[*Note: This is an important essay by one of the leading chemists and industrialists of his day, Hugh Lee Pattinson, nearly four decades on from Mulcaster's paper on the subject, a transcript of which is also available in 'Dukesfield Documents'. Pattinson's paper was given as a lecture in Newcastle in October 1831, presumably at the Literary and Philosophy Society's premises which the Natural History Society still shared at the time. Pattison was employed by Beaumont in the following spring. It was at WB Lead's Blaydon refinery that Pattinson developed and brought into full scale production the Pattinson process for desilvering lead. A number of letters in 'Dukesfield Documents' refer to the development and commercial impact of Pattinson's new process.*

This paper was published in the Transactions of the Natural History Society of Northumberland, Durham, and Newcastle Upon Tyne, *(Vol II, Part 1, 1832, pp. 152-77). The original pagination is retained in this transcript as there are page number cross-references in the text refer to the printed pages. However there are a couple of references late in the text to a different pagination - presumably that of Pattison's original manuscript. Images of the plates are included approximately where they are located in the original document.*]

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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 Mr. H. L. PATTINSON.

READ, Oct. 17, 1831

The total quantity of Lead ore, produced in the northern mining districts annually, is about 70,000 bings, of 8cwt. avoirdupois each, or 28,000 avoirdupois tons. Nearly the whole of this quantity is Galena, which, on reduction, yields Lead containing from two to twenty-four ounces of silver per fodder of 2lcwt. or 2352 lbs, The other varieties of Lead ore which occur, are Carbonate and Phosphate of Lead, but they are always found in situations near the surface, and in comparatively small quantities.

The Galena is principally cubical, but some veins produce steel-grained, compact, and antimoniated Galena, Cubical and steel-grained Galena are often variously blended together, and every variety is, in most cases, intimately mixed with Spar and Vein Stone, or *Rider*, as it is provincially called, when brought out of the mines. Each vein contains generally a peculiar, and frequently a distinguishing, species of Spar and Rider. The Spars are Fluate and Carbonate of Lime, Pearl Spar, Sulphate of Barytes, Baryto-calcite, and among them may be included Blende and Iron Pyrites. The Riders differ nearly as much. In some veins they consist of fragments of the adjacent strata, apparently cemented together by interposed spar or ore; and in others, the Rider is a hard and (as the miners term it) burnt, or soft and friable stone, strongly impregnated with iron.

However these substances are intermingled with the ore, they ought to be removed as much as possible in the process of washing, for, except this is done entirely, the residual portion affects the ore, and gives it a peculiar character in the subsequent operation of smelting. The

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ore itself may be cubical, steel-grained, or antimoniated, or a mixture of two or the whole of these in various proportions; and, besides heterogeneous impurities, it frequently contains a greater or less proportion of iron, as an ingredient in its composition; these circumstances render its quality so various, that, when laid down at the smelting-house, it is very difficult to pronounce two parcels from different veins, or from the same vein in different strata, exactly alike. It consequently happens that one variety of ore is sometimes found, without any very obvious cause, to be much more refractory in the fire and less easily reducible than another, and among a number of parcels this difference is occasionally very considerable.

At nearly all the smelting-houses in this district, the practice prevails of smelting the ore from each vein, where the quantity is considerable, by itself, although most smelters admit that a mixture of different kinds of ore has frequently a very beneficial effect in promoting the reduction of each. In smelting ore from the same vein, it is the practice to treat the different portions, into which it is divided in the washing process, separate from each other; that is, the portions called, technically, *sieve ore* and *smiddam*, are smelted separate from the *slime ore*, lest the latter, which is in very small particles, should be driven away by the draught and blast, by which the former is roasted and reduced into Lead.

The process of smelting may be most conveniently described under four heads, viz.:—

Roasting of the Ore.
Smelting in the Ore Hearth.
Smelling in the Slag Hearth.
Smelting of Hearth Ends and Smelters' Fume.

ROASTING OF THE ORE.

The process of roasting is nothing more than heating the ore to a proper temperature in a reverberatory furnace, during which it undergoes a change, by the partial expulsion or acidification of the sulphur it contains, which renders it afterwards more easily reducible.

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At Plate I., Fig. 1, is a perspective view of the Roasting Furnace.

Its bed or bottom, inside, upon which the charge of ore is spread to receive the action of the fire, is usually about six feet square, quite flat and formed of fire bricks, set upright upon their ends, and in contact. The fire-place is 3 feet 4 inches long, by 1 foot 4 inches broad, which, with the roof and sides, is formed of fire-bricks, enclosed by solid masonry, and strongly bound together by iron bars. The *tease-hole*, through which coals are supplied to the fire, is not represented in the figure, being, in this case, on the opposite side of the furnace. Three doors are usually formed on each side when convenience admits of it, through which, and an end door *b*, the ore can be turned and raked backwards and forwards; the middle door *a* in front, is made larger than the others, for the purpose of more easily introducing and withdrawing the charge of ore. Immediately below this door is a trough *c*, 18 inches deep, 2 feet wide, and 4 feet long, filled with water, into which the ore is suffered to fall red hot when raked out of the furnace; and directly above this door is a wide-mouthed sheet-iron tube, *d*, communicating with the chimney, through which the unwholesome effluvia of the ore is conducted away, without injuring the workmen, during the operation of withdrawing the charge. A moveable iron screen *e* is at the same time placed over the trough, against the side of the furnace, within which the ore falls, effectually preventing the escape of noxious vapour.

Although the construction and size of the roasting furnaces, at most of the smelting mills in this district, are nearly alike, yet considerable difference is found in the rate and mode of working them. At some places, two men manage a furnace, into which one bing of ore is put at a charge, and the furnace is charged and drawn five times in eight hours. Each pair of men work 8 eight-hours-shifts per week, and are relieved at the end of each shift by another couple, who work with them alternately eight hours on and eight off; in this manner roasting eighty bings of ore per week in one furnace,

At other places three charges, making together four bings of ore, are worked in eight hours by one man; and three men, working each six shifts per week, roast in one furnace seventy-two bings of ore; and,

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at other mills, the quantity roasted in eight hours by one man is three bings, at three charges, and thus three men working each 6 eight hours' shifts, roast but fifty-four bings of ore per week.

The manner of conducting the process of roasting is the same in all cases. The proper charge of ore is spread evenly over the bed of the furnace to the depth of two or three inches, and the fire is at first pushed moderately, during which the ore is frequently turned and stirred, in order that the whole may be uniformly heated, but care is to be taken that no part is prematurely fused. If the fire is judiciously managed, the charge gradually attains a dull red heat—a greater heat is then given and the ore vigorously stirred, when, in a little time, it begins to feel soft and adhere slightly to the tool, in which state it is withdrawn from the furnace. The roasting process is conducted in the best manner, when great care is taken to apply the heat very gently at first, to keep, by constant stirring and change of place, the temperature of the whole charge as uniform as possible, and to withdraw it at the proper time from the furnace.

After the furnace is properly heated and working, two Winchester bushels, or about 1½cwt. avoirdupois, of free coal, are required to roast one bing of ore; but some varieties of ore can be more easily reduced into the pasty state, mentioned above, than others; that is, they fuse at a lower degree of heat, and this in proportion to their purity.

