

LEAD SMELTING IN WELSH FURNACES AT PONTESFORD, SHROPSHIRE

By Hazel M. Martell and Michael C. Gill

SYNOPSIS: - This is the third paper translated from the French original by the authors (Martell and Gill 1989; 1990). Like the others, it is a detailed, contemporary description of a metallurgical process, made by M.L. Moissenet, a French mining engineer, and published in the *Annales des Mines* as *Les Usines à Plomb de Pontesford, près Shrewsbury (Shropshire). Traitement de la galène au four gallois (Moissenet 1862)*. Wherever possible, the text has been presented as a fairly literal translation, except where repetition or usage rendered this undesirable. As a guide for anyone wishing to make a comparison with the original text, the latter's page numbers are given in square brackets. A biographical note on Moissenet is contained in Bick (1986).

The Mining and Smelting Magazine (Vol. 1, Feb 1862 p120) clearly had a high regard for the *Annales des Mines*, and said of it: "This famous periodical, by far the most renowned publication in the world connected with mining and metallurgy, has long been particularly celebrated for the descriptions which, from time to time, have appeared in its pages on the mines, mining appliances and machinery, and metallurgical processes of other countries. To a great degree this may be accounted for by the natural dearth of subjects available in a country so comparatively poor in mineral resources as France, particularly when compared with the supply of highly cultivated ability afforded by such corps as the French Ingeneurs des Mines - a corps selected by competition from the choicest youth of France. But to whatever cause it may be attributable, to the *Annales des Mines* is due the credit of being generally foremost in describing the mining and metallurgical processes in use in every part of Europe, being even not unfrequently beforehand with local engineers. In this country they have certainly managed to go ahead of Englishmen in describing many of our most important operations. Le Play was the first to give any complete description of our modes of copper smelting. Coombes was one of the earliest to teach Europe and our own engineers what extraordinary machines we possessed in the Cornish condensing engines, the details of whose duty had previously been laughed to scorn. Even in our own time, M. Moissenet has given by far the best, and indeed the only complete, description of the Cornish method of tin dressing".

Account of the lead works of Pontesford, near Shrewsbury, Shropshire. Treatment of galena in the Welsh Furnace. By M.L. Moissenet, Mining Engineer.

Purpose of the account. - The metallurgy of lead is one the most important branches of England's mineral industry. Amongst the methods used for smelting lead ores, the one called Welsh, which is used in the big works around Holywell, in Flintshire, is of the premier rank. As well as at these vast establishments, the Welsh furnace is also used in various localities, including Pontesford, near Shrewsbury.

Having visited several works in Flintshire, and recently (September 1860) the smaller ones at Pontesford, it appears useful to give a brief description of the latter. Because their size is limited by the price of fuel, they are more comparable with conditions found in various places in France.

Nevertheless, one of the gaps met in this account is as follows. The companies own both the mines and the works, and only rarely buy small parcels of ore; they do not assay

the concentrates and the various products, such as dross, slags and fume. It is, therefore, impossible to give an account of the loss in metal, which is necessary [445] to appreciate the method's value. Thanks to the uniformity of the concentrates, however, they are guided by observing the yield.

Other than the smelters' skill, the yield mainly depends on the good state of the reverberatory furnace. This, at Pontesford as in Flintshire, is carefully constructed and maintained. The fairly detailed description of the Welsh Furnace and the smelters' work is based on information given on site. It ends with an evaluation of the operation's cost.

Situation of the works. - Three companies dominate the lead district near Shrewsbury. Of these, Snailbeach is the largest; followed by Stiperstones; and finally White Grit.

The latter mines are furthest from Shrewsbury; the works of the first two, which are the ones studied, are contiguous. They are at the foot of Pontesford Hill, on the outskirts of the village of Pontesbury, 9 miles to the south-west of Shrewsbury (Fig. 1). The Snailbeach works serve the mine of that name, 5 miles from Pontesbury. The neighbouring company has several mines of lesser importance, working under the general title of Stiperstones Mines, at a distance of 8 or 9 miles. The ore is taken to the works by carts. The pieces of lead are then taken to Shrewsbury, where they are fabricated into red lead, rolled lead, pipes and lead shot at the factory of Messrs Burr Bros. This absorbs all of the Stiperstones' output and a quarter of that from Snailbeach. The Pontesford lead only contains 2 oz of silver per ton [446] and so its great purity is very good for making sheet lead and red lead. As a return load, the carts take coal and coke, brought from the neighbouring coalfields to Shrewsbury by railway.

The lead strata in West Shropshire. - The map (Fig. 1) has been copied and reduced from the sheets of the Geological Survey. The key in the margin gives their order of deposition:-

- H Alluvial
- G New Red Sandstone
- F Coal Measures
- E Wenlock Shales (Upper Silurian)
- D Caradoc or Mid-Silurian [= Upper Ordovician today]
- C Formation of Llandeilo, Bala and Snowdon (Lower Silurian) [= Middle Lower Ordovician today]
- A Red and Green Sandstone, conglomerate and schist beds (Cambrian rocks). N.B. the French use of *schist* means either shale or slate in this context.

FIG. I. MAP OF PART OF SHROPSHIRE.

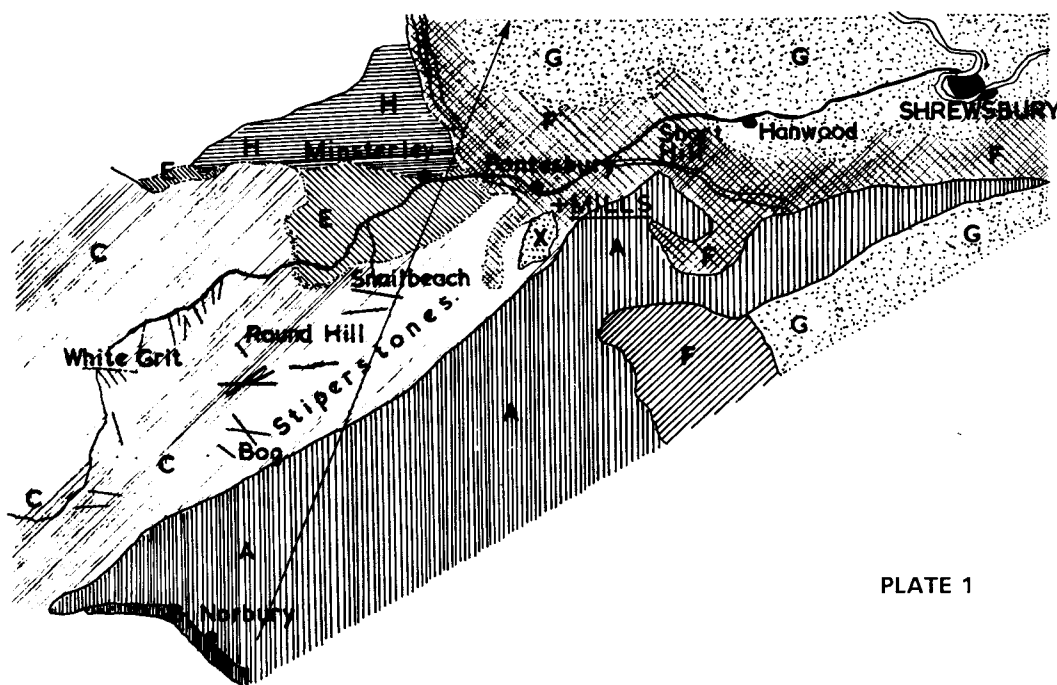


PLATE 1

Adjoining this ground are volcanic rocks. Some are contemporary and inter-mixed with the Lower Silurian schists, while others, Hornblende and Trapp rocks, are later. Pontesford Hill belongs to the latter (x).

The region has been described by Sir R. Murchison in the *Silurian System* (1839) and *Siluria* (1854). He gives a section from the Longmynd massif, in the direction ESE - WNW, through the Stiperstones and the Shropshire lead district.

At the eastern end of the Longmynd is met dark, imperfectly cleaved schist and grey schist with coarse sandstone, reddish sandstone, ironstone and some conglomerates. These rocks, up to here without known fossils, form, under the title of Bottom Rocks, the base of the Lower Silurian beds (formation 1 of Sir R. Murchison: its depth attains 26,000 feet). These beds have been called [447] Cambrian by the Survey. They slope from SSW to NNE. They are vertical in the east, but plunge towards the west under the following strata:

Incompletely developed graptolite schists, occupying the place of the *Lingula* flagstone in Wales. Next are the Stiperstones quartzites. These gradually pass to sandstone, with intercalation of green and talcy schists, as they go NNE towards Nils Hill quarries, near Pontesbury.

The remarkable Stiperstones strata, with the Lower Schist (formation 2x), breaks up into Greywackes without Longmynd fossils and copper veins, fossiliferous schists and sandstone of the Shelve and Corndon lead district, which constitute the equivalent of the Llandeilo formation (2. thickness 14,000 ft). In the latter are first met dark schists with graptolites, then dark coloured, hard flagstones. These are sometimes lightly micaceous, but often calcareous with white veins of calcium carbonate. The principal fossils are trilobites. Finally come shales, schists and sandstones.

Snailbeach Mine. - This has been worked for a long time and, having shared the reputation of the now-abandoned Bog, it still supplies nearly two-thirds of the lead produced in the

county. Its importance, therefore, requires more detail to be given than is strictly necessary for a description of the ores smelted at Pontesford (Davis 1969 ; Allbutt and Brook 1969; Brook and Allbutt 1973). Besides the Snailbeach main vein, another has been found 40 yards to the south (South Lode). The main vein is not thrown by any cross-course.

The country rock belonging to the Llandeilo beds is a hard, quartzy schist, lightly micaceous and of a [448] greenish-grey colour. In the west it alternates with soft shale. The direction of strike is 22° east of True North, following the Longmynd and the beds dip to the W.N.W. at about 60°.

The vein outcrops along the length of the north facing side of the hill. It fades underneath the latter at about 18°. The general direction of the vein is east - west; but there are large variations, which are listed below:

- South 89° West (average direction)
- North 88° West
- North 81° West
- South 67° West

A little to the south of South 67° West. The rich parts principally run east to west.

The position of the oreshoots will be best understood if the arrangement of the workings is described first. Old Shaft is sunk vertically to cut the vein at a depth of 80 yards; the levels are reckoned from its collar. The adit, at 110 yards, outfalls half a mile to the west, where a waterwheel used to drive the pumps by flat-rods running along the adit. For a long time this was sufficient to drain the mine but it has now been replaced by a steam engine and a main shaft. The latter, which started 38 yards [449] higher on the hillside to the south of Old Shaft, cuts the vein at the 282 yard level and reaches the 372 yard level. Its actual depth is, therefore, (372 + 38) = 410 yards.

