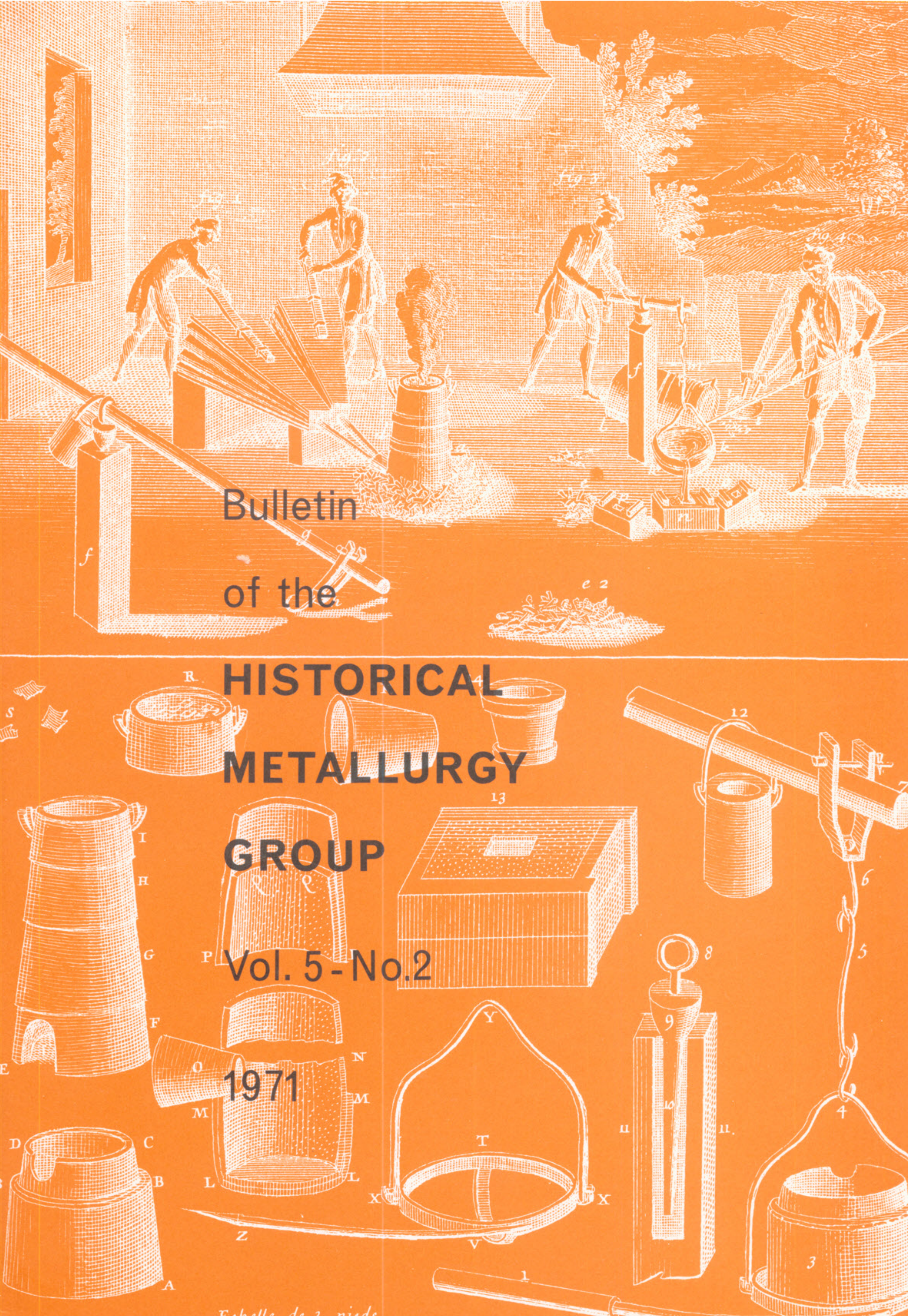

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Contents

An account of the method of smelting lead ore as it is practised in the northern part of England

JAMES MULCASTER

Editorial Note

Two copies of this MS exist, one in the Library of the Literary and Philosophical Society of Newcastle upon Tyne and the other in the Central Reference Library, Wigan, Lancs. The first and major part consisting of 118 pages is almost the same in both MSS, and one is clearly a copy of the other, but the Newcastle MS concludes with the Sixth Process on the reduction of litharge, and in the Wigan MS this is signed by the author and dated January 1795. Whilst this is the end of Newcastle MS, the Wigan MS continues with a glossary of terms used in the preceding account, and then follows with a description of the methods actually used at Langley Mill, concluding with some memoranda dated to 27 January, 1806, making 164 pages in all. The two MSS are not in the same hand and there are differences in the spelling.

We can conclude that the Newcastle MS is the original and dates from about 1795. In some places specific dates are mentioned, such as 1775 and 1793 in regard to the assays. We can safely assume that it represents the practice in the Northern Pennines during the 20 years 1775-95 and perhaps somewhat earlier.

The Wigan addendum shows that little change took place between 1795 and 1806, but presumably the author felt that the particular practice at Langley Mill should not go unrecorded.

The author, as the writer states in the MSS, was agent to the Governors of the Royal Hospital for Seamen at Greenwich. The assigning of the proceeds of the Northumberland and Cumberland mines and smelters for the upkeep of Greenwich Hospital arose out of the forfeiture of the estates of the Earl of Derwentwater after the rebellion of 1715.

James Mulcaster was appointed agent in 1768; he had two brothers, one of whom was joint agent at Langley and the other principal agent at the refinery at Blaydon, near Newcastle. He thus belonged to a family with strong metallurgical connexions and was personally experienced in all that he described.

We are indebted to the Newcastle Literary and Philosophical Society and their librarian Mr C. Parish for permission to publish this MS. It is hoped to publish the concluding section in the Wigan MS on some other occasion. The transcription was made by Elizabeth Tylecote, to whom we are extremely grateful.

An account of the method of smelting lead ore, as it is practised in the Northern part of England, containing an explanation of the several processes the ore undergoes, from the time of its being brought to the mill, to that of its being finally manufactured into saleable lead and bullion there; together with some account of the mode of washing lead ore so as to make it fit for smelting, and a description of those substances, mineral and fossil, with which the lead ore in Alston Moor is generally accompanied, and the effects they have upon it in smelting.

By JAMES MULCASTER

One of the Agents at Langley lead mill belonging to the commissioners and governors of the Royal Hospital for Seaman at Greenwich in the county of Kent.

ON ORE-HEARTH SMELTING: PROCESS 1ST

I call it ore-hearth smelting to distinguish it as well from what is done in the slag hearth as from another mode of ore smelting which I hear Mr Gilbert* calls cupola smelting, but which I always, and I think with propriety, called furnace smelting, a mode upon which, as I have never see it, I cannot say anything, but having been long and intimately aquainted with the other, I shall endeavour to describe it with such abilities as I possess, hoping that if I should sometimes fall short of perspicuity, the walk of life in which I have moved, will be allowed to be my excuse.

The form of a smelting hearth being shown in the accompanying sketches [Fig. 1], I now proceed to inform you that to commence smelting, the bellows being put in motion, the hearth is filled with peats, a sort of wall of the same is made in the front of it (for our use I shall shew presently) and a fiery and already kindled one is placed amongst them just before the muzzle of the bellows, from which a conflagration catches, this presently communicated to every part of the hearth; to increase which, and to give the fire more firmness, durability and vigour, some shovels full of coal are cast upon the top, after which, and when it is seen that such mixed fuel is sufficiently in combustion, a quantity of brouse is also given upon the top, which brouse is a mixture of ore imperfectly reduced to lead and slag, coal cindered or half burned, and lime, being a stock formerly the contents of the same hearth, which has been drawn out of it at finishing its preceeding fill of working; and as in the kindling of a common coal fire, the cinders left at the time the fire has before been burning generaly enter first into the composition of a future one, so this brouse with now and then a shovel full of fresh coal, is at intervals given, til in about half an hour, the whole, and also the filling of peats, those in the front excepted, is expended; then those last, being now well kindled, are taken down and placed in a cast iron pot called the sump, in order that it may be sufficiently heated for the reception of the lead when that begins to flow, which it does not until several watchings and settings-up (terms I shall explain by and by) are performed, and commonly not until some raw ore is given, and the brouse has aquired such a degree of heat as will dissolve between 4 and 5 cwt of lead, a quantity which is generaly left at the end of every fill or shift of working in, or for, the bottom of the hearth called the pan, where such quantity must be, and in fusion too, before any lead unfreed can issue: But this quantity being now increased by the continual trickling down through the interstices of the incumbent brouse of such other lead as is by this time exuding from the ore, copiously or otherwise as that lead happens to be free or refractory, this first receptacle of it overflows and gives the watchmen notice that they may, by tapping, take as much of it away as they suppose is made or extracted every fire, by which fire is meant the times between the watchings and settings-up of the hearth as they are called and which are thus performed.

One of the smelters, for they always work in pairs, with a strong poker first stirs or heaves up the whole of the brouse in the hearth and then draws out about one half of it upon a sort of shelf or apron of cast iron which lies joining the front or foreside of the hearth. This is called the workstone

* Mr. Gilbert is principal agent to the Duke of Bridgewater and is now working some lead mines in Alston Moor for Lord Carlisle & Co.—Mr. G. is also a partner.

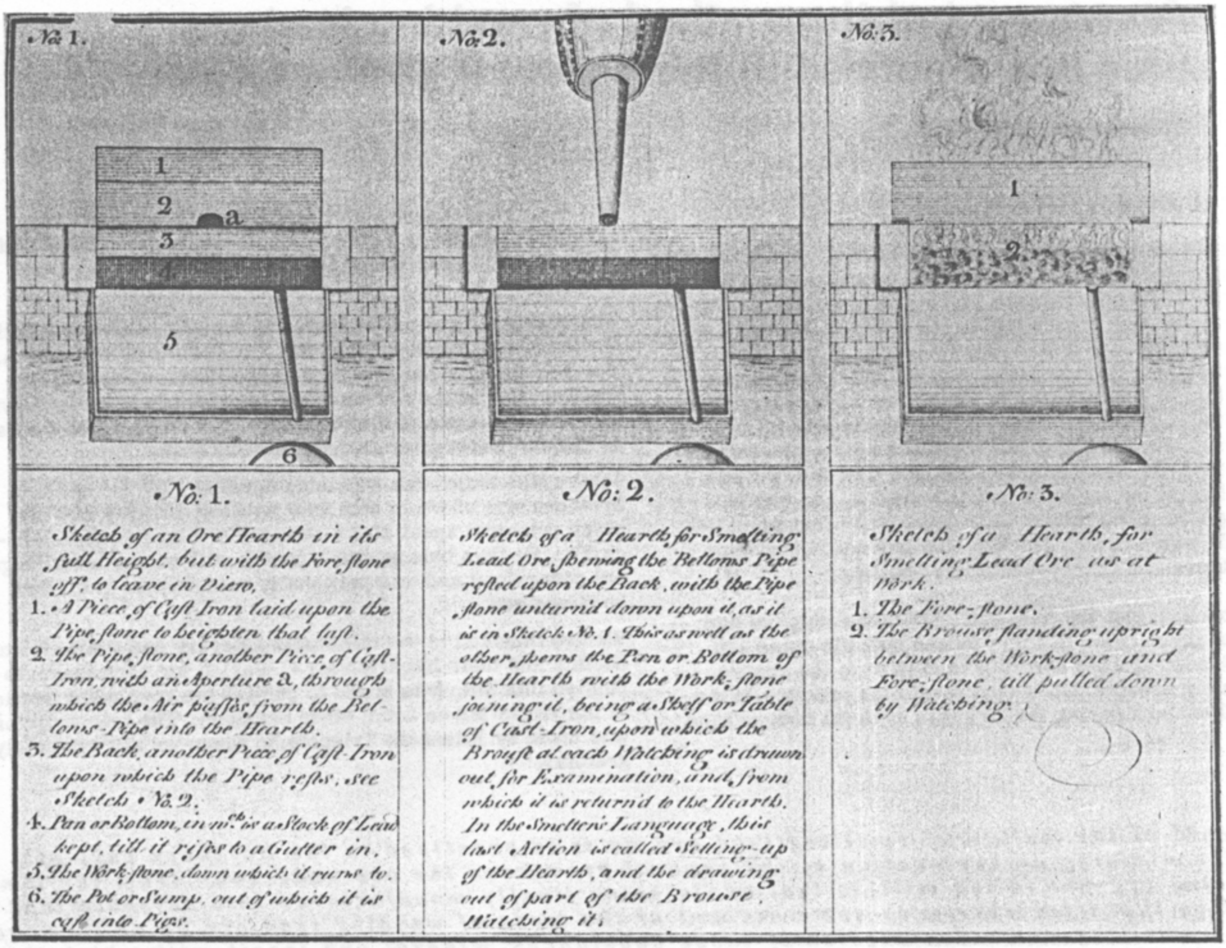

Fig. 1 — Ore hearths for smelting lead ores.

and in it is a groove or gutter which communicates with the pan (of which this work-stone forms one side) through which the lead passes to the sump from whence it is cast into pig moulds. This performance is called watching, and during the time this is doing, the other watchman with his shovel, cleans the muzzle of the bellows of such brouse as is against it and places his peat (of which more hereafter) which done, the two men join in casting off the slag, serving with the necessary coal and lime and replacing the brouse in the hearth by casting it in at, or upon the top, which being made level, so much fresh ore as they judge may be digested before another watching comes on is given upon the top, where it undergoes a temporary roasting, which fits and prepares it a little for its being brought as it is in the next watching, into the most vehement part of the fire. These watchings and settings-up, as replacing the brouse in the hearth is called, are generally performed once in every five minutes, so that the labour of smelting seems to consist chiefly in an often repeated pulling down and making up of the same fire, for which I shall endeavour to account; and first for the watchings, which are as well stirrings-up as pullings-down, and are in both cases unavoidable, because without the first (a frequent stirring) the whole mass of the brouse, tending as it always is to vitrification, would soon become so compact a body that neither could the fire, agitated by the bellows, pervade every part and cranny of it, as it ought to do to operate rightly upon it, nor could the lead, as it perspires from the ore or unexhausted parts of the brouse in the hearth find a passage down through it to the bottom, where it ought to be speedily to be out of danger, for whilst it is suspended in the upper parts of the hearth, it is in a state of evaporation and waste; but from hence it may be taken at pleasure, only the ordinary reserve in the pan must be kept unimpaired. Such pullings-down, or rather pullings-out, of part of the brouse are also necessary because they give the smelters in the first place an opportunity of discharging that brouse of such parts of it as can, in this process, be no further operated upon, id est the grey or ore slag, and which is distinguishable from the rest of the brouse by its being less heavy, and by its light red glow, as being more intensely hot; in the next place, if they have judgement, such frequent drawings-out of part of the brouse inform the workmen of the state and temperature it is in, that if it be too hot, they may lessen, or if too cold, increase their ordinary quantum of coal, that if they see it distempered by a ropyness which will sometimes so seal up its pores that no lead can issue, but is confined to the wasting of it, they may by an increased application of well-slaked lime, effect a cure of that; And lastly the drawing so much of the brouse out of the hearth, and thus frequently affords an opportunity of properly, and in due time, renewing the peat, from 9 to 12 inches in length of which, if dry, is expended every fire, and a very necessary article it is, indeed this mode of smelting could be scarcely carried on without it, for besides its being greatly auxiliary to the coal, the position it is placed in, that is, just before the muzzle of the bellows, and being a light and spongy substance of itself, it causes a light lying in that part of the other more heavy contents of the hearth, and as the wind board of an organ distributes the current of air from the bellows to every pipe in that instrument, so this, and a projecting of about 2 inches of that piece of cast iron called the pipe stone, over the back upon which the pipe rests, causes the stream of air, at its first discharge from the bellows to expand and carry vigour to the action of the fire equally in every part of the hearth; and therefore it is that throughout the whole extent of it, a square of 26 inches in length, by 22 inches in breadth and 14 or 16 inches in depth, the lead is extracted from the brouse and ore by the frequent watchings mixed with it, and in my opinion not by a total and promiscuous dissolution or fusion of the lead and slag (which are the constituent parts of lead ore so far as smelting makes the analysis of it), but by a progressive perspiration or exudation of the former from the latter, until an almost total separation of them is effected: Thus upon the brouse, or parts of the ore so heated as to be accounted such, the lead appears first in very small particles, but these, if the ore be free, soon increasing in bulk, becomes too heavy to remain suspended and falling upon others, are precipitated with them down thro' the openings of the brouse to the bottom, where they are imbodyed with that stock of lead, 3 or 4 inches in depth, which I have said is, and for reasons I am going to give, ought always to be kept there; one of which reasons is that it generally facilitates the labour of watching, by preventing a growing or adhering of the brouse to the bottom of the hearth, which, if it should be suffered to do so, would render that work, already sufficiently arduous, almost impracticable. Another reason why such a stock is kept is, that as it covers the whole bottom, and has the whole of the brouse floating upon it, it is thereby open to receive all such lead as is continually falling off from that brouse, as it is also to discharge by the ricker or gutter I have before mentioned, all such redundancies of the same lead as from time to time happen.

ON SLAG HEARTH SMELTING: PROCESS 2ND

The operation of smelting in a slag hearth differs from that of an ore hearth in this, that in the ore hearth, the ore to be operated upon does not undergo an entire liquefaction or fusion of all its parts, but only a partial one by having its lead, or the greatest part of it, sweated out of it, as I have observed in my former letter; on the contrary in this, whatever is to be worked upon, suffers a total dissolution. This hearth also differs from the other in its construction, and in the materials of which it is formed, for the ore hearth is, and must be, composed of pieces of cast iron only, whereas this is composed of such pieces, and also of free-stone.

The pieces of cast iron used, and the disposition of them, in the constructing of this hearth are, first, one flat piece for a bottom or foundation, next, and upon it, another piece 18 inches in height and 28 inches in length for a back, upon which the bellows pipe is rested at equal distances from its two ends and to which the back is joined, so as with it to form 3 sides of a square (of a size I shall mention below), 2 other pieces 5 or 6 inches in height called bearers, because upon their ends opposite to, and at 26 inches distance from the back, are rested what are called the fore-stones, consisting of 2 to 3 more pieces built one upon the other to the height of 33 inches including the 5 or 6 inches left vacant under them by the nethermost one being supported by the bearers. This opening into the hearth between the bearers and under the fore-stones is 18 inches wide and is increased to 9 or 10 inches in height by a lowering of the floor at the entrance or threshold of it to facilitate the descent of the lead and slag from the hearth to the sump. What remains of the structure, i.e. from the bearers on the sides and from the back upwards to the top is, and must be, of free-stone laid in good clay, because cast iron or any other substance yet tried, exposed in any of those parts would presently be run down and wasted; and even free-stone itself is not so durable, but that frequent, indeed daily reparations are found necessary. The dimensions of this hearth when completed, are 26 inches in length from the back to the forestones by 18 inch width, 33 inches depth, inside measure. But to illustrate what I have now said of its form and composition, and what I have yet to say of its manner of operating, I have enclosed drawings of a slag hearth with references. [Fig. 2].

Having premised thus much of its form and construction, I come next to the manner of smelting in a slag hearth; preparatory to which the bottom of it to the height I have shown in the section, the passage from thence to the sump and the sump itself are filled and covered with coal-ashes, which I shall, as the workmen do, sometimes call dust; this done, a

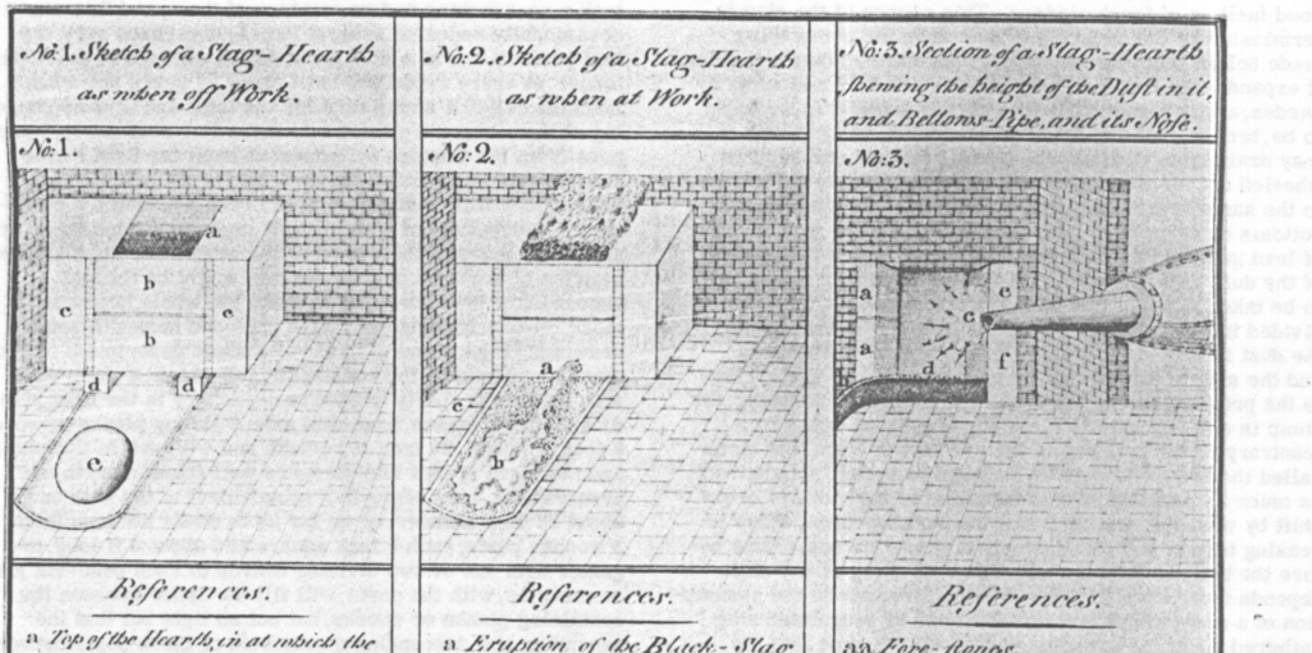

Fig. 2 — Slag hearths for recovering lead from the slags.

kindling, by a filling of peats is put in the hearth, and the bellows is let loose upon them, by the action whereof the whole is presently in a blaze, and then some cinders are superadded, which, from this time forward during the shift, is the only sort of fuel made use of in this operation, and upon which when well heated and when the peats are expended or much charred, a part of such substance as is intended to be smelted, whether grey slags or litharge slags and test bottoms with a flux of black slags is given, which in this now intense heat gradually dissolves into a sort of coarse glass or black slag and lead, which as they are formed descend together upon the dust in the bottom of the hearth, where such dust is for an use very similar to that of the glands in animated bodies, i.e. to cause a secretion or separation of the lead—the more fire from the slag—the more gross substance. In other words lead is too heavy, and when in fusion too subtile a body to float upon coal-ashes; slag on the contrary is too light, and at the same time too thick a substance, though in fusion, to sink in such ashes; consequently when two such substances are distinct (and passing through the fire of a slag hearth makes them so), and when they are deported, as here, upon that into which the one will sink and upon which the other must float, a separation of them will of course follow. This bed of dust is of further use as a proper conveyance from the hearth to the sump of the slag upon, and of the lead beneath, its surface. Down through it to the sump the lead spontaneously and imperceptibly makes its influx; but for the slag, when the workmen suppose there is a sufficient accumulation of it in the hearth, they open a passage by tapping close under the fore-stone, when a pretty copious and intensely hot stream of it generaly follows, as (if all goes right), it continues to do without intermission, until the shift of 12 or 14 hours continuance is finished, this stream being incessantly fed and supplied by such slag as is formed in, and poured down from, the upper and interior parts of the hearth and produced there by the fusion of such materials as are at the time under operation, and with which the hearth is charged occasionally from time to time upon a good fuelling of fresh cinders. This course of the slag is terminated by the covering of dust upon the sump being made hollow from its reception, where after many wrigglings it expands into a sort of cake (see sketch 2), cools so as to harden, and is turned off into a corner, when it is, or ought to be, broken, that any lead that may have escaped with it may drain from it; after which being further cooled, it is wheeled out for the stamp mill or sometimes brought back to the same hearth as a flux for litharge slags and test bottoms or refractory grey slags. When there is a quantity of lead gathered in the sump it is known by the quagginess of the dust upon it, and if it is thought such that some ought to be taken away, in that case the stream of the slag is divided into the corner where the cakes of it are thinner the dust is turned up, a pig is cast, the dust is replaced and the slag is turned into its ordinary course again. This is the practice during the time of working. At finishing, the sump is entirely emptied into pig moulds, at which time (contrary to the practice in the ore hearth when that stock called the brouse always is, or ought to be left unimpaired), as much as possible of it is expended at the close of every shift by what the smelters call the burning-down, which is ceasing to give any fresh supply of slags for some time before the bellows is taken off. The well doing of any shift depends much upon the hearth being fortunate in the assumption of a nose, which is a protuberance of coagulated slag gathered about the entrance of the bellows-pipe into the hearth, and which, if of a right form, (but that is fortuitous or accidental for no skill of the workmen can give it), is of great use; because without it, as no peat is used here as in the ore hearth, the stream of air from the bellows would be so poured in upon one part of the fire as almost to destroy and extinguish it, whilst the other parts would be left as dead and inert as if no bellows were in action; but by this nose, that stream is divided into several channels, and is thereby poured diverse, as I have by the little dartings from it in the section endeavoured to show, by which means the whole contents of the hearth are pretty equally acted upon.

