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# ORE-HEARTH SMELTING (VOYAGE METALLURGIQUE EN ANGLETERRE)

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## SYNOPSIS

*Lead smelting is a fascinating, if little understood, topic in which there is a growing interest. There are some contemporary accounts*[1,2,3,4,5,6] *but a number of valuable descriptions are inaccessible because they were written by foreign observers in their native tongues. The following translation, from Voyage Metallurgique en Angleterre,*[7] *by Hazel Martell, with technical and historical advice from Mike Gill, was felt to be of especial importance because it was prepared by graduates of the School of Mines, in Paris. Wherever possible, the text has been presented as a literal translation, except where repetition or usage rendered this undesirable. The smelting section is part three, of the second volume, of an extensive study of mining and metallurgy in Britain. A translation of part two, the mineral processing section, also by Martell and Gill, was published in the Bulletin of the Peak District Mines Historical Society*.[8]

The "voyage" was jointly written by Pierre Armand Dufrenoy, Jean Baptiste Armand Louis Leonce Elie de Beaumont, Pierre Leon Coste and Auguste Perdonnet, following a visit to Britain in 1823. It first appeared in the *Annales des Mines* between 1824 and 1827, and was then published as two volumes in 1830.[9] The second edition, from which this translation is taken, was published in 1839 after correction and considerable augmentation.[10] Nevertheless, it is clear that the techniques described are those of the mid 1820s.

The French description is based on that published by Westgarth Forster but it is supplemented by the authors' observations and those of Monsieur Sentis. To facilitate comparison with the original text, the latter's page end numbers are given in square parentheses. A large section was not translated because it is either available elsewhere or is not relevant to ore-hearth smelting. The section on refining lead, pages 585 to 589, has not been translated and will form the basis of a further paper. Pages 589 to 595 are based on Westgarth Forster's version of Farey's account of smelting in reverberatory furnaces.[11,12] Because both the latter are widely available, they too have not been included. The section on smelting in reverberatory furnaces, pages 597 to 625, was translated and published by De Archaeologische Pers.[13]

This paper does not seek to trace the ore-hearth's origins but, in many places outside Britain, it is called a Scotch-hearth. The authors remark that Scotch hearths were used at Pesey, in Britanny, and the hearths used at Dubuque, in the U.S.A., were described as such by the Iowa Geological Survey, in 1899. From their descriptions, however, it is clear that both were ore-hearths. The origin of the ore-hearth remains to be proved. It has, however, recently been shown that, in the sixteenth century, ore-hearths were introduced to Derbyshire from the Mendip; where, it was suggested, they may have been developed with

German influence.[14] This explanation is inadequate, however, because it ignores the earlier development of waterwheel powered, bellows-blown hearths in northern England.[15]

There is no evidence that the ore-hearth was developed in Scotland but it was used there. For example, the remains of an eighteenth century ore-hearth were found at the Pate's Knowes smelter in Wanlockhead.[16] It is, nevertheless, possible that Scotland did provide France and the Low Countries with lead smelting technology because it had strong and ancient links with them, whereas England did not. This may have led to the adoption of the name Scotch-hearth.

## THIRD PART

## METALLURGICAL TREATMENT OF LEAD MINERALS (SMELTING)

## THE FURNACES USED IN THE METALLURGICAL TREATMENT OF LEAD MINERALS

### 1 Cupola or Reverberatory Furnace

The cupola, which is now used exclusively in Derbyshire for lead smelting was imported there from Wales, around 1747, by a company of Quakers. The first established in this country was built at Kalstadge, near Ashover.[17] [575].

In the works where the construction of this sort of furnace is most perfected, they are externally 8 ft. long by 6 ft. wide in the middle and 2 ft. high in the centre. The hearth, placed in one of the extremities, is separate from the body of the furnace by a stone called a fire bridge, which is 2 ft. thick and leaves only 14-18 inches between the upper surface and the arch. On leaving this point, which is the most elevated, the dome is gradually lowered as far as the opposite extremity, where it is no more than 6 inches in height above the sole. At this extremity are found two openings, separated by a triangular prism of refractory stone, which proceeds into a large channel 1.5 ft. wide and 10 ft. long, which bending or curving upwards, is joined in a continuous manner to a chimney 55 ft. in vertical height. The passage above this is covered by flat stones carefully joined together with refractory clay and which can be removed when the deposit which collects there needs cleaning.

One side of the furnace is called the labourer's side; it has a door for throwing coal on the grate and three little openings, each around 6 inches square. The openings are closed with removable plates of cast iron; they are [576] lifted when the work necessitates that air circulates or when the materials contained in the furnace are stirred. On the opposite side, called the working side, are found five openings, as follows: three similar and opposite to those which have just been described and which are closed in the same way with removable cast iron plates, and lower down two others, which, respectively, serve in the discharge of lead and slags; it is also on this side that the opening of the ash pit is found, set out in a manner which makes it easy to release from underneath the bars of the grate when the coal, in coagulating forms a mass thick enough to hamper the draught. At the bottom of the ash pit there is a sheet of water in which the fragments of burning coal which pass through the grate are extinguished.