The drifts are generally 50 yards apart and joined to the shafts by crosscuts. At the 372 yard level, the shaft is 40 yards from the wall of the vein. The workings extend

horizontally about 800 yards to the east of the shafts and 400 yards to the west.

The intersection of the beds of schist with the vein gives, according to the direction of the latter, a dip of between 45 and 55°. This is why the oreshoots dip to the west side. Six have been discovered. The biggest, situated to the east of the shafts, has been followed for almost 150 yards at the same level (Collins 1875).

To the west, the alternations of micaceous schist with soft shale correspond with an impoverishment of the vein which has no value in the shale. Towards the east, in the lower courses of the ground, however, a white veined, and extremely hard, quartz schist has been met. After 300-350 metres in this rock, one is under the old workings in a better, greenish coloured, schist with white veins, where the vein produces good galena in fine grains. The mine's future appears to be in the east, and a new shaft, destined to become the centre of operations, is being sunk there.* The vein is up to 10 feet wide in the rich part, but in the shale it is very thin.

Vein Materials: - The following minerals are found

Two kinds of Galena. The major part is cleavable with facets. In several places, and in [450] the east, however, the galena is of a fine grain (steel lead). Both varieties are poor in silver.

Blende, also of two kinds. The first is of a yellowish colour; the second is brown and compact. The blende is found in specks and sometimes in large pieces, but it is never intimately mixed with the galena.

Iron pyrites; little specks abound.

Calcite, well crystallised and very cleavable, forms much of the principal gangue and surrounds the metallic minerals.

Barytes is crystallised and found only in parts of the mine. In 1858 Snailbeach sold 30 tons of barytes ready for crushing at the price of £1/ton and in 1859 49 tons of blende.

Quartz is not common, but is found where the vein is in hard ground.

Finally are found some fragments adhering to the country rock. At Snailbeach, little nests of bitumen have been found in the vein matrix. Quite near to Pontesbury a vein of galena and blende, with a gangue of opaque quartz, in which the same substance abounds, was explored 50 years ago. Even now, abundant fragments on the dump give, when broken, a look of black and viscous bitumen.

Economic Data: - The following data will allow engineers to calculate the approximate expenditure in the mine and the smelting works. By comparing the total production, it is possible to find the approximate cost price of a ton of slime ore, and see what is the important profit achieved by the

* This was for Chapel Shaft, which turned out to be a disappointment. It was either for this work, or the New Engine Shaft, that the following advertisement appeared in the *Mining Journal* (1 Jan 1859, p.1, col.3, bottom).

Wanted, a second-hand winding engine, about 20 inch cylinder, with winding cage (drum), boiler etc - Messrs Eddy & Son, Carleton Grange, Skipton.

Snailbeach mine.

There are three steam engines. The first is a 60 inch Cornish pumping engine, with a 10 foot stroke. The diameter of the [451] pumps is 9.5 inches and their stroke 9 feet. There is very little water. The second engine is used for winding, and the third drives the crushing cylinders. The coal costs 18s 6d per ton. To this price must be added 3s 6d per ton for transport from Pontesford to the mine.

About 350 men work underground; and 50 dress the ore.

From 1853-1859, the average monthly output was 218 tons of concentrate. In the summer of 1860 this rose to 250-300 tons.

The recent introduction of the Yorkshire method has palpably diminished the expenses and the loss of ore. The cost of labour for dressing is now 6s 6d per ton of concentrate. Previously it was 16s 0d per ton. Enormous quantities of ore were also lost in the waste.** Even with the current procedure, however, the loss of lead is still considerable, and the process could advantageously be taken further than it is, prudently returning to an average price of around 16 shillings.

The nature and the results of dressing are as follows. - Even in the rich parts, the vein produces very few lumps of ore. Because of the need for a nearly pure concentrate, breaking and sorting by hand can only be used to separate lumps of waste, all the rest is sent to the crushing cylinders.

Because the galena is not finely disseminated, and the gangue is soft, however, it can be crushed into lumps of over 3/8ths diameter before being fed through the cylinders. Most of the ore is then recovered by sieving because the smelt works only handles fine concentrates. [452]

The sands and slimes are enriched in the round buddle and then in the square buddle. The greatest losses occur during this part of the treatment. The sieving waste also contains a notable quantity of galena. On assay, the concentrates give around 81%. The content of the slimes, from the washing of fine gravel and mud, which form only a small part, is 66-69%. Any foreign matter remaining in the concentrates is composed of the various gangues listed above; but it is probable that carbonated lime, adhering to the grains of galena, dominates in the coarse concentrates; whereas most of the blende is found in the slimes. Finally, each class of product has only traces of quartz and schist.

When the concentrates are weighed at the smelt works, an extra 200 lb. is added to each ton, making the weight of a

** The new manager was Stephen Eddy, the Duke of Devonshire's Mineral Agent, and Manager of the Duke's Grassington and Cononley Mines, in Yorkshire. A biographical note is given in Gill (1987).

The following account of Eddy's rationalisation appeared in the *Mining Journal* (18 June 1859 p.435, col.3 (middle)).

MINING IN SHROPSHIRE - Practical management. About 2 years ago, the Snailbeach Company's profits were falling and it called in S. Eddy to report. He concluded that too many men were working under the bottom levels, from which water was lifted manually. As a result, he (and son) were appointed to manage the mine and their first act was to lay-off 170 men and boys and stop all the under levels. They then set to work finding new deposits by crosscutting, remodelled the dressing floors and smelt mills - the profits have already risen tenfold.

FIG. 2. SKETCH OF THE PONTESFORD WORKS

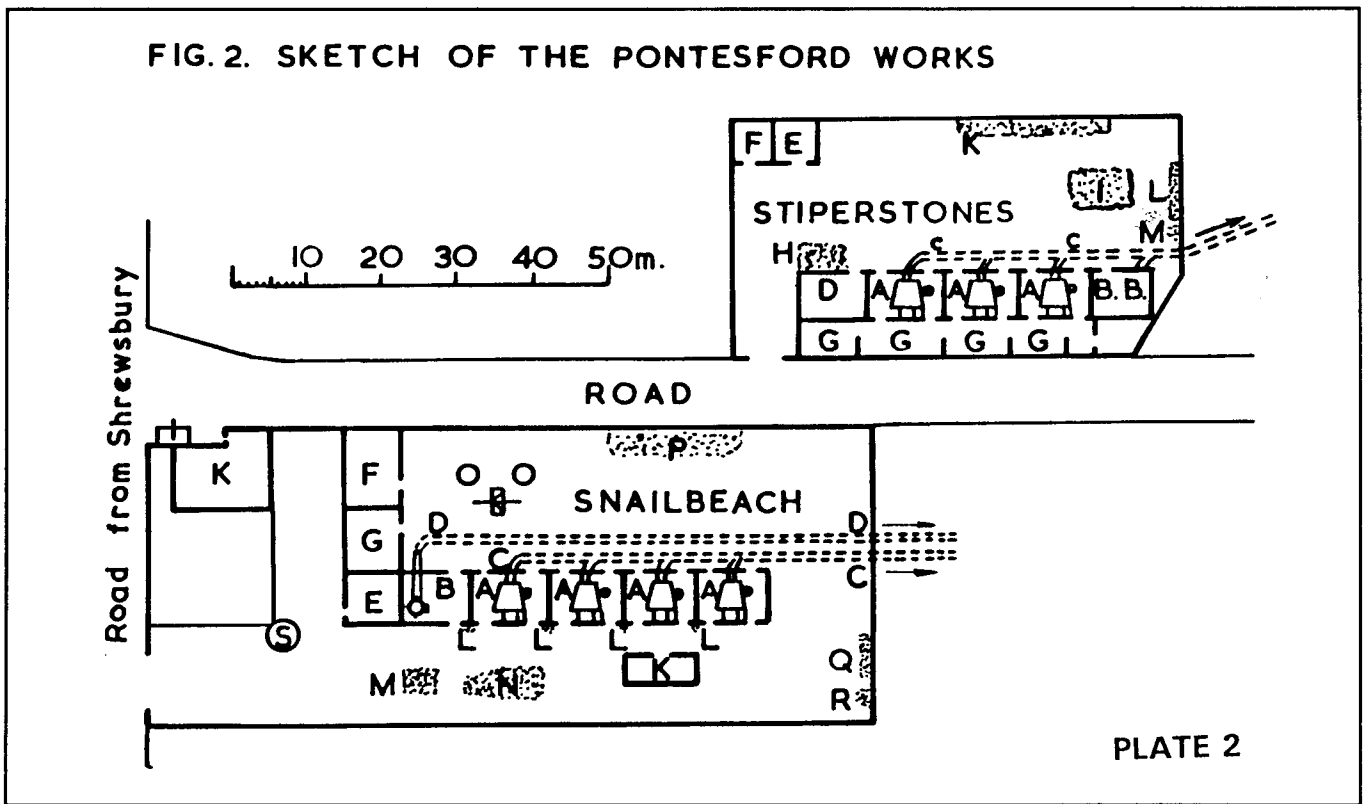


PLATE 2

'ton' at the mine ($20 \times 112 + 200$) = 2440 lb. The English practice is generally to buy lead concentrates by the ton of 21 cwt (= 2352 lb.), with no allowance for moisture. The excess 88 lb. corresponds to the small loss through transportation and above all hygroscopic water. This normally constitutes around 3.5% of the weight of the mineral content, represented here by 85.4 lb.

It appears that, except in times of commercial crisis, the value of a ton of non-argentiferous lead concentrates, as rich as those from Snailbeach, can be fixed at £13 15s. [453]

Minerals of Stiperstones. - Stiperstones gets its concentrates from various mines and treats a little lead carbonate with the galena. This mixture promotes reaction and makes work easier. The yield is a little less than that of Snailbeach, but in contrast there is less blende. The Stiperstones company also works deposits of witherite. The mineral is very pure, and many of the lumps are of a translucent fibrous nature. At the mine, they are sold for £3 10s per ton, or, with carriage (of £1), £4 10s per ton delivered to London.