I shall conclude by observing that as ore hearth smelting makes a division of the ore into lead and grey slag, so this makes a subdivision of the grey slag into lead and black slag. And that the subdivision, black slag is yet further divisible, which gives occasion for process 3, according to my arrangement, i.e. black slag, stamping, washing and smelting—of which in my next—for though in fact the whole, or nearly so, of my substance that has fairly passed through a slag hearth is reduced to lead and black slag, yet as those slags are porous, some lead will of course be lodged in them, and some will also adhere to them, on which account it becomes necessary that they should be pounded.

ON THE STAMPING, WASHING AND SMELTING OF BLACK SLAGS, WITH A DESCRIPTION OF A STAMP MILL: PROCESS 3RD

In the close of my last, I think I observed that the operation of slag hearth smelting reduced such substances, as passed properly through it, into what we call black slag, a sort of coarse glass and lead; yet the separation of them is not so entire but that in the pores of the former several particles, and sometimes not small pieces of the latter will be lodged, which cannot be wholly drained out of the cakes whilst hot and recently turned off from the sump, wherefore a further breaking of them has been found necessary and this was formerly done by means of bucker and drag; the first a sort of hammer such as is now used at the mines for producing the ore, with a long shaft or handle called a brashing bucker; and the other a strong toothed iron rake, wherewith to drag off or separate the less from the more crushed parts; after the bucker had been used, in order to do the picking of such larger pieces of lead as happened to be beaten out and to the small being carried to the buddle, there to undergo a washing, by which the smaller particles (and on the whole a good deal) of lead were obtained; and that the rounds, as they were called, might be thrown aside, as was the practice, in heaps, where they lay sometimes for many years, until some person, at an advanced price per fodder of lead obtained, undertook a re-crushing and re-washing of them; and this was occasionally repeated several times, at perhaps very distant periods, and at a still progressive advance of price per fodder, at every repetition until about 50 years ago when a machine called a stamp mill for the total and at once pounding of them was introduced into these Northern parts, I suppose from the Cornish tin mines; at least the first I ever knew erected was under the direction of a Cornish man. Since which time a stamp mill has been accounted a necessary appurtenance of a smelt mill, and now I think there are almost as many of the one as of the other, therefore any description of the form of a stamp mill might be thought unnecessary here, however to make the whole business more clearly understood, I have enclosed herewith some drawings [Figs. 3 and 4] in aid of a short description of that machine. Towards the constructing of which, a waterwheel with its axle properly cogged is necessary in the first place: At 4 inches distance from this axle, 2 strong planks of wood, 8 feet in length, 20 inch in breadth and $4\frac{1}{2}$ inch in thickness and mortised at foot into sleepers well fixed in earth are erected with their edges (not broadsides) to the axle and about 26 inch asunder, or so far as to admit between them 3 wooden posts, each 6 inch square and about 8 ft long, together with one or two dividing boards to each post—viz just so many as, with the posts, will fill the space between the containing planks or cheeks, but not so light but that the ascending and descending movements of those posts between the boards may be with ease and with as little friction as possible. Between those separating boards or two sides, and between four wooden bars, put across from cheek to cheek, i.e. two on each side, and upon which those boards (see their form in drawing [Fig. 4-d]), are hung by notches or indentures, which renders them immovable, whilst the posts are in motion; between those I say, each post or stamper moves upwards and downwards, as it were in a groove. Each stamper is increased in weight by about 7 stones and in length by about as many inches of cast iron fixed into a mortise in the lower and by a tenon formed of the metal itself in the casting (see drawing [Fig. 4-M]). Each stamper has its respective cogs, commonly 4 in number and is lifted by them by a hold or handle, which is a

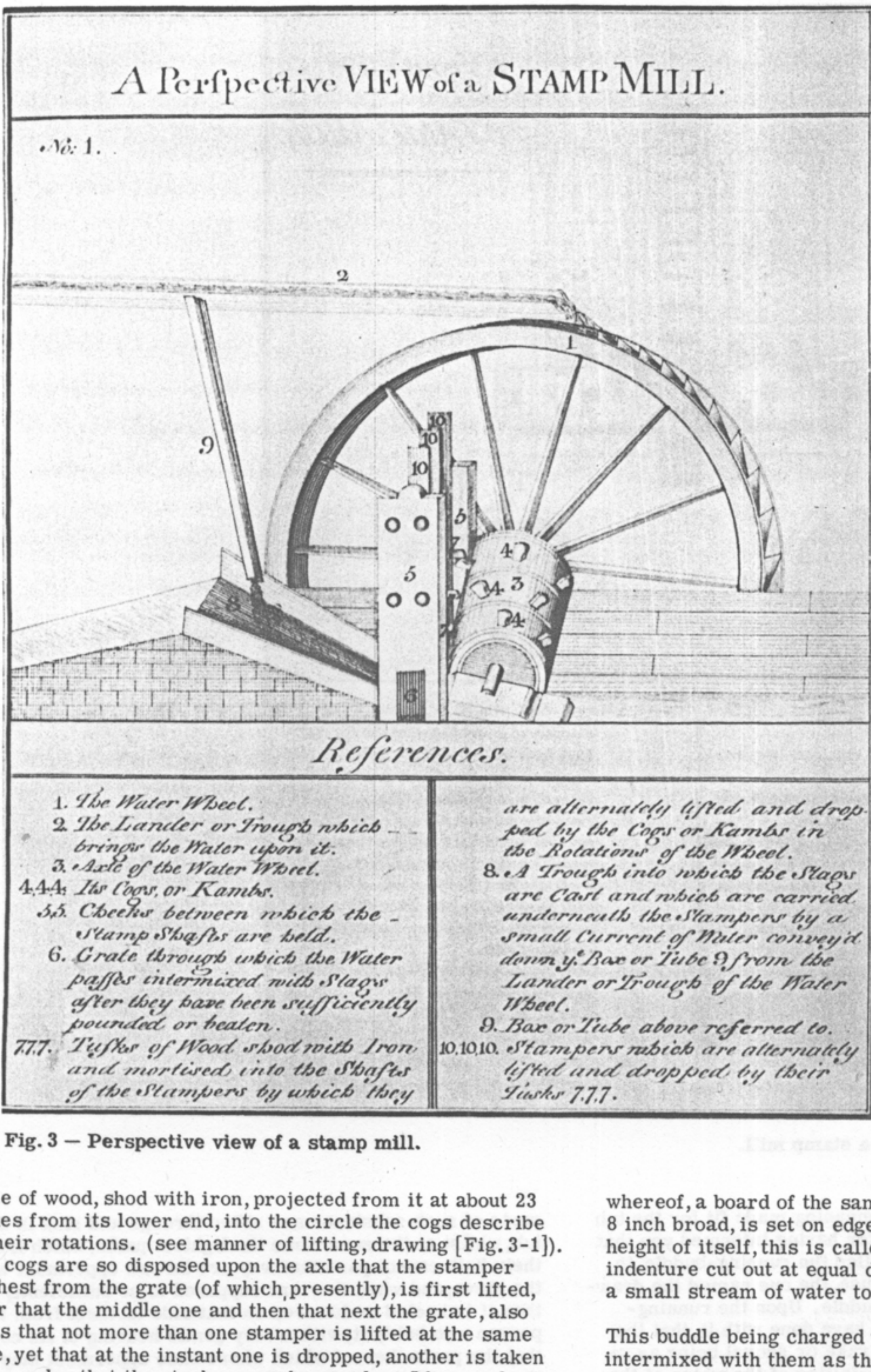

Fig. 3 — Perspective view of a stamp mill.

piece of wood, shod with iron, projected from it at about 23 inches from its lower end, into the circle the cogs describe in their rotations. (see manner of lifting, drawing [Fig. 3-1]). The cogs are so disposed upon the axle that the stamper furthest from the grate (of which presently), is first lifted, after that the middle one and then that next the grate, also so as that not more than one stamper is lifted at the same time, yet that at the instant one is dropped, another is taken up, in order that the strokes may be regular. I have only further to observe that the mill is served with slags, by a quantity of them being cast into a sort of wooden trunk or hopper sloping at bottom, and into which a small current of water is made to fall (see drawing [Fig. 3-8]), by which and a tremor occasioned by the motion of the machine itself, they are carried under the stamper, from whence, when sufficiently pounded, to pass through it, they, with the lead beaten out of them, are by the same water, aided by the falls of the stampers discharged thus: The grate (see drawing [Fig. 3-6]) fixed in the outer cheek upon a level with the floor upon which the stampers fall, where they with the water, are received into a wooden dent called a trough, by which they pass to the pit, a hole dug in the earth, walled on the sides and paved at the bottom, out of which they are cast and carried to the buddle, which buddle is only a piece of floor of wood or stone laid very little sloping, about 6 ft. in length and 2 ft. in breadth. On the one side whereof, a board of the same length as that side and about 8 inch broad, is set on edge and backed with earth to the height of itself, this is called the buddles-head, as a gap or indenture cut out at equal distances from its two ends for a small stream of water to pass through is called its eye.

This buddle being charged with the pounded slags and lead intermixed with them as they fall from the mill, to the quantity of 5 or 6 bushels at a time, the necessary water which is kept running near at hand for the purpose is turned into it and a channel made for it close to the head-board of the buddle; which done the washer with his shovel or coal rake, begins to make new channels for it across the first, continually pulling or turning over a part of the heap to the side next him with the water running amongst it until he has passed in this manner through it to the other end, where he turns off such light (being supposed the worthless) parts as the water has driven to the skirts of the heap, leaving the remainder in a semicircular form. These tails (they are called tails at a smelt mill, but at the lead mines cuttings), being disposed of by being cast away, he again turns the water into the buddle, and passes through the heap in the same manner as at first, repeating such putings-through of the buddle, with the circumstances of diverting the water from it and discharging a quantity of tails at every repetition until he judges his work (what is still left in the buddle) suf-

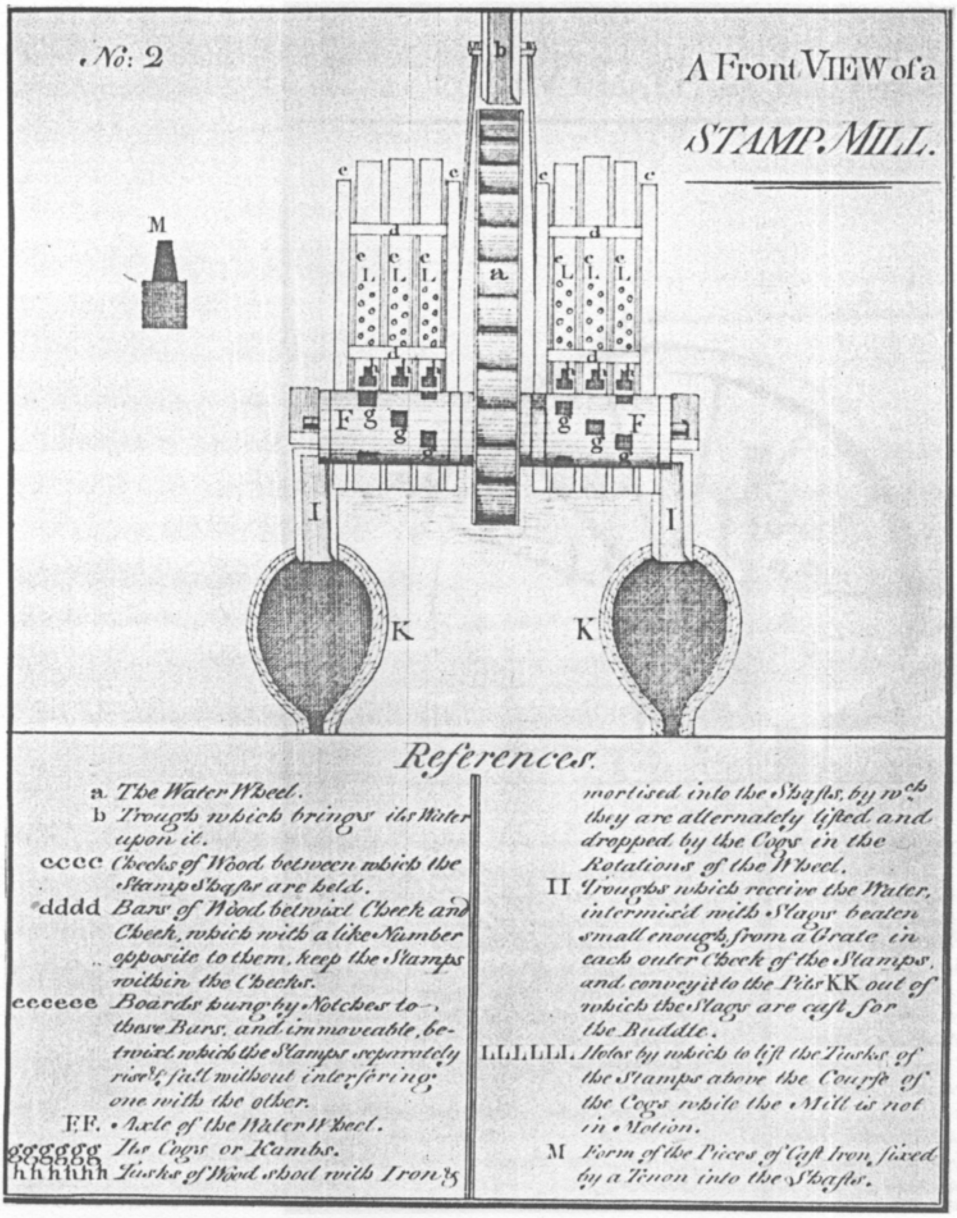

Fig. 4 — Front elevation of a stamp mill.

ficiently dashed, as it is called, meaning made fit for the tub and sieve, to which I proceed, after having informed you that this just described is what is called the running-buddle, to distinguish it from two other in use, the one named the draw-buddle and the other the trunk-buddle. Upon the running-buddle I would observe, and then have done with it, that the several strokes of the washer's rake or shovel being as so many radii whereof the lye or in-falling of the water of the buddle is the centre, it is towards that point that the thing valuable (lead here or ore at the mines) will be collected; its weight resisting the water, at the same time that the light and worthless substances are born down by its current to which they are certainly exposed by the action of the water above described.

After such buddlings have continued for several days or weeks and sometimes months and a good deal of dashed work is laid up, in order to a making-up, as a final cleaning is called, then a tub is provided, about 3 ft. in height and 2½ in diameter, filled not quite but almost so with water, and also a sieve, which is a small wooden vessel with two handles and a bottom of wove wire. Into the water of the tub this sieve, with a charging or loading of about one gallon of such substance as is to be washed, is immersed nearly up to its brim, where being tossed to and fro for some time, the minute parts of such substance are sifted through and sink in the tub, whilst at the same time the lightest parts, which from their bulk cannot pass that way are thrown uppermost within the sieve, and when they are supposed to be sufficiently so, then it is heeled or lowered on that side furthest from the person who holds it, with a very gentle heaving of its contents, that the parts thereof which where once uppermost may continue so until the whole of those contents are got to the depressed side and are almost ready to get over its brim. This is called a setting and is followed by what is called a setting-off, which is a bringing of the sieve from its heeled into an horizontal position, continuing in the meantime the same gently heaving and tremulous motion, thereby to cause the light parts, which were uppermost whilst the sieve was stouped to fall down upon the vacant part of its bottom, and to the skirts of its more heavy contents, which done, it is taken out of the water and placed upon a bar of wood or iron for a rest and laid across the top of the tub, where, to skim off the light parts, which at this first setting are generally fit only for the waste or cutting heap, a small instrument called a limb is used, being a semicircular piece of board, about 8 inch. long, hedged with iron on the curved side; and such is the disparity of the weight of lead and black slag that the separation often is effected by one or at most two such settings and settings-off. But at the mines where there are many bodies almost as ponderous as ore and where that ore is frequently brangled-in with those bodies, such settings must be repeated perhaps several times; first to take off what can be accounted only refuse, and then if the work be much brangled, as is too often the case, to discharge it of that which should be returned to the knock-stone, there to undergo a further pounding which is not the case with that which is now our subject, there being nothing intermediate between lead and black slag, so that when the former is as much as may be cleansed from the latter, it is then fit for smelting, or rather melting, for it is chip-lead, only some of it a little drossy.

I come now to that part which has passed through the sieve which is called smithorn or smiddon with which at times the tub will be so filled that the bottom of the sieve will strike upon it; and when this is observed, the tub is then emptied of it and it is carried to the buddle, where with a less powerful stream of water it undergoes as many pullings-through, in manner as described before, as will make it clean and when it is so, it is joined to that prepared in the sieve as being equally fit for smelting; only at the conclusion of every making or dressing-up (as well here as at the mines) there will be a remainder which cannot be made perfectly clean in the buddle, but is too valuable to be cast to the waste heap and upon which therefore a further operation with the sieve, called letting-in has been found expedient, which is thus performed: A Sieve with a bottom of smaller wire and more close worked than the first is generally chosen, upon the bottom whereof a bedding or cover about one inch in depth of chip lead here put of some heavy substance of ore at the mines is spread and which is of such a size as shall merely prevent its going through the sieve, but not larger. Upon this bedding a quantity, perhaps 3 or 4 quarts of these smithorn tails as they are called, is laid and which being levelled and smoothed over with the limb, the sieve is taken down from its rest and with a very steady but gentle heaving motion is sunk almost to the brim in the water, where the same motion continued for some time, by this means the whole contents of it, including the bedding are in some degree as it were afloat, during which the most heavy and most valuable particles penetrate through the bedding (the superior weight of which keeps it still undermost) and also the wires of the bottom and are deposited in the tub, leaving the light and worthless part resting upon the bedding, from which, the sieve being taken out of the water, it is skimmed and cast to the waste heap. A dexterity herein is one great qualification in a washer. No process in washing saves more of a valuable mineral, and at the same time makes it more clean then this, when well executed. I have seen it so well done that scarce any weighing (I think all washing is a sort of hydrostatical weighing) could have better ascertained the comparative specific gravities of the following bodies. In the sieve, when taking out of the water, the first layer was of the mud sand or grit into which the stone of the mine had been beaten; under that and very distinct from it, was a layer of black jack or lapis calaminaris; this was succeeded by another equally distinct from it of sulphur; under which was the bedding of ore. But here I was concerned to see that the distinction was not so nice, for I observed that the lightest parts of the ore and the heaviest parts of the sulphur were so intermingled that they seemed to be inseparable by any mode of washing, though nothing is more pernicious in lead ore than sulphur. But to return from this digression. If from time to time a surcharge of the bedding of the sieve should happen, as will sometimes be the case, it may be diminished by taking what is needful of the best of it, which with what has gone into the tub after that has undergone two or three puttings-through of the running buddle, may be taken as fit for smelting, though being the produce only of hinder-ends, to borrow a farmer's expression, it cannot be expected to be so hearty as that which had gone before it.

Upon the smelting of the produce of black slags there is little observable, only that it is done in the orehearth; that in the treatment of it in smelting, it differs from ore in this, that being almost all lead, it produces but very little slag; that the watchings to discharge that need not therefore be so frequent; but that such slag as is produced is returned to the slag-hearth and there smelted in a similar manner with other slags.

ON THE WASHING OF LEAD ORE

Having for a long time paid a particular attention to the washing of lead ore, because upon the well-doing of it a success in smelting depended about which I could not be otherwise than solicitous, being paid for my care therein; I have seen, and every one skilled in the business will admit, that towards the thorough dressing of any ore, and that with as little waste of it as possible, the reducing such ore and those impurities from which it ought to be cleansed to an equality in point of size, is a preparation highly expedient, if not absolutely necessary. This will give the former the advantage of the latter under every mode in which washing is practised.

A chip or particle of ore being more ponderous will undoubtedly withstand a current of water longer than a chip or particle of stone or other matter from which ore ought to be cleansed, of the same dimensions, but a chip or particle of stone may be of such a bulk as to outweigh such chip or particle of ore, wherefor under such circumstances to associate them in washing would be improper. For instance, in the first operation of the sieve (the manner of doing which I have before endeavoured to explain), where nothing should be above the size of a good hazelnut, pieces of spar, common stone, black jack, or sulphur, will in water, have a small degree of buoyancy, which ore has not, and which renders them separable from it, if in pieces of the same or nearly the same dimensions; but let such pieces of spar be exposed with smithorn to the impetus of a buddle water, and the result would be that they would resist it, whilst very valuable parts of the other would be borne down by it. Or let the impure, but largest particles (what the washers call the rowny parts) of that smithorn be exposed in like manner with what is commonly called slime ore, which is the smallest of all ore; and the result would be similar, therefore that each part may receive its suitable respective treatment in the dressing, that the pure may outstand the impure in every mode of exposure to water, it is necessary that in the course of procedure in the dressing, the bouse* be so divided as that it shall ultimately produce

shaddered ore
sieve ore
smithorn
slime ore

of all of which in their order, and first of

<u>Shaddered ore</u>: How it got or why it has that name I do not know, but think it would have been more properly denominated hand-picked-ore, for such it is, being what those pieces of the bouse called knockings are, broken into if clean, or if not what is broken off from such, the refuse whereof is called pike-stones, i.e. picked stones, out of which, at some mines, a good deal of ore might be gotten, if the use of a stamp mill† could be had for pounding them, but the ore got would not bear the expense of doing that by hand. This ore needs no washing, being picked as above and carried to the bingstead as clean, though it too often happens that it is not so, owing to sufficient care not being taken to clear it well from stone or by its being left in too large pieces, by which means particles of such stone may be and often are hidden in it. A too anxious endeavour to make a great deal of this sort of ore is a fault, the temptation to which is, that it is done without much trouble and where this is practiced, it also impoverishes the

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* The pieces of lead ore intermixed with spar, in the state they are when they come out of the mine.