The bottom of the furnace is composed of reverberatory furnace slags, to which a convenient form is given by beating them with an iron rabble, or with a strong iron hoe before they are completely solidified. In the labourer's side, this bottom rises almost as far as the surface of the three openings which are used there, and it falls away to the working side to 18 inches below the middle opening. It is at this point, the lowest of the furnace, where the taphole is found. Through this the lead is allowed to flow into a big lead-pan, housed [577] in a niche in the masonry of the furnace. Going away from the lowest point, indicated above, the bottom rises in all directions, forming a basin, in which the lead collects as it smelts. The surface of the bath is ordinarily kept below the bottom of the slag tapping hole, already mentioned above, which is furthest from the heat on the working side.

In the middle of the arch is a little hole called the crown hole, which is covered during work by a thick plate of cast iron. Above the opening is placed a large hopper of wood or iron which ends in an iron cylinder; the material contained in the hopper falls at will on the bottom of the furnace on opening or on closing a trap door placed near its bottom.

### 2 Roasting Furnace

This furnace was introduced, 25-30 years ago, in the neighbourhood of Alston Moor to roast the mineral destined for the Scotch furnace, an operation which much facilitates the work in the latter. (18) Since it was first established, it has successively undergone considerable modification. The model which is thought to be the best today (Figs 1 & 2 Plate I), has a flat surface 6 ft. in length and an almost equal width, having on each side three [578] doors: one M is bigger than the other two and is placed in the middle of the furnace. This serves to introduce and to withdraw the mineral. The other doors N,N are only used to move or stir the mineral. The two doors g,g on the side opposite the heat are used for the same purpose. Through these, with the aid of a rabble, the mineral is spread from the firebridge to the opposite extremity. The hearth B is 25 inches long and 36 inches wide; it is separated from the furnace by a stone wall A, called the firebridge.

To spread the heat more evenly on the mineral, one uses two pipes C,C separated by a triangular wall D. Through these the smoke goes into the vertical chimney f. The fume which is deposited in the chimney is lifted out from time to time by the door O.

The bottom is formed by a row of bricks set in the ground; they are placed on a cast iron plate Q which goes into the firebridge and the wall of the chimney, and which rests also on three pillars of cast iron.

### 3 Scotch Furnace or Ore-Hearth

We call this hearth thus because it is like the one used at Pesey under this name. It has an internal height of 22 or 23 inches. Its horizontal section, always