The least fusible ores are generally the most difficult to smelt, and undergo the greatest loss in that operation. It is well known that a considerably greater produce of Lead can be obtained from the same ore after being properly roasted, than before. This difference is of course variable, but in some instances, 20 bings of roasted ore have yielded 8 or 9 cwt. more Lead than 20 bings of the same ore smelted in its raw state,

At nearly all smelting mills long horizontal chimneys or flues are constructed (generally on the slope of an adjacent hill if practicable), which the smoke from the various processes of smelting is made to traverse before it escapes into the atmosphere. As the heat of the furnace in roasting, if incautiously applied, may volatilize a portion of the ore, and the draught has a tendency to draw along with it some of the smaller

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particles, the fume from the roasting furnace is conveyed into this flue, where the heavy metallic portion is deposited.

SMELTING IN THE ORE HEARTH.

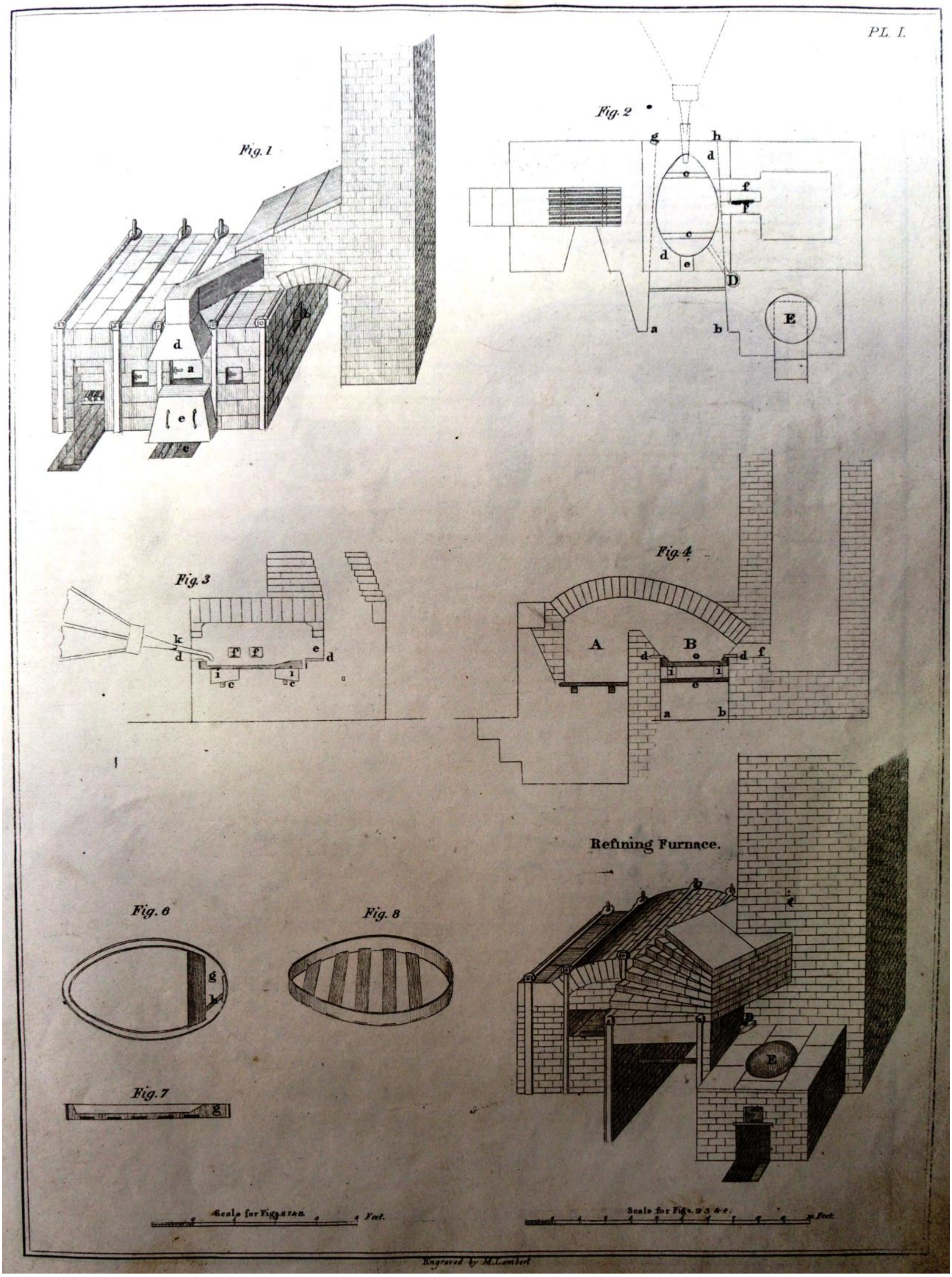
The furnace in which the roasted ore is reduced into Lead is called an Ore Hearth. Its construction is almost exactly the same in all smelting houses in the north of England, and seems to have undergone but little alteration from a very remote period. It may be briefly described as a square furnace, close on three of its sides, and open towards the bottom of the fourth. Immediately in front of this opening is placed a sloping cast-iron plate, the upper edge of which is four and a half inches above the bottom of the furnace, forming a reservoir of that depth, in which the reduced lead accumulates, and out of which it flows, through a channel in the plate, into a pot below, after the reservoir becomes full.