† The Gov. Hse. have lately erected a stamp mill for this purpose nr. Nenthead, by means of which they gained last year from the pikestones about 300 bings of ore, and expect this year I understand to get about 500 more. J. M.

sort which immediately follows and to which I now come, viz the

Sieve ore: In the sieve, however accurately it may be set, the most heavy of its then contents can but take that place in the setting which in my last I have said the real clean ore, or other matter proper for smelting, ought to occupy; but if in the shaddering, all, or almost all of such clean ore be taken away, and none or very little but the most light left, the brangled, or such as is part ore and part stone or other substance, should be returned to the knock-stone for a re-pounding and might after that produce good smithorn if not sieve ore; but such I say, and also the most heavy of the black jack and sulphur will be so nearly of the same weight with such light ore as is left, that after divers ineffectual efforts in the setting, the washers find that they do not separate and thereupon pronounce that the work wants a body (of which they themselves have deprived it as has been shown) and that therefore it cannot be made good ore and so it passes without being made so, leaving at the same time that part to which I come next, i.e. the

Smithorn: In some measure impoverished also, for if the brangled parts which are passed with the sieve ore were beaten down, the quantity of the ore of this kind would be thereby increased and such increase would also contribute to the bettering of its quality; for the more there is of any sort which requires the same mode of washing, the greater probability there is that that part will be well dressed, and how that sort which I am now upon should be managed to be so with the least loss of its quantity I have endeavoured to shew in my last letter, i.e. by a sufficient buddling by the workmen being not sparing in taking off the tails and letting in those tails, all which being done by good hands, this will be well saved and at the same time will be as valuable as any ore; but the method of dressing this does not extend to what I have made my fourth and last division, viz

Slime ore: As the sieve ore is derived from the shaddered and the smithorn from the sieve ore, so is this last, as being of a still smaller size, derived from the smithorn, being separated from it in a manner which I shall shew presently and indeed to preserve the latter perfectly, they ought to be separated previous to the former undergoing any sort of washing, but in the dressing of ore from the bouse, the prices paid per bing for washing will not permit that such a tedious process should be carried into practice, so that this slime ore is either left in the smithorn with its attendant impurity called sludge, much to its detriment in the smelting, or it is washed away and goes to the waste heap; the best that for a time can be made of it, for from thence it is recoverable when the cuttings are washed by the trunk-buddle or lew, of the uses whereof I come now to speak, and first of the trunk-buddle, which consists of a piece of trough or wooden aqueduct about 2 ft. in length and 10 or 11 inches in width and depth, next of a small box 18 inches in length by 14 in depth and width fixed in the earth somewhat below the level of the trough, out of which box is a passage (see drawing [Fig. 5]) which expands to the width of the trunk itself, which is a sort of flat chest 9 ft long, 3 broad and 10 or 12 inches deep, with an outlet for the water at the lower end of about 8 inches in width, which compleats the composition. The first use of this buddle is to effect a separation of the slime ore from the smithorn in order to their being dressed separately and it is thus performed. A pretty strong stream of water is turned into the trunk, into which one person (commonly a boy) casts shovels full of the matter to be separated at intervals and as often as he sees it is born down by the current into the box, when another keeps stirring and troubling it in the water by which means the lightest and most minute particles are set

Fig. 5 — Ore dressing floor (in the original drawing the water is coloured blue).

afloat and are carried over the above passage by the water and fall with it into the trunk, against the head board of which the most valuable parts are deposited, whilst the more light and worthless are born further down (see drawing [Fig. 5]), from which however that nothing of value may escape, a quantity of still water is constantly kept in the lower end of the trunk by placing stops or obstructions (small pieces of wood) in the outlet for the water gradually and as the matter is seen to rise in it, so as that the water and that matter may be kept nearly upon a level. The principal object of this first procedure being to effect the separation just described, no part is by it made clean: of that which remains in the box and which as often as it is seen to be freed from the light and minute parts is cast out, the cleaning is compleated in the running buddle and by letting-in as I have elsewhere described, but that which goes over into the trunk is perfected in its dressing there in the following manner: As soon as the trunk is once filled or nearly so, the water is turned off and the most ory part, viz. that next the head board is cast out upon one heap; then what lies next, proceeding downwards is cast upon another heap, and if what lies immediately behind that is also seen to contain some ore, then a third heap is made of that, after which the trunk is cleansed from the remainder which can only be accounted refuse, and repetitions of what I have now been describing are made until the whole matter in hand is so gone or passed through or until the heaps cast out become such in quantity that a compleating of a dressing of them is seen necessary, which is thus performed: The trunk is made clean, water is turned into it, which falls in an equally diffused stream over the whole length of its head board, along which quantities of those heaps taken upon a shovel are drawn to and fro, the water washing them gradually off until the chest of the buddle is filled, the stops in the outgoing of the water being placed as in the first operation above described. At every passing through in this manner, the ore approaches nearer to being clean, and at last if they are repeated sufficiently often, it will be perfectly so, not even excepting what is contained in the second and third heaps; only to make that clean will require a greater number of such repetitions. And thus much of the use of a trunk-buddle of which I have taken notice before that of the lew and draw buddle, it being a more expeditious and in my opinion more safe mode, and therefore I think its use preferrable to theirs. However, I shall endeavour to describe these two latter and their use. First the lew, which is a sort of sieve, the wooden part whereof for the sake of lightness, is made of lath, and the bottom not of slight, but pretty close canvas, having nothing to pass through it but water. In form it resembles those sieves with hair or silken bottoms which are used for the bolting of wheat flour; only on each side of this is a sort of crooked handle, by which, when used, it is made to float and roll upon the water of a tub, at the same time that there is a sort of effort made to depress it in it; by which double and seemingly contradictory movements, in the management of which some dexterity is required, their joint purpose is effected. The pressing downward being done that a springing up of the water through the bottom of the sieve may put the matter wherewith it is charged into a sort of fluidity, of which state of it advantage is taken by the rolling motion, to throw out the most light parts, which go over its brim and outside in the tub, out of which they are taken and carried to the draw-buddle, for the form of which I refer to the drawings [Fig. 5] and shall only observe that across the in-falling of the water is a piece of board upon which, when at work, the washer stands with his face to the buddle and the matter to be washed being in small quantities and occasionally turned into the right hand corner, he draws it with his coal rake into the fall of water, as it pours over the head board in an equal stream of 10 or 12 inches in breadth (as in the trunk-buddle), until the buddle is filled almost to the height of the head board, when the work is sorted in like-manner as is that of the trunk buddle, those drawings being repeated as often as circumstances require, until the whole is thereby made clean, though not, I think, either with that speed or safety with which the same may be done in the trunk buddle. What remains in the lew to be made clean undergoes the same process as that which is left in the box of the trunk buddle, which I need not repeat. I have only further to add, that all sorts of ore after the shaddered are made either from dashed work, which is prepared for the sieve from the smallest of the bouse, as it is drawn from the mine in the running buddle, where the most gross parts of its impurities are thrown off; or from knock-back, which is such, as falls off in the shaddering and has passed upon the knock-stone under the bucker, or being found brangled in the sieve, is returned thither for repounding.

I shall only make one observation more which is, that if ore, to be well dressed and well saved, ought to be sorted as I have above sorted it, how absolutely necessary is it that each part of it should be so well done as not to require a re-doing at the mill, whither all sorts are brought and laid together promiscuously; for to rewash it well and with safety, an analysis or separation of it into its different sorts should be made which would be too tedious and expensive and is therefore never practised.

I should advise that this letter might be looked upon as No. 1st and then, from a recapitulation of what has gone before, it will appear that I have been endeavouring to shew first by what sort of treatment lead ore, after it is raised or gotten out of the mines, is made fit for smelting, with the several modes of procedure therein. Secondly a description, and as well as I have been able to give it, an explanation of the first process in smelting called ore-hearth smelting. Thirdly, the same of slag-hearth smelting; and fourthly I have shewn the manner of stamping, washing and smelting black slags, which last compleats the total procedure of lead to be obtained from the ore by our present mode of practice, and which lead is thus finally fitted and made ready, either for immediate sale, or for refining, but to which of those uses it ought to be put, can be known only by that which I have proposed to call, process 4, or assay-making, which I purpose making the subject of my next letter.

ON THE ASSAYING OF LEAD: PROCESS 4TH

On finishing my last I think I observed that after the whole produce of lead was collected from the ore by means of the different processes, I have endeavoured to describe and explain, it remained to be determined whether such lead ought to be sold or detained for refining, which could be done no otherwise than by that further process which I have called assay-making, or by making an assay of it: but I would be understood to mean of the lead of those ores only with the properties whereof we are unaquainted, or of which we are in doubt, there being several long worked mines, the character of the lead of which is so well established by repeated trials, that my assay of it would be unnecessary, yet as the ore of the same vein may be and often is raised from a variety of beds or strata, and variations of its bearings of silver* may consequently happen, frequent assayings are therefore requisite, especially of the lead of such ores as have been found to contain little more silver than will just bear the expense of refining, or so little that it will not bear it at all, for instances have been frequent of such variations happening in each, as that the one has fallen below refinable and the other has risen above it so as to leave a profit worth attending to. Ore lead which has generally been found to contain between 8 to 10 oz. of silver per fodder (21 cwt), will seldom fall below refinable, but the slag lead of the ore may, and often does, and therefore should not be passed either for sale or for refining without an examination of assay. A like examination should be made (and which we practise) of the lead from which it was extracted, at the close or final cleaning up of every cake of silver, to know if the refiners have done their duty. Having said all that is necessary of the utility of assay-making, I now proceed to the manner of doing it.

The furnace in which we do it is in construction so simple that I shall hope the two sections of it herewith sent [Fig. 6] will be sufficient to enable any person so to understand it that a description of it in words will be unnecessary. For the forming of the assay-test or copal as I find the learned assayists call it, we take of the same ashes the refiners use,

* Variations in the quantities of silver produced from given quantities of lead.

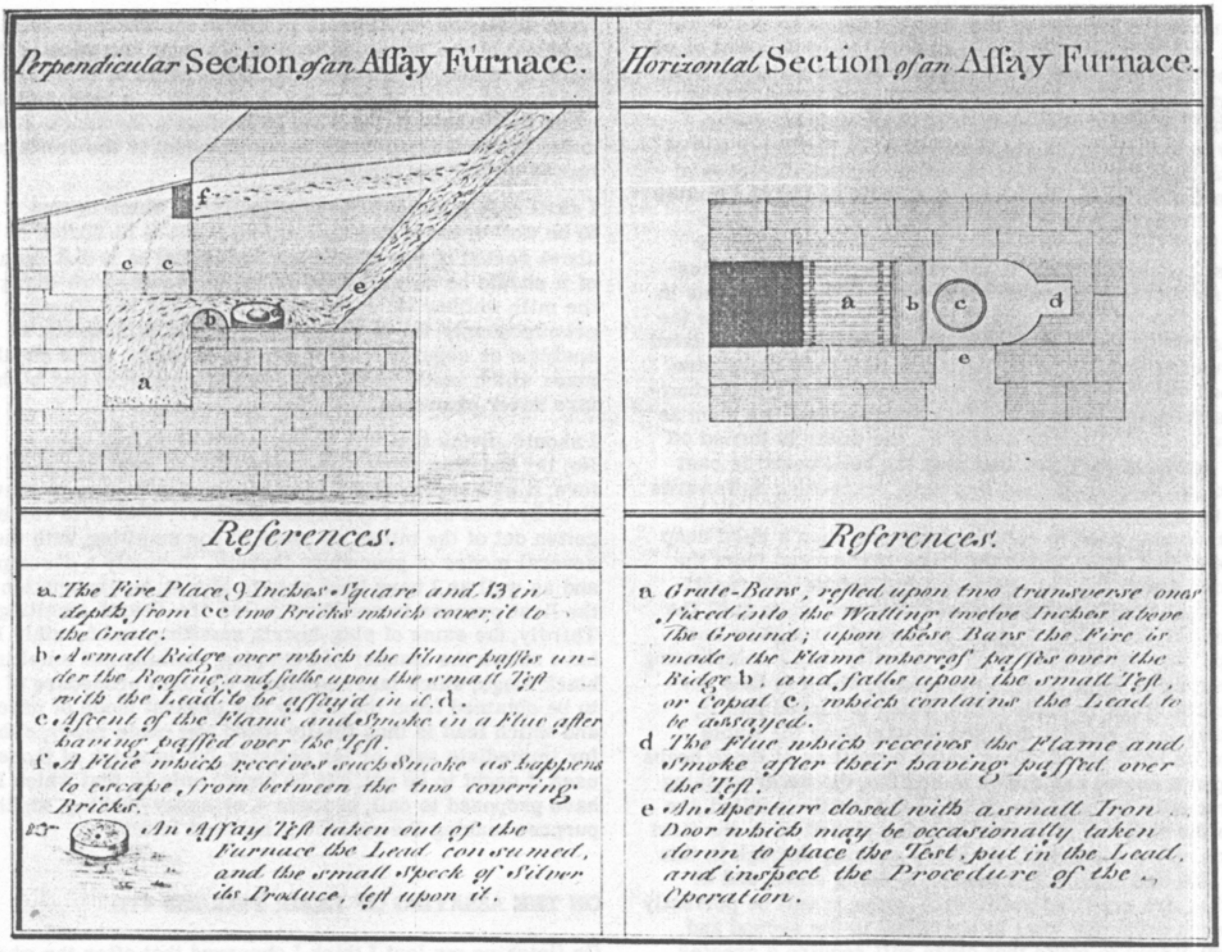

Fig. 6 — Assay furnaces for silver assay by cupellation.

which is a mixture of about 4 parts bone and one fern ashes, moistened so as that when pressed in the hand, they will not fall to pieces, but continue in a ball; these are beaten into a small iron hoop about 5 inches in diameter and 1½ inch depth until it is quite full, when with a round pointed knife we scoop or hollow the ashes in it, leaving those towards the brim the highest until we judge the concavity may contain 1 lb., ½ lb. or ¼ lb of such lead as is intended for an assay. This test being first sufficiently annealed or dried, is placed as level as may be in the furnace for the reception of the lead to be tried, which that it may be a just sample of the whole, is taken a chip from each pig of every particular parcel intended to be assayed, and those chips being melted and well mixed together, so many pounds, half pounds or quarter pounds as are designed for assays are cut from the lump so melted and mixed and as soon as the furnace and test in it are thought sufficiently heated, one of the pieces of lead is placed upon the test, where it is presently in fusion and takes a form, if I may be allowed to borrow a similitude from Milton, like "a drop on dust conglobing from the dry", by which I mean that it assumes a partly convex surface, not a flat or rather concave one, as water will when poured into a wet vessel. Upon this surface the scum almost instantly breaks, if the heat be intense enough the whole mass becomes as bright as silver and presently some litharge is formed and is seen to play to and fro upon it, a part whereof passing to the edges of the metal, is absorbed by the test or copal, whilst the rest is carried off in vapour, so that in about half or three-quarter of an hour, if the process be properly conducted, a quarter of a pound of lead, by this double waste of it, will be wholly expended and nothing left but such a particle of silver as it may happen to contain and with no more need be done but to weigh it accurately, and to calculate from the quantity of lead in the assay and the silver produced from it, how much silver in the same proportion of fodder of such lead will contain; and experience having convinced us that this may be done with such precision that a very trifling disparity, if any, ever happens between the produce of silver from lead in the great work and of the same per assay, we therefore confide in the latter for determing whether any lead will or will not bear the expense of having its silver extracted from it in that work which we call refining, and which will be the subject of a further letter.

To the process of assay-making I might here put a period having, I think, said all I can upon the usefulness of frequent assayings and of our manner of doing it, were it not that about two years ago our great practice herein suggested a thought which I could not then help entertaining and which I own rather haunts me yet, and chimerical though it may appear (the reverse of an old man)—yet I cannot let slip this opportunity of mentioning it. It will be a case to me similar to that which some people experience in relating their dreams, however frivolous and uninteresting they may appear to others. This of mine I read to Mr Hollier,* when he was at Langley Mill and he seemed to think that I am right in the conjecture.

I set out by supposing from what is now doing at Bill Quay, Bells Close and other places, that there are some mineral substances which contain silver from which it cannot be extracted unless such bodies be first in fusion with lead, with which it then incorporates and from which it is extractible by that operation which we call refining, and I have been led to think that we may not be quite sure whether the silver which we obtain by that operation be really inherent in the lead ore, or whether it may not be other yet unnoticed mineral body intermixed with or adherent to it and which being in fusion with the lead, in the operation of smelting is attracted by and becomes incorporated with it in quantities

* A gentleman who had the management, a few years ago, of a refinery at Bells Close near Lemington.

Names of the mines from which ore was raised	Bouse ore lead, silver				Cutting ore lead, silver				Differences of produces of silver			
	oz.	dwt.	gr.	10th	oz.	dwt.	gr.	10th	oz.	dwt.	gr.	10th
Brownley hill, Moss Cross, North vein, Guddamgill Burn Cross vein	7	16	9	2	11	10	7	2	3	13	12	
Cars west of Nent	4	13	2	4	5	—	10	8	—	7	8	4
Blagill	7	7	—	—	9	1	7	2	1	14	7	2
Thorngill	7	7	—	—	9	2	12	6	1	15	12	6
Middle Cleugh	10	15	14	4	13	4	14	4	2	9	—	—
Rampgill	9	6	4	8	10	13	3	6	1	6	22	8
Scaleburn Moss	8	6	14	4	11	—	12	—	2	13	21	6
do. " (Cutting ore rewashed).*	—	—	—	—	9	11	2	4	1	4	12	—

* I have examined several assays in my father's possession at Langley Mill, which seem to establish the certainty of Mr. Mulcaster's conjecture being well founded. Signed J. M.

proportionate to the more or less there may be of such mineral substances as I have supposed to contain silver or to the richness or indigence of them.

That all lead contains more or less silver, I have not the least doubt, but whether that may not be owing to every lead ore having an attendant or accompanying silver ore, variously circumstanced as to quantity and quality, I am really in doubt, because there are some circumstances, indeed some irreconcileables which seem to countenance such a conjecture. Such as the yet unknown reason why all unrefined lead does not produce silver in equal quantity, but chiefly we observe that the ores from which we obtain most of it are the least separable, nay that they are almost totally inseparable from the other mineral bodies which accompany them in their natural state in the mines. Bodies which may, and undoubtedly do, cause part of their lead to be wasted by protracting the operation of smelting, but which may notwithstanding enrich it by the accession of their silver.

It is also to be observed that when an assay is made of ore, to know what proportions of lead it contains, it is generally, but very improperly made of the most clean or picked parts of it, which is no just sample of the ore in gross, and when an assay is made of the lead so obtained to ascertain the quantity of silver it contains that has always been found to fall short of the assay of the same lead procured from the ore in the gross and in the ordinary way of smelting. The disparity between the produces of silver from the ore and slag lead of the same ore makes more for than against my supposition, for silver is easily soluble with lead. An ore hearth smelting heat may bring the greatest part of it off and what is left in the slag may be only the draining of such substances as I have supposed in like manner as the lead got from the slags may be called the final draining of the ore.

Be all this as it will, as our cutting ores of every sort are always ill dressed, have great quantities of every kind of matter with which they were intermixed and connected in the mines, run down with them in smelting and consequently if any such substance as I have suppose should exist, they must have the greatest share of it; therefore we always think it right to make assays of the lead of our cutting ore of every sort that a comparison of the produce of silver from it, and from the lead of the bouse ore of the same mine may be had.

At the time of writing this I know nothing of the result, but if it should be that the lead of the cutting ore is found much the richest in silver, I should not therefore insist that my hypothesis was established, because I am aware that it may be objected and with an appearance of reason too, that the lightest parts of the ore, such as will go off in the cuttings contain the most silver, but to which I beg leave to reply that I think such light ore will be of the refractory kind, that it will not be easily discharged of its lead, nor, if it has any, of its silver; that it will be the most likely of any ore to carry the most of each to the slag hearth and that consequently the lead obtained there, ought to be the richest, but which in no one instance has ever been found to be the case, and which I think puts it past a doubt that the least refractory parts of any ore are productive of the most silver. In confirmation of this it is said that in air-furnace smelting the lead run off at the first tapping, will be found richly worth refining whilst the after-drainings, which must be the produce of the most refractory parts of the ore, will contain but very little silver and this, it is said is one great advantage of that mode of smelting.

In the latter end of the year 1781 and subsequent to my writing the above, my brother and I made assays of the lead of as many sorts of cutting ore as we had at that time by us, in order to make the comparison I had proposed and the several results were as subjoined [see Table above].

From the above I think it is clear that if the silver we attain is really inherent in the ore, it is not equally so throughout the whole mass of it. Scaleburn Moss cutting ore, you see, by rewashing produced almost $1\frac{1}{2}$ oz. of silver less per fodder of lead than the same ore did when smelted as rend from the mines, from which circumstance and from the whole of the above comparative view of the produces of silver from bouse and cutting ore lead, I think it is equally clear that in the ore washing we do cast off something which contains silver, but whether that something is or is not a light ore (an heavy ore it cannot be), or some other substance, I remain in a scepticism, towards the cure whereof the above experiments have not at all contributed, on the contrary, I have been led by them, perhaps ignis fatuus like, to consider what are the observable fossil and mineral substances which accompany the lead ore in the Alston Moor mines, and this I shall make the subject of my ensuing letter.

CONCERNING THOSE SUBSTANCES WITH WHICH THE LEAD ORE IN ALSTON MOOR IS GENERALLY CONNECTED OR ACCOMPANIED

I now proceed to shew what are the observable or most obvious mineral and fossil bodies which accompany or are connected with the lead ore in the Alston Moor mines. I shall call them by the names they go by in that country, for indeed I do not know them by any other, neither am I much aquainted with their respective properties further than as I have observed those properties to affect the operation of smelting, when (as is too often the case), the ore is not well dressed or separated from them at the mines; and I give my observations upon them, as will be seen more as an appendix to what I have formerly said upon ore washing and smelting, than with any intention to shew the probability of some of them containing silver, for which notion I acknowledge I have nothing but conjecture, founded on such reasons and results of experiments as I communicated in my last. Indeed if there should be any grounds for my suspicion what I have been doing in this letter, i.e. distinguishing the substances with which the lead ore is found mixed, would be one necessary step towards the investigation. If however, I were quite sure, which I am not, nor perhaps ever may be, that some of these bodies did contain silver, I should not therefore advise their being kept mixed with the ore for the sake of obtaining it; for I am convinced that the doing so would occasion a waste of lead, in value more than equivalent to that of any silver which could be gained. At the same time, if it were certain that some of the following bodies contained silver, I am quite clear that it ought to be got in some more cheap way than that of fusing the substance which contained it with lead itself, perhaps it might be effected with the grey slag of such ore only (as is practised by Mr. Hollier with his mineral or minerals which contain silver and we suppose gold also, but no lead) until that metal is communicated to and incorporated with the other, as it is produced during their joint fusion from the grey slags, and from which the more rich metals are separable by the ordinary process of refining, as I observed in my last. It is beyond a doubt that there are somewhere bodies which contain silver without any admixture of lead, and why may not some of those bodies therefore be found in a lead mine.