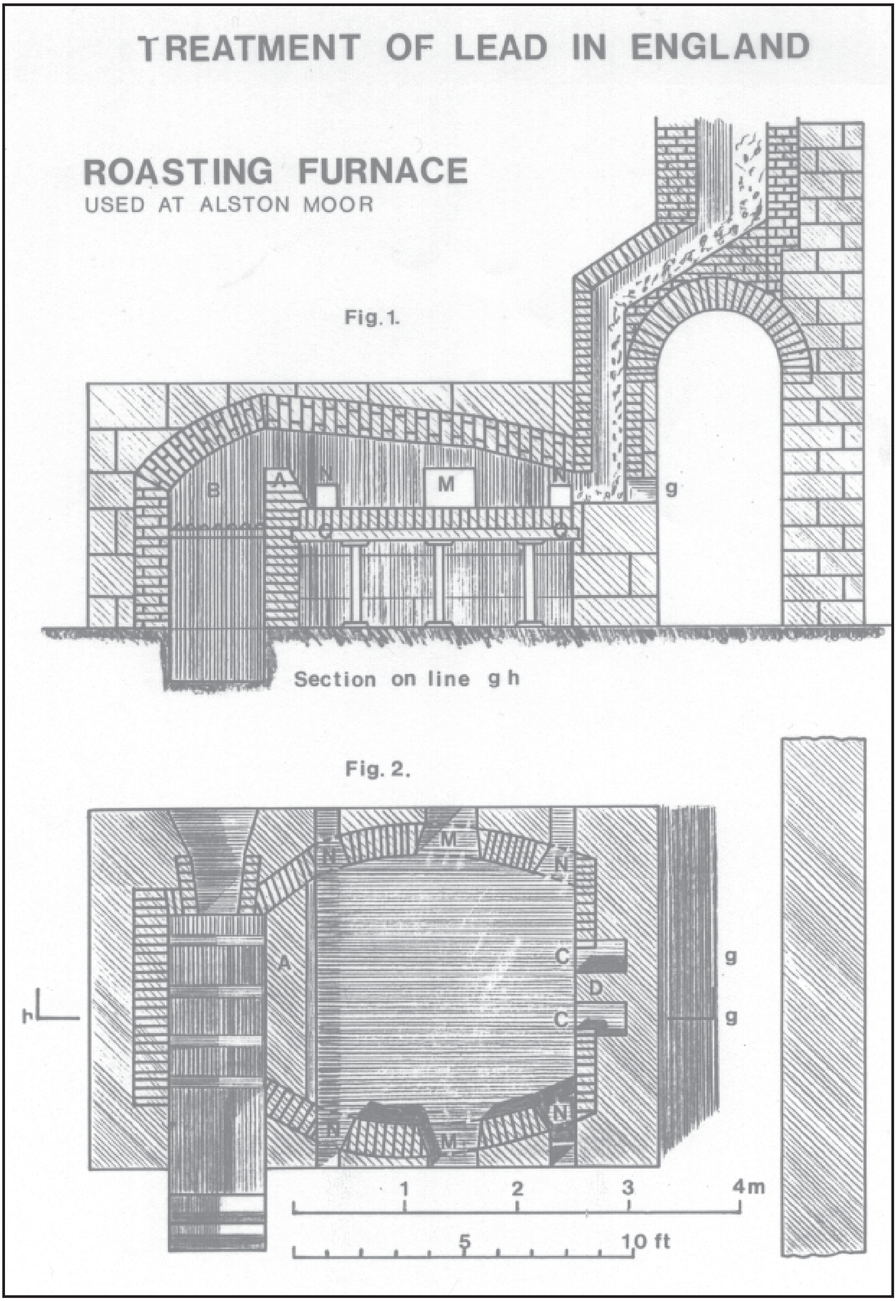

TREATMENT OF LEAD IN ENGLAND
ROASTING FURNACE
USED AT ALSTON MOOR
Fig. 1.
B
A
N
M
N
g
C
C
Section on line g h
Fig. 2.
M
N
N
A
C
g
D
C
g
h
N
N
M
1
2
3
4m
5
10 ft

*PLATE I*

[579] rectangular, varies in its dimensions according to the height to which it is made, as can be seen in Fig 1 Plate 11. The sole and the sides are made of cast iron; the sole AB is formed from a slab of cast iron 2.5 inches thick, bordered on its back and sides by a rim AC 2.5 inches thick and 4.5 inches high. In front of the sole is found another slab of cast iron MNM'N', called the workstone. This is surrounded on its front and sides by a rim an inch high and an inch thick; it slopes from back to front, and its rear rim, placed at about 4.5 inches above the surface of the sole, is separated from it by an empty space q, which is filled with a mixture of bone ash and finely powdered galena; moistened and ground together. This mixture forms an in penetrable mass to the molten lead, which, after having filled the basin at the bottom of the hearth, runs naturally along the riggot gh (of nearly an inch deep) made in the workstone. The lead then collects in a melting pot P set under the front of the workstone.

The sole's rear rim is surmounted by a piece of cast iron Dc, called the backstone, [580] 28 inches long and 6.5 inches wide, on which the tuyere is placed. It supports another piece of cast iron EF, called the pipestone. This is hollowed out in the middle of its bottom edge to accommodate the tuyere. This piece is set 2 inches forward into the hearth, of which the back wall is finally topped by another piece of cast iron FH, also called the backs tone.

On the side rims, of the sole, are placed two pieces of cast iron called bearers. Each is about 5 inches in width and height and 26 inches long; they protrude an inch or two over the back rim of the workstone, and help to keep it solidly in place.

The bearers, together with several rows of refractory bricks, support a piece of cast iron LL', called the forestone. This has the same dimensions as the backs tone, on which the base of the blowing machine rests. Each end of the forestone is in contact with a cubic piece of cast iron, 6 inches on the side. This is called the keystone and is supported by masonry. Finally, the spaces remaining between the two keystones and the back part of the hearth are filled by two pieces of cast iron exactly the same as the keystone [581].

The front of the hearth is open for a height of about 12 inches from the lower part of the forestone to the upper part of the workstone. The workmen work through this opening.

On leaving the Scotch-hearth, the fumes often go into a long flue which slopes very gently upwards. In this are deposited all the particles of lead-fume which they are carrying. These flues, which are often more than 100 yards long, are usually 5 ft. high by 3 ft. wide internally. They always end in a vertical chimney.[19] The particles which are deposited near the entrance to the flue need to be washed. It is not necessary to wash the rest, however, and the whole can then be returned to the roasting furnace to be roasted and sintered, or equally well taken without any preparation to the slag-hearth.

## 4 Slag Hearth

The slag-hearth has been used at Alston Moor for more than a century; during which it has undergone big modifications. (20) The empty inside of those actually