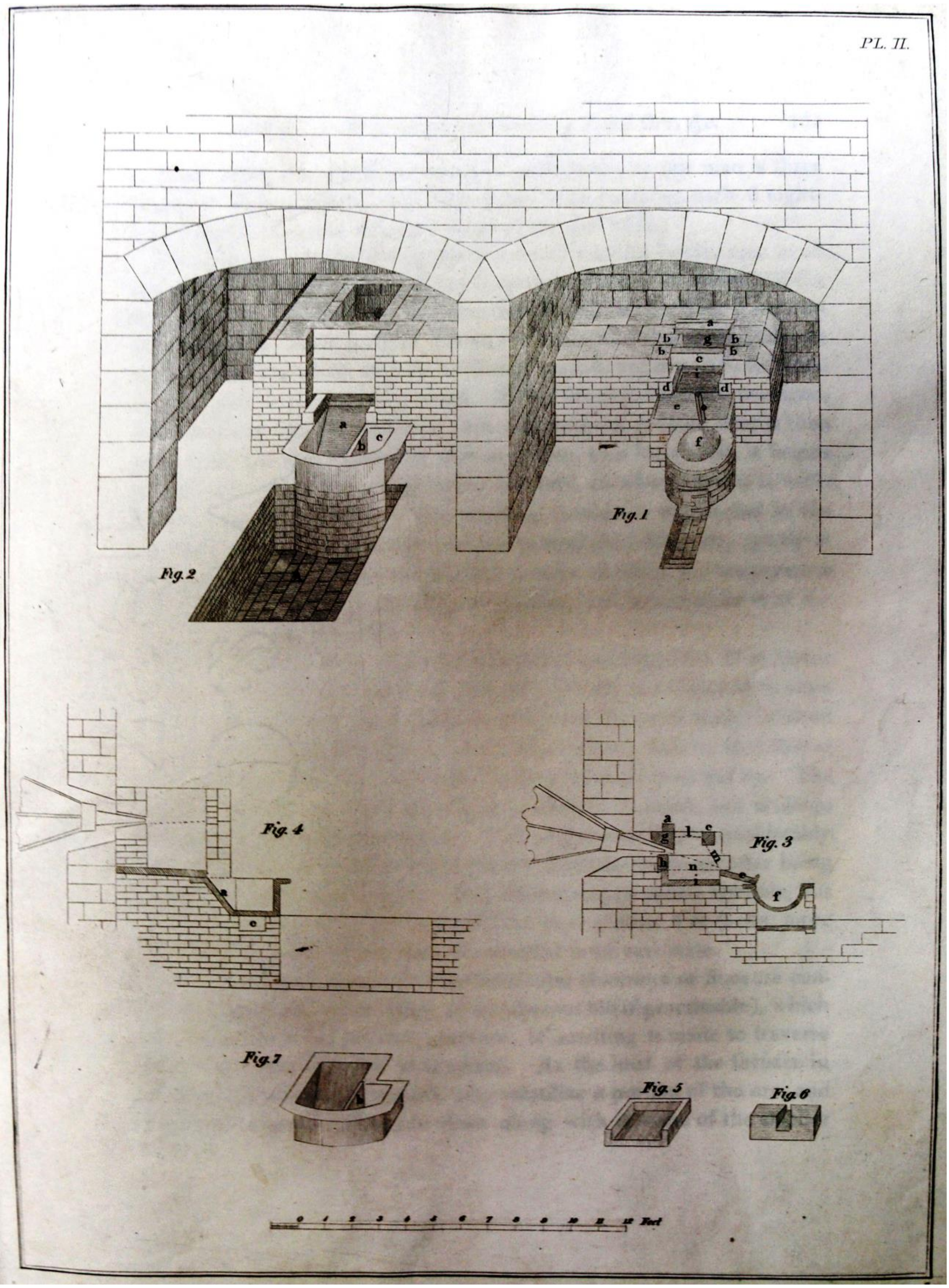
To construct an ore hearth, twelve pieces of cast iron are necessary, (exclusive of the melting pot, *f* , Plate II., Figs. 1 and 3), viz.;—

A hearth bottom, Fig. 5 and *i*, Figs. I and 3, 22 inches square, inside measure, the bottom 3 inches thick, and the sides 3 inches thick and 4½ deep. In building an ore hearth, it is usual to place the hearth bottom upon a layer of sand a few inches deep above the brick or stone bed, A workstone *e*, Figs. 1 and 3. This is a plate 3 feet long, by 1½ broad, and 2½ inches thick, having a raised border an inch high on its two ends and front side, with a channel *o*, Figs. 1 and 3, 2 inches wide, and 1 deep, running diagonally across it. It is placed at a slope of three or four inches from its upper to its under edge.

Two bearers *d*, *d*, Fig. 1, being square prisms of cast iron of 6 inches a side, by 26 or 28 inches in length. There is an advantage in making these long, as they can be turned when worn at one end, and, as they project over and rest upon the workstone, they tend to keep it firm in its place.

A backstone *h*, Fig. 3, upon which the bellows-pipe rests, as in the figure. It is a parallelopiped 28 inches long, 6½ in height, and 5 inches broad.


PL. I.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Refining Furnace.
Fig. 6
Fig. 8
Fig. 7
Engraved by M. Lambert



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A pipestone *g*, Figs. 1 and 3, being a prism 10 inches square, and 28 inches long, with an opening to admit the bellows-pipe, as in Fig. 6, where it is shewn separate, and lying upon what is its upper part when properly placed in the hearth.

An upper backstone *a*, Figs. 1 and 3, a parallelopiped 28 inches long, 4 inches deep, and 5 inches wide, which completes the back part of the hearth.

A forestone *c*, Figs. 1 and 3, 26 inches long, 6½ inches deep, and 5 inches broad, and

Four keystones being exact 10-inch cubes of iron *b, b, b, b,* Fig 1. The two cubes nearest the back of the hearth, are placed upon the bearers *d, d*, so as to correspond with them on the inside, and are thus 22 inches apart; but the two cubes in front are made to lie against the ends of the forestone, and are consequently 26 inches distant from each other.

The forestone itself is moveable to a certain extent. It can be placed at the distance of 10 inches from the backstone, by being put in contact with the two keys nearest the back, and it can be lowered down so as to rest upon the two bearers *d, d,* if necessary, and in that case would be only 6 inches above the upper edge of the workstone. In Figs. 1 and 3, it is represented 12 inches from the back of the hearth, and supported by a fire brick at each end, placed upon the bearers; its under edge being thus 11 or 12 inches above the workstone, which is its usual position. The various castings are secured in their places by brick-work, and the top of the hearth is finished level with masonry, to receive any particles of ore, called *hearth ends*, that may be expelled by the blast. Each hearth is placed under a chimney supported by an arch (as shewn in Figure 1), and communicating with the horizontal flues already referred to, by passages through which the fume and smoke are conveyed away.

In Figure 3, the pipe of the bellows is represented to enter the hearth 6½ inches above the level of the upper edge of the workstone, which regulates the surface of the lead when the hearth is in a working state, but it more frequently happens, that by the bearers and hearth-bottom

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sinking down a little behind, the nozzle of the bellows is not more than 3 or 4 inches above the surface of the Lead. The blast is always directed downward into the hearth, so as to cut the upper edge of the workstone, as shewn by the dotted line leading from the bellows-pipe in Fig. 3, by which means it is more thoroughly distributed through the contents of the hearth. In Figure 3, there is a space shewn between the workstone and hearth-bottom. This is generally filled up with fire clay, or a mixture of slime ore and bone ashes, properly moistened with water; but a plan sometimes adopted, is to have the hearth-bottom and workstone cast together, which renders stopping unnecessary. Another modification of the hearth, adopted by some intelligent smelters, is making the bottom, instead of 4½ inches, 10 or 12 inches deep, by this means increasing the quantity of lead retained in the hearth, and proportionally lessening its tendency to get too hot, during the process of smelting.