The substances I have proposed to observe upon are I think distinguishable into:

1st Stone
2nd Sulphur
3rd Black jack
4th Spar
5th Coke or coky spar
6th Copper ore
7th Soil
8th Plate

of all which separately and in their order and first of <u>stone</u> of different sorts and going by various appelations, such as limestone, hazel, fire—or free stone, and slate, as the sills or strata in which the ore is found happen to be, but differing from stone found in ordinary situations in this, that they are commonly more or less what the miners call burnt, i.e. much hardened by having been in, or lain contiguous to a vein. The stone found in the latter position is called rider, i.e. that which forms two cheeks between which the veins which carry ore are held. All the different kinds of stone are extremely averse to vitrification, and if brought into that state along with the ore, they are to a smelting hearth (if I may be allowed to borrow a term which expresses an animal function), of hard digestion, by which I mean that stone of any sort goes so hardly and with such difficulty, into slag, that to continue the medical style, the necessary evacuations are interrupted, the whole mass of the brouse becomes thereby vitiated and the hearth is surcharged with it; fresh ore therefore cannot be exhibited, or but in very small quantities. Consequently little or no lead can be expected and a remedy must then be sought, which is generally in an application of more fuel, agitated by a more increased effort of the bellows than is requisite for the reducing of the ore itself, by which the produce of lead is greatly wasted, besides that this remedy is often ineffectual; for I have frequently known hearths thus circumstanced so distempered that the digestive quality of their brouse has been quite destroyed, and it has not been but with difficulty and loss that a supply of the most clean and free ore could bring about the necessary purgation, by a discharge of slag, which alone could effect a cure.

<u>Sulphur</u>. This is a most pernicious mixture in lead ore, and as I have elsewhere shewn, is with the greatest difficulty wholly cast out of it. Exposed to such a degree of heat as is necessary for the smelting of ore, it becomes intensely hot, spreads an excessive glow throughout the whole of the brouse or ordinary contents of the hearth, such as lead cannot sustain without being wasted by it, goes but a very little of it

Assays made by Messrs Mulcaster at Langley Mill.

No.	Names of the Mines from which the ore was raised.	Bouse Ore Lead Silver in the oz.	dwt.	gr.	10th	Cutting Ore Lead Silver in the oz.	dwt.	gr.	10th	Difference of the produces of silver. oz.	dwt.	gr.	10th
1	Thorlergill Syke & North Vn.	21	5	1	8					3	19	15	—
	Do. (Seemingly not fine)					25	4	16	8				
2	Slote (rather mixed)					8	16	9	6				
	Do. (pure)	7	14	8	4					1	2	1	2
3	Carrs. (Bouse & Cuttg mixed)	4	13	2	4								
	Do. (Cuttings only)					5	—	10	8	—	7	8	4
4	Windy Brow	17	12	19	2	13	14	19	6*	3	17	23	6
5	Nentsberry Haggs	20	18	22	8	27	16	3	6	6	17	4	8
6	Carrs West of Nent	4	5	18	—	8	18	20	4	4	13	2	4
7	Lough Vein	6	17	4	8	7	11	21	6	—	14	16	8
8	Brownley Hill North vein	8	1	16	8	19	7	2	4	11	5	9	6
9	Guddamgill Moss	15	1	8	4	13	16	20	4*	1	4	12	—
10	Lough Vein	6	14	18	—	7	14	8	4	—	19	14	4
11	Windy Brow	8	4	3	6	8	1	16	8*	—	2	10	8
12	Brigal Burn	9	11	2	4	8†	11	12	—*	—	19	14	4
13	Hangingshaw & Cowhill × Vein.	4	13	2	4	7	9	10	8	2	16	8	4
14	Middle Cleugh	10	13	3	6	12	14	19	2	2	1	15	6
15	Lough Vein	5	10	6	—	6	2	12	—	—	12	6	—
16	Longholehead	8	18	20	4	9	11	2	4	—	12	6	—
	1791 Nov. 24 Cowsletts Cross vein	3	6	3	6					8	4	3	6
	1792 Jan. 6 Do. Cutting					11	10	7	2				

The above assays were made at different times from the year 1775 to the year 1793, & those Nos marked * are the only instances where the produce of silver from the bouse ore lead has exceeded that from the cutting.

† Sandy coloured cutting.

into slag or scoria, but is mostly expanded in its substance by evaporation and causes an immense waste of the lead in the same way. I suppose this is the ore of sulphur, properly so called or brimstone. A person I saw at Keswick, an agent for a Copper work, informed me that when it abounds in the copper ore, they are obliged to roast it out before they carry the ore to the smelting furnace; that in so doing, by some sort of contrivance they collect a considerable quantity of good sulphur or brimstone and that so inflammable is this mineral, that it need but be kindled once to turn with vehemence without the aid of any other fuel. Having formerly been an Alston Moor miner, he added that the sulphur of the copper ore, so far as he could judge, does not at all differ from that in the Alston Moor lead mine.

Black jack (or lapis calaminaris). In form this substance often resembles the foregoing, and on that account is by some believed to be of the same quality and only differing in colour, viz. that the one is a yellow or golden coloured and the other a black sulphur; from which opinion I differ, because having heated a piece of the former red hot and passed my nostrils over it, I was sensible of a very strong sulphureous or brimstony smell; but having done the same with a piece of this, I could not perceive that my olfactory nerves were affected at all: I therefore think that this is not a sulphur ore but suspect, from some appearances I have observed upon it when hot, that it may contain an arsenick.

This is a more common mixture with lead ore than sulphur and it is not less mischievous in the operation of smelting.

So deceiving also is it, that in the mine and by candle light it is often taken for the ore itself; even in daylight, if it be of the shining black sort, a sprinkling of clean ore smithorn, which the washers are artful and knavish enough to give it, will so disguise it, that it may be and often is taken for good ore, until a shower of rain falling upon it discovers the fraud. From what I have observed upon washing, it appears that this mineral being a lighter body than sulphur, the ore might by care and honesty in the washers be more easily freed from it in the dressing than from the other, yet as it seldom is so where any of it is dug up with the ore, I have had frequent occasions to observe its effects upon smelting and have seen that if they are less violent, they are more lasting, and therefore equally injurious to it as those of sulphur. Like that substance, the greatest part of this is consumed by evaporation, but this being less, or perhaps not at all a combustible, the waste of it is more slow and vexatious. I have also observed that but a very small part of its substance goes to slag, and that whilst it is extremely averse to taking that form itself, it hinders every other body joined in operation with it from doing so; that when it abounds in any ore, it causes the best tempered brouse to go into a dark inert and heavy mass, which the blast or stream of air from the bellows cannot pervade, but which instead of preserving its horizontal direction and thereby invigorating the whole operation is repelled and wasted by being thrown upwards, which the smelters call the metal not taking the blast, that under such circumstances the perspirations of the lead from the ore are extremely slow and the ducts by which it ought to descend to the receptacle of it in the bottom of the hearth are so shut up by the close texture of the brouse, that the particles of it hang in a slow but consuming fire and the produce is thereby greatly wasted.

Spar. If this be of the light, free and almost transparent sort, it is the most harmless mixture which can be left in lead ore. Directly contrary to both the foregoing, this in a moderate smelting heat digests into a very light and distinguishable slag, at the same time greatly promoting a like disposition in such other bodies as happen to be in the fire with it. Being a more light body than most of the others with which lead ore is generally found mixed, a smaller quantity of it is therefore left in the ore after dressing, which is not a great fault, for the ore with which it is found is most commonly of so free and fusible a quality of itself, and so exempt from other heterogeneous and refractory mixtures, that it has no need of this as a flux. Perhaps it might be used to advantage as a flux in smelting some of our most refractory ores, but indeed the Alston Moor lead mines do not produce much of it, at least very little of that sort, without which, as I have been told, there are some fat rich lead ores in the Yorkshire Sun-Dales, as they are called, that can scarce be got smelted and which is brought sometimes from a considerable distance to be used as a flux.

Coke or Coky Spar. Of this there is great plenty in the Alston Moor mines. It is a close, heavy, opake and extremely refractory substance. Sometimes so glitteringly white and also so very heavy, that it is mistaken for white lead ore. In some of the mines the larger pieces of the ore, the shaddered especially, are so veined and threaded by it as to be rendered inseparable from it without breaking the ore down, greatly to its waste. No substance I have yet mentioned is more obstinate or more averse to going into slag, in which form the hearth should be discharged of it, than this; indeed it can scarce be made to take that form at all, for I have broken pieces of slag, of which this substance vitrified ought to have formed a part, and I have found it rendered more brittle indeed, but not at all deformed by having been in the fire, nay I have almost burnt out the bottom of a crucible containing some of it without being able to effect more than a partial fusion of it; so that what has been said of the several sorts of stone, as to their effects upon the operation of smelting, is equally applicable to this.

Copper ore. With the lead ore of the North Vein at Middle Cleugh there is often intermixed an indigent copper ore, so poor, that it is not worth preserving as a copper ore. When this happens, the connections between this and the lead ore are so close and the transitions from one to the other so frequent, that they can never be got entirely separated; so that a good deal of this is carried with the lead ore to the smelting hearth. In a crucible exposed to a moderate heat, this fuses with facility and in a smelting hearth its promptitude thereto gives the brouse a wet-like creeping and ropyness which no application of lime can absorb or correct, but in the attempt to do which, such a quantity is generally used, that the slags, thereby with difficulty strained, can scarce be run in the slag hearth unless they are fluxed or mixed with those of another kind of ore or which no such profusion of lime at the first fire was necessary. At the same time that this mixture impedes the operation of smelting and thereby wastes the produce of lead, it also discolours it much giving it a disagreeable copper-coloured freckle upon its surface, but I do not apprehend that it otherwise affects its quality, perhaps it may better it, for if there should be any silver in the copper ore, which I suppose is possible, I have no doubt that the lead will enrich itself by the attracting of it during their joint fusion in the operation of smelting.

Soil. This is so light a body and often so like garden mould, that excepting some little which may adhere to the shaddered ore (which does not undergo the operation of washing) all of it goes off in the washing, if that should not be very ill done indeed; and consequently as so very small a quantity of it ever continues with the ore, until it is brought to the furnace, it cannot observably affect the smelting of it. Ore which has scarce any other mixture with it in the mine but this is commonly of the free and productive sort.

Plate. Of this fossil many beds or strata are met with in the lead mines in Alston Moor, some of them several fathoms in thickness, between which are the several sills or strata of stone of every sort. When this lies deep and is compressed so much as to have acquired a great degree of firmness, it has the name of plate (as I have called it) but nearer the surface where the compression is not so great and it lies more lax, it takes the name of chiver, perhaps a corruption of shivers, into which it goes on being loosened from its bed, as does also the strongest plate on an exposure for some time to the open air. Both of them I think, are rather of a clayey than of a stony or sandy composition, for they will grind, or may be trodden to a tough and cohesive clay, which I believe would not easily vitrify in the fire; wherefore I conclude that if any plate should be left with the ore until smelted, it would not be easily got rid of in the way of slag, and therefore would be a hurtful mixture; but as no great quantity of ore is got in plate beds, and as what is got there is easily dressed from it, I can only conjecture what effects it might produce in smelting.

ON THE REFINING OF LEAD: PROCESS 5TH

It is customary and certainly right, when a person is taken into a lead manufactury as a workman, not to employ him in the highest branch of it or that of the first repute all at once, but so make him aquainted with, and to prove him in, the subordinate parts first. In this manner it was that I had my initiation into it and in this order it is that in my correspondence upon the subject, I have endeavoured, but with what degree of information I know not, to conduct you step by step to that almost final process in it which we call refining, by which if the obtaining of silver from lead is to be understood, as doubtless is its primary intention, in that case it is a misnomer, it ought rather to be called extracting; but if what is consequential of that extracting be intended, then the name is proper enough, for by it the lead itself is refined so as to be of more value as lead than any other that has not passed through the same operation.

Until of late I had been induced to believe that the practice of this art was of no high antiquity in England, at least in these Northern parts of it; that it had not been of more than 100 years continuance, that until within that period we, to our own loss and their emolument, sold all our lead to the Dutch or Germans who alone possessed the mystery of refining or extracting its silver from it. But since a journey I lately took to Keswick in Cumberland I have altered my belief as to the time that refining may have been practised in this Island; for at a place called the Dutch Houses, there where several sorts of minerals and the slags or scoriae of them had from time to time been dug up, I found that amongst other things, several pieces of the litharge of lead had been picked up and I myself found some amongst the rubbish. Now this litharge could not have been found there unless a refining had been carried on there at some time or other; of which time to inform myself, I enquired of a very aged but intelligent man, who had lived all his life in that neighbourhood, if he could remember any sort of work going on at the Dutch Houses, or if any of the buildings had been standing in his time. His answer was that the spot of ground had born the same appearance it now has, i.e. mostly overgrown with grass, furze or broom, ever since he could remember anything. Neither did he ever hear the oldest people living in his time say that they had known it otherwise, but that they had a tradition, that the place got its name from a smelting of metals having been carried on there by Dutch people in former times. From these circumstances I am led to think that this art has been practised for a much longer time, even in the North of England than I had once imagined.

In the reign of one of our kings, I have forgot which, history informs us that there came a people to England from some country situated to the east of it, from which circumstance they were called Easterlings, who brought our silver coin, then sadly debased, to that standard of purity it has ever since retained, and from whom, by a contraction of their name—Easterling—it got the appellation of Sterling, which it has to this day. Those people no doubt were refiners, and perhaps were the first who introduced the art into this kingdom; and as the Dutch, from the situation of their country with respect to us are easterns or easterlings, perhaps the Dutch Houses may have been occupied by some of them, and from thence acquired the name.

But that which brought refining into such general practise in this country was that act of the legislature which William and Mary entitled 'An Act to prevent disputes and controversies concerning Royal Mines' by which every proprietor of a mine of Copper, Tin, iron or lead, got a right to keep and work the same, notwithstanding its being claimed as a Royal mine from its containing gold or silver; but with reserve that the Crown and all claiming under it should have the privilege of purchasing all the ore raised out of such mine at the following prices per ton, viz.

Copper ore, made clean and fit for smelting, £16
Tin ore (that raised in Devon and Cornwall excepted), £2
Iron ore, £2
Lead ore, £9,

which price is equal to £3.12.0 for our Bing (8 stones), a rate at which most of our lead mine adventurers in these parts might be happy to have their ore demanded, though it should contain what is thought a good deal of silver; for if it did, it would be only by chance if the scanty produce of lead did not bring it to nearly an equal value with ore which had not silver in it worth the extracting at all, so that none in these parts need to fear having their ore claimed on account of their mine being supposed a Royal one.

That some sorts of lead did contain more or less silver and that it was extractible from lead, would be discovered somehow and at some time; but how or when perhaps history itself is silent. These discoveries may have been made from very remote antiquity and how they probably might be made I shall venture to give my conjecture, and the rather, as in the cause of doing that, I shall necessarily fall upon some explanations in the processess of refining and reducing, which I think I can convey as clearly in this way as I could when I come to shew our present mode of doing those works.

That most sorts of lead contained some silver, I have conceived might have been discovered in some such way as that in which we now make our assays as thus: A quantity of lead having been perhaps fortuitously at first, exposed to a certain degree of the heat of pure flame, —please to take notice, I here mean that emanation issuing from any sort of fuel in bulk or substance whilst burning—I say lead thus exposed would be observed to emit a vapour from which it would be judged to be in a state of dissipation and waste; what had been seen to happen to water under similar circumstances would naturally lead to that. A sensible diminution of its bulk would soon be observable, curiosity would wish to see if it were a totally evaporable body and the result would be that some though perhaps a very small part of it would be found not to be so; that a small something did remain upon which the fire seemed not further to act, nay that ceased to be in fusion, though the force of the fire was increased and which upon examination would be found to be pure silver. Now this is exactly our assay making; this serves to shew us that there is silver in lead and in what quantity; and would with repeated experiments serve to convince those first assayists that silver was obtainable from it; but here I apprehend they would be somewhat at a loss. They would see that though it was obtainable, yet that it was not so but at by far too dear a rate; that exclusive of the tediousness of the process and the enormous expense of fuel, it could not be procured but by the total consumption of the lead, which at that time of however low a value, would doubtless be of more than the silver to be obtained. The means of extracting it without the entire waste of the lead would then become a very desirable object and no doubt many fruitless experiments would be made in search of them, before the right modes, or those now in practice, were found out; until at last it would be noticed by some lucky observer, that upon the surface of lead exposed to such a heat as I have supposed, something more light then the rest and resembling oil or fat upon water, did swim and fluctuate previous to its formation into, and flight in vapour, and by a further felicity of thought, it might be conceived, that if that something which would be and which I shall henceforth call litharge, could be intercepted before its evaporation, there was a probability that it had parted from its share or proportion of the silver preparatory to its sublimation and also that some use might be made of it, if means for preserving it could be discovered, as a step to which a skimming off would be judged the most likely and for that purpose the use of bellows would be readily suggested. Litharge would be thus obtained, but then how to reproduce any lead from it, if any should be left in it, would remain to be discovered. Re-exposed to a similar degree of heat with that which first produced it, it would be found to be a fusible substance; but on being suffered to cool, it would be found to retain all the properties of litharge, unless the fire had been so vehement as to vitrify it. It would be found that in its conversion from the lead, that had suffered a privation of something, its phlogiston, inflammable principle or I know not what, by which all its properties as lead, such as malleability and facility of fusion seemed to be totally annihilated, but I fancy an accident might soon discover that that lost something was restorable; that the putting this litharge in such a heat as first formed it, i.e. a flame reverberated upon its surface, and at the same time in immediate contact with or touching any sort of fuel in substance would restore it. That by some sort of communication to it from the substance, not flame of the fuel, lead became reproducible from litharge with improved qualities as lead, by the same process which had separated it wholly, or nearly so from its silver, as would be found by making an assay of it. The lead would be also purged of its more gross or earthy parts, that is it would be refined. The manner of recovering lead from litharge which I have just been describing is what we call air-furnace reducing, and is what we practise here at a variable loss viz. from an eleventh to one fifteenth part of the lead originally refined.

Some lead is also reproducible from its sublimate or fume which is a whitish coloured soot arising from the sweepings of the refining and reducing chimneys, but that any lead was obtainable from this is a recent discovery to the merit whereof I think my brothers * and self have a just claim; for until we found out that lead might be got from it by a proper management, many tons of it were cast away as useless, both at the Governor & Co. and Sir Thomas Blacketts works, though with us here it has upon being smelted produced one half its weight of lead which is nearly as much as some of our middling sorts of ore can be made to do. I have looked into Dr. Watson's Chemical Essays, but do not find that either he or any of the smelting people he has conversed with, has known anything of lead being obtainable from fume, or as he calls it sublimed lead. He speaks indeed of its being sold to the painters at £10. - or £12. - per ton, and that it might be converted into red lead probably to more advantage. Either of these ways of disposing of it would no doubt be better than any smelting of it.

From what has been said above, it will be perfectly understood that the conversion of lead into litharge is not effected by the application to it of any sort of fuel in substance, however hot, but from the flame issuing or streaming from such fuel whilst burning; and that on the contrary lead is not recoverable from litharge by the heat of pure flame only, however strong that may be, unless the litharge be at the same time in immediate contact with, or touching some sort of fuel or combustible matter in bulk or substance.

These particulars being explained I now proceed to a description of our present method of doing the business of refining, and of the apparatus necessary in it, to shorten which last I send some drawings of the principal articles used in it viz. 1st a sketch of the iron frame into which the ashes are beaten for a test 2nd another of the same with the ashes beaten into it and scooped out as a test fit for use.

3rd, a perpendicular section of 2 refining furnaces and the shaft of their joint chimney; 4th, a horizontal section of the 2 refining furnaces, the one with the test represented in it, charged with lead and with its surface ruffled into small waves by the action of the bellows as when at work, the other with the test also, represented in it but showing the position in which a cake of silver commonly lies upon its bottom where it is taken off, i. e. made clean. All which, by help of the references annexed to them will, I hope, be sufficiently intelligible. [Figs. 7 and 8]

By the two sections it will be perceived that the refining furnace is a sort of oven of a square form, opening gradually into one more oval with an arched but unequally curved roof and consisting of two chambers or apartments, the one square, which is the place of the fire, its bottom a grate and roof sharp, the other more oval, which is the place of the test whereof that forms the bottom and over which the roofing is flattish. Between those two parts is a ridge of brick work about 20 inches in breadth and 18 in height, the reason for which is that nothing of the fire but its flame may pass to the test with the lead in it to be converted into litharge. From the fire and over this ridge the necessary quantity of flame is poured into the place of the test and as its passage from thence to the shaft of the chimney is only by two small flues, it is so beaten back or reverberated upon the surface of the lead, as to have the effect desired. The preparation of the test is as follows: The iron frame which is to contain it (see drawing [Fig. 8]) being laid firm upon a ground floor, it is filled rather to a heaping, with a mixture of 4 parts bone, and one part fern ashes, moistened so as just to clod when grasped in the hand; and this mixture being beaten down with a sort of iron pestle, other layers of the same ashes are laid on and also beaten down until the frame is quite filled, when with a small spade and other instruments, it is scooped out, so as when finished for use, to have pretty much the form of a flat bottomed boat, as is shown in the drawing. It is thus made ready for the furnace, whither it is carried by two men, and being placed upon a fir deal by that it is shoved over two bars of flat iron fixed into the mason work of the furnace from which it is propped into its place and its junctures with the furnace are made very light with lutings of clay to exclude the cool air from without and that no smoke or flame may escape from within. To anneal or dry the test without splintering it, a slow fire is at first put upon the grate of the fireplace, which is quickened gradually until its humidity is entirely exhaled, which commonly is in 5 or 6 hours at farthest. It is then heated by a strong fire, to fit it for the reception of its charging of lead, in quantity about 5 cwt. which is given it at some places by that quantity being first melted in a pot and from thence handed into the test by a small iron ladle or spoon and at others it is filled by sliding the pigs in at the feeding holes, one after another, with their ends within reach of the flame, by which they are gradually melted off until the charging is completed.* Soon after which, if the fire has been sufficiently kept up, some litharge will be seen to fluctuate upon its surface, and the bellows made to play upon it, by the stream of air from which such litharge as is formed, and continues now to be formed, is driven towards the breast or forepart of the test; over or across which a gutter, called the gate, is cut by which the litharge passes to the hole in the entrance into the test through which it falls to the floor, where it is suffered to gather into such heaps or clods as the workmen find it convenient to bear away upon a shovel to replenish the test with lead in lieu of that which is now constantly converted into and carried off in litharge. A pig of it is always kept in one of the feeding holes, more or less within reach of the flame as its more quick, or more slow melting off is required, in order to keep up the proper stock of lead in the test in which the workmen are directed by observing to what distance backwards the test is covered with litharge, distinguishable from the lead not vitrified by its being of a less bright or of a cloudy red colour. If the test be covered far back with litharge, then the pig is pushed forwards, or sometimes dipped in the hot lead of the test to hasten its melting off; but if the lead not converted into litharge, or only partially so, be seen very near, then the feeding pig must be made to recede, otherwise a foul-running, as the running of lead imperfectly converted into litharge is called, will ensue. This being more ponderous than litharge, which is lead calcined, is distinguishable from it by its falling quicker or with greater velocity from the test, and rebounding more from the ground or clod on which it breaks. It is also known to a good and experienced eye by its being more of a bright or white red colour than litharge. But if the gate or channel for the litharge be firm and free from flaws, with care in the workmen and at no hazard of foul-running, a piece of lead of 1 cwt. will be run off in good litharge in less than 20 minutes and a faultless test will before it is worn out frequently run off 84 of such pieces, which is equal to 4 fodders of lead. A test is worn out or becomes unfit for further use, either by the hot lead corroding and eating up its bottom, to the danger of its bursting in that part or by the channels through which the litharge issues being so sunk, that a sufficient stock of lead is not left in the test; for as all the silver which is to be expected from the lead previously run off in litharge from the same test is necessarily involved in

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* Mr Mulcaster has two brothers, one joint agent with himself at Langley Mill and the other principal agent at the late Sir Thomas Blackett's refinery at Blaydon.