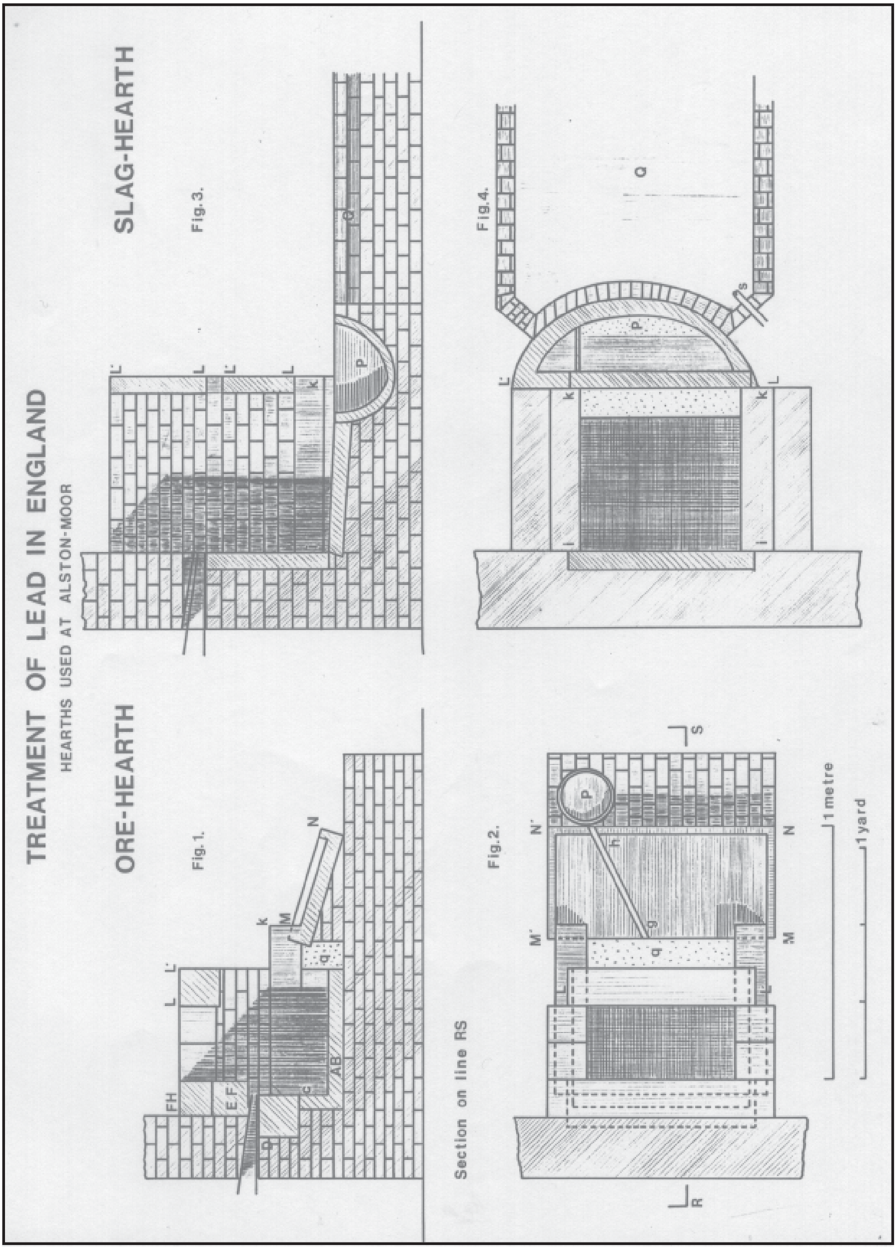

TREATMENT OF LEAD IN ENGLAND
HEARTHS USED AT ALSTON-MOOR
ORE-HEARTH
SLAG-HEARTH
Fig.1.
Fig.2.
Fig.3.
Fig.4.
Section on line RS
1 metre
1 yard

PLATE II

used (Fig 3 & 4, Plate 11) is a parallelopipedon 26 inches long, 22 inches wide and 33 inches high. The sole is formed by a slab of cast iron 23 [582] thick which slopes slightly from back to front. On this rest the supports ik (bearers) which are pieces of cast iron like those of the same name in the Scotch-hearth. These bearers support the front of the hearth, which is made of two pieces of cast iron LL' called forestones. These are about 12 inches in height and 26 inches in length and separated from each other by a row of refractory bricks 2 inches high. These go up as far as the upper piece. Between the lower plate and the sole is a hole about 7 inches high. Like that part of the back wall situated above the tuyere, the side walls of the hearth, above the bearers, are made of open-grained free-stone. That part which is below the tuyere, and which is about 20 inches high, is made of a cast iron slab. The tuyere, placed at 20 inches above the sole of the hearth, is a little more than 2 inches in diameter.

The bottom of the hearth is filled to about 2 or 3 inches below the tuyere, with well compacted, partly burnt coke {which acts as a filter for the molten slag and lead}. At each change of smelting shift, it is necessary to remake this filter and repair the inside of the hearth [583] above the tuyere, with the exception of the front, which is all of cast iron.

In front of the hearth is a receptacle P, divided into two compartments by a partition which does not quite go to the bottom. The biggest of these compartments is also filled with compacted, partly burnt coke. Further along is a hole Q full of water, into which constantly flows a little stream of cold water from the tube S. The slags, in running from the hearth, pass over the coke-ashes in the receptacle, and fall into the water, where the coldness makes them burst into little fragments; this makes them easier to wash and to separate from the lead which they contain. To produce the best effect, it is necessary that the stream of cold water arrives in the hole as near as possible to the point where the slags fall in. The holes full of water have only been used for the last 25 years.[21] Formerly, coke-ashes were not put in the receptacle, and slag as well as lead went in there. The former congealed on the surface, and was lifted off as cakes, which were stamped to make them washable and by this means separate the grains of lead found in there.