Fuel. - The Pontesford smelt works are on the edge of a coalfield. For a long time locally won fuel has been used, but the seams dip northwards and the workings have only followed them a short way. There are three seams called the Half Yard, Yard and Thin Coal. To the north of the works, the Snailbeach Company is sinking a shaft which should reach coal at 130 yards.* At Short Hill Colliery, on the Shrewsbury to Pontesford road, the Half-Yard Coal is worked. The coal is brought to day in big blocks, but it is very pyritous, and the price of 15s per ton does not encourage the works to use it. Instead, they bring a good quality, lightly pyritous coal with a long flame from Shrewsbury, at the price of 10s per ton. It is carried in hefty, four horse waggons which also take the lead to the town. Each one brings three tons of coal in blocks at the price of 5s per ton for the distance of 9 miles. At the works, the coal is thus 15s per ton. Coke from Ruabon costs 20s at

Shrewsbury, or 25s a ton at Pontesford. [454]

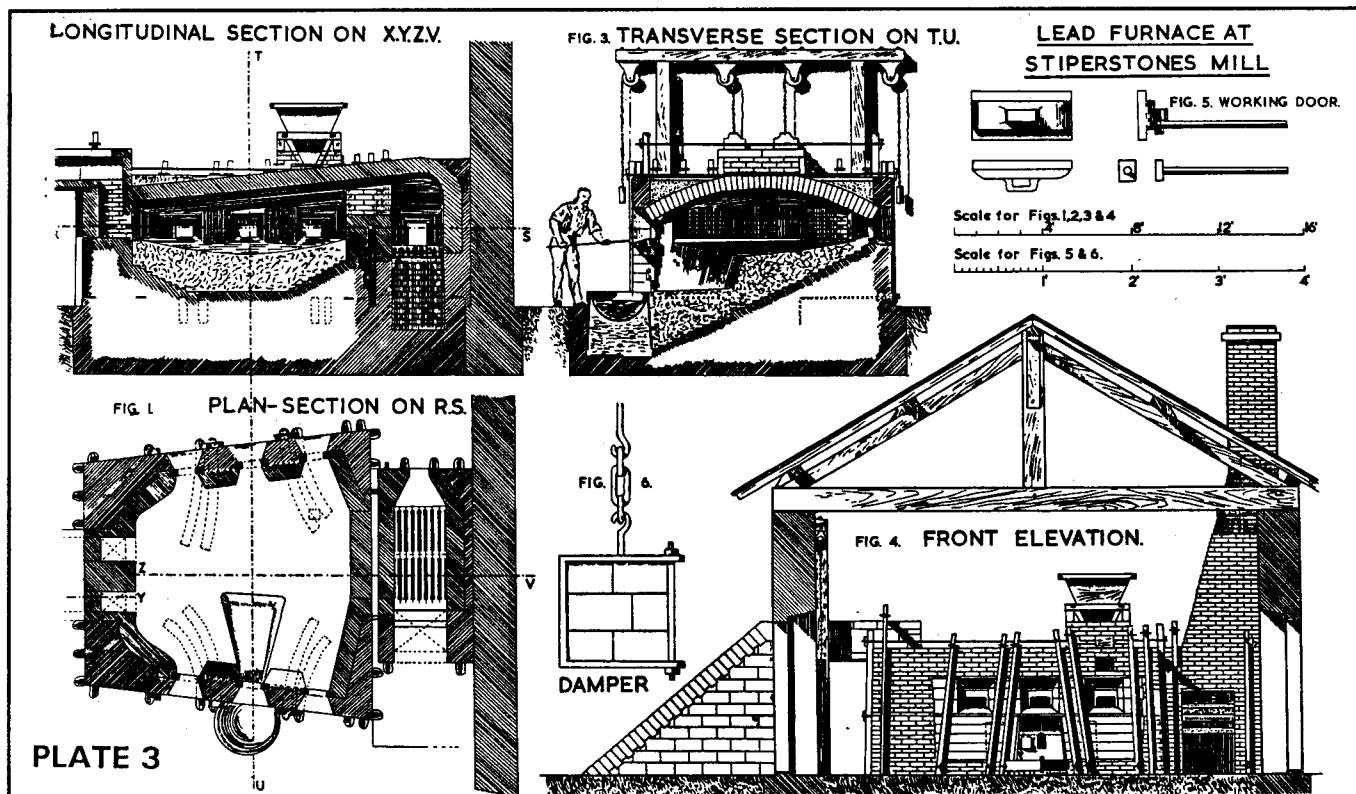
Arrangement and make up of the works. - The Welsh method is used for lead rich concentrates and is best when the gangue is calcareous. It has two principal operations. The first is a treatment by reaction in a big reverberatory furnace with 6 doors. This is a far better method which gives a much greater yield. The rich slags, which make up most of the charge in the second operation, are removed from the furnace. These slags are sent to the slag hearth, where they produce lead and slags. The latter are often thrown out, but any which contain granules of lead are crushed mechanically and returned to the slag hearth. Part of the fume from the two operations is caught by the condensation apparatus. The muddy materials recovered are first dried, then they are sintered in the reverberatory furnace, and finally reduced in the slag hearth.

The Stiperstones and Snailbeach works are on flat ground near Pontesford Hill and almost on the road side. They are separated by a road running parallel to the buildings. The sketch (Fig 2) and the following key, give an idea of their layout:

STIPERSTONES

- AAA 3 reverberatory furnaces
- BB slag hearth and bellows house
- C underground flue for the furnace gases
- D store

* *British Parliamentary Papers, Mining Accidents*, Vol. 7, 1864, pp.515-517. Two years after Moissenet's visit, the Snailbeach company closed its Pontesford smelter and moved to a new mill, about half a mile from the mine and linked to it by a tramway. The mine also then had a 60 inch pumping engine and four others (including one at the smelt mill). A new engine was being erected in July 1863.



- E forge
- F office
- G store-place and paved floor for the concentrates
- H coal [455]
- I deposit for the rich slags from the first operation
- K slags
- L bricks
- M refractory clay

SNAILBEACH

- AAAA1 four reverberatory furnaces of which one (A1) has five doors
- B Castilian furnace with three tuyeres
- CC flue for gases from the reverberatory furnaces
- DD flue for gases from the Castilian furnace
- E a steam engine for the fan and the pumps for the condensers
- F forge
- G store
- H office
- I weigh bridge
- K store-place for the concentrates
- LLLL coal
- M coke
- N rich slags
- O slags; mechanical preparation
- P store for fume
- Q bricks
- R refractory clay
- S reservoir of water feeding the condensers

The Stiperstones works has three six-doored reverberatories; but only one was working in 1860. It also has little

Flintshire slag-hearths. Snailbeach has four reverberatories, one of which, a recent model with five doors, is giving good results. The slag hearth has been replaced by a Castilian furnace, recently imported from Yorkshire (Gill 1993). Outside the courtyard of each works there is a big chimney, linked to all the furnaces. The flues and condensation chambers at Snailbeach are well built. They have not had recourse to suction machines, like those used at Dee Bank, Bagillt, near Holywell, which are powerful and efficacious but expensive. [456] Nevertheless, the general effect of the arrangement is satisfactory. This subject is discussed below.

Description of the apparatus. - Reverberatory furnace at Stiperstones. - During my visit, a furnace which had been well used was being repaired. The drawings (Plate 3, and Plate 4, Fig. 5) are based on this apparatus. Details of the construction and of those interior arrangements not visible to me were given by the chief mason. Plate 3, Fig. 1, is a sectional plan at the level of the doors. The sole presents the shape common to Welsh furnaces; it is a trapezium with rounded corners, which link up to the sides of the furthest doors.

An interior basin, like a well, with almost vertical sides, receives the lead as it is produced. The casting is done in a cast-iron pot lodged outside, in the centre recess. This side of the furnace is called the front side, and the chief smelter works there. The assistant, at the back side, serves the three doors and loads the hearth. Fig. 1, shows that the axis of the sole does not pass through the middle of the fire grate. This and the bridge are set back so as to take the flames away from the well. The two flues take the fumes down a steep slope into the communal flue leading to the chimney. The flue is underground. This is an economical arrangement, but disadvantageous from the point of view of draught. The only purpose of the little chimney near the back of the hearth (Figs. 1, 2, 4) is to remove smoke and steam from the ash pit.

Principal Dimensions: [457]

	ft.	ins.
Hearth: Breadth in the direction of the furnace axis	2	6
Length of the grate	4	6
Bridge: Length	4	0
Thickness of bridge at the axis of the first two doors	2	0
or from the bridge to the axis of the first two doors	1	6
Sole: from the axis of the first doors to that of the second	3	0
from the axis of the second doors to that of the third	3	0
from the axis of the third doors to that of the back	2	3
Total length of the sole	9	9
Approximate width reckoned between the inside edges of the frames of the two opposing doors.		
	ft.	ins.
Axis of the first two doors	10	0
Axis of the second two doors	9	6
Axis of the third two doors	9	0

If we take off the thickness of the pillars of refractory masonry, which project nine inches from the frames of the doors, the lengths measured on the same lines are: 8 ft 6 ins, 8 ft 0 ins, 7 ft 6 ins. At the base of the furnace the distance between the extreme sides of the flues gives the width of the sole as 3 ft 3 ins. The flue floors are level with the sole, and their widths are: front 11 inches, back 12 inches. Their common height is 12 inches. Vertically, they keep the same widths, but their depth (in the direction of the furnace axis) is 13 inches. They are separated, at this point, from the interior of the furnace by a 6 inch brick. The front flue is narrower than the back one because the gases are carried from that direction. For the same reason, the middle of the grate is set back 10 inches from the axis of the sole. The top of the grate (see Fig. 2) is 2 ft 8 ins from the ground. [458] The level of the working openings is 4 inches higher, being 3 ft 0 ins from the ground.

	ft	ins
Counting from the grate to the bridge	1	4
bridge to the sole	1	0
grate to the arch in the middle of the hearth	3	2
middle of the bridge to the arch	1	7
height from the arch to the bottom of the furnace between the flues	1	6

Well and Pot. The sole is made of slag (Figs 2, 3), with a well fashioned in it. The workmen keep them both in good repair. The casting hole, in a plate of cast-iron, is situated 8 inches above the sole and 2 ft 4 ins below the doors. From the plate towards the centre of the furnace, the well is 3 ft 6 ins deep. Its width at the bottom is 2 ft 0 ins, but towards the plate it is reduced by several inches. The bottom begins at the level of the casting hole, but it tends to drop through use. The walls are very slightly inclined.

The pot is a cast-iron boiler with an internal diameter of 2 ft 6 ins and a depth of 20 inches. It projects 8 inches from the sole and is consolidated and held together by a frame of iron

stays drawn together by an iron hoop 4 inches wide and half an inch thick.