In proceeding to smelt by means of an ore hearth, two workmen are required to be in attendance from the beginning to the end of each smelting shift, the duration of which is from 12 to 15 hours. The first step in commencing a smelting shift, is to fill up the hearth-bottom and space bellow the workstone with *peats*, placing one already kindled before the nozzle of the bellows. The powerful blast very soon sets the whole in a blaze, and by the addition of small quantities of coal at intervals, a body of fire is obtained filling the hearth. Roasted ore is now put upon the surface of the fire, between the forestone and pipestone at *l*, Fig. 3, which immediately becomes heated red hot and reduced; the lead from it sinking down and collecting in the hearth-bottom. Other portions of ore of 10 or 121bs. each, are introduced from time to time, and the contents of the hearth are stirred and kept open, being occasionally drawn out and examined upon the workstone, until the hearth-bottom becomes full of lead to the dotted line *n*, Fig. 3. The hearth may now be considered in its regular working state, having a mass of heated fuel, mixed with partly fused and semi-reduced ore, called *Brouse*, floating upon a stratum of melted lead. The smelting shift is then regularly proceeded with by the two workmen, as follows :—The fire being made up into the shape represented by the dotted line at *l*,

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and *m*, Fig. 3, with the flame and blast principally issuing between the forestone and workstone, as at *m*, a stratum of ore is spread upon the horizontal surface of the *brouse*, at *l*, and the whole suffered to remain exposed to the blast for the space of about five minutes. At the end of that time, one man plunges a poker into the fluid lead, in the hearth bottom below the *brouse*, and raises the whole up, at different places, so as to loosen and open the *brouse*, and in doing so, to pull a part of it forwards upon the workstone, allowing the recently added ore to sink down into the body of the hearth. The poker is now exchanged for a shovel, with a head six inches square, with which the *brouse* is examined upon the workstone, and any lumps that may have been too much fused, broken to pieces; those which are so far agglutinated by the heat, as to be quite hard, and further known by their brightness, being picked out, and thrown aside, to be afterwards smelted in the slag hearth. They are called Grey Slags. A little slaked lime, in powder, is then spread upon the *brouse*, which has been drawn forward upon the workstone, if it exhibit a pasty appearance; and a portion of coal is added to the hearth, if necessary, which the workman knows by experience. In the mean time, his fellow workman, or *shoulder-fellow,* clears the opening, through which the blast passes into the hearth, with a shovel, and places a peat immediately above it, which he holds in its proper situation, until it is fixed, by the return of all the *brouse*, from the workstone into the hearth. The fire is made up again into the shape before described, a stratum of fresh ore spread upon the part *l*, and the operation of stirring, breaking the lumps upon the workstone, and picking out the hard slags repeated, after the expiration of a few minutes, exactly in the same manner. At every stirring a fresh peat is put above the nozzle of the bellows, which divides the blast, and causes it to be distributed all over the hearth; and as it burns away into light ashes, an opening is left for the blast to issue freely into the body of the *brouse.* The soft and porous nature of dried peat moss, renders it very suitable for this purpose; but, in some instances, where a deficiency of peats has occurred, blocks of wood of the same size have been used with little disadvantage. As the smelting proceeds, the reduced lead,

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filtering down through all parts of the *brouse* into the hearth bottom, flows through the channel *o*, Fig, 1. into the pot *f*, out of which it is laded into a proper mould, and formed into pigs.

The principal particulars to be attended to in managing an ore hearth properly, during the smelting shift, are these: *First*,—It is very important to employ a proper blast, which should be carefully regulated, so as to be neither too weak, nor too powerful. Too weak a blast would not excite the requisite heat to reduce the ore, and one too powerful, has the effect of fusing the contents of the hearth into slags. In this particular no certain rules can be given; for the same blast is not suitable for every variety of ore. Soft free-grained Galena, of great specific gravity, being very fusible, and easily reduced, requires a moderate blast; while the harder and lighter varieties, many of which contain more or less iron, and are often found rich in silver, require a blast considerably stronger. In all cases, it is most essential, that the blast should be no more than sufficient to reduce the ore, after every other necessary precaution is taken in working the hearth. *Second*.—The blast should be as much divided as possible, and made to pass through every part of the *brouse*. *Third.*—The hearth should be vigorously stirred, at due intervals, and part of its contents exposed upon the workstone; when the partially fused lumps should be well broken to pieces, and those which are further vitrified, so as to form slags, carefully picked out. This breaking to pieces, and exposure of the hottest part of the *brouse* upon the workstone, has a most beneficial effect in promoting its reduction into lead; for the atmospherical air immediately acts upon it, and, in that heated state, the sulphur is readily consumed, or converted into sulphureous acid, leaving the lead in its metallic state; hence it is, that the reduced lead always flows most abundantly out of the hearth, immediately after the return of the *brouse*, which has been spread out and exposed to the atmosphere. *Fourth*, the quantity of lime used, should be no more than is just necessary to thicken the *brouse* sufficiently; as it does not, in the least, contribute to reduce the ore by any chemical effect: its use is merely to render the *brouse* less pasty, if from the heat being too great, or from the nature of the ore, it has a

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disposition to become very soft. *Fifth*.-—Coal should be also supplied judiciously; too much unnecessarily increasing the bulk of the *brouse,* and causing the hearth to get too full.

When the ore is of a description to smelt readily, and the hearth is well managed in every particular, it works with but a small quantity of *brouse*, which feels dry when stirred, and is easily kept open and permeable to the blast. The reduction proceeds rapidly with a moderate degree of heat, and the slags produced are inconsiderable; but, if in this state, the stirring of the *brouse* and exposure upon the workstone are discontinued, or practised at longer intervals, the hearth quickly gets too hot, and immediately begins to agglutinate together; rendering evident the necessity of these operations, to the successful management of the process. It is not difficult to understand why these effects take place, when it is considered, that in smelting by means of the ore hearth, it is the oxygen of the blast and the atmosphere which principally accomplishes the reduction; and the point to be chiefly attended to, consists in exposing the ore to its action, at the proper temperature, and under the most favourable circumstances. The importance of having the ore free from impurities, is also evident; for all the stony or earthy matter it contains impedes the smelting process, and increases the quantity of slags. A very slight difference of composition of perfectly dressed ore may readily be understood to affect its reducibility; and hence it is, that ore from different veins, or the same vein in different strata, as before observed, is frequently found to work very differently when smelted singly in the hearth. It happens, therefore, that with the best workmen, some varieties of ore require more coal and lime, and a greater degree of heat, than others; and it is for this reason that the forestone *c*, Figs. 1 and 3, is made moveable, so as either to answer for ore which works with a large or a small quantity of *brouse.*

It has been stated that the duration of a smelting shift is from 12 to 15 hours, at the end of which time, with every precaution, the hearth is apt to become too hot, and it is necessary to stop for some time, in order that it may cool. At mills where the smelting shift is 12 hours,

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the hearths usually go on 12 hours, and are suspended 5; four and a half or five bings of ore (36 to 40 cwt.) are smelted during a shift, and the two men, who manage the hearth, each work four shifts per week; terminating their week's work at three o'clock on Wednesday afternoon. They are succeeded by two other workmen, who also work four 12-hours shifts; the last of which they finish at four o'clock on Saturday. In these eight shifts, from 36 to 40 bings of ore are smelted, which, when of good quality, produce from 9 to 10 fodders of lead. At other mills where the shift is fourteen or fifteen hours, the furnace is kindled at four o'clock in the morning, and worked until six or seven in the evening each day, six days in the week; during this shift, 5 or 5½ bings of ore are smelted, and two men at one hearth, in the early part of each week, work three such shifts, producing about 4 fodders of lead—two other men work each three shifts in the latter part of the week, making the total quantity smelted per week, in one hearth, from 30 to 33 bings. Almost at every smelting mill a different mode of working, in point of time and quantity, is pursued; in some cases the quantity of ore smelted in one hearth, in a week, by four men, is 40 bings; but a fair rate of working is from 30 to 35 bings per week.