In Derbyshire, slag-hearths are also used to res melt the rich slags and dross from the reverberatory furnace. They are generally found next to each other [584]. They are about 3 ft. high and are very large; they are made of four slabs of cast iron. Some parts of the interior are constructed of refractory bricks; they are surmounted by a chimney. The sole is made of compressed clay and cinders (menu coke). The tuyere is sloping.

In general the hearths are fed by wooden bellows. At the works at Lea, near Matlock, the blowing machine is made of two barrels (cylinders) which move on horizontal axes: each barrel is divided into two equal parts by a fixed plane passing through its axis and is filled with water up to a certain height. The water from one side is linked with that of the other through an opening in the lower part of the partition. Each barrel is oscillated by a rod or crank arm attached to the crank of a waterwheel. At each half oscillation, one of the compartments is open to the atmosphere and fills itself, whilst the other, in contrast, is linked to the nozzle and supplies wind to the hearth.

**Treatment of Lead Minerals by means of the Scotch Hearth**
As we have already said, the Scotch-hearth, described on page 579, is generally used in Northumberland, Cumberland and County Durham, for smelting lead minerals. Formerly, they were brought to this hearth without preparation, now they nearly always undergo a preliminary roasting. In the Scotch-hearth, the sieved mineral gives a more considerable product than the crude mineral, because it forms a more porous mass in the hearth [623] and at the same time, to use the expression of the smelters, it works drier. It also allows the current of air from the bellows to spread itself more completely through the materials in the hearth.

The possibility of roasting taking place is due without doubt to the presence of white lead or carbonate, which is, after galena, the most abundant mineral in these counties. In general it only forms a rather small portion of the mineral; nevertheless, it sometimes becomes very abundant. It has been found in considerable masses at Fair Hill, at Flow Edge, and at the entrance of Hudgillburn Mine, near Alston Moor. The crystallised carbonate of lead (dog tooth mineral) is only found small quantities.

In some mines of these counties, an earthy lead mineral (carbonate or phosphate) is also found in considerable enough quantity to be counted among the minerals. It has been obtained particularly from the Green-Gill West End Mine in the region of Alston Moor.

It must be understood that, in metallurgical treatment, allowance has to be made for the proportions in which the galena is mixed with the other two lead minerals, and also for the nature and the proportion of [624] other substances which are combined or mixed therein.

**Roasting of Lead Minerals**
The charge of the roasting furnace previously described on page 578 is from 900-1100 Kgms of mineral, which is put in the furnace without any addition. Three of these charges are ordinarily treated in eight hours. The fire must be such that a thick smoke or steam is constantly produced on the surface of the mineral but without allowing any of it to cool and form slag. This would disrupt the principal purpose of the operation, which is to burn the sulphur and the antimony and to release the carbonic acid. To prevent this disruption, as soon as the workmen notice some part of the mineral becoming soft or sticky, they renew the entire surface by stirring it transversely or longitudinally with a rabble according to circumstances. From time to time the mineral is moved towards the firebridge, the opposite extremity of the furnace and reciprocally, so that there are no great differences in temperature at the two extremities of the furnace. Uniformity in the temperature of the various points of the furnace is very desirable, but very difficult to obtain, particularly if variable ore is being treated. That which can be done varies in the yield from 2 to 1 the heat to produce. For example, if minerals needing a very feeble temperature are roasted in a furnace constructed for mineral [625] needing a higher one, the flame which plays on the surface of all the charge when it is strongly heated, will only heat the area of the fire-arch when a feeble temperature is produced. The different parts of the furnace are, therefore, heated very

unequally. In roasting, smelting the mineral is carefully avoided; nevertheless, to bring forward this operation, the fine particles of mineral, as well as the metallic dust collected in the flues, are sintered. To prevent the cooling mineral forming a mass, on leaving the furnace it falls into a hole full of water, situated underneath one of the side doors.

“In some works, like that at Nenthead, two men work a roasting furnace. The charge is of one bing of mineral, and the furnace is charged and discharged five times in eight hours. Two pairs of workmen follow each other thus all the eight hours, in a manner to work eight shifts a week.

“Thus eighty bings of mineral per week are roasted, in a single furnace. In other works, a single man roasts, like we have said, three charges in eight hours, so that the three charges represent four bings of mineral, three men each working six shifts per [626] week, roast seventy-two bings of material in a furnace. In a word, sometimes three charges only represent three bings; and, in this case, three workmen only give fifty-four bings of roasted mineral” {Extracted from the Memoirs of Monsieur Sentis, “On the treatment of Lead in Cumberland”}.