* Messr. Mulcaster have lately made experiments to ascertain which of these modes of feeding the test is preferable and the result is, that the former is found to be the most advantagious.

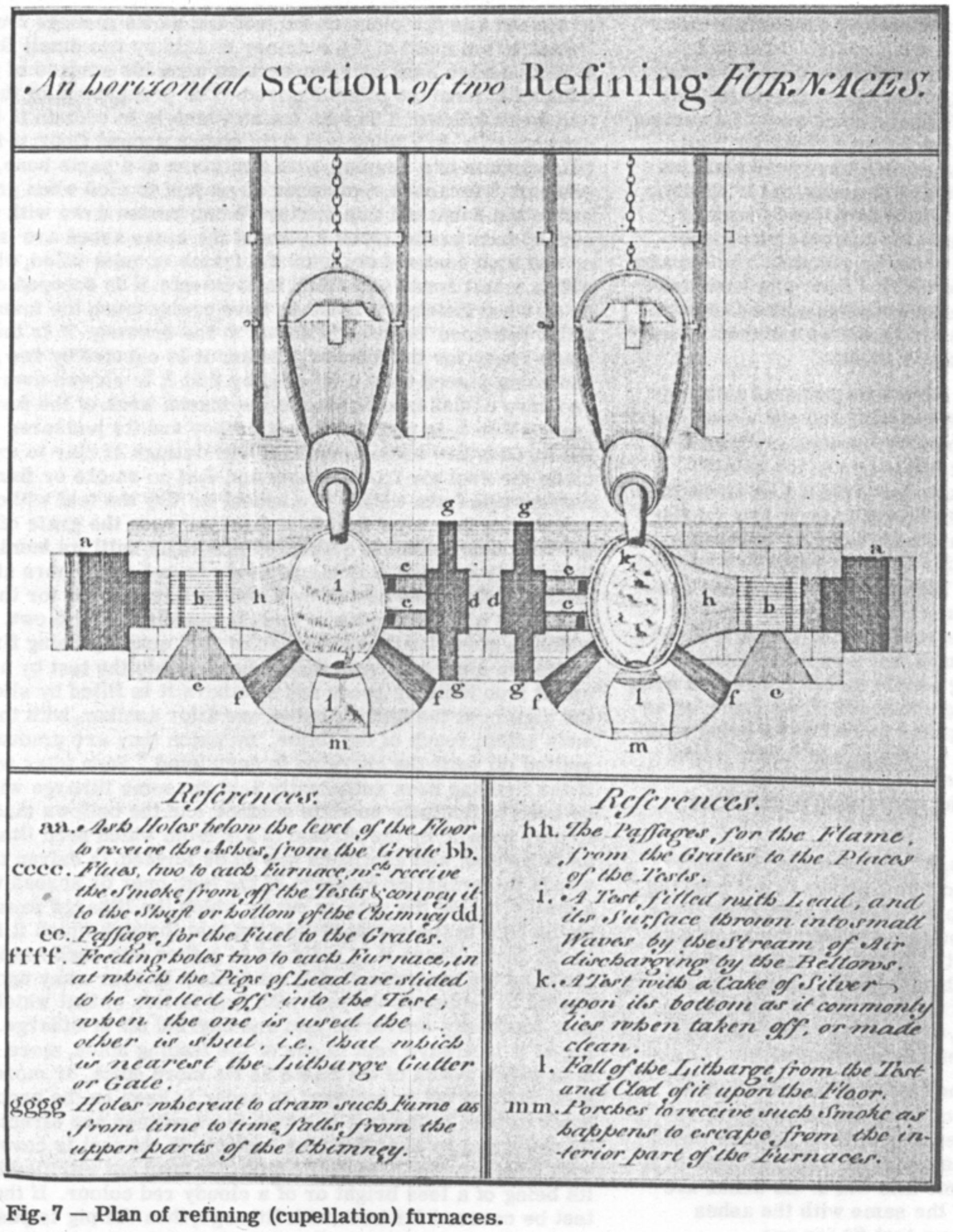

Fig. 7 — Plan of refining (cupellation) furnaces.

that stock however contracted it may be, it therefore becomes hazardous to continue working towards the latter end of the test with a small stock of lead in it; for besides the danger of loss by accidental, but perceptible foul-runnings, experience has shown that considerable quantities of silver will pass off imperceptibly with litharge formed upon the surface of very rich lead; and therefore at Langley Mill (I do not think it is practised elsewhere), we run off our stock out of the test, by inclining it when it has worked about one half its quantity, close up the old channel for the litharge, cut a new one, and refill the test with such lead as we then happen to be working upon; so that at the conclusion we have the silver of each 4 fodders of lead in 2 or 3 pieces of perhaps 1 cwt. each; which pieces when we have the produce of about 20 tests, we further contract by bringing them all into one test by themselves and by running them off in litharge in the ordinary way, reducing the whole to about 2 cwt., excepting 5 or 6 pieces which are reserved for what is called the silver test i.e. that in which the silver is made perfectly clean.

In the running of those rich pieces, both in this test and the former one, though the litharge is made as perfectly such as may be, yet upon trial per assay, we always find that the lead reproduced from it is refineable and therefore we reserve it for a second or repeated refining, by which we have obtained sometimes more than 200 oz. of silver at the conclusion of each year for some time past.

The silver which is intended for one cake being all driven as it were into 8 or 10 pieces of lead of about 1 cwt. each, in the manner I have endeavoured to describe, a test is prepared for its final cleaning or taking off as it is called. The preparing of this test does not at all differ from that of any other, save that a little more pains is taken in smoothing its bottom and making it somewhat more concave than those of ordinary working tests are generally made. This rich lead being all got into the test by a part of it being run off in litharge, instead of one channel for the litharge to issue at, two are now opened, one at each extremity of the hole through which it falls from the test; which are kept open and sunk gradually to make way for the litharge as it is seen to form upon the surface, and is pushed forward by the bellows, which it continues to do and suffer until the whole lead is run off from it and nothing remains but an expanse of pure silver, the approach to which state is notified by a gradual dispersion of that cloud and fiery vapour which until this period of the process hangs and thickens upon the surface of the metal; but this being at last dispelled, the bellows is discharged, the flame retires to the roof of the furnace, and a lake of liquid silver brightens up so as often to reflect the roof and surrounding brick-work of the furnace: or if after the bellows ceases to act upon it, any little impurity should remain, that is commonly exhaled by the unabated force of the fire, whilst the silver yet continues in a liquid state, as it does for some time after the bellows is taken

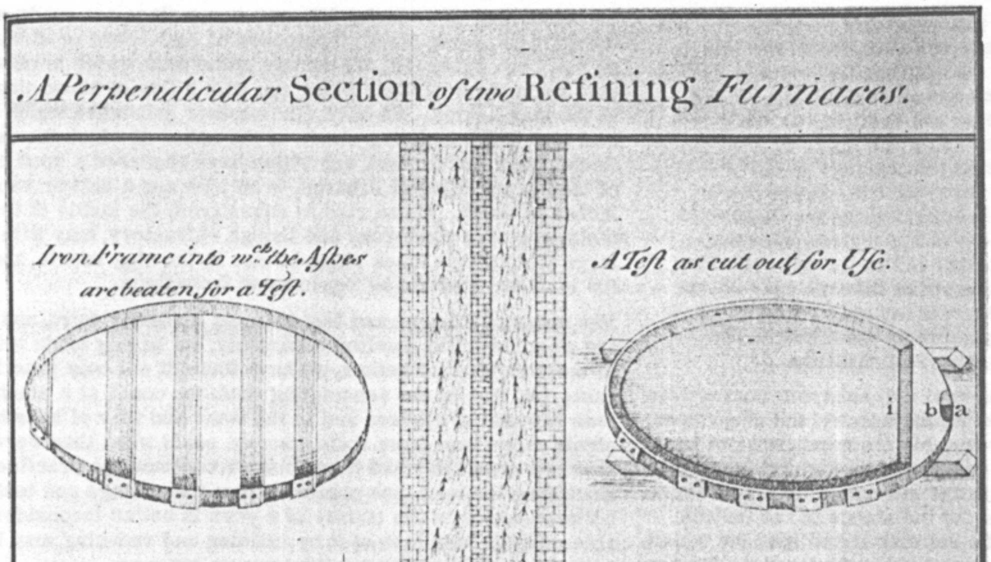

Fig. 8 — Sectional elevation of refining (cupellation) furnaces.

off. At last it begins to crust, or as it were, ice over. The incrustation as it is formed contracts and thereby compresses the yet fluid metal under it so as that this last almost always breaks through some weak part of the crust and often forms very romantic figures. A surprising change now takes place. That which a few minutes before was in reality a silver lake of the most even and shining surface, seems now transformed into an island with mountains, hillocks and gushing rills, all of pure silver. In this situation it is suffered to remain until it grows so cool as to admit of its being taken out of the furnace without any danger of deforming it; and when it becomes perfectly cold, in order that none of its pretty eminences may be lost by falling off, they are beaten down and any ashes of the test or slag of the bricks which may happen to adhere to it, are dressed off and then it is fit for the market. Now though the silver is at last thus left upon the bottom of the test, yet it is not there any time previous to this final purifying of it. So long as there is any lead with it, it is equally diffused throughout the whole mixed mass, that is, a drop taken at the surface, if not litrified would be found equally rich with one taken at any depth in the test. Silver being a more light body than lead cannot subside in it, but litharge which is to lead what froth or foam is to water, being more light than silver, will float upon it and as lead is convertible into litharge, it thereby becomes separable from whatever portion of silver it may happen to contain.

ON THE REDUCING OF LITHARGE: PROCESS 6th

I come now to that process which I have named the last or final one in the manufacturing of lead ore, viz. the reducing of litharge; a work which is done either in the air-furnace, as at Langley Mill and at Mr. Beaumont's refineries, or in the smelting hearth with bellows, as is practised at most of the Governor and Co.'s Mills. But first of the air-furnace.

This furnace, except being of somewhat larger dimensions, is in form much like the furnace for refining, described in my last, and it is also divided in a similar manner by a ridge of brick-work into two cells or apartments, the one of a square form and a grate at the bottom, being the place for the fire, the other in form rather more oval and with an immovable bottom of 4 parts bone and one part fern ashes, beaten into it to a considerable thickness, and encrusted with a coating of black slag run upon it by a vehement heating of the furnace, having been first formed sloping in every direction, to one outlet in the side called the tap-hole through which the lead issues by a cast iron duct or spout to the pot, out of which it is cast into pig moulds hung upon steel yards for adjusting the weight of the pigs. The furnace being first well heated, upon this bottom the charging, which consists of about 32 cwt. of litharge interspersed with a suitable quantity of good but small coals, is laid and a strong flame being made to pour in upon it from the fireplace; that gradually propogates a burning of the coals, first upon its surface and then in the interior parts of the heap; some lead is continually forming and oozing towards the taphole which issues and is disposed of, as has already been noted, until the whole charging is run off, in the course of which, as room is seen to be made by the dissolution and expenditure of the first laid in litharge, more of it intermixed with coals as at first, is from time to time given to about the quantity of the first charging before the furnace is drawn i. e. hath the slag taken out of it previous whereto, much and frequent turning of it over in the furnace with long pokers is requisite that the whole of the litharge may be exposed to the fire and the lead it produces sufficiently drained from it. This and the drawing are pretty laborious to the workmen, as is also the re-charging with litharge.

In my letter upon refining I observed that lead was convertible into litharge by a pure flame acting upon it, and not otherwise; and also that lead was not reproducible from litharge but by some sort of fuel in substance (coals commonly) being put in immediate contact with it; that at the instant of its fusion there was a communication to it from the substance of the fuel of an occult something, which in the refining it had lost, but which, by such communication was restored, and with it all its former properties as lead: Agreable whereto if in the process now before us no heat should be applied, but that which is made to pass in flame upon it from the fireplace, in that case litharge would indeed be found to be a fusible body; a long continued heat of the sort would liquify it, but then it would be only litharge liquified or in the state in which it falls from the refiners test; a still longer continued heat of the kind might probably dissipate the whole of it in vapour, or in time vitrify it, but without a mixture of some sort of fuel in substance with it, no lead would be obtained.

Having given an explanation of the reproduction of lead from litharge according to my idea and conception of it, and which I hope will be satisfactory, I pass to the other mode of process, viz. hearth-reducing, which varies from common ore smelting only in a few particulars. A hearth rather large and a soft blowing bellows are judged suitable for reducing, otherwise the form of the hearth and the machinery for both purposes are the same; as is also the kindling with peats and the forming of a brouse or stock for the hearth; but after that is formed, as the accumulation of slag in the hearth is not frequent, perhaps not more than once in an hour, being chiefly formed from the coal consumed, for no lime is used and the litharge itself having been once pure lead, most of its substance is run down in lead again; therefore the reiterated watchings or drawings-out of the brouse for the discharge of the slag, which in ore smelting are necessary, are not so in this process, yet as the lead runs expeditiously, the serving of the hearth with litharge mixed with coal, which is almost incessant, keeps one of the workmen pretty closely employed, as the wheeling in of the litharge and coals and casting, scumming and setting-up of the pigs of lead and other serving do the other during their shift or fit of working: the length or continuance of which depends much upon the management of the person who attends the hearth, in keeping the cast irons which compose it and the lead cool, that the one may not be wasted, as they are liable to be, by a want of care or judgement, and the other not suffer in its quality by being run too hot; however the shift is generally continued to the running of $2\frac{1}{2}$ or 3 fodders of lead.

To a common observer, this last mode of process would appear the more neat, the lead may be obtained by it looking better, as to outside, than it can at all times be had from the furnace, and yet I do not know how it happens, but we are assured that furnace reduced lead has the preference in the markets, from its being formed the more soft I suppose. Perhaps some of the more gross or earthy parts of the lead may be exhaled in vapour from the furnace, or may be detained with the slag in it, which by the action of the bellows upon the fire are run off with it from the hearth; but then one would suppose that the deficiency in quality might be made up in quantity, which however we believe is seldom the case; for happening to have a person practised in hearth reducing, we made as accurate an experiment as possible and found the furnace preferable in point of produce and therefore we continue the use of it.

By either way of reducing litharge some slags are made, which though light, being mostly composed of coal coked or cindered, as has been observed, yet contain some lead, which is obtainable from them by their being run with a flux of black slags in the slag hearth. We have also another substance which we call test-bottoms, being strata of the ashes of which the refiners tests are formed, and which have absorbed a good deal of lead in the form of litharge, to an inch and a half or two inches in depth. These rise in cakes from the inside of the tests, are very ponderous and though refractory, may with a large flux of free black slags be run in the slag hearth, and the lead they contain be reproduced from them.

The slags of litharge and test bottoms formerly were, and now are at some mills smelted separately, but having made trial of smelting them together, we have found it not only practicable, but that by the associating them we could, at a much less expense of cinders and in the wear and tear of hearths, obtain more lead from them, than we could when they were smelted separately and therefore we continue the practise. Excepting the lead thus obtained from these slags and test bottoms, which in the course of a year is not an inconsiderable quantity, our loss of it by refining and reducing may be estimated at about one twelfth upon an average.

Having now, I think, finished all that has occurred to me upon the art of smelting of lead ore, I shall only take leave further to observe that having from the beginning been determined to write from experience and practise only, I have scrupulously avoided looking into any author for assistance, even in the manner of expressing sentiments that I was quite conscious were my own, having resolved from the time you put me upon writing on these subjects, that whatever you got from me, whether good or bad, should be as original as possible, and if in the course of the work I may have fallen upon any thoughts or made any observations that are new and interesting, I shall then look upon the time that I have spent in it not to have been unprofitably employed.

Explanation of several terms made use of in the course of the foregoing account

Bruce or Brouse	A mixture of lead ore imperfectly reduced to lead and slag, coal cindered or half burned, and lime.
Shift or Fit of Working	Time employed by the workmen in performing any particular piece of work or business.
Sump	A cast iron pot to receive the lead which comes from the hearth.
Brangled	Intermixed.
Shaddered ore	Pieces of ore from the mine, pick'd out as clean, and carried to the bingstead, without undergoing the operation of washing.
Sieve ore	Ore made fit for smelting by means of a sieve.
Smithorn	A smaller kind of ore derived from the sieve ore.
Slime ore	The smallest kind of ore derived from the Smithorn.
Bouse	Large pieces of ore mixed with spar etc. in the state they are when they come out of the mine.
Fodder of lead	Twenty one cwts.
Litrified	Converted into litharge.
Lutings	Plaisterings.
Quagginess	The undulating motion of lead when in a state of fluidity.

The early history of Wortley Forges

R. A. MOTT

INTRODUCTION

For nearly a century, Wortley Upper Forge was concerned in making wrought-iron axles for railway waggons, and the present belly-helve hammers are relics of this practice. The stone inset in the wall of the present main building, bearing the date 1713, shows, at least, that this building existed in that year. There was a mural stone with the same date in the Lower Forge.

Within living memory, the practice of iron-making and fabricating at both forges was identical with that introduced by James Cockshutt in the last decade of the 18th century. In 1793 he returned from Cyfarthfa Ironworks, Merthyr Tydfil, where as manager and partner with Richard Crawshay he had introduced Henry Cort's methods of making wrought iron from pig iron by puddling, with finishing to bars or rounds by rolling instead of hammering. Wortley Forges were therefore among the earliest ironworks outside Merthyr Tydfil where Cort's processes were introduced.

Before he went to Cyfarthfa in 1784, James Cockshutt had been the manager of Pontypool Forge, then the largest finery forge in Great Britain, for a period of ten years.[1] Pontypool Forge was primarily concerned in applying the processes devised more than a century earlier,[2] by John Hanbury, of using plain rolls to roll blooms to plate and plate to sheet for tinning and the subsequent manufacture of tinplates. It also used the Osmund process of fining pig iron to wrought iron to ensure a greater dephosphorization to enable the product to be used for making iron wire.[3]

Whilst James Cockshutt had been in Wales, his brother John had worked Wortley Forges and died in 1798. The father of these brothers, John Cockshutt I (1692-1765), had introduced a tin mill at Wortley in 1743. There is, contrary to the vague statements in Andrews's 'Story of Wortley Ironworks', no doubt that the manufacture of tinplate was a feature at Wortley for about a century and spread from there to Walker's Masborough Works. There is a description of the process of making tinplates of c. 1770 by John Cockshutt II[4].

The Henry Cort grooved rolling mill which James Cockshutt introduced is mentioned in the Wortley lease of 1793, and at least a very early example still remains. It was used for making nail rod to replace a rolling and slitting mill, originally developed by Richard Foley at the Hyde, on the River Stour, in 1628 and which had been much improved and widely applied during the 17th century.[5] According to Andrews, by tradition the Wortley slitting mill was at what was later called Tilt Mill, now represented by an old stone cottage called the Tilt, ½ mile upstream from the Upper Forge. This Tilt Mill was also called Tilt Tin Mill and had two waterwheels and a dam, the outlines of which can still be discerned. I suggest that the first slitting mill, heard of in 1695, was on the site later occupied by the lower Tin Mill and that this site was previously occupied by a bloomery which certainly survived to 1683/4 and was in existence in 1621.

The slitting mill of the last decade of the 17th century gave a new orientation to the trade, and nail rod became a principal product for the nail makers at Mortomley and Sheffield.

During the 17th century the manufacture of rod suitable for wire drawing seems to have been a considerable activity. In fact, we know that, when Old Wire Mill was rebuilt to a two-storey building about 1850, it replaced a single-storey wire mill which had the date 1624 on its lintel.[6] This 1624 wire mill was a very early example of wire-drawing using waterpower, and we must look into the early practice of this art to realise the significance of what was almost the first Wortley enterprise.

The practice introduced nearly 350 years ago became a dominant feature of industry in the upper Don valley, and since there are, at present, near Wortley, three active wire mills the practice has persisted longer here than in any other centre of wire-making. The wire trade of the Don and Little Don valleys provided the raw material for the Redditch needle and fish-hook trade, fine wire for watch springs, the Fox frame for umbrellas and crinolines; at present nearly all the wire of New Wire Mill is exported to America, and still uses a finishing process which John Cockshutt I described two hundred years ago.[7]

The Old Wire Mill is not, however the earliest enterprise in iron of which we have records. The bloomery that can be presumed to have been on the site of the later Tin Mill was leased in 1621 and had previously been leased by, among others, Ambrose Wood.[8] It was in the possession of William Wood in 1683/4,[9] and in 1684/5 Old Wire Mill was leased[10] by Christopher Wood, whilst one of the Woods, in 1695, held the lease of the slitting mill[11]; it seems likely that this Wood was William who had leased the bloomery ten years earlier and that this is an indication that the bloomery site had been converted to a slitting mill. These facts clearly relate the old practice of waterwheel-drawing of wire with the iron made in the bloomery; this is a significant fact because in a bloomery it was possible to dephosphorize,[12] but this was not possible in a charcoal blast furnace, and we know that the Osmund finery process was applied to charcoal pig iron before iron wire was successfully drawn in Elizabethan days. It would not be surprising if, when the Wortley bloomery was abandoned towards the end of the seventeenth century, an Osmund finery was introduced in the Lower Forge to give an iron equivalent to bloomery iron for wire drawing.

How ancient the bloomery was on the Tin Mill site we do not know. When William Wood leased the site in 1683/4, with its mines, quarries, woods, and watercourses, it had eight woods totalling over 70 acres, four fields (the Great Field, Upper Smithy Fielding, Upper and Nether Smith Fields) of 27 acres. It also had Upper Sinder Hill of 10 acres and Synder Hill of 7 acres, names applied to heaps of bloomery slag, and large lumps of bloomery cinder are readily seen today in the woods below the Tin mill dam and the ruined cottages there. There must, however, have been another bloomery site, for bloomery slag is found on the river side by the stepping stones and bridge near the cottages in the by-road near Wortley station, implying a site somewhere near the Lower Forge on the Hunshelf side.

