishman, and S J Fleming: A bronze figure of Tutankhamun: technical studies. *Archaeometry 1980,* **22***(1), 81-86.*

A bronze, gold inlayed, kneeling figure of a king, now in the University Museum, has been identified as a temple image of the young pharaoh, Tutankhamun. In the light of this attribution a compositional analysis, which indicates the piece to be a copper/gold alloy, has been interpreted as evidence that the claims expressed in Tutankhamun's *Restoration Stela* – that he had refurbished the temples, following the damage done by the heretic Akhenaten – were executed, with re-use of old metal to produce the statuary. Supplementary X-ray studies of the figure are also discussed in detail. Author

S J Fleming and J Crowfoot-Payne: PIXE analyses of some Egyptian bronzes of the Late Period. *MASCA Journal, June 1979,* **1**, *(2), 46-47.*

Sixteen Egyptian bronzes have been analyzed by proton-induced x-ray emission spectroscopy (PIXE) for copper, tin, lead, zinc, arsenic, silver, and antimony, and the results are tabulated. JW

S J Fleming: Of Igueghae and the Iguberomwon. *MASCA Journal, June 1979,* **1**, *(2), 48-49.*

Metal casting is supposed to have been introduced to the Benin empire in west Africa by one Igueghae. Two thermoluminescent dates (AD1420 ± 60, 1365 ± 55) from bronze cores of objects from the early period associated with this figure are cited. A third thermoluminescent date (AD

1560 + 40) is given from the core of an object from the middle period, when the Igunerom won (a metal-workers' guild) were active. JW

A A Hassan and F A Hassan: Source of galena in Predynastic Egypt at Nagada. *Archaeometry 1981,* **23** *(1), 77-82.*

Determination of lead isotope ratios from a sample of galena associated with a human burial (Site KH3, XIV, Burial 1) from the Predynastic period and comparison with lead ratios from mines in the Eastern Desert of Egypt indicate that the galena was obtained from mines located in the Red Sea hills of Eastern Desert. These mines are about 180 km from the burial sites, and are accessible *via* Wadi Hammamat. Author

Udo S Kusel: Pre-historic metallurgy in South Africa. *Pap - Int Foundry Conf, 1976, (2) 10.*

The exploitation of Au, Cu, Sn and Fe and their use in prehistoric times as well as the use of bronze and brass were studied. The different types of smelting furnaces, the smelting techniques, ingots and the processing of the metals are studied.

Hamo Sassoon: Iron-smelting in the Hill Village of Sukur, North Eastern Nigeria. *Man, Nov-Dec 1964,* **64**, *174-178.*

In the town of Sukur there has been a revival of the smelting of iron from black magnetite sands found in streams. A cylindrical furnace with forced air is used. Preparation of the ore and the forging process are also described. BAp

Techniques

J N Barrandon: Analysis of coins by neutron activation using californium-252 — application to numismatic studies. *Californium-252: Source Technol. Sci Ind Appl Int Symp Californium-252 Util, Paris, (CONF-760436), 1976, Proceedings.*

Neutron activation using ^{252}Cf was applied to the determination of the composition, particularly Au, Ag and Cu of ancient coins from the time of Constantine.

F Schweizer and P Meyers: Authenticity of ancient silver objects: a new approach. *MASCA Journal, Dec.1978,* **1**, *(1), 9-10.*

The discontinuous precipitation of copper from silver, which starts at grain boundaries and proceeds into the grain with a well-defined front, occurs at low enough temperatures to take place to a measurable extent over archaeological time periods. The kinetics of this process are under study with the objective of obtaining dating and authentication information on silver artifacts. JW

R Cesareo and C Mancini: Non-Destructive analysis of silver alloys by means of low energy x-rays and neutron transmission measurements. *Int J Appl Radiat. Isot 1979,* **30,** *(1), 589-594.*

Transmission of neutrons and of low-energy x-rays was employed for determining the composition of silver alloys, containing Ag, Cu and Pb as predominant elements. Transmission measurements of 0.5 μg ^{252}Cf neutrons allowed the determination of the Ag content, independently of the Pb content, and transmission measurements of ^{241}Am 60-keV x-rays and ^{57} Co 122-keV x-rays allowed the simultaneous determination of Ag and Pb. The transmission methods have the advantage of being non-destructive, simple and allowing systematic measurements on a large number of alloys. Measurements were carried out on standard samples and on Ag coins in 100s measuring time and compared to results obtained by the specific gravity method. The absolute error in the Ag content determination ranges 1-2%.