The quantity of coal required to smelt a fodder of lead, as has been already stated, varies with the quality of the ore. When this latter is of moderate goodness, 8 Winchester bushels, or 6 cwt. avoirdupois, are sufficient to smelt 18 or 20 bings; but, when the ore is refractory, the quantity required is very considerably greater. In general, from 8 to 12 Winchester bushels of coal, or from 6 to 9 cwt., are consumed during four smelting shifts of twelve hours each; and, as the quantity of lead made during this time is from 4½ to 5 fodders, the coal consumed is, after the rate of, from 1½ to 2 cwt. per fodder. The quantity of peats used in the same time is about four small cart loads, being something less than a cart load per fodder of lead. The lime expended is about 12 Winchester bushels, or something below 3 bushels per fodder of lead.

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SMELTING IN THE SLAG HEARTH.

The slags picked out of the *brouse* during the process of ore hearth smelting are subjected to another operation, in. what is called a slag hearth. A view of this hearth, in perspective and section, is shewn Plate II. Figs. 2 and 3. It is simply a square furnace, open towards the bottom of the front side. Its dimensions are various, but a common size is 26 inches from back to front, 22 inches broad, and 36 inches deep, inside measure. The blast enters through the back wall, about 12 or 14 inches from the top, and below this, as the heat is inconsiderable, the sides of the furnace are usually made of cast iron (at working smelting-houses old bearers, or other worn parts of ore hearths, are economically used), but above the blast, where the heat is intense, the sides are formed of the most refractory firestone, or firebrick. A cast-iron plate, 2 inches thick, placed at a slight slope outwards, forms the bottom of the hearth. A cast-iron pan, Plate II. Fig. 7, of a peculiar form, is placed opposite to the opening in front, Plate II. Fig. 2, one lip of which is made to project inwards towards the furnace, and to extend a little below the sloping bottom of the hearth, as shewn in the section *a*, Plate II. Fig. 4. This pan is divided with two compartments, by an iron partition, *b*, reaching nearly to its bottom, and is kept hot by a small fire underneath, which is not represented in the figures, but a section of the flue is shewn at *c*, Plate II, Fig. 4. Below the front of this pan, a square pit, 6 or 8 feet long, and 4 or 6 feet broad and deep, is dug; shewn at *A*, Plate II. Fig 2. Pipes to convey water are laid to this pit, by which it can be kept constantly filled to within a few inches of the top, when the hearth is at work.

The only fuel used at the slag hearth is coke, and the method of working it is as follows :—

The larger division of the iron pan, and the whole space of the hearth below the orifice through which the blast enters, is filled with cinders of a moderate size, generally obtained from below the grate of an adjacent reverberatory furnace. Upon the top of these cinders, and opposite to the nozzle of the bellows, a kindled peat is placed, and the

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whole of the upper part of the hearth is filled with peat and coal, which is continually supplied, with the addition of coke as the fire gets hotter, until an intense heat is produced, and a body of fuel obtained, filling the upper part of the hearth. Some of the grey slags from the smelting hearth, unbroken, as picked out of the *brouse*, are now thrown upon the top, or rather round the edges of the fire, which fuses them rapidly into a liquid glass, and any lead they contain is set at liberty; the blast at the same time tending to reduce any particles of ore which may have escaped the action of the ore hearth. The lead and the melted glass both sink down through the porous mass of cinders placed in the lower part of the hearth; the lead descending more rapidly, both on account of its greater tenuity and superior specific gravity, very soon collects be!ow the cinders, in the metal pan placed to receive it, and filtering through under the division, *b*, is obtained without much impurity in the part *c*, Plate II. Fig. 2, out of which it is cast into pigs. The thick fluid glass, called black slag, after reaching the cast-iron bottom of the furnace, having cooled and thickened a little, does not sink further, but is made to issue through a small taphole, and flow over the cinders placed in the pan, running into the pit filled with water in a continued stream. By falling while hot into cold water, the black slag is granulated, and, as small particles of lead may be carried over with it, through inattention on the part of the workman, or otherwise, the granulated slags are carefully washed at most smelting mills before being thrown away. According to Dr. THOMPSON (*Ann. Phil.* vol. iv.) these slags consist of silex, lime, and oxide of iron, with some alumine, oxide of antimony, and oxide of lead. Their composition must, however, be various, depending upon the nature of the ore from which they are produced; in all cases they are formed from the earthy matter contained in the ore and coal, which the metallic oxides convert into a glass.

In working a slag hearth, the workman's attention is principally required to supply grey slag and fuel as it is melted down and consumed, to keep the nozzle of the bellows clear, and to guard against the metallic lead running along with the slag, into the pit of water.

Two men are generally employed to work a slag hearth, but, at some

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mills, a man and a boy are deemed sufficient; the attention of one is wholly given to the fire, while the other supplies coke and grey slag. The length of a shift is 14 or 16 hours, during which, the quantity of lead made varies from 10 to 21 cwt., according to the nature of the slags. Twenty to twenty four bushels of coke are required to produce one fodder of lead. The quantity of slag lead made in smelting, as may be conceived, is considerably greater in poor and refractory than in rich and free-running ores, but, it may be stated generally at one-thirteenth of the lead yielded at the smelting hearth, so that it is usual to reckon, in large transactions, 13 twelve-stone pigs of common lead, and 1 of slag lead, to the fodder.

HEARTH ENDS AND SMELTER'S FUME.

In the operation of smelting, as already described, it happens that particles of unreduced and semi-reduced ore are continually expelled from the hearth, partly by the force of the blast, but principally by the decriptation of the ore on the application of heat. This ore is mixed with a portion of the fuel and lime made use of in smelting, all of which are deposited upon the top of the smelting hearth, as mentioned in page 157, and are called hearth-ends. It is customary to remove the hearth-ends from time to time, and deposit them in a convenient place until the end of the year, or some shorter period, when they are washed to get rid of the earthy matter they may contain, and the metallic portion is roasted at a strong heat, until it begins to soften and cohere into lumps, and afterwards smelted in the ore hearth, exactly in the same way as ore undergoing that operation, for the first time, already described.

It is difficult to state what quantity of hearth-ends are produced by the smelting of a given quantity of ore, but, in one instance, the hearth-ends produced in smelting 9751 bings, on being roasted and reduced in the ore hearth, yielded, of common lead 3l5cwt, and the grey slags separated in this process gave, by treatment in the slag hearth, 47cwt. of slag lead; making the total quantity of lead 362cwt., which is at the rate of 3cwt. 2qrs. 231bs. from the smelting of 100 bings of ore.

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The long horizontal chimnies, or flues, mentioned at page 153, into which the smoke and metallic vapours, from the roasting furnace, ore hearth, and slag hearth, are conveyed, contain, at the end of some time, a copious deposit called smelter's fume. This fume consists of Sulphuret, and, probably, also of Sulphate of Lead, which have been volatilized in the different processes, mixed, like hearth-ends, with a quantity of earthy matter, from the lime and coal used in smelting. It is generally suffered to accumulate, either in or out of the chimnies, until the end of the year, when it is washed, to remove the earthy matter, and the heavy residue is roasted until it coheres into lumps, and smelted in the slag health exactly in the same way as grey slags, described at page 163. The quantity of slag lead produced from the smelter's fume, deposited in smelting 9751 bings of ore, was 500cwt.; being at the rate of 5cwt. 0qrs. 14lbs. of lead per 100 bings of ore.