Framework and Door. Cast-iron Plates. - The framework and doors are made of cast-iron. Three big cast-iron plates must be described first. One, called the air plate, supports the wall of the reverberatory below the bridge and leaves a 4 inch gap for the circulation of air between itself and the wall of the hearth. It also stops lead from seeping into this side of the sole. Its dimensions are: length 6 ft 0 ins; height 20 inches. [459] Its thickness is 3 inches, tapering over its height from 6 inches at the upper edge. This is level with the fire-grate. The tapping and the back plates are fixed on the two long sides of the furnace. They are both 5 feet long by 20 inches high. The back plate is only 1 inch thick, but the other is 2 inches, widening to 3 inches after 6 inches from its bottom. In the tapping plate, 4 inches above the smelting hole, is a hole 4 inches wide by 9 inches high. Two hinges, fixed to the casting, support a small rectangular door 8 inches high. When this door is closed, a space remains above it for the access of cold air on to the lead in the well. A strong bar of 4 inch angle-iron is placed above and in front of the plate. We will come back in a moment to the parts which complete the smelting recess.

Doors. - Each of the six openings is fitted with a cast-iron frame, which is 10 inches wide and 6 inches high. In section, the cast-iron is a 4 inch square. The framework rests on the masonry. Inside, the sole is flush with the opening, and the two vertical sides are overlapped by refractory pillars. Outside, the recess is entirely lined with iron. The door is a plate of cast-iron 13 by 7 inches. It is 1 inch thick on the sides, but in the middle it is reinforced with a handle in which one inserts the head of a tool which looks like a bolt. The tool's shaft is 18 inches long. Each workman has one for taking off and putting on the doors, which are only leant against the frame {see Fig. 5, pl.1}.

Recesses. - (Plate 4, Fig. 5). In each of the reverberatory's sides, there is a horizontal stay [460] set in the masonry at fire grate level (2 ft 8 ins). Each is 6 inches wide by half an inch thick and forms the base of all three recesses on the same side. It supports a band of iron 8 inches wide and half an inch thick. This begins level with the outer openings of the frames and slopes down about 3 inches over a length of around 8 inches. At 20 inches above the stay a band of iron of equal section forms the upper lintel of the recess. Behind, supported on it and on the upper side of the frames, an iron sheet, 9 inches wide and half an inch thick, runs across this section and supports the arch.

Between the centre recess and the other two, three iron bands, curved at their extremities and cut as necessary, strengthen the non-refractory masonry. On the furthest side of the recesses, similar bands, which are only bent once, project about 1 ft 0 ins from the furnace side. This is common to two sides of the reverberatory. On the front side (Plate 3, Fig. 4), below the doors, are placed ten bands of iron, five to each side of the smelting recess. They curve to a tag which is joined to the tapping plate. They are a little over 4 ft 0 ins long by half an inch thick, and the lower edge of the bottom one is level with the smelting hole.

On the back side (Plate 3, Fig. 3) of the centre door, two hooks are set into the vertical framework, mentioned below; on these hooks is placed a 1 inch diameter iron bar, about 3 ft 6 ins long. This bar is level with the opening and supports the tool during work.

Framework. - In addition to the pieces already described, the iron framework is made of near vertical bars set against the walls of the furnace, and [461] horizontal ties, some of which are external, above the arch, and others built into the masonry. The bars are about 3 inches by 2 inches and 6 ft 6 ins long, bearing on their narrowest side. The tie-bars are 6 inches by half an inch, and have an eye at each end through which the bar passes and is held by an iron wedge.

The position of these various pieces is shown in the figures and explained by the preceding details. It would, however, be helpful to explain the peculiarity of the lower stays adjoining the centre door. The depth and the shape of the well means that instead of four rectangular bands, eight curved stays are used. Each one is set about 4 ft 6 ins into the masonry, and its end, bent at a right angle, is 1 ft 0 ins into the structure. This separates them from the well, and from the end of the sole made from slags.

Hearth. - The grate has two groups of eight bars. Three iron rods, one at either end and one in the middle, support the ends of these bars. The latter are 2 ft 3 ins long, making the grate 4 ft 6 ins long. The only opening on the back side is the stoking door. It has a 1 ft 0 ins square cast-iron frame at the entrance, with a removable door. This door has {fig.6} an iron frame filled with refractory bricks and is hung on a hook by a chain from an iron bar. This lets it move sideways, but when left to itself it covers the frame. From the latter to the grate, the opening's width increases from 1 ft 0 ins to 2 ft 6 ins. The wall is 18 inches thick and has an horizontal break level with the bars (2 ft 8 ins from the ground). The air arrives under the grate from the front side. The door of the furnace hall is 8 ft 6 ins from the hearth.

The ash pit is 1 ft 0 ins below ground level. It [462] holds water into which the clinkers fall, making steam which reduces wear on the bars. The chimney for the steam is built immediately in front of the hearth. It is 2 ft 6 ins broad and 2 ft 0 ins deep at the base. Its top is 20 feet from the ground, or around 5 ft 0 ins above the roof. From the foregoing, it is clear that the chief smelter can only poke the fire underneath the grate. For poking the top, a horizontal opening 4 inches high is made at the side. It is formed by three strong 4 inch bars. One of them closes the rectangle of the grate and so prevents all longitudinal movement of the bars, with which it is level. The other two, which are fixed 4 inches higher, also support the arch of the hearth on the chimney side.

Flues. - In some furnaces the horizontal part of the flue is built on the ground and steps are needed to get from one side of the room to the other. The arrangement shown in Figs. 2, 3, 4, which leaves a passage of 5 ft 2 ins (= 2 ft 8 ins + 2 ft 6 ins) high, is preferable. Two iron bars are placed at this height. One is on the end of the furnace, the other opposite it on the wall of the hall. Transverse bars carry the masonry of special bricks, which are described below. From the sole underneath the overlapping bricks is a vertical distance of 3 ft 7 ins. The two flues lead into a single opening made in the wall and the gases descend into an underground channel in a flue inclined at 45° and built like a buttress. The sheet metal damper doors (Figs. 2, 3) are suspended on a system of pulleys by chains ending in counter-weights at the height (4 ft 6 ins) of the workman's hand. After working for some time, the damper door's lower edge is eaten away by the corrosive gases, [463] so that when the door is lowered, the flue is not completely closed.

Hopper. - The hopper's position is determined by the following coordinates: (1) from the corner of the furnace adjoining the hearth door, measure 2 ft 9 ins along the back face; (2) then 3 ft 6 ins from this point perpendicular to the sole's axis. This gives the centre of the 6 inch square opening in the arch. It also corresponds to 1 ft 9 ins from the bridge and 2 ft 6 ins from the 1st door at the back. The concentrates fall as a conical heap on the sole, and the workmen spread them in front of the bridge and all around the back of the well. The hopper's shape is an inverted, truncated pyramid. Its top is 3 ft 6 ins square, and it is about 3 ft 0 ins high. To support it, the side walls are built 14 ins above the upper edge of the furnace, which is 6 ft 10 ins from the ground (Figs. 2, 4). On these one brick thick plinths two small beams, of 6 ins by 4 ins, are placed across the arch, and on these is placed a 3 inch square wooden frame. From the latter, four iron bars support a slotted frame of sheet iron which houses a slide-valve in the same metal. The wooden frame also carries the hopper, of which the bottom is level with the slide-valve but does not press on it. The apparatus can be quickly dismantled when necessary. The workmen load the charge from a ladder. They carry it on their shoulders in a box holding 1 cwt. The hopper is filled at the start of the following operation. [464]

Construction of the Reverberatory. - External dimensions. At Pontesford the foundations are 3 ft 0 ins deep. They are made of brick on the structure's perimeter, and packed with sand in the centre. At ground level the outside dimensions are:

		Ft.	ins.
Large base)	13	0
Trapezium of reverberatory) Small base	10	0
Height)	13	0
Rectangle making	af	1	9
up the hearth	ed	2	6
(Pl. 3, Fig. 3) that which allows	ef	8	9
	eg	4	9

The breadth eg is sub-divided in four places: (1) thickness of the masonry supporting the wall of the hall 14 ins; (2) width of the hearth 2 ft 6 ins; (3) wall beneath the bridge 9 ins; (4) finally a gap of 4 ins between this wall and the reverberatory. The vertical dimensions have already been given.

Sole of Slag. - As the masonry rises, iron bands are built into it and, when the level of the grate and the two side stays (2 ft 8 ins) is reached, the interior cavity is set out using two strings. After this, the bricks are replaced with slags. Next, two points a & b (Plate 3, Fig. 1) are marked at ground level in the furnace, 3 ft 6 ins from the face of the front doors opposite the centre one and 2 ft 0 ins apart. From points a & b (at a height of 2 ft 8 ins) a string aa bb, with the summits c & d (2 ft 8 ins) gives the following three inclined planes (see Figs. 2 and 3):

abab	(cross-section) making with the horizon	24°
ada	side of bridge	30°
bcb	side of flues	23°

On the front side, the refractory masonry is vertical.

The pot is set in puddle-clay [465] surrounded by masonry, and stiffened by iron ties. In spite of these precautions, lead often infiltrates below the pot and gradually lifts it.

After the arch is built, the sole is made. This is a long and difficult task, using poor slags and quartz gravel. The

materials are first partly fused by a strong blast of heat, then successively beaten, with a gavelock and spade, until the well is formed and the sole slopes towards it. The edge of the well is about 10 inches below the working openings. This type of sole is almost impermeable to lead and lasts for a very long time because the workmen take care to keep its surface in good repair. The thickness of the slags in several places is as follows:

inches	
4	along the rear doors
12	along the bridge
14	towards the flues
8	at the bottom of the well
30	at the front of the well

Arch. - The construction of the arch is guided by three principal lines. Two of these are the horizontals, level with the top of the door frames. The third is a line held in the plane of the sole's axis, 3 ft 2 ins above the middle of the grate at one end, and the other at 20 inches measured vertically above the same level on the outer face. The inside of the furnace is filled with fine slags, which are packed to the shape of the arch, and rows of refractory bricks are then laid on them. This done, the slags are removed by shovel through the openings.

Refractory Parts. - The refractory parts are shown in Plate 3, (Figs. 1, 2, 3). They are nearly always one [466] brick thick. A small space is left between them and the ordinary bricks and filled with brick rubble.

Here is some information about the materials used.

Refractory Bricks. - There are around 300 bricks to the ton. They cost 40 shillings per 1000, to which must be added 18 shillings for transport, making 58 shillings for the 1000 bricks at the works. Their dimensions are 9 ins by 4 ins by 2.5 ins.

Ordinary Bricks: There are 373 of these to the ton, and the price is 44 shillings per 1000. The dimensions are the same as refractory bricks, except the length is 8.5 inches.

Special Refractory Bricks. Some large bricks are used at the following places: (1) above the hearth's charging door; (2) at the bottom of the grate at the start of the arch; (3) for the bridge; (4) for the vertical walls of the flues at the end of the furnace. These bricks are 2 feet by 1 foot by 6 inches. The horizontal parts of the flue are constructed entirely of bricks, 2 feet by 1 foot by 4 inches thick.