It should be noted that the names of parishes are apt to be confusing in relation to the Wortley sites. At the northern end of the bend in the River Don which encircles the Upper Forge is the junction of three parishes, Penistone, Tankersley, and Silkstone, the boundary between the two last parishes being subsequently the stream which flows past Rockley Furnace. Upper Forge is usually described as being in Hunshelf, part of the parish of Penistone which lies mostly to the west of the River Don, though this parish also extends to the east of the river to include Upper Oxspring. Lower Forge is to the east of the river and so is in what was anciently the chapelry of Wortley in the parish of Tankersley. Thurgoland was, and is, in the parish of Silkstone and included Old Wire Mill, New Wire Mill, and Tilt Mill. The old Tin Mill, like Upper Forge, was in Hunshelf. Thus when in a marriage settlement of Jane, daughter of Matthew Wentworth of Bretton, to Robert Rockley in 1567, the latter was to put into trust, for settlement on himself and his wife, all his manors and lands 'except a furnace with lands in Thurgoland in the tenure of Margaret Corbet, widow, and others',[13] it appears that this bloomery was in the parish of Silkstone and had belonged to Margaret Corbet's first husband, Thomas Wortley, who died in 1543, a date so near to the Dissolution of the

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Text of a lecture delivered to the Sheffield Trades Historical Society on 12 October 1970.

Monasteries as to allow one to assume that this bloomery had probably belonged to the religious. We shall see later that about the date of the first known lease of the Wortley bloomery, in the reign of James I, Sir Francis Wortley had an interest in a bloomery at Midgley on part of the Barnby estate, near the Wortley's manor of Newhall. There are also records of a bloomery of the Earl of Shrewsbury at Oxspring c. 1589 for which records of production[14] are known, and similar values could be expected for the Wortley bloomery of the 17th century.

It may be noted that the Ganister coal seam, which outcrops on the left bank of the Little Don and then, after joining the Don at Deepcar, along the left bank of the Don in Wharncliffe crags, had above it several thin seams, the Hard Bed Band and the Upper Band, each with 5 to 6 ft of clay below and ironstone bands above.[15] It would be the latter that would be the source of ironstone for the bloomeries at Wortley and Oxspring. There is a waste tip opposite the lane to Tin Mill Cottages, just short of the bridge over the Don on the road from Deepcar on which ironstone balls have been found. There were old shafts on Hunshelf Bank and the outcrop of these clay-coal-ironstone bands would be that worked in the 17th century. In the bloomery lease of 1683/4 the coal mine of Sidney Wortley is mentioned.

One other point should be mentioned in these introductory remarks tracing back the Wortley enterprises. It will be shown later that there are no leases for finery forges which name the Upper and Lower Forges before 1658, but I hope to establish later that both came into operation before the Civil War.

Before ending this introduction, mention should be made of the early practice of making iron in bloomeries in the parishes near Wortley by the religious houses. Rievaulx Abbey (founded 1131) had bloomeries in Stainborough, in the southern part of the parish of Silkstone probably soon after its foundation, for the earliest deed of 1166 is a confirmation by the son of the first grantor.[16] The Rievaulx monks also had fabricating forges (fabricas) in the parish of Tankersley near Pilley, perhaps on the site of the later Rockley smithies. In 1170 the monks of Byland Abbey were making iron in the Emley-Bretton area. In the 12th century, also, the monks of Bretton Priory, an offshoot of Byland, were making iron near Emley.[17] Before the Dissolution of the Monasteries, Matthew Wentworth of Bretton Hall, who died in 1505/6, was operating bloomeries formerly belonging to Bretton Priory.[18]

In ending this introduction mention should be made of the fact that a finery forge could not operate without a charcoal blast furnace and, before the Civil war, there were charcoal furnaces operating in Yorkshire only at Rievaulx and Chapeltown, both of which had their own forges.

The 1854 O.S. 6 inch to 1 mile map shows well the distribution of Old Wire Mill, New Wire Mill, Tilt Mill, Upper Forge, Lower Forge, and the Tin Mill with the Wortley corn mill along the river Don with its somewhat circuitous route. Nevertheless, there was little over 2 miles between the Old Wire Mill and the Tin Mill site of the bloomery, the earliest erections.

THE WIRE MILLS

Wire-drawing as a handcraft was ancient and was practised in the 14th century in York, Bristol, and other old cities, the craft being protected by charters and by the periodical prohibition of imports. Coarse wire was produced by drawing iron rods of the thickness of the little finger through a wortle or drawplate by means of a 'brake' i.e. a series of hand levers like the spokes of a wheel, the wire being wound on to the shaft. Fine wire was produced by a girdler wearing a girdle to which the coarse wire was secured by pincers; the girdler sat in a swing seat and propelled himself away from the drawplate by pushing with his feet.[19] The annealing of the wire between successive stages of drawing, the raising of a scale to hold the lubricant (for which purpose rape oil and tallow were also used), the descaling by a number of physical processes and the final descaling in a balm bath (which is still practised at New Wire Mills) were important features of the process.

The mechanization of this old craft, by using a crank on a waterwheel shaft[20] instead of the brake and the girdle, was introduced in Germany at Lüttich in 1513 and Nuremburg in 1532.[21] In 1568 the Society for Mineral and Battery Work was formed and a patent enrolled in the names of William Humphrey and Christopher Schutz, which included the making of brass latten or sheet, wire of brass, iron, and steel, and the manufacture of iron and steel for armour.[22] The manufacture of calamine brass and of brass wire was started at Tintern, but it was not until 1587[23] that iron wire was successfully made there. Sir Philip Sidney of Robertsbridge (Sussex), Edmund Roberts of Hawkhurst (Kent), and David Willard of Tintern were given a licence to bring over 100 aliens to start the making of steel and of iron wire. Steel-making at Robertsbridge, using cast-iron plates made from hematite ores in Wales, has been fully described,[24] but there are no early records of making iron wire in the Wealden area. At Tintern we know that the Osmund process of iron making was introduced before iron wire was successfully made there. Humphrey himself went to Beauchief, Sheffield, and introduced bellows-operated lead smelt mills which rapidly displaced the older bolehill procedure. Before he died in 1582, Humphrey was concerned in a number of injunctions in the Court of Exchequer to stop others from using his lead-smelting process.[25]

Sir John Zouch set up a wire mill at Mackeney (Derbyshire) and had to suppress it in 1581 and again in 1583. In 1603 a wire mill was started at Chilworth (Surrey) but had been suppressed by 1606. Another claim for infringement of the Society's monopoly was settled by the granting of a licence for 10 years.[26]

Old Wire Mill, opposite Huthwaite Hall, where production ceased in the 1930's, was rebuilt to its present two-storey structure about 1850 to replace the older single-storey structure of 1624. This Old Wire Mill must therefore have been one of the earliest of its type in England. We may presume that it was used to make wire from the blooms made at the bloomery. There is a surviving lease[8] of the bloomery, the essence of which is:

> 2 April 1621. Sir Francis Wortley leased to Sir Francis Fane, Sir Robert Beaumont, Francis Burdet and Edmund Cundy for 21 years 'divers Iron Smithies & premises for working & delfs & mines of Ironstone in Thurgoland, Dodsworth & Silkstone with leave to get 12 score dozens of charcoal out of the wood in the district of Wortley with services of colliers & gravers at a yearly rent of £5'. The 'Iron Smithies' consisted of 'houses, buildings, stringe hearthes, bloom hearths, dames, streams, goyts and watercourses thereto belonging. . lately in the tenure of Matthew Stafford, John Turneley and Ambrose Wood deceased'.

The description is unmistakably for a waterwheel-operated bloomery formerly worked by, among others, Ambrose Wood deceased; it is clear that charcoal was to come from the woods in Wortley and should have been sufficient to make 240 blooms each of 2 cwt or 24 tons per annum.

It may be noted that, in the same period, on 14 January 1619/20, Sir Francis Wortley had acquired a 'fourth part of the Iron Smithies, Mills, Forges, Mines &c of Silkstone' for £40 p.a. from Thomas Barnby.[27] These would be the same as 'The Midgley bank Smythies, being ironworks belonging to Sir Francis Wortley'[28] on the river Dearne, near where Bank furnace was later built.

The fact that Ambrose Wood had previously been a partner in the bloomery leased to Sir Francis Fane and others in 1621 suggests that the enterprise, with the building of the wire mill in 1624, was a development of the handcraft of wire-drawing which had flourished in Barnsley. We have few details of this trade. William Bower, wire-drawer, was baptized at Barnsley in 1583 and his son, Leonard, was also a wire-drawer.[29] It is a reasonable assumption that the Barnsley Smithies were the source of the iron used for wire-drawing in Barnsley in Elizabethan days. In 1624, the year in which the Wortley Old Wire Mill was built, it was stated[30] that George Wood was paying £12 for certain lands 'lying near the Smithies at Barnesley Berkes, the Smithies being now decayed'. In 1589 there was a case in the Court of Exchequer[31] in which two Woods, father and son, who worked two corn mills and a fulling mill belonging to the crown, sued George Woodruff who had erected two waterwheels 'adjoining unto a paire of Smythies or Iron Mills within the p'ishe of Royston'. According to Hunter,[32] the Barnsley Smithies were founded in the 12th century. Another statement in the legal case of 1589 was that the iron mills had, for 40 years, paid an annual rent of £8 to the crown, a low rent suitable for a fabricating forge such as would be required for making the rods for wire-drawing.

We must now return to Sir Francis Fane who, with others, (Cundy being Sir Francis Wortley's attorney) leased the Wortley Bloomery in 1621. Sir Francis was the son of Sir Thomas Fane of Badsell, near Tonbridge (Kent) who, as his second wife, had married Mary Nevile, daughter and heiress of Lord Abergavenny, the lineal descendant of the first Earl of Westmorland.[33] Sir Thomas, about the time of his second marriage, worked two charcoal blast furnaces and two finery forges near Tonbridge.[34] The chief seats of the senior branch of the Neviles, Earls of Westmorland, were Raby and Brancepeth Castles, Co. Durham, but the Earl of Westmorland had forfeited his estates in the Catholic uprising of 1568. Other branches of the Neviles lived in Yorkshire at Liversedge, Chevet, and Wakefield.[35] Sir Francis Fane had, in 1615, on the occasion of the first marriage of Sir Francis Wortley, advanced him a loan based on a mortgage on Sir Francis Wortley's manors.[27] He had also, in 1618, with three others, leased from John, Lord Savile, the iron forge (bloomery) on the Kirkstall Abbey site, Leeds.[36] In 1624 he succeeded to the Earldom of Westmorland and died in 1628. Although he retires from our story, we may see in his leases of Wortley and Kirkstall Abbey Bloomeries an intention to build finery forges in both places, with charcoal blast furnaces nearer the better ironstone supplies, to develop the wire trade which had apparently not then been instituted in the Wealden area as originally intended.

The earliest leases which have survived of both Wortley and Kirkstall Abbey finery forges are both dated 1658, the Wortley (Upper and Lower) being leased to John Spencer I and Kirkstall Forge to his son-in-law Russell Allsop and William Fownes II, nephew of Elizabeth, sister of John Spencer I, with William Cotton I, son-in-law of this Elizabeth, as chief clerk (manager) of both groups of forges. Before dealing with the ramifications of the Spencer family we should look at the activities of William Fownes I, who married Elizabeth Spencer, for his experience in iron making was an essential factor in the introduction of finery forges at Wortley and Kirkstall.

THE SPENCER PARTNERSHIPS

William Fownes I, husband of Elizabeth Spencer, is first heard of with his partner William Boycott operating Ifton Rhyn charcoal blast furnace with Fernhill and Maesbury Forges in Western Shropshire.[39] Their iron was sent to the river Severn and thence to the Hyde slitting mill. In 1635 these partners brought a Bill of Complaint against Thomas Myddleton for diverting a watercourse.[40] Myddleton was the son of Sir Thomas Myddleton (1550-1631), a former Lord Mayor of London and the grandson of a former Governor of Ruabon Castle who had bought an estate in Chirk in 1595.[41] Thomas Myddleton married the daughter of a younger branch of the Saviles of Lupset, Yorks., and was living at Hasledon Hall, Wakefield, when his wife died a year after their marriage. When his father died in 1631, Myddleton decided to develop the Chirk estate and in 1634 became a partner with two Shropshire ironmasters in the existing Ruabon blast furnace, Denbigh, and built Pont-y-blew Forge, Montgomery. The competition of Myddleton and his partners seems to have caused Fownes and Boycott to leave their ironworks. Boycott stayed in Shropshire and his son was concerned in Willey and Leighton Furnaces and three forges.[42] Fownes appears to have gone to Wortley some time between 1635 and 1639, in which latter year Myddleton had taken over the former Fownes-Boycott ironworks.[40]

William Fownes I died in 1647, and when his widow made her will in 1657 she described her son-in-law William Cotton I as 'of Wortley Forge in Hunshelf'[43] i.e. Wortley Upper Forge.; she was buried in Wortley. William Fownes I had a brother Gilbert whose son William Fownes II was one of the partners in Kirkstall Forge in 1658, and Gilbert himself was described in 1651 as a partner of John Spencer I of Thornhill, where both Bank and Barnby Furnaces were built.[44,45] Since, in his will, William Cotton I described Thomas Dickin I as his cousin, it seems most likely that Dickin had married a daughter of one of the first generation of Fownes. Thomas Dickin I was a partner in Kirkstall Forge 1675-92 and his son, Thomas II, was the sole lessee of Wortley 1695-1700.

The brother-in-law of William Fownes I, Randolph Spencer, lived at Criggon, Montgomery, which, though in Wales, was a chapelry of Alberbury church, west of Shrewsbury. Since Richard le Spencer was the vicar of Alberbury in 1300,[46] the family name occurs in the parish registers from 1571, and John Spencer II, son of Randolph, was baptized there, we can conclude that only Randolph and Elizabeth of the first generation that we are concerned with had remained in their place of origin. John Spencer II, when he was aged 21 in 1650, went to his uncle Walter at Barnby Furnace. Walter Spencer was married to Frances Barnby of Barnby Hall, the aunt of Thomas Barnby (1600-living 1654), the last male of 16 generations of Barnbys, one of whose daughters married John Allot of Bentley Grange, near Bank Wood, the site of Bank Furnaces.[47] It is convenient to record here that John Spencer II married, as his second wife, Margaret Hartley of Cannon Hall, that his son John III, also a lessee of Wortley Forge, married Ann Wilson, whose brother Matthew Wilson was of Wortley Forge, whilst Ann's sister Susanna married the Rev. Thomas Cockroft, the father of the first John Cockroft of Wortley Forge.

John Spencer I, who took the first known lease of Wortley Forge in 1658, died in the same year and was buried at Wortley. Soon after his death, his son Edward had a three-fifth share in the Fownes-Spencer partnership and sold one-fifth to Russell Allsop, his brother-in-law; William Fownes II had his father's one-fifth and John Banks acquired the one-fifth share of William Cotton I, though the latter acted as chief clerk of the group until 1667,[48] when he withdrew to partner Myddleton in his Denbigh ironworks and Colnbridge forge in which he and Thomas Dickin each had a half-share.

Thus, although we do not know the original Fownes-Spencer partnership arrangements, we have seen that, in 1658, John Spencer I, his son Edward, his son-in-law Russell Allsop, with William Cotton I and William Fownes II, respectively son-in-law and nephew of William Fownes I, were concerned in the leases of Wortley and Kirkstall Forges. John Spencer II was at Cannon Hall with Barnby Furnace as his chief interest, though he entered the Kirkstall partnership in 1676. Bank Furnace was not mentioned by name in the Wortley lease of 1658, though it was presumably 'the furnace' which was included in the lease of 1678 for a rent of £20. The lease of 1683 is specific:[50] 'Those two Iron fforges for making Iron commonly called Wortley fforges in the parishes of Tankersley, Penistone and Silkstone and all that furnace for founding or melting Ironstone to Sow Iron commonly called Bank ffurnace situate & being within the parish of Thornhill'. Bank Furnace was built in the Newhall manor of Sir Francis Wortley. It is mentioned by name in all leases of the Wortley Forges from 1683 to 1793,[51] so that we can assume that it was built by Sir Francis Wortley at the same time as the Wortley refinery Forges.

CANNON BALLS

One of the most interesting of early relics at Wortley are the cannon balls, but the story of these has been corrupted. Firstly, the widow of the Royalist commander in the north during the Civil War referred in her memoirs to the 'casting of iron cannon and other instruments and engines of war'. Secondly, the Gunner General from Woolwich who inspected them in 1888 gave an incorrect assessment of their calibre and Andrews, who recorded the bare facts, was led into idle speculation. It is, however, possible to record this interesting story without speculation.

In making alterations at the Lower Forge in 1868, three cannon balls were found below the floor.[52] They were of $14\frac{3}{4}$, $2\frac{1}{2}$, and $1\frac{1}{4}$lb weight. The largest would fit a culverin and the smaller ones the Stuart field guns. In the lease of 1658, the Lower Forge was described as a 'shot fforge'. Contemporary correspondence in 1643, when the Marquis of Newcastle was Governor of Sheffield Castle, refers to 'the shot makers at the forge'. This evidence shows that the shot was forged, not cast, and that Wortley Lower Forge was used by the Royalist forces for forging shot in 1643.

After the capture of Sheffield Castle by the Royalist forces in May 1643, the Marquis of Newcastle appointed Sir William Savile, third baronet, as governor of the Castle but, since he was engaged in manoeuvres in the field, he had as his deputy Major Thomas Beaumont, a relative and eventual heir of Sir Richard Beaumont, who was a partner in the lease of the Wortley Bloomery in 1621. Before quoting extracts from the correspondence, which is given in full in Hunter's 'Hallamshire', it should be noted that bullets had the contemporary meaning of shot.

The correspondence opens three weeks after the capture of Sheffield Castle in 1643.

> Savile to Beaumont, 29 May, from Pontefract castle. . . for bullets I pray be still diligent
>
> Savile to Beaumont, 3 June, from Pontefract—For the bulletts that are alreddy made, if you think the way be safe, send them to the castle att Pontefratt & write to the governor there to keepe them for me.
> I shall desire to heare what becometh of Sir Francis Wortley & how the case standeth with him & his force.
>
> Savile to Beaumont, 7 June, from Pontefract—Send me a load of bullets tomorrow & some 12 men at least to guard it.
>
> Savile to Beaumont, 21 June, from Heath—bee sure you want not any money neither for yourself nor your friends, soe long as any Roundhead hath either fingers or toas left, within tenn myles of the castle.
> I have received the bulletts according as you write, and shall hereafter desire you to send me the sizes as well as the number of the bullets. Wee are now upon our march towards Leeds.
>
> (Savile died at York in January 1643/4 and the Marquis of Newcastle assumed the governorship of Sheffield castle)
>
> Marquis of Newcastle to Beaumont, 13 February 1643/4, from Newcastle—For bulletts and grenades, I pray you deliver from time to time so many as Colonell Belasye commander in chief shall send you warrant for.
>
> Jo. Watkinson to Beaumont, 15 February 1643/4, from York—You may perceive by the coppy of his E^eys^ letter & this note both here inclosed, that his Lordship desireth these quantities of iron shott to be sent to him at Newcastle, with what speed may bee. I must entreat you to send to Mr Clarke at Doncaster all the severall sorts of shott, and what you want of any kind of them, to get the shott-makers at the forge to make that quantity to be sent to his Ex^cy^ & the like quantity to remain in our stores. I pray them to be made with what possible speed you can. . .

Sir Francis Wortley, an ardent Royalist, raised a troop of dragoons when the Civil War began in 1642 and waged a guerilla war against the Parliamentary forces. He was, however, captured at Walton, Wakefield, just before the battle of Marston Moor in July 1644 when the Royalists were defeated. The Marquis of Newcastle and the Earl of Arundel of Hallamshire escaped to the continent. A demand was made for the surrender of Sheffield Castle and, when this was refused, the Parliamentary forces brought up a culverin and the 'Queen's pocket pistol' (presumably a mortar) and breached one wall. The Castle then surrendered and among its contents were 'twenty tuns of great iron shot'. Sheffield Castle was ordered to be slighted and demolished and the Civil War in the north was virtually over.

Sir Francis Wortley was imprisoned in the Tower of London, where he died in 1652.[55] His heir, Col. Francis Wortley, was captured in the garrison at Ashby-de-la-Zouch and, in 1646, was fined £300. His uncle, Sir Edward Wortley of Turnham Green (Middlesex) was summoned to show why the manor of Wortley and three others should not be sequestrated. It is recorded that Frances, wife of Col. Francis Wortley, stated on 6 January 1651/2 that her husband was imprisoned for a debt of £200, and that 'He had neither estate nor credit to pay the fine of £300, his estate of £2,000 being sequestrated and paid to the garrison'. In 1655 Sir Francis Wortley, the second baronet, took the Oath of Abjuration and his estates were to be restored to him.[55] His uncle, Sir Edward, was a Parliamentarian and presumably it was because of the unsettled state of the Wortley estates that it was he who, in 1658, leased the Wortley Forges to John Spencer I. We can presume that, on the Restoration in 1660, Sir Francis Wortley, the second baronet, was in full possession of his father's estates.

These records give fairly convincing evidence of Wortley Lower or Shot Forge in 1643. Another record can be quoted here to indicate the existence of a Wortley Forge in 1641. In 1644 the Corporation of Doncaster enquired about the amount of iron delivered to their wharf on the River Don during the preceding 14 years by Mr Cotton of 'watley forge', implying the interest of William Cotton I in Wortley Forge in 1641.

THE WHARNCLIFFE RECORDS

The Inventory of the Muniments of Lord Wharncliffe, a folio MS[27] which, with the muniments, are now in Sheffield City Library, has summaries of the deeds. These show, in particular, the financial difficulties of Sir Francis Wortley, first baronet, before the Civil War. The mortgage on his chief manors of Newhall, Carlton, Wortley, Hunshelf, Pilley, Swinton, and Hoyland Swaine in 1615 to raise a settlement for his first wife, has already been mentioned. By 1627 he had debts of £700 and he attempted to settle these by selling his manors of Beighton and Hackenthorpe to his mother, then the Dowager Countess of Devonshire, for £5,000 but, by 1630, this bargain had been annulled. The reason for this appears to be that, in that year, Sir Francis mortgaged to Anthony Crofts his manors of Wortley, Pilley, Hunshelf, and Hoyland Swaine for 40 years for a sum of £7,800. This bargain was, however, replaced, in 1635, by another with his mother. In this he agreed to grant the same four manors to his mother for ever for a sum of £20,000, the manors to be re-leased to Sir Francis for five years for a yearly rent of £1,600. Sir Francis also agreed to discharge his debts to Anthony Crofts and others and to settle the manor of Carlton upon himself for life with the remainder to his only son.

This last settlement seems to have been affected and the manors were to be put into the hands of Sir Henry Crofts (who had married one of the sisters of Sir Francis) and Sir Edward Wortley, brother of Sir Francis, as trustees for the Dowager Countess. On 23 May 1638 there were articles of agreement[57] in which Sir Francis agrees that before Michaelmas he will deliver into the hands of the Dowager Countess his Yorkshire manors (excluding Newhall) but including 'all and sundry the messuages, Mills, Iron Smithies, mines, quarries and watercourses'. Two days later there was a similar agreement[58] for him to surrender the manor of Newhall, Middleton, and Midgley including 'Messuages, Lands, Tenements, Milnes, Meadows, pastures, common waies, watercourses, Mynes, Quarries' in the parish of Thornhill.