The proportions stated above are by no means to be considered invariable, for the quantity of lead produced at a smelting establishment, from time to time, by the hearth-ends and smelter's fume, from a given quantity of ore, cannot probably be very uniform, and must depend a good deal upon the care and skill exercised in conducting the various operations. If no more than the due degree of heat is used in each process, the deposits under consideration are likely to be less than if a strong heat is injudiciously applied.

CORRESPONDENCE OF PRODUCE WITH ASSAY.

As the smelting process is liable to great mismanagement, through inexperience or inattention on the part of the agents or workmen, it is a matter of some consequence to know how far the quantity of lead obtained by smelting in the large way corresponds with the absolute quantity contained in the ore operated upon, and, for this purpose, it is a common practice to have the ore accurately sampled and assayed prior to smelting. The purest Galena is a compound of

1 atom Lead	13	86.66

1 atom Sulphur,	2	13.33
	15	99 99

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But this quantity of Lead can never be obtained from it by assaying in the dry way. With great care, as far as 82 or 83 per cent, of Lead maybe obtained from a very pure piece of cubical Galena, by treatment with borax and tartar, in the hands of an experienced assayer. In the large way Lead ore is seldom dressed quite pure, and does not often yield more Lead to the assay than 77 or 78 per cent. Ore, assayed to yield 77 per cent of Lead, contains, besides, probably, 4 or 5 per cent., which is oxydized, or volatilized, before reduction in the process of assaying. In estimating the value of a sample, reference is only made to its absolute produce by assay, no regard being paid to the probable quantity of lead it may contain, beyond the assay produce.

It is never expected, in the large way, to obtain the quantity of metal indicated by the assay, but some ores in smelting approach much nearer to it than others. A customary allowance is to deduct 5 parts from the assay produce of 100 parts of ore, which is equivalent to making an allowance of 1 cwt, of Lead for every ton of ore. Besides this, an allowance of 2 or 3 per cent, or more in wet weather, must be made for moisture in the ore, when weighed over at the mine, as the sample assayed is, in all cases, perfectly dry. It is found, in practice, in almost every case where a large quantity of well-dressed ore is skilfully and carefully smelted, that the allowance of 5 parts of Lead from the assay, or 1 cwt. of lead for every ton of ore is rather more than sufficient to cover the loss in the smelting process, without taking into account the Lead obtained from the hearth-ends and smelter's fume.

REFINING OF LEAD

The quantity of silver contained in the greater part of the Lead raised in the northern mining district, is sufficient to render its extraction profitable, and it is of the greatest importance that the process of refining should be performed in the most perfect and economical manner, in consequence of the enormous quantity of lead continually submitted to this operation. It is well known that the separation of Lead and Silver is effected through the difference of oxidability between these two metals, silver remaining unaltered when exposed to the air of the atmosphere at

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a high temperature, and Lead, under the same circumstances, becoming rapidly converted into the state of a protoxide ; which, when formed in the large way, is called Litharge. The refining process is therefore performed, by exposing the Lead containing Silver to a strong blast of air, at a high temperature, in a furnace properly constructed to allow the Litharge to separate as it is formed, and to admit of the continual introduction of Lead as the operation proceeds, and the ready removal of the cake of Silver obtained at the end of the process.

The furnace for this purpose is called a Refining-furnace, a plan, longitudinal section, and cross section, of which, Plate I. Figs. 2, 3, and 4, very clearly display its construction. It is a small reverberatory furnace, the fire-place of which A, Plate I. Fig. 4., is very large, compared to the size of its body B, rendering it capable of exciting an intense heat. Some of the objects to be attained in the construction of this furnace already stated, render it necessary that its bottom should be moveable, in consequence of which, an open space is left quite through under the body of the furnace, from back to front, which is formed by two walls of brick work *a b*, Figs. 2 and 4. The distance of these walls in front, at *a, b,* Fig. 4, is 36 inches; but they approach together at the back of the furnace, and at *g h*, Fig. 2, the space between them is but 28 inches, which, to prevent a draught of cold air underneath the furnace bottom, is closed with iron doors. At the height of 16 or 17 inches from the floor two strong iron bars are laid across between these walls, and firmly secured in the brick-work at each end ; both these are shewn at *c c*, Figs. 2 and 3, and the front one at *c*, Fig. 4. Above these bars, and at the height of 27 inches from the floor, a plate of cast iron, having an elliptical opening in the middle, the transverse and conjugate diameters of which are 46 and 28 inches respectively, is laid across, from wall to wall, as shew at *d d*, Plate I. Fig. 2, and in section at *d d,* Figs. 3 and 4. Instead of a square plate, as shewn in the figure, a broad elliptical ring, supported by bearers, is sometimes used; but, in either case, the brick-work forming the body of the furnace, is built upon this plate, and is made to extend to, and surround, the edge of the elliptical opening; except a small aperture

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in front, 6 inches wide, by 9 inches high, as shewn at *e*, Fig. 3. The two flues *f f*, Figs. 2 and 3, communicate with the chimney, and in other respects, except those to be afterwards noticed, the furnace is finished in the usual manner.

The bed or bottom of the furnace when in operation, is formed by a shallow elliptical vessel, called a test or test-bottom, the construction of which merits particular attention, as it is an important part of the refining apparatus. Plate I. Fig. 8, represents an elliptical iron ring, 4 feet long, 2 feet 6 inches broad, and 4 inches deep, outside measure. The thickness of the iron is five-eighths of an inch, and across the bottom of the ring, are five bars, each 3½ or 4 inches broad, and ½ an inch thick, firmly rivetted into the ring, with the under surface of each level with its lower edge. The ring is filled with a mixture of one part by measure of, fern ashes, and ten parts of ground bone ashes, well incorporated and moistened with a little water, until a small quantity, when compressed in the hand, is found to cohere slightly together. In filling the test ring, it is placed upon a level floor, and this composition strongly beat into it, with an iron rammer 5 or 61bs. weight (similar to those used by founders for compressing sand into moulds), until it is quite full, and the surface of the mixture perfectly level with the upper edge of the ring. A sharp spade is then taken, with which a part of the composition is removed, so as to form the test into a flat dish of the shape represented in Fig. 6, and in section, Fig. 7, a longitudinal section of which, in its proper situation, is also shewn at Fig. 3, and a cross section at Fig. 4. The bottom of this dish is about 1¾ inch thick between the bars, and the part *g*, Fig. 6 and 7, called the breast of the test, is 5 inches thick, the remainder of the circumference being 2 inches thick, and sloping inwards to increase its strength, as shewn in the figures. Across the breast of the test, a furrow or small channel, called a gateway *h*, Fig. 6, is cut diagonally, one inch wide and three-quarters of an inch deep, as a passage for the Litharge; and it is made near one side of the breast, in order that a similar passage may be cut on the other side, after the test has been some time in operation, and the first gateway has become worn down by the stream of Litharge. A space 1½

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inch wide, and 7 or 8 inches long, is cut out between the front of the breast and the test ring, in order that the Litharge may flow down from the test, without coming in contact with the iron.