Morven N Leese: A statistical study of Welsh Bronze Age metal artifacts. *Proceedings of the Annual Conference on Computer Applications in Archaeology, 1979, 45-52.*

The application of statistical methodology to the interpretation of analytical results on bronze-age metalwork. In this particular project there is insufficient information to allow provenancing of the artifacts. Hypothesis-testing methods are compared with pattern-seeking methods like cluster analysis, and an example is given of hypothesis-testing applied to the problem of whether arsenic was added to bronzes. JAH

H Mommsen and T Schmittinger: Test analysis of ancient Au and Ag coins using high energy PIXE. *Archaeometry 1981,* **23** *(1), 71-76.*

The applicability of the high energy PIXE-method for non-destructive quantitative analyses without the use of standards is shown in a comparative analysis of three Au-coins and two Ag-coins. The Au-coins are of various provenance, the Ag-coins are from Athens (before 475 BC) and belong to the Asyut hoard. The aim of this test analysis is to show that the PIXE method can give satisfactory results in a short time, even if applied in a very simple and straightforward way.

C D Radcliffe ***et al*****: Gold analysis by differential absorption of gamma-rays.** *Archaeometry, 1980,* **22**, *47-55.*

Describes a method for the quantitative analysis of gold in thin silver objects (eg coins): its advantages are (1) a cross section through the entire object is analysed, (2) no sampling is required, (3) no detectable radioactivity is induced.

Authors (abridged)

H Ballczo and R Mauterer: Non-destructive ultramicro-analysis of archaeological objects. I. Complete analysis of stream samples of antique metal artifacts (ca 100 g). C. Gold, silver and 'electron'. *Fresenius' Z, Anal Chem 1979,* **299**, *(1), 46-68 (in German).*

Ultramicro samples from ancient metal artifacts were dissolved in aqua regia, and Pd, Au, Ag, Cu and Pt were determined as their colored complexes with dithizone. Ru, Rh, Os and Ir do not react with dithizone, and can be determined in the aqueous solutions by known methods. The analytical procedures for these noble metals, which required only 100 μg samples, was similar to that previously described for copper, brass and bronze.

H Ballczo and R Mauterer: A simple method for the investigation of ores and metals by means of a small corundum pin. *Mineralische Rohstoffe als kulturhistorische Informationsquelle, 1978, 159-172 (in German).*

A new method is described. With a small corundum pin, a minute amount of substance is stripped off the piece of metal or ore to be analyzed and subsequently brought into solution by nitric acid. Different colors are obtained from different metallic elements by addition of measured potions of precisely 10^{-4} or 10^{-5} M solution of dithizone in chloroform, while the conditions, such as the pH-value, are changed for each element. The elements copper, zinc, lead, silver, cadmium, bismuth and gold can be analyzed quantitatively This is very convenient for the analysis of coins. RCAR

Kazimierz Seikowski: Chemical composition of slag inclusions in old bloomery iron. *Study Mater Dziejow Nauki Pol, Ser D, 1978,* **9**, *133-147 (in Polish).*

The light, dark gray, and black phases were separated in slag inclusions of old products from bloomery irons. The light phase comprised mainly $Fe_2 0_3$ or mixed Fe and Mn oxide, the dark gray phase mixed silicates of Ca and Mn, and the black one mixed oxides or silicates containing Al, Ca and P.

R S Young: Analysis for gold. *Gold Bulletin, Jan 1980,* **13,** *(1), 9-14.*

A brief review of methods of analyzing gold: fire assay, gravimetric analysis, colorimetric and spectrophotometric methods, atomic absorption, emission spectrography and x-ray fluorescence. The paper gives no detail, merely discussing the situations in which the various methods of analysis are most useful. WAO

The abstracts are now being edited by Dr Paul Craddock and the Honorary Editor would like to acknowledge his help and that of many others. He is very grateful to the following who are actively participating:- D R Howard, J W Butler, P S Richards, H F Cleere, H W Paar, N Mutton, M Goodway, A P Greenough, J K Harrison, W A Oddy, M M Hallet, J Piaskowski, D G Tucker and E C J Tylecote. Some of the abstracts are taken from the periodical 'Art and Archaeology Technical Abstracts' and we are grateful to the International Institute for the Conservation of Historic and Artistic Works, London and New York, for allowing us to reproduce them. We are also grateful to the Council for British Archaeology who allow us to use material from their abstract journal, British Archaeological Abstracts (B A A) and to Miss C Lavell the editor. Finally, through the courtesy of Dr R Pleiner, honorary secretary of the Iron Committee of the International Union of Prehistoric and Protohistoric Sciences (CPSA) we are allowed to reproduce items from the Bulletin of that Committee.