Refractory Clay which is used as much for construction as for repairs, and for plugging the tapping hole, costs 20 shillings per ton.

Lime, of which only a small quantity is consumed at Pontesford, costs around 16 shillings per ton.

Repairs. - Reverberatory furnaces, in spite of hard work, last a very long time. This is the result of careful construction, and the fact that they are not allowed to get too hot. The part most exposed to the flames, the arch, only needs occasional repairs. [467] The portion which extends from the hearth beyond the bridge must be renewed every two years, but the rest of the arch lasts five years. The outer arch uses 2000 bricks, in other words around 800 bricks per year are

consumed.

Tools. - (Plate 4, Figs. 6-19) Below is a list and the principal dimensions of the smelters' tools.

Tools for working on the sole		
Fig. 6.	Paddle:	inches
	Long	12
The dimensions of the plate		
	Width	6
	Thickness	0.5

The handle is about 6 ft long of 1.125 inches square iron; the extremity is in rounded iron about 3 ft long. The total length of the tool is 10 feet.

Fig. 7. Rake: width 8 ins; height 5 ins; rounded iron handle of 1 inch diameter.

Fig. 8. Paddle used to poke and stir up the clinker at the end of the operation; width of the handle 4 ins.

Fig. 9. Hammer for hitting the handle of the tools, before removing them from the furnace, to detach any materials sticking to them.

Tools for the hearth

Fig. 10. Scoop for loading the coal; height 13 ins; width 10 ins; length of handle 2 ft 8 ins.

Fig. 11. Sledge-hammer for breaking the blocks of coal.

Fig. 12. Bar for poking the fire.

Fig. 13. Large rake for cleaning out the cinders, made of sheet-iron 8 ins high by 20 ins wide. Socket of iron and handle of wood; total length 11 ft 6 ins.

Tools for casting

Fig. 14. Bar for piercing the tap-hole and for stopping it up with clay. This is an old paddle handle.

Fig. 15. Perforated ladle to remove the slags from the outer basin; width 7 ins; height 10 ins; total length 4 ft 10 ins.

Fig. 16. Perforated round ladle for the remaining ashes.

Fig. 17. Ladle for casting the pieces; 10 ins diameter; 4 ins deep; handle 3 ft 8 ins. This holds 44-46 lbs of molten lead.

Fig. 18. Cast-iron mould. The pieces are taken out whilst still hot using two little iron bars and not moving the mould.

Fig. 19. A hooked pole to transport the still hot pieces of lead from the furnace hall into the works' yard.

Layout of Hall. - The smelting works has a hall for each reverberatory furnace. This is very convenient because each furnace is run by a team of partner-workmen. The sketch (Plate 4, Fig. 3) gives the layout of a hall at Stiperstones. The following key shows the position of the objects used by the smelters.

A	Reverberatory	GG	Benches
B	Front side	H	Moulds
C	Rear side	II	Flue
D	Coal	K	Store-place, and paved floor for the concentrates
EE	Lime	LL	Water for the ash-pit
F	Refractory clay		

On each end of the furnace there is a space of 14 feet, making the total length of each hall (2 x 14 + 13) = 41 feet. The width between the building's long sides is 20 feet. The walls are 13 feet high, and the roof's timber work is nothing special.

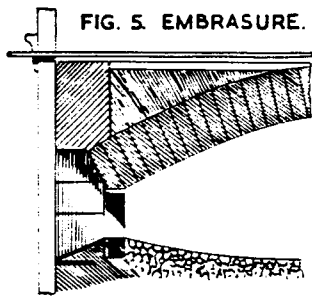


FIG. 3. FURNACE HOUSE-STIPERSTONES

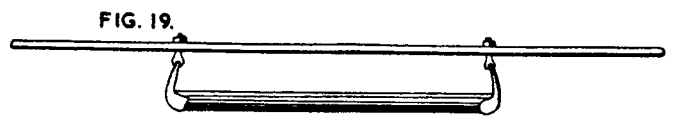
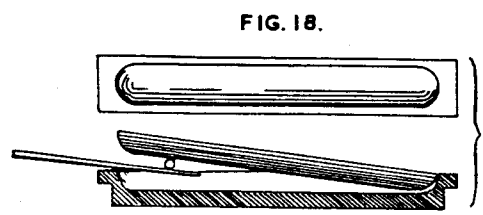
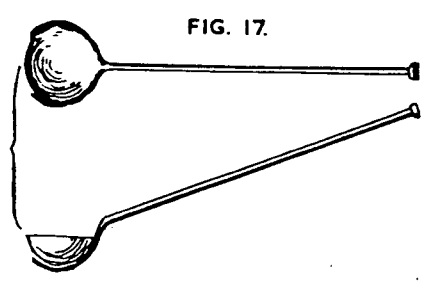
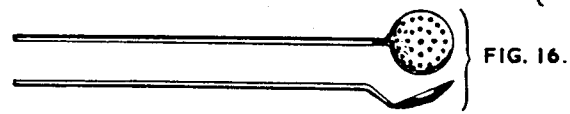
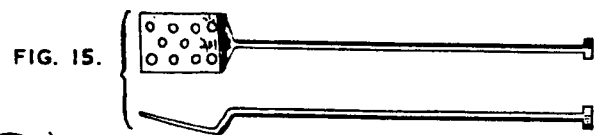
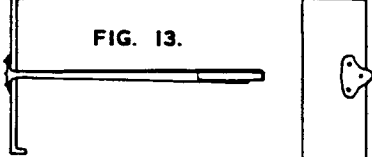
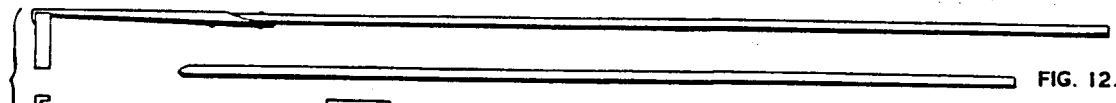
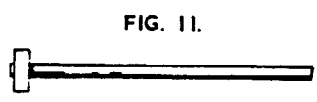
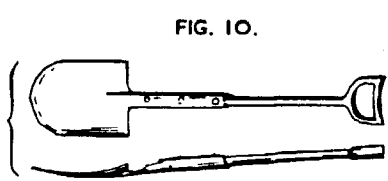
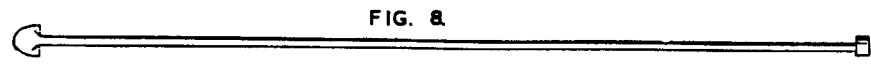
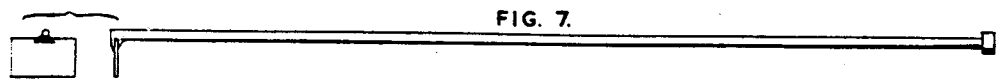
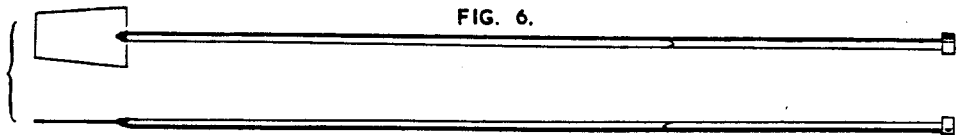
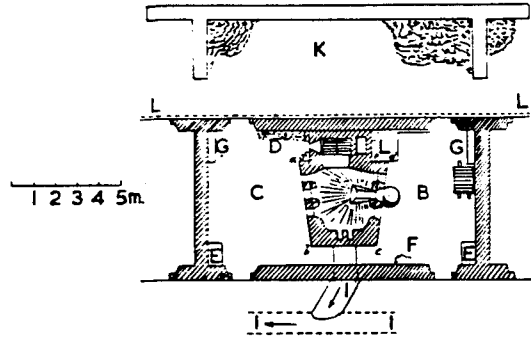


FIG. 4. CONDENSATION OF FUMES

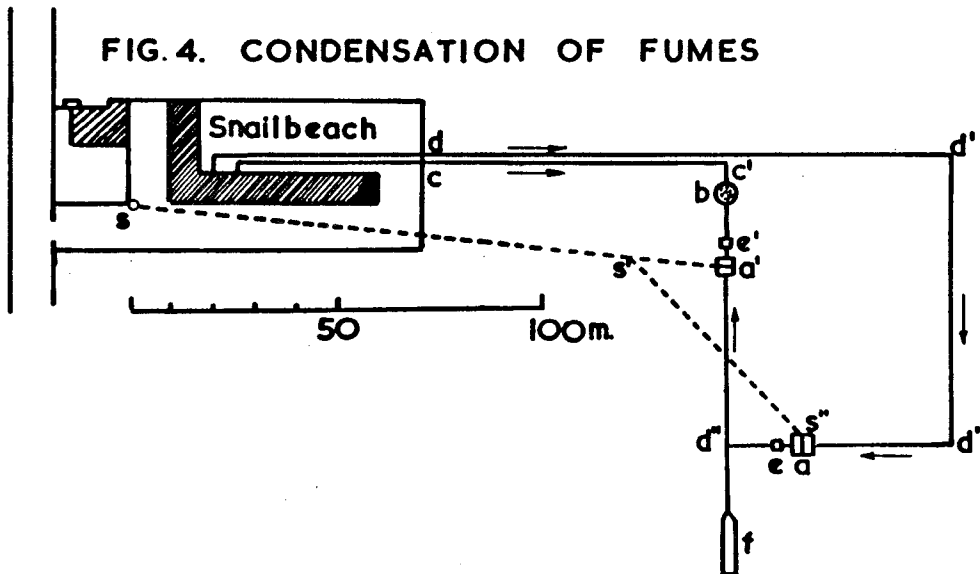


PLATE 5

The Five-door Reverberatory at Snailbeach. - In 1858, one of the four furnaces at Snailbeach was rebuilt and an important modification was introduced. On the front side, the door next to the flues was omitted, and the well, pot and former centre door were set back about 16 inches. This was done to increase the surface on which the concentrates are spread. In the six door furnace the concentrates form a sort of crescent of which the narrow part [469] is in front of the bridge, and the widest part is between the rear door and the well. The space in front of the last front door (here omitted) is only used for re-smelting the scum from the pot.

The five door furnace has the following advantages: (1) the concentrates spread on a bigger surface, form a thinner bed, making less work for the workmen during roasting; (2) the part of the sole thus established is well exposed to the flames, but the well is shielded from much of their action. The first front door suffices for re-smelting the scum.