Instead of bone and fern ashes, mixed together in the proportions stated, it is a better practice, and one gradually coming into general use, to make the tests of a mixture of one part of the best American pearl ashes, to forty parts of bone ashes, by weight. The pearl ashes, reduced to fine powder, and perfectly dry, are thoroughly incorporated with the bone ashes, and the compound is then moistened to the proper degree with water, after which the test ring is filled in the usual manner. From four to five pounds of pearl ashes are required for each test, the bone ashes for which weighs from 12 to 13 stones avoirdupois.

The test, thus constructed, is applied to the opening in the iron plate already described; the flat part of its circumference, being previously smeared over with a luting of bone ashes and water of the consistence of paste, and it is then firmly secured in its place by four iron wedges *i i,* Figs. 3 and 4, which rest upon the iron bars *c c.*

When the test is properly fixed in this situation, and thoroughly dried by the application of a gentle heat, it is ready for the reception of Lead, which is poured into it, with an iron ladle, through the channel *D*, Fig. 2, being previously melted and kept nearly at a red heat in the pot *E*. About 5cwt. of Lead is required to fill a new test to the working level. A mode of feeding the test is sometimes practised, which consists in suspending a pig of Lead, or an iron weight, from a beam above the melting pot, by means of a chain, and allowing it to dip into the melted Lead when made to descend, so as to force the Lead displaced by its introduction, directly into the test through the channel *D* ; which in that case must be a little lower than the lip of the melting pot. Some refining furnaces are not constructed with the channel *D* ; but, instead of it, have an opening in the brick-work of the furnace, on each side of the test, through one of which a whole pig of Lead is introduced, and gradually melted down into the test by the heat of the fire; being pushed further in, from time to time, as the lead is consumed. An opening on each side of the test is considered necessary, in order that

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the Lead may be always introduced, on the side opposite to the gateway working at the time, to prevent the possibility of its being carried by the stream of Litharge, over the breast of the test in its metallic state; and, in some instances, to be afterwards mentioned, where so large a quantity of Lead is refined in a test, as to render it necessary to have three gateways, the Lead is introduced through an opening behind, daring the time that the middle gateway is at work.

The last part of the refining furnace to be noticed, is the aperture behind, for the admission of a current of air, supplied by a powerful double bellows, worked by machinery. This aperture is formed by a conical iron tube *k*, Plate I. Fig. 3, called a muzzle, walled into the brick-work forming the back of the furnace; its larger end outwards, receives the nozzle of the bellows, and its smaller end projecting into the furnace, over the inner edge of the test, is bent down slightly, and its orifice compressed into an oval form, so as to deliver the blast with sufficient force upon the surface of the Lead, and at the same time to spread it out towards the sides of the test. Much care is usually bestowed upon the construction of the muzzle, as the proper direction and distribution of the blast, is a point of great consequence to the working of the furnace.

Refining furnaces are generally built double, that is one on each side of the upright chimney; but, excepting in the direction of the draught, and consequent situation of the fire-places, there is no difference whatever between them. The fume and smoke from both, are conveyed into a division of the horizontal flue, mentioned in pages 155 and 156, separate from that containing the smoke from the roasting furnace, ore hearth, and slag hearth, with which they are not suffered to mix. Here they deposit a heavy grey powder, called refiner's fume, which is principally Oxide of Lead.

The test being properly placed in its situation, cautiously dried, and filled with Lead as already detailed, is exposed with its contents to the flame passing over it, until the lead attains a bright red heat, at which period the blast of air is made to play upon its surface. The oxygen thus supplied, rapidly produces a stratum of fluid Litharge, which is

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propelled forwards by the blast, and forced through the gateway, over the breast of the test; its place being supplied by a fresh quantity, so as to keep up a continual stream. The Litharge concretes into lumps as it falls, which are removed from time to time by the workmen in attendance, who take care, by the addition of fresh quantities of Lead, to keep its surface in the test always at the proper working level. In this way the operation proceeds; but as the hot Litharge gradually wears down the gateway, so as to render the test incapable of holding a sufficient quantity of Lead, it becomes necessary to make a fresh gateway, generally after two fodders of Lead have been refined. When this is done, the blast is suspended, the old gateway is stopped up with a paste of bone ashes, a fresh channel made on the other side of the breast, and the test filled up with Lead to the proper level, as at first. The process then proceeds again, until two fodders more of Lead have been oxydized, when the second gateway being also worn down, until the test does not contain more than one cwt. of Lead, the wedges supporting it behind are slackened, and those in front taken away, and the fluid Lead, called technically rich Lead, is poured into an iron pot 18 inches in diameter, running upon a carriage with four wheels. This rich Lead, containing the Silver of four fodders of original Lead (usually from 30 to 40 oz.) is cast into a pig and taken away, a fresh test is applied to the furnace, and four fodders of lead worked in it, in the manner described, until 50 or 60 pieces of rich lead are obtained. A test is then made, the bottom of which is somewhat concave, instead of being flat like those already mentioned, and in this the rich Lead is carefully refined, yielding, at the end of the process, a cake of Silver weighing from twelve hundred to eighteen hundred ounces. The rich lead is treated in the same way as ordinary lead, except perhaps more carefully, and after the last piece is introduced, the gateway is made deeper with an iron tool, from time to time, as the surface of the Lead subsides by its gradual conversion into Litharge; and, from this period until the cake of Silver is rendered pure, all the Litharge then flowing is kept separate, as it is apt to carry along with it a portion of Silver. The part received is called rich Litharge, and may contain

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on an average 20oz. of Silver per ton; it is generally worked up at the end of the year, by being reduced into Lead and again refined. As the cake of Silver becomes nearly pure, it is most essential to keep it constantly in fusion, for, if once suffered to solidify, it is very difficult to excite a sufficient heat to melt it again. The fire is therefore urged with great violence, until at length the whole of the Lead being oxydized, the formation of Litharge ceases, and the mass of melted Silver appears pure and beautifully resplendent. At this stage, it sometimes happens that drops of melted slag from the furnace roof fall down upon the fluid Silver, in which case they are carefully brought to the edge of the melted metal, and raked off upon the naked part of the test. The blast from the bellows is now stopped, the fire is slacked, and the Silver suffered to cool; which it does, very gradually, first at the surface, forming a solid crust over, a portion remaining fluid below. When the temperature has fallen sufficiently, this also becomes solid, and in the act of doing so, a large quantity of nearly pure oxygen gas is expelled from it, and at the same instant its particles expand considerably, so as to break the crust already formed, and force out a portion of Silver, to the height of three or four inches above the rest of the cake. Occasionally particles of melted Silver are projected out of this mass, to a distance over the naked part of the test, and the sides of the furnace, by which a loss of the precious metal is sometimes sustained. After having cooled sufficiently, the cake of Silver is removed from the furnace along with the test, from which it is then separated without difficulty; and if any slag or portions of the test are found to adhere to it, they are cleaned off, and it is ready for sale.

During the working of each test it gradually absorbs Litharge until saturated, and the portion thus combined, is sufficient to pay the cost of extraction. For this purpose, the old tests are broken to pieces, and smelted in the slag hearth, mixed with a portion of black slag, in order to render the bone ashes more fusible
; the black slag used being run in lumps for the purpose, and not granulated in the ordinary way. The produce of this fusion is a description of lead called test-bottom

Lead, which is very hard, and of inferior quality.