**Smelting Lead Minerals in the Scotch Hearth**

When a smelting shift is completed in a Scotch-hearth, part of the mineral, known as browse, remains in a state of semi-reduction mixed with cinders and slag. It is found more advantageous to conserve this, rather than the crude, or even roasted, mineral, to begin the next smelting. To ignite the hearth, one begins by filling up the interior with moulded peat in bricks of about twelve inches in length by three inches wide and three inches thick. Those bricks which are placed at the back are heaped up without order, but those at the front are carefully arranged into a wall. A brick of flaming peat is then placed in front of the tuyere which is put into play and the wind from this rapidly spreads the combustion. To increase the heat, and to make the fire last longer and burn steadily, some shovelfuls of coal are thrown on top of the peat. [627] When the different substances are well alight, a certain quantity of browse is thrown on top. After this (and sometimes before all the browse has been thrown onto the fire) the greater part of the hearth’s contents is pulled onto the works tone with a large iron rake, called a Gavelock. The mineral waste, called grey slag, which an experienced smelter distinguishes by its superior brightness to that of the browse, thrown by a shovel to the hearth’s outside right hand corner. The browse left on the workstone is then thrown back into the hearth and supplemented with a little coal if necessary. If the browse is not cleanly enough separated from the slag, lime is added. This, by virtue of its affinity for clayey, silicious and ferruginous substances, dries up the materials, as the smelters say, and reunites the earthy parts into lumps or balls. If, on the contrary, the clayey, silicious and ferruginous parts which contain the ore are too refractory, lime is also added to make them more fusible and make them reunite in lumps or balls. One sees an example of the two methods of [628] the action of lime in the treatment of lead in the reverberatory furnace. In throwing the lime onto the materials covering the sole, the fusion of the earthy parts is encouraged and they run and float on the surface of the bath. By throwing a new quantity of lime on the surface of the latter the smelted matters are transformed and recovered as a dry mixture of lime and slag.

The latter, called grey-slag, contain from 1/10th to 1/15th[22] of lead. They are smelted, at a higher temperature, in a slag-hearth to recover their lead. We will describe this operation later; but we now return to the procedure in a Scotch-hearth. After the browse has been thrown back into the hearth, as we have already said, several shovelfuls of mineral are spread out over it. Before this operation, and after lifting off the slag, however, half of a brick of peat is put in front of the tuyere.

This substance, being extremely porous and combustible, not only prevents anything entering the tuyere, but also disperses the wind throughout the hearth. As the orifice of the tuyere [629] is only about two inches in diameter, if this or similar means are not employed, the wind would simply pass in a thin stream. That done, and after an interval of ten to fifteen minutes, determined by the smelter, the hearth's contents are again drawn onto the works tone and the grey-slag is sorted and removed. A new piece of peat is then put in front of the tuyere and coal and lime, in the right proportions, are added. The browse is thrown back into the hearth and a new quantity of mineral loaded on top, and left in the hearth for the time indicated above. The same work, repeated for fourteen to fifteen hours, forms what is called a smelting shift; during this time between 2000 and 4000 Kgms and more of lead are obtained.

**Duration of the bottom of a Scotch Hearth**

"Some precaution has to be taken when the Scotch-hearth has become-too warm after working the twelve to fifteen hours, which makes up a smelting shift. It is then necessary to let it go cold again, and this cooling down lasts for five hours for a smelting shift of twelve hours.

**At Nenthead**

"3600 to 4000 Kgms of roasted mineral are smelted in one shift, by two men who work four shifts from Monday morning until 3pm on Wednesday afternoon. Two other workmen then follow them, and also work [630] four shifts finishing the last at 3pm on Saturday. During these eight shifts, two workmen obtain a little over nine to ten fodders of lead from the smelting of thirty-six to forty bings of good quality mineral.

"At the Nenthead works, the shift is made up of fourteen to fifteen hours work, and the hearth is lit in the morning at four o' clock and continues to smelt until six or seven o'clock in the evening. Two men thus treat from fifteen to sixteen-and-a-half bings of roasted mineral in the first three days of the week, producing around four fodders of lead. Two other workmen carry out the same work in the last three days and thus from thirty to thirty-three bings of mineral are smelted in six days.

**Fuel Used**
"The quantity of coal needed to obtain a fodder of lead necessarily varies with the quality of the mineral. Sometimes 600 Kgms suffices to smelt eighteen to twenty bings, but, if the mineral is refractory, it takes as much as 800 Kgms.

"Generally, 600-900 Kgms are consumed in four shifts of twelve hours each. As the quantity of lead obtained in these four shifts is from four-and-a-half and five fodders, between 150 and 200 Kgms of coal are consumed for one fodder of lead. The quantity of peat used is of little importance. As to the lime, a little more [631] of it than 600 Kgms per fodder of lead are consumed" (Extract from the Memoirs of Monsieur Sentis).

By this process, the purest part of the lead, as well as the silver, are, so to speak, sweated from the materials with which they are mixed without anything going into fusion but these two metals allied with each other. It appears that the feeble temperature used in the Scotch-hearth is the principal reason for the purity of the lead which it produces.