The fact that, in May 1638, there was no mention of a furnace in the manor of Newhall and only 'Iron Smithies' in Wortley and Hunshelf suggests that Sir Francis wanted the capital before he built Bank Furnace and the finery forges at Wortley, where the bloomery still persisted.

LEASES OF WORTLEY IRONWORKS

Wh. D.*	Year	Date	Lease starts	ends	Years	Lessee	*B	Rent (£) UF	LF	BF*	Cords of wood	Price s/d	Remarks
503	1621	2 April		1642	21	Ambrose Wood et al. See below (Wh. D. 113)	5				600[1]		1. 240 dozen charcoal
missing				1663	21								
missing				1684	21	Robert Dundy							
526	1683/4	1 Jan.		1704/5	21	Wm. Wood	40				(included		
113	1642	13 July		1664	—	Robert Woolrich et al.		400[2]			2000	4/-	2. Including wood
missing						Mary Wood (LF)							3. do. do.
576	1658	18 May	24 June	1667	9	John Spencer[4]	—		500[3]		1800	5/-	4. Dies same year, his son
missing				1676	9	Edward Spencer?							Edward taking lease?
577	1676	1 May	24 June	1683	7	Wm. Simpson	—	20	20	20[5]	800	6/6	5. 'the furnace' Manager
578	1683	24 June		1690	7	do.	—	20	20	20[6]	700	6/6	6. 'Bank furnace' D. Heyford
579	1688	22 Dec.				John Eyre							Partner of W. Cotton
580	1689	7 Oct.	29 Nov.	1695	5	Lionel Copley II					350		7. Son of T. D. I at
581	1695	25 Sep.	29 Sep.	1703	7½	Thomas Dickin II[7]	—		90				Kirkstall Forge (KF)
582	1700	25 March		1707	7½	T. D. II J. Spencer III	—						Manager T. Woodhead of KF
583	1706	20 March		1713	7½	John Spencer III	—		90				Manager Matt. Wilson
584	1712	4 Sep.		1723	8	do.	—		90			7/6	
586							—	—	—	—			Wood at Newhall
587	1722/3	1 Jan.		1738	15	do.							
588	1738	24 Jan.				Wm. Spencer	—		120			7/6	
589	1740			1746	6	do.							
missing	1746			1765?		John Cockshutt I							
missing	1765?			1789?		John Cockshutt II							
590	1793	25 March		1814	21	James Cockshutt	—		185[8]				8. Includes rolling mill
missing	1814			1819?		do.							
missing	1819			1849		V. Corbett							
missing	1849			1871		T. Andrews I							
missing	1871			1907		T. Andrews II							
missing	1907			1929		J. & B. Birdsall							

*Wh. D. = Wharncliffe Deed, Sheffield City Library; B = Bloomery; UF = Upper Forge; LF = Lower Forge; BF = Bank Furnace

At the beginning of 1641 (N.S.) the Dowager Countess leased[59] the manor of Newhall to Sir Edward Wortley. In a deed of 13 July 1642[60] it was mentioned that Sir Edward Wortley and Sir Henry Crofts (his brother-in-law) were to be the trustees, after the death of the Dowager Countess, of the manors of Wortley, Pilley, Hunshelf, and Hoyland Swaine. In this deed and two others[61,62] of the same date, there are references to the ironworks. Robert Woolorth and George Dancy, both of Gray's Inn, and Henry Haughton, gentleman, were to be allowed to take yearly for the remainder of the forty years period 2,000 cords of wood and underwood for the necessary use of 'the Ironworks in and upon the said premises as also as much Ironstone and Iron mine as the furnaces and forges... shall from time to time use'. In one of these deeds[62] the manor of Wortley is specifically mentioned and they were to pay £400 per annum and to take all the profits of the manor.

Here, at last, in a Wortley deed is the first mention of forges, but the furnaces would be the bloomery for which the ironstone was required.

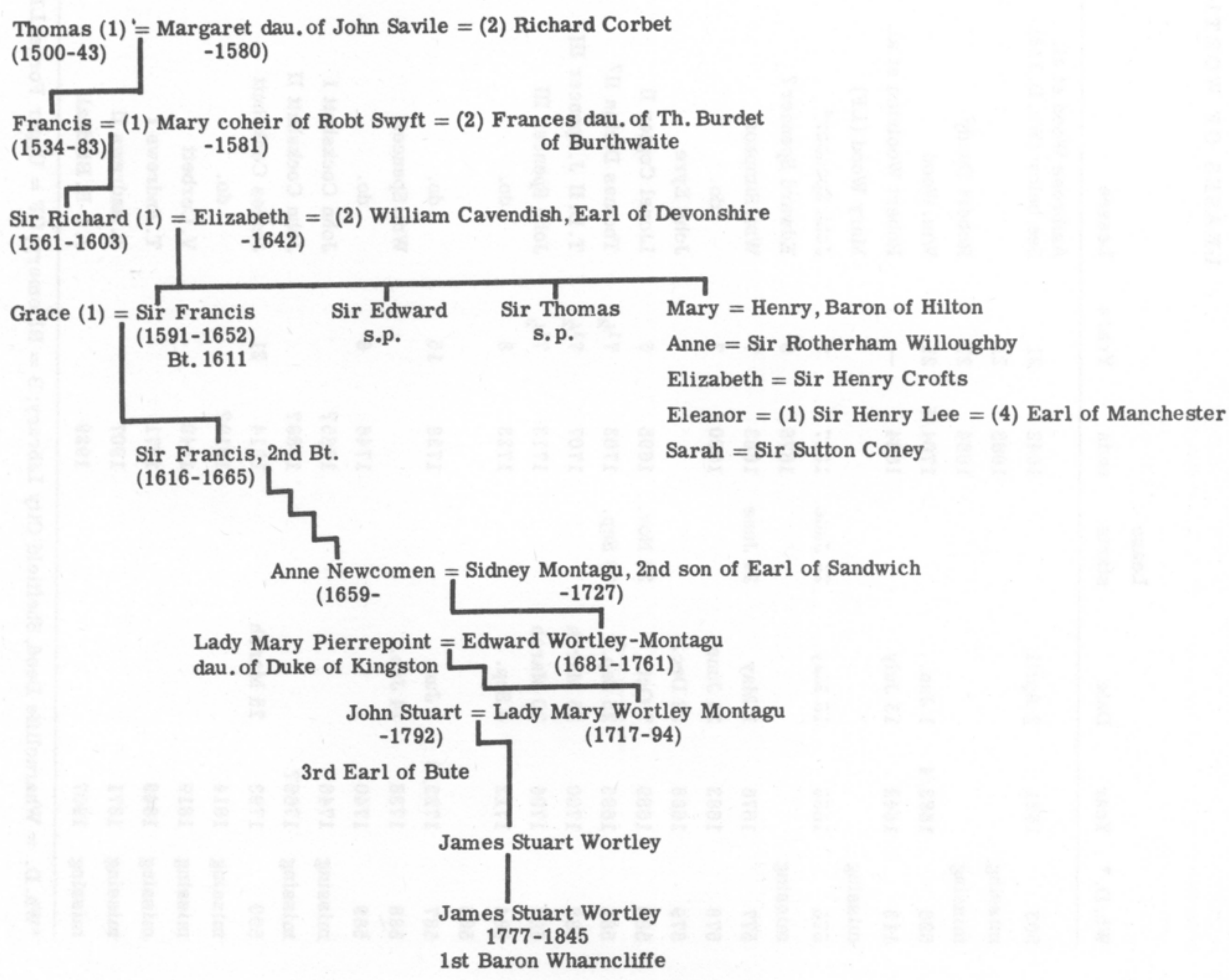
One other deed from the Wharncliffe collection may be mentioned. At the beginning of 1684 (N.S.) Sidney Wortley leased to William Wood[9] of Coatefield, husbandman, for 21 years at a yearly rent of £40 all the lands in a schedule attached including woods and underwoods, watercourses, mines, and quarries. The schedule attached is damaged but enough can be deciphered to show that there were eight woods totalling 71 acres, four fields totalling 27 acres, and two sinder hills totalling 17 acres. This grant, with its woods, ironstone, and watercourses can be no other than the bloomery site at Tin Mill, 'sinder hill' being a common name for heaps of bloomery slag which can be seen in large lumps 50 yards below the ruined cottages. In the deed it was mentioned that the lessee was to see that all the corn was ground in the mill of Sidney Wortley.

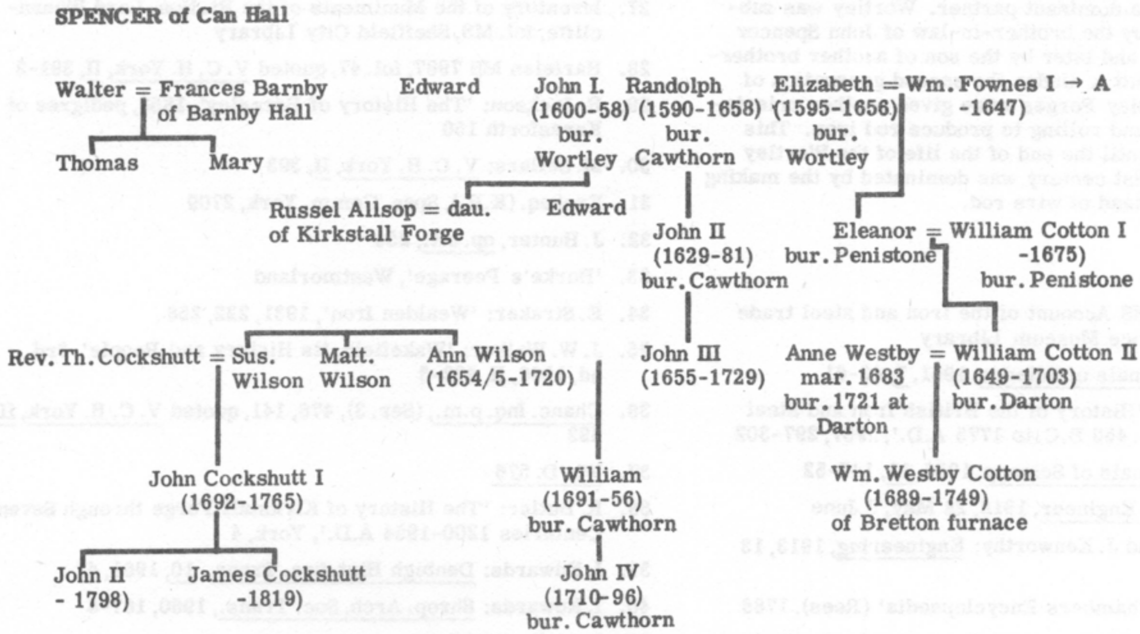
There seems to be no reason to doubt that, financially, both Bank Furnace and the two Wortley Finery Forges could have been built by May 1639, but we have only the vague statement of the Doncaster Corporation implying that 'watley forge' was in existence in 1641, the references to the 'forges' in the deeds of 1642, and the more definite indication of the existence of the Lower or Shot Forge in 1643. The first known nine leases of the Wortley Forges were always for short periods, the first two from 1658 being each for nine years; 18 years before the lease to John Spencer I on 24 June 1658 would make the original lease in June 1640, which is the best estimate we can make for the origin of the Upper Finery Forge and Bank Furnace.

We should not be misled by the language of the lease of 1658, as was Dr Andrews in her note in the second edition of 'The Story of Wortley Ironworks'. She, or rather Miss Meredith, omitted the significant word 'shott' to describe the Lower Forge: 'All that fforge late in the Tenure or occupation of Sir Francis Wortley scituate & being in Hunshelfe in the county of York and also two ffyneries one Chafery one Hamm^{r} with their Appurtenances in Hunshelfe aforesaid and all that shott fforge called by the name of the New Hamm^{r} or Lower fforge & lately Erected and built by the said S^{r}ffrancis Wortley situate & being in Wortley in the said county of York & also two ffineries one Chafery one Hamm^{r} and Houses thereto belonginge... now or late in the term or occupation of Mary Wood...'

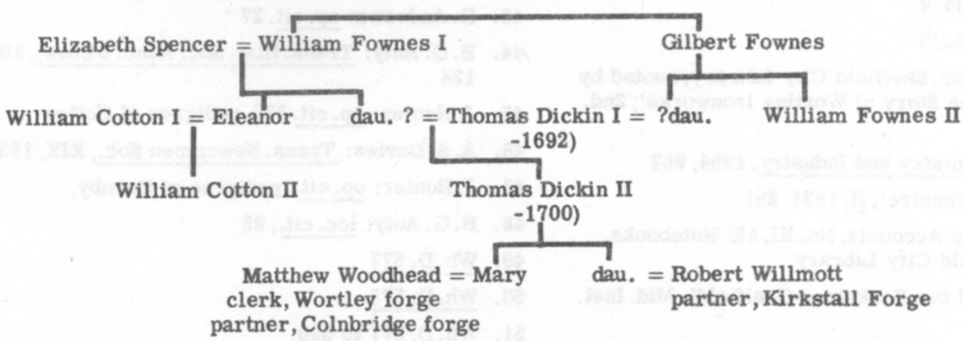
The words 'lately erected' had not the sense of immediacy which they gained at the beginning of the 19th century and

WORTLEY of Wortley, Hunshelf, Pilley, Hoyland Swaine, Newhall etc.





A. Suggested source of cousinship of William Cotton I and Thomas Dickin I



the 'New' Hammer only meant that it was erected after the Upper Forge. The terms 'shott forge', 'ffyneries' 'Chafery no doubt baffled the archivist and she omitted them. Other significant omissions were that the Lower Forge was 'late in the tenure of Mary Wood' and that the Upper Forge was 'late in the tenure of Sir Francis Wortley', who died in 1652 and was in the Tower from 1644. Since his mother died in October 1642, there may then have been a settlement in which he recovered his manors.

Though the language of the records for 1641, 1642, and 1643 lacks the precision of the lease of 1658, the grant of wood from Wortley for the ironworks in the three deeds of July 1642 is conclusive evidence that these were something more than the smithies of 1621. In the lease of 1621 the bloomeries were allowed 240 dozens of charcoal from the district of Wortley. Allowing $2\frac{1}{2}$ cords of wood per dozen of charcoal, this is equivalent to 600 cords of wood annually. In the deed of 1642 the lessees were allowed to take 2,000 cords of wood, which would leave 1400 cords for the forges, which would make 560 dozens of charcoal, sufficient to make 200 tons of wrought iron per annum. In the lease of the two finery forges in 1658 the lessee was allowed 1800 cords of wood.

CONCLUSION

We have seen that the Wortley family had an iron bloomery in the parish of Silkstone in the region of Henry VIII and another, perhaps, near their manor of Newhall in the parish of Thornhill, in the reign of James I. Their bloomery in Wortley, which was leased in 1621, had previously been leased by Ambrose Wood and others; since this was let for terms of 21 years, it is likely to have been in operation in 1600. The Old Wire Mill was built in 1624 as one of the earliest power-operated wire mills other than Tintern, where the practice was introduced from Germany. Lands, tenements, and waterways totalling 42 acres-2-39 to Richard Wordsworth on 2 February 1684/5 for a rent of £16 for a period of 17 years may be the New Wire Mill.[63] The bloomery was last leased in 1683/4 for 21 years, but was probably abandoned before its period and converted into a slitting mill to give a new impetus to the forges by converting their bar into rod or nail iron for the nailors of Mortomley. In 1743 the old slitting mill was converted into a tin mill and tinplates were made. If there is any truth in the tradition, it would be that in 1743 Tilt Mill was built as a slitting mill to replace the old slitting mill converted into a tin mill.

The Upper and Lower Forges were worked in conjunction with Bank Furnace, also belonging to the Wortleys, perhaps the third charcoal blast furnace in Yorkshire, if we forget the short-lived Wadsley and Kimberworth furnaces, which were converted into forges. John Spencer I and his brothers were concerned in Barnby Furnace. William Fownes I was concerned in the first finery forges at Wortley and Kirkstall and his son-in-law was clerk of both. The Wood family had a particular interest in the Wortley Bloomery, the wire mills, and the first slitting mill. The initials WW on the mural stone of the Lower Forge of 1713 were probably those of William Wood, the last lessee of the bloomery in 1683/4, who took over the slitting mill which replaced it; he may have been the manager of the Lower forge in 1713, when some alterations, perhaps new hammers, were put in at both forges.

The influence of William Cotton I and his son William II was greater than that of the Spencers until 1700, when John

Spencer III became a dominant partner. Wortley was subsequently operated by the brother-in-law of John Spencer III, Matthew Wilson, and later by the son of another brother-in-law, John Cockshutt I. Under the second generation of Cockshutts the Wortley Forges were given another orientation using puddling and rolling to produce rod iron. This practice prevailed until the end of the life of the Wortley Forges, though its last century was dominated by the making of railway axles instead of wire rod.

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A metallurgical examination of a bronze sword found in the Thames at Battersea

H. H. COGHLAN

This specimen (Newbury Museum S. 223) is a portion of a Middle Bronze Age sword which has been broken towards the hilt end; a small piece has also been broken off from the tip or point (Fig 1). The portion remaining measures 320 mm in length with a maximum width of blade of 42mm, and a maximum thickness of 8 mm, tapering to 2. 5 mm in thickness at the point. It may be seen from the cross-sections that the blade is symmetrical, and the cutting edges were carefully sharpened by secondary grinding and honing, which shows as parallel bands some 3 to 4 mm in width along the edges of the blade. The patination upon the metal is chocolate-coloured, stable in appearance, and with no superficial evidence of active corrosion. The general condition of the blade is good, with the exception that considerable lengths of the cutting edges have been bent over by rough use or hammering. The undisturbed patination suggests that this damage occurred in antiquity; the metal of the cutting edges must be ductile since in places it has withstood bending over through considerably more than 90° without cracking or fracture. Patination upon the fractures, both at the hilt and at the point, indicates that the sword was broken in antiquity. Visual inspection of the break at the hilt end showed that fracture had taken place through a zone of defective metal, since a very large void, measuring approximately 2.5 × 5mm, showed in the plane of fracture near to the centre of the casting, and adjacent to the cutting edge another void was seen.

As this broken portion of a sword is of little value for museum display, it was decided to make a thorough examination of the blade. The following samples were taken for metallographic work: Section A–B is a longitudinal section, of about 20mm in length, removed from the hilt end. This section includes the plane of fracture. Sections C–G are complete transverse sections through the blade and include both cutting edges; they are taken at approximately equal spacing along the length of the blade. Section H is a longitudinal section of about 8mm in length, removed from the tip or point; it also includes the plane of fracture. As well as the above-mentioned sections, a number of analysis drillings were made along the length of the blade for the purpose of checking the segregation of lead, if any, in the metal. These drillings are numbered 1 to 8, and their position is shown in Fig. 1.

The composition of the metal, expressed as percentage figures is: Sn 9.3 (by chemical determination); Pb 4.0; Sb ~ 0. 05; As ~ 0. 05; Bi ~ 0. 02; Ni ~ 0. 2; Ag ~ 0. 01; Au nd; (<0. 001 if any); Zn nd (<0. 01 if any); Fe ~ 0. 05; Mn nd (<0. 01 if any); P nd (<0. 02 if any); Co ~ 0. 005; Si ~ 0. 1; Al nd (<0. 01 if any).

Except in the case of tin (chemical), the above figures are expected to be accurate to ±50% of the value. It is interesting to note that the impurities are within those laid down by the British Standard for the nearest modern equivalent alloy—B.S. 1400, Alloy L B 3.

In the process of casting long and slender objects such as swords, gravity segregation of certain elements, and in particular of lead, may occur. The lead results from the drillings made at positions 1 to 8 in Fig. 1 are:

Position 1: 4. 2%	Position 2: 4. 1%
Position 3: 4. 2%	Position 4: 4. 0%
Position 5: 4. 0%	Position 6: 4. 1%
Position 7: 4. 1%	Position 8: 4. 0%

From these figures it is clear that there has been practically no gravity segregation of the lead, and this suggests that there was little inclination given to the mould during casting. On the other hand Moss[1] examined a portion of about 250 mm in length from a broken Irish Bronze Age sword, also from the Newbury Museum. Here twelve drillings, each of from 0.44 to 0. 58 g for chemical analyses, were taken along the length of the sword to test for segregation of lead and tin. The tin content of this specimen is similar to that of the Battersea one, but the alloy is more highly leaded. No segregation of the tin was recorded, but there was appreciable segregation of the lead, the values for this element being 11. 8% at one end of the specimen and 13. 7% at the other end.

Examination of the polished but unetched metal of the various sections showed that the patination is thin, and there has been remarkably little penetrative corrosion. Hence, the environment must have been remarkably favourable for the preservation of the bronze. In section A-B the metal is unsound, with high porosity and casting voids. The fracture clearly occurred through two large voids, one of the voids measuring approximately 3 mm × 2 mm (Fig. 2). The metal of section H is poor with considerable porosity, and fracture has taken place through a very large casting void which cut through about three-quarters of the metal. In the case of sections C to F, the metal is unsound with much porosity and a frequent occurrence of casting voids. These defects are all internal, and no blow-holes or voids appear upon the surface of the sword (Fig.3). Apart from the general porosity, some twenty-eight large voids were counted in the various sections, and no doubt there are many more voids present in unexplored parts of the sword. Hence, as a working weapon the sword would be very unreliable and certain to break in service. In a number of places the cutting edges of the blade have been much bent over by rough use (hammering),

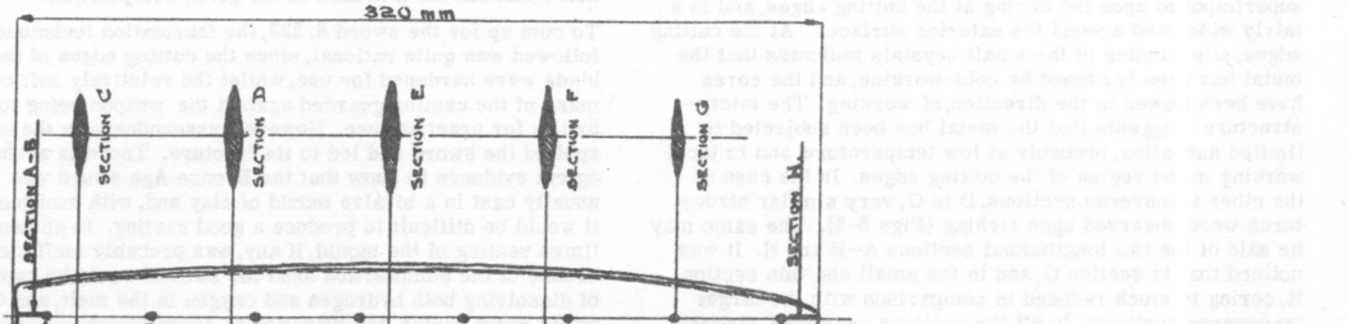

Fig. 1 — Diagram showing positions at which various sections were taken, and position of the analysis drillings 1 to 8.