At Snailbeach, the rear flue is twelve inches wide like those at Stiperstones, but the front one is only ten inches wide instead of eleven.

The Castilian furnace at Snailbeach. - No description of the little Welsh slag-hearths will be made, and only the principal dimensions of the Castilian furnace at Snailbeach are given (Coste & Perdonnet, 1830).

It is a cylindrical vat, with an internal diameter of 3 feet, built in refractory masonry one brick thick and supported by hoops and vertical bars of iron. At 39 inches above the sole are three tuyeres spaced at 90° and which could be called lateral and rear. From the latter to the bottom of the furnace is only 9 inches. The brush is packed in a gentle slope as far as the breast. From the bottom of the furnace to the charging opening, above the rear tuyere, is 2 feet 6 inches. On the front and below the breast, next to the masonry, is a cylindrical cast iron pot lined with brush. It is about 2 feet 4 inches high. Its base is formed from two separate uprights of 2 feet 6 inches and joined by a semi-circle. The brush here is loose enough so that during working there is a

discharge and separation of the lead and [470] slags. On the left the lead, having arrived in the bottom of the basin, falls by a tap hole, 10 inches from the sole, into a cast iron pot, from where it is taken for casting. On the right a slope leads the slags into the water, where they solidify and granulate.

From the front, the furnace looks like a cylindrical column up to seven feet above the sole, then slightly conical for the next eight feet. A curved ramp takes the gases and fumes down from a level of fifteen feet to the underground flue. The furnace is blown by a fan making 1600 RPM, and driven by an 8 HP steam engine.*

Condensation of fumes at Snailbeach. - Plate 5 gives the general layout of the condensing apparatus at Snailbeach. The flue from the reverberatory c,c' is 180 yards long and leads to a 100 foot high chimney b. That of the Castilian furnace d,d',d'',d''' is 500 yards long. It makes three right angled bends before coming back to the chimney. The gases pass through two identical condensers a,a'. These are like brick sentry boxes, with gables and a roof with two gutters. Their height, from the bottom of the flue is 18 feet, this being 12 feet above the ground. Their internal dimensions are 7 feet wide by 8 feet long, but a vertical partition, about 16 feet high from the bottom of the flue, forces the gases to rise then descend in the space of 7 feet by slightly less than 4 feet. The steam engine pumps water from the reservoir s through pipes s,s',s'', one branch of which ends in the middle of each chamber's gable. Above the brick partition is a double, oscillating chute, which pours [471] water alternatively into the two gutters. From these, the water falls as spray into the two parts of the chamber. In addition at ground level are some bearers supporting a 2 foot thick bed of branches on which the water spreads, and which the fumes must pass through to rise and then fall. Beyond the chamber is a little hole e,e' where the condensate accumulates until it

* An engine of this specification was used to pump water from the Greenhaw Bottom Shaft, at Grassington, which was abandoned in 1858. The engine was never used again at Grassington, and it is interesting to speculate that it may have been sent to Shropshire.

is let into the tank f. Here it is semi-dried and then returned to the works. The flue is 4 feet wide by 6 feet high and is level with the ground which unfortunately slopes slightly in the direction d',d". The draught would be adequate for the furnace with tuyeres, but it is not enough for reverberatories. An attempt to link the latter with the 500 yard flue has been abandoned in favour of the direct flue c,c'.

Working the reverberatory. - The work in the reverberatory at Stiperstones will be described first, and then that at Snailbeach. This will be followed with some comments about the treatment of slag and fumes in the latter works.

In the Welsh reverberatory, using identical concentrates and fuel, the operation's progress can be varied by the following: (1) weight of the charge; (2) duration of the work; and (3) amount of work expected from the workmen. The last strongly influences the other two and gives the smelters chance to increase their earnings by demanding greater effort from them. This was seen more clearly at Snailbeach, than at Stiperstones and, from this, rather than from the nature of the mineral, spring the differences between the works.

The reverberatory is worked by a team of four partner-workmen, of which only two are present at once. They usually work 12 hour shifts. The concentrates and fuel are [472] left in the door near the smelters (see sketches in Plate 3, Figs. 2, 3), and so they only have to weigh and load it.

The furnace's six doors are designated by the following numbers, going from the bridge to the flues:

Front side 1, 2, 3
Back side 4, 5, 6

Numbers 1 and 4 are, therefore, nearest to the bridge and 2 and 5 are the centre doors etc.

Work at Stiperstones. - The following example uses the second shift after Sunday's shut down, beginning at midday on Monday (Gill 1992).

Midday. - The charge, which weighs 21 cwts, is dropped on the sole. It consists of 20 cwts of galena and 1 cwt of lead carbonate, well mixed. A little slag, which cannot be detached with the paddle, remains on the sole. In the well is metallic lead, on which a little lime has been spread.

The furnace is red-hot, and as the concentrates are spread with the rabble through doors 1, 4 and 5 they sizzle and release steam. The damper doors start off closed but are progressively raised. The fire is stoked with coal from time to time until 1.30 pm. Between midday and 2.10 pm the furnace is stirred four times through doors one and four, leaving the others closed. These stirrings are about half-an-hour apart and each one only lasts a few minutes.

2.10 pm. - The first cooling begins. Doors 1, 2, 4 & 5, and the hearth door are opened. The hearth, which has not been stoked since 1.30, is poked, and the fire allowed to die down. Finally, the damper doors are fully opened and cold air flows in through the working openings [473].

Near the bridge the concentrates, which are 6 inches thick, are beginning to fuse; they are divided with paddles, and turned over through the other doors, the lumps which have fallen into the well are finally recovered and spread around the sole. At 2.25 pm door 5 is shut, and at 2.35 pm all is in place.

2.35 pm. - The hearth is stoked with coal and the damper door is closed. This firing lasts from 55 minutes to an hour and then the second cooling begins.

3.30 pm. - Everything is opened again for the second cooling. From the bridge to the middle of the sole, the concentrates are partly fused and a little lead has begun to run towards the well. The concentrates at the end of the furnace are still only a little fused. As in the first cooling they are gently stirred, this time working through door six. This stirring lasts ten minutes and at 3.40 pm, with all doors remaining open, the lead begins to run.

The hole is opened by striking with a pointed gavelock reddened in the fire. When the contents of the well have run into the pot, the hole is immediately plugged. The little door in the tapping plate is used for this. A plug of refractory clay is put on the end of the gavelock and pressed from the interior to the exterior, until the clay comes out of the hole. At the same time the interior of the cast iron slab is covered to protect it against the action of the new metal bath. Two or three pieces of small coal and a few handfuls of shavings are already in the pot, causing it to boil vigorously and produce flames and smoke. Using the square skimming ladle, the workman stirs the materials well for 6 or 7 minutes. The oxy-sulphurous slags rise to the surface, and the two [474] smelters skim them off, first with the shovel, then with the square skimming ladle, and throw them respectively through doors one and three on to the sole at each side of the well.

The action of coal on this very oxidised scum produces lead without special work. The mineral is stirred for a while through doors one and four, then they are closed. The hearth is charged and the dampers are lowered. The second cooling ends at four o'clock.

4.00 pm. - During a blast of heat, the casting of the pieces of lead begins. The two workmen do this together. One of them uses the round skimming ladle to skim off a small quantity of scum, which is composed of lightly oxidised lead, and strikes the tool on the ground to clean it. When the metal's surface is clean, one of the smelters ladles it into the moulds. There are ten of these, placed horizontally on stands. When one mould is full, the other workman cleans the surface of the piece, using two small boards between which he delicately lifts the few slags which have gathered. These slags, as well as the last scum from the pot, are sold in Shrewsbury, where they are used in the making of lead shot. This income only forms a negligible fraction of that from metallic lead. The smelters take turns at casting, and make ten pieces of 160 lbs each in 20 minutes.

The fire is then drawn, by gradually opening the fire doors, and from 5 o'clock to 6 o'clock the workmen vigorously stir up the materials several times. During this time, the major part of the lead flows into the well. For this work the doors are only opened when necessary.

6.00 pm. - At 6 o'clock the third [475] and last cooling begins. The furnace has reached a bright red heat. The stirring is continued for fifteen or twenty minutes. Any agglomerated matter which has fallen into the well is pulled back to the surface, and, to facilitate this, a very small amount of lime is thrown on the well. The slags on the sole are detached as far as possible and drawn up to the bridge, where they are mixed with a little small coal.

At **6.30 pm**, the doors are closed, and, after a blast of fire lasting 15 minutes, the slags are worked by the paddle through doors one and four. Finally, some minutes before seven o'clock, the slags remixed and blackened by an excess of coal, are withdrawn through door four with the rabble and dropped to the ground. Any necessary repairs are made to the sole and at 7.00 pm the operation is finished.

Economic Data. - The charge of 21 cwts (2352 lb.) of concentrates makes ten pieces of 160 lb. each, or 1600 pounds of metallic lead. This is a yield of 68.027%, but by

assay gave 75.5%. Because the mineral is weighed wet at the smelt works, and the smelters use under-weight, a charge weighing 100 is really 77.5 (ie. 1822.8 lb.). The reverberatory at Stiperstones thus gives around 88 per cent of the lead contained. The loss through volatilisation is small, and most of the remaining 12% is found in the rich slags. This excludes the small quantity of leady products mingled with the smoke of the slag-hearths and collected in the flue and condenser.

The work at Stiperstones is repeated every week, in the same conditions, as follows. The first charge is introduced on Monday at 5.00 am and the operations continue until Friday at [476] 10 pm. This is a total of 113 hours divided thus:

Sixteen operations of 7 hours each	112
Tapping lead and repairs at the end	1
	113
Or then again	
Eight shifts of 12 hours	96
one shift of 17 hours	17
	113

The smelters must also remake the fire during the night from Sunday to Monday. One of them relights it at 7 o'clock in the evening and, starting at 2 o'clock in the morning, actively urges the fire so that the furnace will be red at 5 o'clock. This prolonged shut down is unnecessary, but it is local custom.

16.80 tons of concentrates produce 11.428 tons of lead. The smelters, paid on piece-work, receive 4s 6d per ton of lead obtained. This is 51s 5d for the labour, and 12s 10d per man. The work consumes 11 cwts of coal per operation, but the 'putting in fire' uses 0.63 tons, so that 9.43 tons of coal are burnt each week. Of the 11 cwts, half is burnt in the four first hours, and half for the period of reaction and reworking. The furnace is only really very hot during the penultimate hour. Thus the consumption of iron from the tools is very small, being around 2 cwts per month. The amount of lime used is almost insignificant.