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The deposit called refiner's fume, is removed from the horizontal flues from time to time, and is frequently ground up with oil, forming a very cheap and durable paint; but the quantity produced is generally too considerable to admit of the whole being disposed of in this way, and the surplus is reduced by being roasted almost to fusion, and then worked in the slag hearth, in the same manner as grey slags. As might be expected, the Lead obtained from the test bottoms and refiner's fume, contains but a very small portion of Silver.

Instead of converting into Litharge but four fodders of Lead in each test, as already mentioned, some refiners are in the habit, of working twelve or thirteen; but, in this case, the tests are constructed with peculiar care, and the bottom, sides, and breast are made thicker than usual. The Litharge from four fodders of Lead, flows through the first gateway made on one side of the breast, and when the quantity of Lead in the test is reduced to about a cwt., it is cast into a rich pig: four fodders of Lead are then worked through another gateway, on the opposite side of the breast, yielding a pig of rich Lead in the same manner; and, for the remaining four fodders, a gateway is made across the middle of the breast. By adopting this method of working, the loss from the Lead absorbed by the test bottoms is considerably lessened, and a great saving is made in the expense of tests; but the process is rendered slower, as it is necessary to work at a low degree of heat. The saving in tests is not what it appears to be at first sight; for those made to refine the larger quantity of Lead, being thicker and stronger than the others, require a larger quantity of bone ashes.

The rate of refining varies a little, from the cause just stated. When four fodders of Lead are oxydized in a test, it is usual to accomplish this in from 16 to 18 hours; and six tests, or 24 fodders of Lead, can be very easily converted into Litharge, in one furnace, by three men in a week. The quantity of Coal consumed is about four Winchester bushels, or three cwt. avoirdupois, per fodder of Lead. In cases where 12 or 13 fodders of Lead are refined in a test, it is customary to work but one test in a week, in one furnace, which is only half the quantity stated above; but here also, three men by managing two furnaces refine 24 to 26 fodders of Lead per week.

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REDUCING OF LITHARGE.

The reduction of Litharge into Lead is an easy process, and, in the great way, is very expeditiously performed, in a reverberatory furnace almost exactly similar to the roasting furnace already described, except that its bed or bottom, instead of being flat, is made to slope towards an opening in the side, through which the reduced Lead is conveyed, by means of a cast-iron channel, into a pot, to be finally made into pigs for sale. The inside of a roasting furnace is generally made somewhat elliptical, about 6 feet long, and 5½ broad, and a furnace of this size, worked by three men, at 8-hours shifts each, is capable of reducing, without difficulty, all the Lead oxydized in two refining furnaces, each working six tests, or 24 fodders per week. After the reducing furnace has been properly heated, the process is commenced by covering its bottom with a stratum of coal, which taking fire, very soon forms a mass of ignited fuel some inches in thickness. Upon this the charge of Litharge mixed up with a small quantity of fresh Coal, is thrown, and a furnace of the size mentioned, will hold from two to three tons. The reduction goes on rapidly, and the furnace is supplied, from time to time, with fresh Litharge, until the quantity added is such as will produce from 4 to 5 fodders of Lead; the charge is then suffered to run down, with the addition of fresh Coal, to promote the reduction, as it seems to be required. At the end of nine or ten hours, the whole of the Litharge is reduced, and, at the bottom of the furnace, there remains only a portion of slag, called Litharge Slag, which is raked out while still hot to prepare for the next charge.

This Litharge Slag is formed by the vitrification of the earthy matter contained in the Coal used in reduction, and, as a small quantity of Lead is unavoidably united with it, it is afterwards worked over in the slag-hearth with black slag, in the same way as the test bottoms, yielding what is called Litharge Slag Lead, which, like Test-bottom Lead, is of inferior quality and contains little Silver. It is of importance that the best Coal should be used to mix with the Litharge, in order that the slag formed may be as little as possible. The Coal required for

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reducing is about 4½ Winchester bushels, or near 3½cwt. per fodder of Lead reduced, including the quantity mixed with the Litharge.

The quantity of Test-bottom and Litharge Slag Lead made in refining may be variable; but, in several cases which have come under the writer's notice, they have, together, amounted to one thirty-second part of the original Lead refined.

The produce of Lead from the refiner's fume, treated as described in page 40, has appeared to be, in the only case submitted to the writer's consideration, about 1 per cent, on the total quantity of Lead undergoing the refining process; but this deposit must be very much modified, like the hearth ends and smelter's fume, by the degree of heat at which the refining furnaces are worked, it is therefore impossible, perhaps, to make a statement which will exactly correspond with experience at every smelting establishment.

CORRESPONDENCE OF THE PRODUCE OF SILVER WITH THE ASSAY, AND LOSS OF LEAD IN THE PROCESS OF REFINING.

The practice is very general of assaying the Lead to be refined previous to the process, by taking a chip from each pig, melting the whole together, and submitting a known weight to cupellation. It frequently happens that the quantity of Silver obtained in the large way, is greater than that indicated by the assay, the reason of which is, that the Litharge, as it sinks into the small cupel, carries with it a minute portion of Silver, rendering the button obtained rather less than it ought to be; but, by reducing the Litharge absorbed by the small cupel back into Lead, with Black Flux and Borax, and refining this Lead a second time, another minute button of Silver is obtained, which added to the first button, generally indicates a quantity of Silver in the lead under examination, with which its produce in the great way, when carefully refined, very closely coincides, taking into account the small portion of Silver unavoidably carried over with the Litharge, and found in all samples of refined Lead, to the extent of from half an ounce to an ounce per fodder. It will easily be conceived that if the small process of cupellation has been carefully performed at first, with a due degree of heat and in

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a good cupel, the second button of Silver will be exceedingly small, and that it will be larger as these particulars have not been attended to.

Where assays of Lead ore, for Lead and Silver, have been extensively made, to determine the quantity of both metals which should be obtained from the ore by melting and refining, the produce in the large way has been found in most instances very nearly to correspond with the assay after making an allowance on the Lead of 5 parts from the assay, or 1 cwt. of Lead for every ton of ore, as stated at Page 28, and multiplying the quantity of lead indicated after this allowance, by the proportion of Silver carefully determined by the assay.

The loss of Lead in the refining and reducing processes, is usually estimated, in the first instance, at one-twelfth of the quantity refined; but, when the deposit of refiner's fume is melted up, and the Lead extracted from the test-bottoms and Litharge slag, the ultimate loss becomes not more than one-fifteenth, and with some smelters one-sixteenth of the original quantity. The loss sustained is least when the refining furnace is worked at a low temperature, but it is not expedient to reduce the test to the lowest degree of heat at which the oxydation will go on, for, in this case, the Litharge, at the moment of its formation, is not sufficiently fluid to allow the particles of Silver to separate from it, and combine with the remaining Lead in the cupel; they are thus, as it were, entangled in the Litharge, and carried with it over the breast, by which the produce of Silver is materially diminished.

Lowbyer, Alston, Sept. 5, 1831.