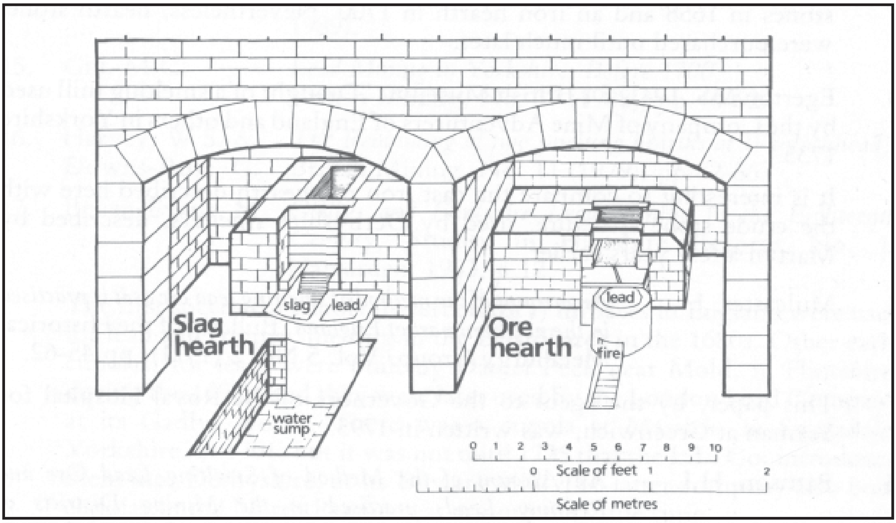
**Smelting Slags from a Scotch Hearth in a Slag Hearth**
Before the slag-hearth, described above on page 582, is lit its lining is repaired and the filter remade from its interior to the reception basin. The rest of the empty space is then filled with bricks of peat, and after one of these bricks of peat has been lit it is placed in front of the tuyere, which at the same time is put into play. This spreads the fire throughout the mass. Then a layer of coke is thrown onto the burning peat and, as soon as it gets hot enough, a layer of grey-slag, or whatever other material one wishes to treat, is spread on top of it. From time to time, when convenient, coke and slag are thrown on, layer by layer. In this operation, the slag and the lead are induced to [632] a state of perfect fluidity; but the latter separates itself from the former in passing across the bed of partly burnt coke, which acts as a filter. The slag cannot pass through because of its viscosity. As soon as he finds some perfectly smelted slags on the box, the workman makes a hole in it, about an inch in diameter, with a crooked poker. The slag flows through this hole, and, unable to penetrate the box which covers the reception basin, runs in a flaming torrent into a hole full of water. Here it splits into little grains which are ready for washing.[23] The lead which passes through the box gathers in the small compartment of the basin P, from where it is taken and run into pigs.

The lead obtained by smelting grey-slag is always more impure than that extracted from ore in an ore-hearth. It is never perfectly separated from the materials combined with it, and it is hardened by the action of the coke, which impregnates it with carbon. Consequently the slag-hearth must only be used when the ore-hearth works inefficiently or extremely slowly, as when carbonate of lead is treated.

A suitably proportioned mixture of galena and very grey or black-slag can also be smelted in a slag-hearth. The separation [633] of lead sulphide takes place by virtue of the affinity of sulphur for the iron contained in the slag, with which it combines. When the slag contains much iron, recognisable by its darker colour, less is needed.

**Number of Workmen**
Two workmen suffice for a slag-hearth; sometimes one of them is a child; the length of a shift varies from fourteen to sixteen hours, during which from 1000 to 2100 Kgms of lead are obtained.

**Quantity of Coke Consumed**
The quantity of coke consumed is at most 1800 Kgms for each fodder of lead produced. The quantity of grey-slags resulting from this smelting is obviously variable. Nevertheless one can generally estimate them at one-thirteenth of the lead produced (Extract from the Memoirs of Monsieur Sentis).




*PLA TE III. General layout of lead smelting hearths, reproduced from 'An account of the method of smelting lead ore and refining lead, practised in the mining districts of Northumberland, Cumberland and Durham, in the year 1831' by H.L. Pattinson.*

## NOTES

1. France, R.S. — *The Thieveley Lead Mines* 1629-1635, Lancashire & Cheshire Record Society, 1951, Vol.109.

   The smelt mill at the King's Lead Mines at Thieveley, near Burnley, used a stone hearth, which was blown by a foot-blast.

2. Martyn, J. — *An account of some observations relating to natural history, made in a journey to the Peak in Derbyshire,* Philosophical Transaction, Royal Society of London, 1729, No.407, Jan-Feb., pp.22-32.

"The furnace, which I saw near Wirksworth, was very rude and simple, consisting only of some large rough stones, placed in such a manner as to form a square cavity, into which the ore and coals are thrown stratum super stratum; two great bellows continually blowing the fire, being moved alternatively by water. ... When the ore is melted, it runs out an opening in the bottom part of the front of the furnace, through a small channel made for that purpose into a cylindrical vessel, out of which it is laded into the mould."

Bolton MSS: Grassington Lead Book 1698-1710. Martyn's description of the Wirksworth furnace is vague and it may not have been an ore-hearth. Nor, do we known how typical it was of Derbyshire practice. The Grassington Barmaster's smelt mill accounts record the purchase of hearth stones in 1658 and an iron hearth in 1700. Nevertheless, hearth stones were purchased until much later.