The expenses can be summed up as follows: [477]

	£
Labour 19.66 days (days of 12 hours), at £0.13	2.57
Coal, 9.43 tons at £0.75	7.07
Tools, lime and various charges	0.60
Special expenses per week	10.24

Yielding as follows	1 ton of mineral treated	ton of lead obtained
	£	£
Labour 1.17 days at 0.13	0.15	1.75 days 0.22
Coal 0.561 tons at 0.75	0.42	0.825 tons 0.63
Various	0.04	0.05
Totals	0.61	0.90

In order to make further detailed criticism of the operation of the Welsh reverberatory, some observations on the work at Stiperstones are necessary to understand why the process at Snailbeach is superior. The details of the various stages and their duration are as follows:

2 hours spent steadily warming up the mineral. During the last hour of this operation, the furnace's temperature does not increase. The charge is so large that, in spite of the lining being at red heat, it is necessary to stoke the hearth to attain

the point where oxidisation can begin. Nevertheless, this takes place at the end of an hour and a half.

½ hour spent in cooling permits the atmospheric air both to oxidise and cool the materials.

1 hour after stoking, the fire returns to the temperature favourable to oxidisation and the reaction between the sulphur and the oxidised parts starts.

½ hour for the second cooling almost completes the formation of the proportion of oxides needed for the final reaction.

2 hours are taken for stoking up, stirring and for running the lead.

1 hour finally for reworking and for lifting the slags.

7 hours. Duration of the operation. [478]

The following criticisms can be made of this division of labour: (1) the stokings and coolings are both too long; (2) the furnace gets too hot; (3) first the agglomeration, then the start of the reaction are reached much too quickly; (4) the doors must then be left open for a long time to prevent fusion of the materials; (5) instead of maintaining the temperature around the point of oxidisation, therefore, it varies too much. On the other hand, in spite of its good layout, the lead should not be left in the well during any great part of the following operation. These inconveniences can be avoided by paying the smelters more, and they are mitigated at Stiperstones by the ease with which the minerals can be smelted.

Work at Snailbeach. - At Snailbeach the cycle begins with the furnace empty except for that part of the sole next to the well on the front side, where a small residue of the scum lifted from the pot is found. Then a charge of 24 cwts of galena is spread using a rabble. In the five doored furnace the thickness of the charge near the bridge is only 4 inches. After two hours, when the mineral is turned over and smoothed four times, a period of oxidisation begins. This lasts four hours and is made up of frequently repeated coolings and firings. Six hours after loading, the temperature is raised, and during this period of two hours, with regular vigorous stirrings, the major part of the lead runs towards the well. At the end, any slags remaining on the sole, or on the surface of the well, are pulled together at the bridge and reworked by adding a little lime. They are then withdrawn through the door in the centre of the rear and dropped on the workshop floor.

Tapping begins eight and a half hours from the start. The pot is skimmed. The skimmings are mixed with coal and put on [479] the sole in front of door one. They give their lead without perceptible work. The metal runs into the well and from there into the pot during casting. The sole is repaired and the operation finishes at the end of nine hours.

During roasting, the coolings and the firings only last around fifteen minutes each. This means that eight coolings and eight firings are made in four hours. Care is taken not to produce metallic lead. As soon as the temperature of reaction is attained, doors one and four are quickly opened, followed by two, three and five. As cooling progresses, the workman stirs steadily, alternatively towards the bridge and towards the flues. By these precautions, oxidisation occurs steadily, and the oxidised parts are well mixed in the mass of the materials. There is no agglomeration to prevent oxidisation and most of the metallic lead can be obtained during reaction. In the latter period, the fire is urged in a lively manner. Then, opening only the doors needed for work, the workman gathers the agglomerated materials and

detaches any which stick to the sole. The reworking leaves three hundredweights of dry, yellowish slag, which is around forty per cent lead by assay.

The moulds are suspended from a steelyard during casting, and the pieces all weigh exactly 140 lbs.

Economic Data. - From a charge of 24 cwts, 14 pieces, weighing 17.25 cwts, are obtained. This is a yield of 71.873%.

One week's work at Snailbeach: From Monday morning at 5 o'clock to Saturday morning at 11 o'clock, is equal to [480] 14 operations of 9 hours, giving a total of 126 hours, distributed as follows:-

9 shifts of 12 hours	108
1 shift of 18 hours	18
Total	126

16.80 tons of concentrates produce 12.075 tons of lead. The smelters receive £0.30 per ton of lead made, which is £3.62 for the team, or £0.905 per man. 12 cwts of coal are burnt for every 21 cwts of concentrates. Because the 'putting in fire' takes 8 cwts, however, an extra 0.5 cwts must be allowed for each 21 cwts of concentrates, making 10 tons of coal per week. When the smelters successfully economise on this figure, they receive £0.125 as a fixed bonus. This is attained so rarely, however, that it has not been included in the cost of labour.

The special expenses of the reverberatory are as follows:

		£
Labour	21 days at £0.17	3.62
Coal,	10 tons at £0.75	7.50
Tools, lime, sundry		0.64
Special expenses per week		11.76

Yielding as follows	1 ton of mineral treated	£	1 ton of lead obtained	£
Labour	1.25 days @ £0.17	0.21	1.82 days	0.30
Coal	0.595 tons @ £0.75	0.45	0.828 tons	0.62
Sundries		0.04		0.05
Totals		0.70		0.97

Work at the Castilian Furnace. - The slag is smelted in a three-tuyered Castilian furnace. It is charged in alternate beds of slag and coke all round the furnace. The work is very rapid and it is possible to treat 100 tons of slags in a week. In less than a month, therefore, all the slags produced by the four reverberatories in one year can be treated. The slags yield about [481] 32% and the consumption of coke is only 0.224 ton per ton of slag.

Opinion on the loss of lead. - The Snailbeach method aims to extract a very large proportion of the lead contained in the concentrates by the reverberatory. Neither time, nor fuel, nor labour are spared to achieve this. In order to appreciate more fully the results obtained, and especially the metal lost in various operations it will be of great interest to know, at least approximately, the content of the concentrates treated and of all the secondary products. As noted at the beginning of this account, the assays were flawed, and the verbal information on this subject was always exaggerated. Nevertheless, with care, an opinion can be reached which, though far from complete, is reliable.

The following example is based on the annual treatment of 3000 tons of concentrates. The average assay is 80% lead. The concentrates are weighed wet, but it is a good weight, so that a charge of 1000 lb. actually contains 810 lb. of lead.

The reverberatory furnace, for a yield of 71.873%, gives 2156.19 tons of lead and 375 tons of slags. The slags contain 180 tons of lead, which is 40% [sic = 48%] by assay, but only yield 32%, or 120 tons of lead, in the Castilian furnace. Of the 60 tons forming the difference between the content and the yield, 12 remain in the slags and 48 are volatilised. Of the latter, 25 tons of fume are recovered which yield 12 tons of lead. [482] This can be tabulated as follows:

Yield of 3,000 tons of concentrates containing 2430 tons of lead		TONS
Reverberatory furnace		2156.19
Castilian furnace		120.00
Fume		12.00
Total yield		2228.19
Total loss		141.81
		2430.00

Neglecting the lead produced by smelting the fumes, the loss is subdivided thus:

Lead volatilised by the reverberatory	93.81
Lead volatilised by the furnace with tuyeres, deduction made of lead extracted from fumes	36.00
Lead remaining in the slags	12.00
	141.81

The loss of lead is only 5.71% [sic = 5.84%].

This figure will appear very small and it might not always be reached at Snailbeach in spite of claims to do better. Nevertheless, with concentrates supposedly containing 81 per cent of lead, a furnace in good repair and experienced workers, this good result would be little improved. Perhaps it will be easier to believe when the advantages of the Welsh furnace have been shown, and a comparison made between it and the other reverberatories used on the continent.

Statistics. - The Mineral Statistics quoted below were published by Robert Hunt from 1853/4 to 1860.

Table of the production of concentrates and metallic lead

YEAR	SHROPSHIRE CONCENTRATES		LEAD		SNAILBEACH MINE CONCENTRATES		LEAD	
	Tons	Cwts	Tons	Cwts	Tons	Cwts	Tons	Cwts
1853	3508	0	2528	0	2817	0	2010	15
1854	3797	0	2729	10	2425	0	1753	0
1855	3310	16	2420	0	2591	4	1873	0
1856	4407	19	3228	15	2945	0	2120	0
1857	3349	15	2560	15	2266	12	1746	11
1858	3994	12	2993	7	2237	15	1840	13
1859	4062	14	3008	6	3024	15	2277	17
Total	26430	13	19468	13	18307	4	13621	16
YEARLY AVERAGE								
	3775	17	2781	5	2615	6	1945	19

In this table, the ton of concentrates is 21 cwts, whereas the ton of lead weighs 20 cwts.

The information on the production in concentrates and metallic lead [483] from Shropshire (Burt et al 1990). In spite of their well known accuracy, however, these data are only compiled from the owners' simple declaration and they are not authenticated, as in many other cases, by public sales. Also, the recent improvements at Snailbeach, and the resulting temporary irregularity in the production of secondary products, does not allow total confidence in the data for the yield of minerals in this works. Nevertheless, they give an interesting indication of the district's production and the relative importance of Snailbeach.

Comparison of annual averages, therefore, suggests that 74.407 tons of lead were extracted from each 100 tons of concentrates at Snailbeach, while all of Shropshire only averaged 73.66 tons of metal. The true yield, however, is 20/21sts of the above figures, which is 70.864 at Snailbeach, and 70.152 for the county. By applying the same correction to some [484] of the returns of this period we once more come across the irregularities mentioned above for Snailbeach. Thus 1854 gives us an apparent yield of 72.29, and a true yield of 68.84%.

In 1858, Mr Hunt notes that part of the lead was extracted from the preceding year's slags. In adding together the figures for 1857 and 1858 we have:

	tons cwts		tons cwts
Minerals	4504 6	Lead	3587 4
of which:			
Apparent yield	79.64%	True yield	75.847%

Finally, in 1859, we have:

Apparent yield	75.37%	True yield	71.78%
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In the latter year, the monthly production reached around 252 tons of mineral and 190 tons of lead.

Advantages of the Welsh Furnace and of the Snailbeach Method. - Having described the reverberatory and the smelting process in detail, it is appropriate to emphasize the advantages resulting from either the apparatus or the Pontesford method. To do this, the principles of treating galena by reaction must be considered.

Operations in the reverberatory are always divided into three periods: 1. Heating and oxidisation; 2. Reaction; 3. Reworking. These divisions are more theoretical than absolute, however, and in most smelting works the reaction occurs in several phases separated by as many roastings. The first period is, therefore, prolonged by merger with the second. Inversely, the reaction, which releases molten lead, often begins spontaneously during roasting. [485]

The nature of the mineral is critical and, given identical apparatus, can induce big variations in the progress and the results of the operation. For galena which is rich in lead and poor in silver, the operation is best done by clearly observing these divisions: (1) roasting in the right conditions after a steady heating, and at not too high a temperature; (2) reaction brought about by blasts of the fire and vigorous stirrings, giving most of the metallic lead quickly and leaving very little material to be reworked; (3) whenever possible, the latter is done quickly, to leave only a small quantity of slag to be sent to the slag-hearth.

Operation at Bleyberg-Carinthien.

Duration	Starting time	Lead obtained	Total
Hours	Length of time in hours	lb.	lb.
		The furnace is empty, the sole repaired; the temperature is above dark red; the hearth no longer produces flames.	
0			
	3		
3			
	4	154	
7			
	7	124-133	
14			
	1	44	
			322-31
15			
		220	220
	8		
23	23		
			542-51

Comparison of the cost of treatment with the value of the lost metal shows that, within limits, even for poor lead, there is profit in increasing costs if the loss in lead is also diminished. The latter is proportionally greater in the Castilian furnace, even with good condensation apparatus, hence the importance of only having a little slag. In the reverberatory, the loss by volatilisation is only considerable if the last two periods are prolonged, because they are done at temperatures high enough to release lead vapours. Thus it is necessary to shorten these periods by returning to the first.

All these conditions can be summed up as follows: "Obtain the largest possible proportion of metallic lead in the reverberatory furnace". This is accepted in most smelt works treating galena which is rich in lead and poor in silver; but, why is it done in such variable ways and why, with identical minerals, do certain [486] localities only attain it at great cost in manpower and fuel, whereas others, and Pontesford is one, succeed without exaggerated consumption? It can only be accounted for by the arrangement of the reverberatory, and, among the favourable details of the Welsh furnace, the best appears to be the large number of working openings.

Usefulness of the numerous openings of the Welsh furnace: The state of the reaction can be observed. As soon as a speck of the matter is oxidised, if the temperature can be raised to cherry red, and it is in contact with sulphur, the

[489] lead flows. Theoretically, the galena should be in fine particles. The oxidised particles and those remaining as sulphide should be in exact proportions. Finally the latter substances should be thoroughly intermixed. In these conditions a blast of fire for several minutes would give lead almost without stirring. In practice, however, this can only occur if the period of oxidisation has been very well managed, by (1) repeatedly poking and turning so as to mix and spread the oxidised parts over the surface of all the sulphide; (2) not reaching the temperature of reaction during this period, or recooling the materials as soon as they are seen to be at that point.

The first condition can always be achieved by the vigorous efforts of the workmen. The second demands that the furnace is suitably arranged. This is done with the doors of the Welsh furnace. The terms "firing" and "cooling" perfectly describe the use of these doors. Firing is done with the doors closed. When they are removed, the cold air (cooling) arrives level with the hot materials and they oxidise and cool at the same time. The stirring spreads the oxidising action and also renews the [487] surfaces exposed to the flames during the next firing. After a cooling, the length of which depends on the previous temperature and on the condition of the materials, the furnace is heated again to give oxidisation. It is erroneous to confuse the firing and cooling in a Welsh furnace with the blasts of fire and mixings for reaction that, in other methods, take up a great part of the operation. The words "firing" and "cooling" are valuable expressions.

At the end of the second period, that is the last cooling, lime is added to help thicken (dry) the more or less molten minerals that are going to be re-worked. Thanks to the layout of the furnaces at Snailbeach, and the well-paid and skilful workers who put in the necessary time, the minerals can be adequately prepared to allow the second period to be short and efficient. Thus most of lead is obtained and only a few materials are left to be re-worked. The latter are generally called oxo-sulphurous, being, as shown by M. Rivot (*Traite de Metallurgie*, Vol. II, p.37), a simple mixture of oxides and sulphides in a physical state that prevents reaction. These are produced when the temperature is higher than is necessary for the reaction, and, above all, by the pressure of tools during the hot mixings. If, therefore, the second period is quick, it is possible to avoid their abundant formation. At the same time the loss from the reverberatory through volatilisation is also diminished.

Summary Comparison with the process at Bleyberg de Carinthie. - Before examining the above result further, and giving absolute evidence of the benefit of the number of openings of the Welsh furnace, a concise comparison of the Pontesford method with that of Bleyberg (Carinthie) is necessary. Here, identical minerals are treated in a reverberatory [488] with no doors for the access of cold air, and oxidisation is only caused by flames from wood and the hot air which goes through the grate. This comparison is based on that given in M. Rivot's treatise (pages 298 to 316), which has a complete description with a drawing of a reverberatory.

Sulphide minerals poor in silver, with a lead content of 65 to 72% by assay, and supposedly 65 to 66% in the example given. Limey gangue, with a little blende, traces of quartz, clay, and iron pyrites. Fuel - exclusively wood. Extended furnace sole, sloping towards the working door, which opens below the slope; exterior collecting pot, in a recess in front

of the door. Principal dimensions:

	Length ft ins	by	Width/Height ft ins
Sole	11 5		
Hearth	4 5		1 6½
Space over the bridge	3 3		0 10
Slope	2 5½		1 7½

The following sums up the principal details of the operation, the length of the periods and the quantities of lead obtained at various times

In 23 hours, 913 lb. of concentrates are treated, giving 542 to 551 lb. of lead. This is a yield of 60%. The content is 65 by assay, but it is estimated to be really 69, the loss of lead has been 9 or 10 of metal per 100 parts of mineral, or 14 to 15% of lead content. Less than half of the lost lead remains in the slags. For each ton of concentrates, no less than 1.6 tons of wood are consumed, together with 2.417 operations (of 23 hours) of skilled work and 2.040 days of labour, being about 7 days' work. The wear on the tools is very great. The high cost at Bleyberg proves the truth of the statement, "*Obtain the largest possible proportion of metallic lead in the reverberatory furnace*". . [490] The operation drags out because the roasting cannot be well done. Although the gases are always oxidising, they are always hot because of the lack of access for cold air. It is, therefore, impossible to get speedy oxidisation without reaching the temperature of the reaction; hence, the first and the second periods overlap. This produces lots of matters which need re-working, plus a notable loss by volatilisation, and excessive consumption.

Having sought to show the advantages of numerous openings, it is necessary to give the dimensions and the relationships of the principal surfaces of a Stiperstones' furnace:

	Square Feet
Surface of the sole: around	78
Surface of the grate	11
Passage for flames above the bridge	6
Front flue	0.9
Rear flue	1
One working door	0.2
Six working doors	1.2
Hearth door	1

Approximate Relationships:

From the grate to the sole	= 1/7
From flues to the grate	= 1/6
From six doors, plus the hearth door, to the grate	= 1/5
From one door to the flues	= 1/10
From the flues to the seven doors	= 9/10

Particular measures taken against loss by volatilisation. - At Bleyberg 6 or 7% of the lead content is volatilised. If a parallel is drawn with the working conditions at Carinthie and at Pontesford, it is clear that too low a figure has not been used in evaluating the loss at the Welsh reverberatory at around 4%. The respective durations of the operations, particularly of the hot periods, justify such a difference. It is, however, also necessary to take account of the furnace layouts. At Bleyberg, the lead and the gases go over a steeply sloping sole, which is also very overheated and very long. The lead is removed from the causes of loss only on reaching the external pot.

At Pontesford, the axis of the grate is set back 10 inches towards the back side. The flames are carried above the [491] concentrates, away from the front side where the lead flows. The vault is raised about a yard above the grate, and the principal gassy current is away from the materials. The lead reaches the well, in the form of a deep hole, without a long journey. Finally, the door in the tapping plate allows a trickle of cold air onto the surface of the metallic bath.

Manpower; Production. When smelting identical concentrates in different furnaces, and with workmen of diverse energies, the quantity of material passed in a given time depends on two variables: (1) the nature of the apparatus, and (2) the smelters' skills. Denoting by c the weight of a charge in lb., by d the duration in hours of the operation, by a the weight of concentrates passed in twelve hours, that is to say the measure of the activity of the furnace

$$a = 12 \frac{c}{d}$$

which gives:

	Value of A	Wt treated per man in 12 hours
Stiperstones	4028	2014
Snailbeach	3583	1792
Bleyberg	476	238

The German workman treats eight times less concentrates than a Welsh smelter in the same time, but the latter's productivity, although probably superior, cannot be in the proportion of eight to one. This demonstrates the inferiority of the furnace at Bleyberg.

In spite of its importance, the comparison of these two methods will be taken no further, so as not to deviate from the original plan, to establish a parallel between the Welsh and the Breton furnaces. The latter, used in France, has three working doors in the front face, and enjoys in consequence one advantageous feature of the English reverberatory. [492]

Economic Advantage of moderate activity. - In allowing 300 working days per year it suffices to multiply the daily activity by 600 to get the weight of concentrates which can be treated by a furnace in a year. Thus we have annual activity for:

Stiperstones	1096 tons
Snailbeach	975 tons

In the big Flintshire smelting works, where production is forced, Welsh furnaces are charged with 1 ton every 6 hours, giving an annual output of 1280 tons. This saves labour and fuel but, when done too quickly, the operation is not as efficient in the first period as that at Snailbeach. The furnace gives less metallic lead and more slags, and the loss amounts to 10% of lead content. Here, as everywhere else, there is an advantage in not forcing production, and experience shows that economic superiority remains with moderate activity. This is well understood at Snailbeach.

Conclusion. - This discussion is far from concluding that Welsh furnaces ought always to be preferred for smelting galena. It is important to recall the circumstances in which they are prepared and the conditions in which they succeed. For smelting very argentiferous lead ores, the French furnace has many good points. A high yield should not, however, be expected from slimes and, in this important case, the

reverberatory gives way to the slag hearth. For galena which is poor in silver and rich in lead, particularly with a slightly quartzitic gangue, the Welsh furnace will assuredly give good results. In places which only have wood to burn, a very small modification to the Welsh furnace will make this fuel very easy to use.

When other methods are established, local habits and the workmen's traditions should be seriously considered. There must be a balance between the familiar process and the adoption of a reverberatory which, if well maintained, consumes less fuel and manpower, and permits a high output and a small loss of metal. These advantages are all independent of the country where it is used.

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Where units were given in metric and imperial units, the former have been omitted for clarity. The conversion factors used were:-

1 pound (£)	=	25 francs
1 foot	=	304.8 mm
1 ton	=	1016 kgms
1 cwt	=	50.8 kgms
1 lb	=	453.59237 gms

NCMRS Northern Cavern and Mine Research Society
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