3. Egerton MS. 1941, f.1 British Museum. "Draught of a smelting mill used by the Company of Mine Adventurers of England and others in Yorkshire 1735".

It is interesting to compare the cast iron ore-hearth described here with the crude stone structure, used by Derbyshire smelters, described by Martyn a few years earlier.

4. Mulcaster, J. *An account of the method of smelting lead ore as it is practised in the northern part of England*, Bulletin of the Historical Metallurgy Group, Vol.5 No.2 (1971), pp.45-62.

This paper, by the agent to the Governors of the Royal Hospital for Seaman at Greenwich, was written in 1795.

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11. Forster, W. *A Treatise on a section of the strata from Newcastle upon Tyne to Cross Fell,* (Alston 1821, pp.371-376).

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13. Coste, P.L. & Perdonnet, A.A. *Smelting of lead ore* in *reverberatory furnaces as performed* in *Great Britain* (1830). Ed. Alex den Ouden, De Archaeologische Pers, Eindhoven, 1986.

14. Kiernan, D. *The Derbyshire Lead Industry in the Sixteenth Century,* (Chesterfield: Derbyshire Record Society, Vol. 14, 1989).

15. Gill, M.C. *Lead Mining* in *Yorkshire: Before 1700,* British Mining, No.37 (1988), pp.46-62.

16. Harvey, W.S. & Downs-Rose, G. *The Rebuilding of two smelting hearths at Wanlockhead,* British Mining, No.11 (1979), pp.82-86.

17. Beven-Evans, M. *Gadlys and Flintshire Lead Mining* in *the Eighteenth Century,* Studies in Flintshire Records No. 1, Hawarden, 1963, p.12.

The first successful cupola (reverberatory) furnaces in England were used for lead and copper smelting in the Bristol area in the 1680s. Other early cupolas, for lead, were built by Daniel Peck near Mold, in Flintshire, during the 1690s, and they were later used by the London Lead Company at its Gadlys works. There was a cupola at Marrick, in Swaledale, Yorkshire, in 1701, but it was not until 1735 that the L.L.Co. introduced them into Derbyshire, at its Bowers Mill. The latter company also built cupolas in the North Pennines at around the same time.

18. Where and when roasting was first done separately is not known. North Yorkshire Record Office, ZLB 2/10: The Raygill Mill, in Swaledale, was used for roasting Old Gang ore between 1805 and 1807. A roasting furnace was added to the New (Old Gang) Mill at the end of 1807.

19. The first known horizontal flue in Britain was built at the Middleton Dale Upper Cupola, in Derbyshire, in 1778. It appears that its value was a providential discovery, resulting from the need to build a remote chimney on the side of a hill to prevent lead fume contamination of pastures adjoining the mill.

Smelters in Northern England adopted flues but their conservatism meant that, by the 1830s, many mills only had flues about 100 metres long. For example, the Greenside mill, at Glenridding, had a short flue until 1841, when it was greatly extended. Nevertheless, the Octagon Mill, in Arkengarthdale, had one 835 metres long by 1821 and when Jaques &

Co. leased the Old Gang Mine in 1828 they undertook to build 600 yards of new flue. The Allendale, Hunstanworth and Langley Mills all had very long flues by 1841 and the flue from the Grassington cupola mill was extended between 1849-1852.

British Parliamentary Papers, Industrial Revolution Children's Employment Volume 8, Session 1842, p.736.
Bolton MSS: Grassington Mines Tutwork Setting Book 1845-1856.

20. Slag-hearths have a long history. By the sixteenth century, bole slags were resmelted at high temperatures, which produced the characteristic black, glassy slags. It is likely that the bellows-blown shaft-furnaces, developed in the sixteenth century, also smelted slags. In early mills, slags were often treated in the ore-hearth. The Ellerton Mill, in Swaledale, had a slag-hearth in 1683 which was replaced by a new one at Thomas Wharton's Low Mill, in 1685. NYCRO *R/Q/R 5/214*.

For a discussion of the Spanish slag hearth see:-
Willies, L. *Derbyshire Lead Smelting in the eighteenth and nineteenth centuries*. Bulletin of the Peak District Mines Historical Society, Vol.11 No.1 (Summer 1990), pp.1-19.

21. Dickinson, J.M., Gill, M.C. & Martell, H.M. *Lumb Clough Lead Smelting Mill, Sutton in Craven, Yorkshire*, British Mining, NMRS, Vol.1, 1975. pp.1-10.

The excavators proposed this use for a small sump near the ore-hearth at this mill.

22. Foster gives 1/50th, p.381. 1/15th is most likely, see note 23.

23. Gill, M.C. *An assessment of lead smelting processes and the use of XRF for the analysis of resulting slags*, Historical Metallurgy, Historical Metallurgy Society, Vol.20 No.2 (1986), pp.63-78.

This paper gives the results of a series of analyses of black slags, using X-Ray Fluorescence, which ranged between 0.1% and 13.7%, with an average value of 4 per cent lead, by weight.

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