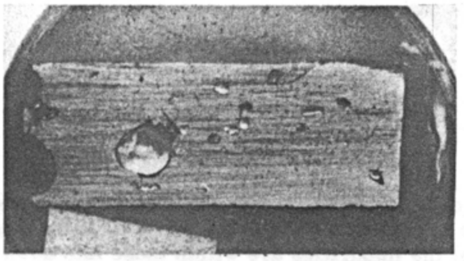

Fig. 2 — Section A—B, showing the large casting voids through which the sword was fractured × 3

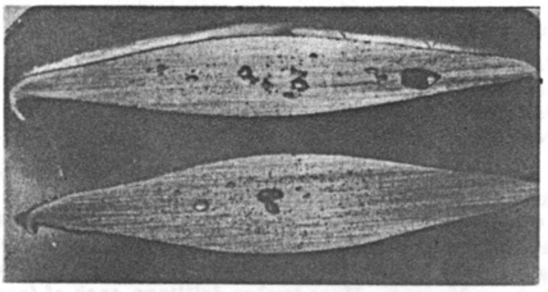

Fig. 3 — Section F (top), and section D (bottom), showing porosity and casting voids typical of the metal in the various sections examined × 2

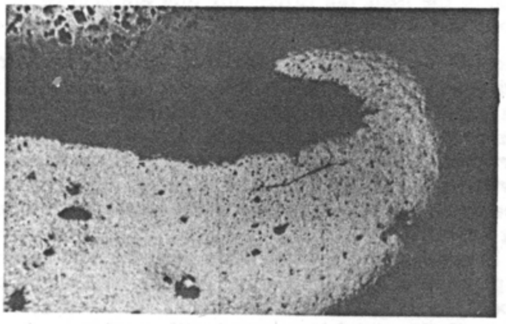

Fig. 4 — Section E: the tip of the ductile metal of one of the cutting-edges has been bent over without fracture through 180° × 40

and in section E the edge has been bent round through no less than 180°(Fig. 4). To withstand such severe treatment without cracking shows that, at the cutting edges, the bronze is ductile and of good quality.

Etching of transverse section C revealed a strongly cored structure with equi-axed twinned crystals of low grain size superimposed upon the coring at the cutting edges, and in a fairly wide band around the exterior surfaces. At the cutting edges, slip banding of the small crystals indicates that the metal has been hardened by cold-working, and the cores have been flowed in the direction of working. The microstructure suggests that the metal has been subjected to limited annealing, probably at low temperature, and to local working in the region of the cutting edges. In the case of the other transverse sections, D to G, very similar structures were observed upon etching (Figs 5-6). The same may be said of the two longitudinal sections A—B and H. It was noticed that in section G, and in the small and thin section H, coring is much reduced in comparison with the larger transverse sections. In all the sections examined, discrete particles of lead were observed. Very little $\alpha\delta$ eutectoid was seen in the various sections, which is rather unexpected in a bronze containing 9.3% Sn that has not been extensively annealed and worked.

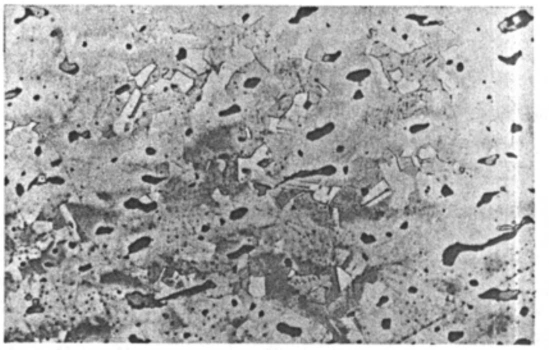

Fig. 5 — Section E: recrystallisation and relics of coring at about 5 mm from the cutting-edge. Non-metallic inclusions and lead (black markings) are seen etched × 140

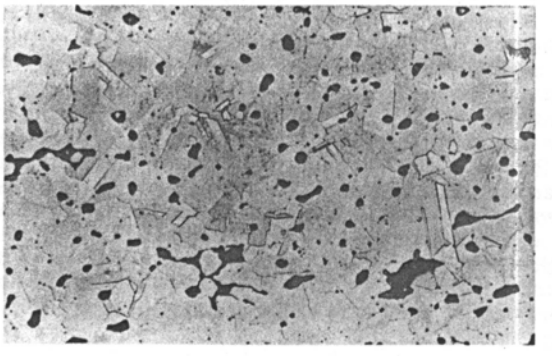

Fig. 6.—Section G: recrystallisation in the mass of the metal near the centre of the casting. In this section coring is much reduced and only faint core-shading remains. Etched × 140

The following hardness determinations were made on the trasverse sections:

	On one cutting edge	On the other cutting edge	Mass of the metal. Centre of the casting.
Section C	124 HV_5	123 HV_5	82 HV_5
" D	124 "	126 "	79 "
" E	111 "	107 "	— defective metal.
" F	146 "	137 "	86 HV_5
" G	116 "	104 "	81 "

From the above figures it will be seen that, throughout the length of the portion of the blade examined, the cutting edges have been hardened by cold-hammering. The hardness attained is moderate and by no means so high as often recorded in the case of cutting tools such as axes and palstaves The metal in the centre of the casting remains in virtually soft condition for a bronze of the given composition.

To sum up for the sword S. 223, the fabrication technique followed was quite rational, since the cutting edges of the blade were hardened for use, whilst the relatively soft centre mass of the casting guarded against the weapon being too brittle for practical use. However, unsoundness in the casting spoiled the sword and led to its fracture. There is archaeological evidence to show that the Bronze Age sword was usually cast in a bivalve mould of clay and, with such moulding it would be difficult to produce a good casting. In ancient times venting of the mould, if any, was probably inefficient; bronze of the composition used for swords would be capable of dissolving both hydrogen and oxygen in the melt, and these would react during solidification to cause steam porosity. Heating of the mould would be necessary in order to assist casting, but it would not be easy to keep a slender sword mould of clay, perhaps of over 2ft in length, at a suitable temperature to receive the metal poured.

Finally, it is of interest to mention three Late Bronze Age swords from Ballycroghan, near Bangor, Co. Down, reported upon by Jope.[2] In these swords the metal was poor and porous and, in fact, one of the swords appears to have been discarded because of unsoundness of the casting. Again, four broken portions of Bronze Age swords in the Newbury Museum were examined.[3] In three of these swords the metal is highly unsound and porous. In the fourth sword the metal, while not quite so defective, is porous and of poor quality. Hence, the sword from the Thames at Battersea does not stand alone as an example of the difficulty found in casting the Bronze Age sword, and it appears open to question if a good working sword was available before the coming of iron.

ACKNOWLEDGEMENTS

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Cyclical operations at Roman bloomeries

H. F. CLEERE

One of the most noticeable features of the slag and refuse heaps at the large Roman bloomery sites in the Weald of Kent and Sussex is the stratification that they exhibit. When a section is cut through one of these banks, either deliberately or accidentally, the material is seen not to be a random mixture of debris but to consist of a series of distinct layers, each composed of different materials.

This phenomenon was first recorded by James Rock,[1] who observed it at Beauport Park, Battle, and described it as follows:

> 'The mound is made up of a series of layers, each layer being about 10 inches thick; the mound being conical in section, the layers follow each other in the same form, like the coats of an onion when cut through...... it should be further explained that those layers are each formed of a series of thinner layers. These thinner layers are usually four in number; the lower one of charcoal, some of which is perfect, not having been consumed; then burnt earth; then iron scoriae; then comes burnt clay; then charcoal again, and so on, through the whole heap.'

Elsewhere in his paper, Rock refers to the same layering as being in evidence at the Chitcombe bloomery.[2] The present author has observed the same phenomenon during his excavations at Bardown, Wadhurst.[3]

The appearance of a section through one of these heaps can be judged from Fig. 1, taken from Rock's paper (and reproduced by Straker in the standard work on the subject[4]).

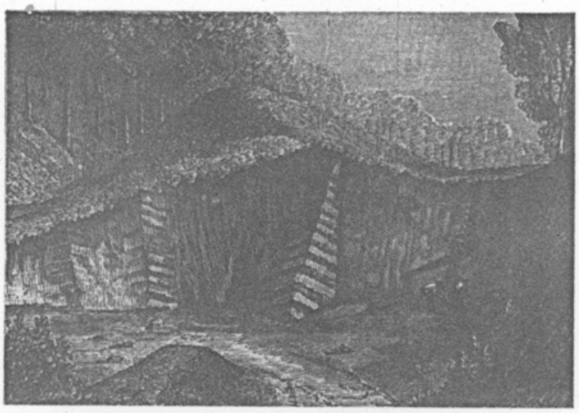

Fig. 1 — The cinderheaps in Beauport Park (from Straker[4])

This somewhat idealized view of the stratification was taken when the great heap at Beauport Park was being quarried away about a hundred years ago to obtain the Roman bloomery slag for road metalling; nothing is to be seen on the site at the present time. A more authentic reproduction of such a layering is given in Fig. 2, recorded by the present author at Bardown some years ago.

Rock, followed by Straker, saw this layering as being direct evidence of the method of ironmaking used:

> 'The process of ironmaking used here seems to have been simply to form a mound of earth, then to cover it with charcoal; upon this to place the ironstone or ore, and to cover the whole with clay, probably with some arrangement for the passage of air, to secure the combustion of the charcoal when ignited; the molten iron running off from the ore to the bottom of the mound.'

Straker reproduces this passage without comment,[5] although it is fair to add that he does correctly describe the direct reduction process that operates in a bloomery in an earlier passage[6] where he emphasizes that the iron settles as a spongy mass at the base of the furnace. Nevertheless, he adduces the evidence from Beauport Park to support the view that iron was smelted in two ways: in the conical heaps that Rock describes and in the flat circular furnaces of some 8-9 ft diameter that he had found at Footlands and Ridge Hill.[7]

Examination of Fig. 1 shows that the 'conical heaps' were considerably larger than the structures found at Footlands and Ridge Hill; reference to the toiling figures in the right foreground indicates that the heaps were about 60-80 ft across, a fact that is confirmed by observation at the site at the present time. Similarly, the layers at Bardown have been found to extend laterally for considerable distances, although rarely more than 20 ft. They are, however, not conical mounds, but rather sloping layers, lenticulate in form, the refuse bank here having built up on the south bank of a small but steep valley.

On this evidence alone, one must reject Rock's view that these layers represent the direct debris of smelting furnaces. Excavations at Holbeanwood[8] have proved that iron smelting was in fact most likely to have been carried out in small shaft furnaces of 12-18 in diameter. Nevertheless, these layers do exist, and they require some explanation.

The layers in the Bardown heap were excavated and examined with great care. It was observed first of all that they contained non-industrial artefacts (mainly pottery) in some profusion, this material having been thrown in from the adjacent 'residential' area of the settlement during the course of their deposition. This, if nothing else, would have militated against the view that the layers represented an ironmaking process in situ, since it is difficult to conceive of a situation where ironmakers would permit domestic rubbish to be thrown into their furnaces.

Analysis of the material composing the layers showed that the charcoal and ore layers consisted principally of fines (-½ in cube). There is evidence from the working area of the site that screening of the charcoal and roasted ore was carried out; experiments in reconstructed furnaces[9,10] have

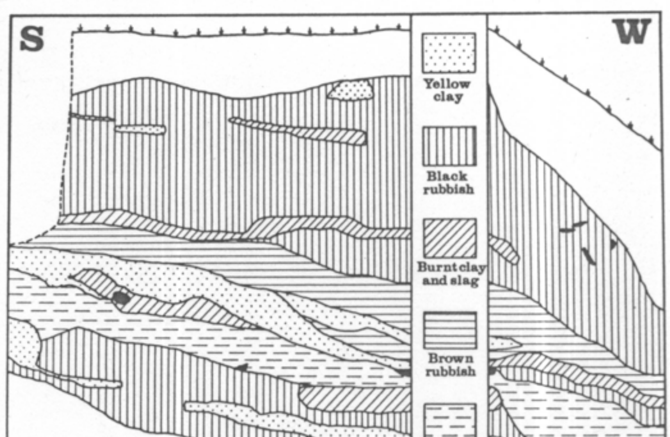

Fig. 2 — Typical section of Bardown slag bank (from Cleere[3])

shown that this was desirable in order to keep the furnace burden reasonably permeable, having regard to the relatively low output and power of the bellows available to the Roman smelters.

The slag layers consisted for the most part of tap slag (i.e. material which had been allowed to run out of the furnace in a molten state). The cinder (i.e. slag which had been left inside the furnace and removed only at the end of the smelt) tended to be associated with the furnace debris layer, although a certain proportion did occur with the tap slag.

One possible explanation of these single-material layers is that during continuous operation of the ore-roasting hearths, charcoal heaps and smelting furnaces, waste material would be allowed to collect at the respective processing areas, and would be cleared away from time to time when the heap became too large. However, Rock's observation of the sequence was apparently a correct one, as sections in the Bardown heap have indicated, and it is difficult to accept that there would have been a pre-ordained 'dumping order' from the different processing areas. It is fair to say, nevertheless, that the Bardown site has produced evidence of dumping around a process unit; a deep bed of ore fines was found in association with an ore-roasting hearth. However, this was a very early structure at the settlement; it was in fact dismantled and covered by a later building, which in its turn was abandoned. It is possible, therefore, to explain this particular find as representing the practice at the site when it was still relatively small in extent and production; certainly, there was no evidence of any dump of ore fines in association with the other ore-roasting furnace found at Bardown, a fact which made its identification difficult when it was first discovered, before the early-phase furnace came to light.

Excavations at the nearby site of Holbeanwood, a working site associated with the Bardown settlement and used during the later phase of the main settlement's occupation, when industrial activities there had been abandoned in favour of a series of satellite sites, suggests that the working areas were kept remarkably clear of waste materials. So far, two working enclosures, defined by drainage gullies, have been found at Holbeanwood, and another is strongly suggested by a separate refuse dump; the two enclosures that have been excavated each contain the remains of six small shaft furnaces. The interior of both enclosures is quite clear of slag, charcoal, or furnace debris, apart from a small amount trodden into the working floors and some clearly defined charcoal storage bins dug into the clay. All the waste material had been dumped into or beyond the drainage gullies.

An alternative explanation for the layering must therefore be sought. It is suggested that this particular mode of formation of the refuse dumps at the large ironmaking settlements at Bardown, Beauport Park, and Chitcombe may be a reflection of some kind of operational cycling being practised at these sites. Thus, one may postulate that there would be a period set aside for charcoal burning, during which time the activities of all the workers would be devoted to the collection of cord wood, the burning operation, and screening of the product; the selected material would then be stored in considerable quantities and under cover, to await the start of the smelting campaign. This would be followed by a period devoted to iron ore mining, roasting, and screening, the product being stocked in a similar fashion to the charcoal. The main item in the cycle would be the smelting campaign, when a number of furnaces would be in operation. Here the principal waste product would be tap slag, with a certain amount of cinder. Finally, there would be a period devoted to furnace repair and reconstruction, which would produce large quantities of burnt clay and cinder. Each of these phases would produce its own characteristic debris, which would be dumped on the refuse heap in distinct layers, the sequence corresponding to the operational sequence.

Reference to Fig. 1 would suggest that, should this hypothesis be correct, one might be able to estimate the working duration of a given site by counting the successive layer groups (rather like tree-ring analysis). However, one suspects that there is a considerable degree of artistic licence in this engraving; the true picture was probably much more like that shown in Fig. 2. A number of trenches were cut into the Bardown heap; the section shown in Fig. 2 shows only one of these. They gave an overall impression of the heap being built up of a series of overlapping 'scales' or lenses of material; certainly, there was no evidence of such layers extending throughout the whole heap in a regular manner, such as Fig. 1 suggests. It will be seen, therefore, that only complete excavation of the entire heap would enable a proper assessment of the number of complete cycles to be obtained, and since the heap measures some 100 yards by 50 yards by up to 9 ft deep, this is hardly a practicable proposition.

The Holbeanwood site might be more amenable to this type of treatment, since it is considerably smaller. It is clear from the amount of non-industrial material (i.e. pottery) found that the site operated for a very restricted period. The stratification in the refuse dumps that have been sectioned seems to indicate that the six-furnace enclosures worked for no more than two or three cycles each, since they showed roughly this number of complete sets of refuse layers. If one year is allocated per cycle, this would suggest a total life for the three enclosures of about nine years. Incidentally, three complete cycles appears to be the appropriate figure, at least for the two six-furnace enclosures, since there is clear evidence that only two furnaces were in operation simultaneously at any given time.

The length of a cycle can only be conjectured as lasting one year. Nevertheless, this sounds not unconvincing, having regard to the Wealden terrain and natural vegetation. The heavy clays in this area support a luxuriant undergrowth of brambles, nettles, and bracken, and exploration for iron ore would not be practicable in summer months, when the land surface is not easily visible or accessible. Similarly, tree lopping for charcoal cords would be simpler in the winter and spring, when the branches were not obscured by foliage. Again, smelting would be much more agreeable during the summer months, when the rainfall is significantly less than it is at other seasons.

Perhaps the answer to this problem could best be found by using pollen analysis on samples taken from the different refuse layers. The presence or absence of the pollens of seasonal plants would give a close indication of the season of deposition of these layers. The author intends to carry out a limited excavation in the Bardown refuse heap at some time in the future to obtain samples for this purpose.

It is hoped that these comments on the composition of some of the refuse heaps on Wealden Roman sites will encourage others concerned with the excavation of early bloomery sites to study their refuse heaps in a new light, so as to throw more light on the possibility of cyclical working.

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Notes and News

A NOTE ON THE DATING OF BLOOMERIES IN THE UPPER BASIN OF THE EASTERN ROTHER

Dates are now available for two of the bloomery sites described and listed in an earlier issue of this Bulletin (Vol. 4, No. 1, 1970, pp. 18-20). Samples taken from the charcoal which was entrapped within the iron slag and from the charcoal which was found intimately mixed with the deposits of slag on the sites concerned were dated by the carbon-14 method. The results are as follows:

Site No. 7: Castle Hill-Home Farm (N.G.R. TQ5597 2803) has been dated to AD 60-90 (Hv 2984).

Site No. 10: Little Inwoods (N.G.R. TQ5620 2397) has been dated to 130 BC-AD 70 (Hv 2985).

C. S. CATTELL

A SWEDISH GROUP FOR STUDYING OSMUND IRON

Osmund is a well known word denoting a special quality of wrought iron. This material played an important part in the Swedish economy for several centuries, during the Middle Ages and later; it was of some importance as late as the 18th century. The oldest known evidence of Osmund being used as a trade-name for iron is found in a Dutch customs tariff dating from 1252. The export of Osmund iron was controlled by the Hanse of Lübeck until King Gustav I checked the Hanseatic influence in the 1520's. The export of Osmund iron finally ceased about a century later.

The quality of Osmund iron, and especially the minimum weight of the pieces, were regulated officially from at least 1340. Osmund iron was exported in barrels containing 480 pieces weighing 20 Llb (Llb = lispund, equivalent to 7.515 kg) or about 150 kg. The regulations prescribed that one Llb must not contain more than 24 pieces, the weight per piece amounting to about 0.3 kg. The price of Osmund iron remained constant at one penning per piece for a considerable period, and Osmund iron was in general use as currency in certain parts of Sweden, especially in paying taxes.

No single piece of known genuine Osmund iron remains to indicate the special qualities that distinguished this material. There are certain indications that the manufacturing process was a direct-reduction bloomery process combined with a special forging technique. However, other sources claim that Osmund iron was produced from pig-iron. The etymology of the word is also not known despite numerous attempts to explain it.

An ad hoc team of fourteen people—the 'Osmund-gruppen'—was formed early in 1970 by representatives of different disciplines. The aim of the group is to study available literary and other sources from various points of view—archeological, historical, technical, and metallographic as well as philological—and also to carry out new investigations. The group met for talks and discussions every other month during 1970 with the intention of presenting some results before the end of the year. Preliminary reports were given at a meeting on 22 October 1970, held in Stockholm under the auspices of Jernkontoret; the papers are to be published. Jernkontoret supports the work of the group financially. The members recently decided to continue their work in 1971. Mr Erik Tholander (Eskilstuna) is chairman and Mr Gunnar Pipping (The National Museum of Science and Technology, Stockholm) is secretary.

EXCAVATIONS AT HOLBEANWOOD 1971

The final season of excavations at the Holbeanwood site in Ticehurst, Sussex (NGR TQ 664 305) took place at the Easter and Spring Bank Holidays 1971, for a total of twelve days. One of the new ironmaking areas found in 1970 was cleared completely (Site B). This proved to cover about 650 square feet, as defined by drainage ditches in the form of a lozenge. The interior contained the bases of six furnaces, identified as bloomery shaft furnaces, of the type found in the original working area (Site A), which also contained six furnaces. Slag and furnace debris had been thrown into and beyond the boundary ditches, the interior being largely free from refuse material. The working surface around the furnaces had been removed by ploughing in part; where it was present it consisted of charcoal and ore fragments trodden into the natural clay. Several postholes were found, which suggested that some kind of roof had been built over the furnaces; however, the structure would appear to have been less substantial than that over the furnaces in Site A, where the discovery of a sleeper beam trench implied that the furnaces were totally enclosed.

Investigation of a third possible smelting area (Site C), where slag and furnace debris and a dump of roasted ore had been found in 1970, was hampered by considerable disturbance resulting from recent levelling on the site by bulldozer, followed by subsequent ploughing. It may be deduced, however, from the large amount of iron slag and furnace debris in the ditch that was fully cleared that this complex had been similar to those which had been better protected (Sites A and B).

Examination of a further area (Site D) lying between Sites B and C revealed a considerable deposit of charcoal and roasted ore, containing almost no iron slag. Further excavation of this area was not proceeded with, since it is covered by a thick layer of redeposited clay subsoil, resulting from modern levelling. It is postulated that this area was used solely for charcoal burning and ore roasting, the products being transferred to the smelting sites (A, B, and ?C) for further processing.

The Holbeanwood site has thus provided evidence of the primary processes associated with ironmaking: the site is surrounded by pits and ponds, which may be assumed to be early iron ore pits; the raw materials (charcoal and roasted ore) were made on Site D; and iron was smelted on Sites A and B (and probably on Site C). There is no clear evidence of forging hearths, on which the spongy iron bloom produced in the smelting furnaces was hammered to consolidate it into a semi-product for subsequent smithing into artifacts; however, it is possible that some of the fragmentary hearths at present identified as smelting furnaces were in fact used for this purpose.

Small finds were again very scarce: a much battered Samian base from Site D was only the second find of this pottery from the entire site. It appears to be a late IInd century Central Gaulish type, but its very poor condition makes this ascription somewhat tentative.

Examination of the layering in the refuse dumps suggests that each of the three smelting sites was occupied and worked for at most three seasons, assuming that operations were carried out on a cyclical basis (i.e. charcoal burning, ore roasting, and smelting were successive rather than simultaneous operations).* This would imply a maximum life for the entire site of no more than ten years, assuming successive rather than simultaneous operation of the smelting sites.

A full report on the excavations will be published in due course as part of the report on the Bardown industrial settlement, of which Holbeanwood is a satellite working place. An interim report was published during 1970 as Sussex Archaeological Society Occasional Paper No. 1 ('The Romano-British industrial settlement at Bardown, Wadhurst' by Henry Cleere).

H. F. CLEERE

* See above, pp. 74-75.

Report on the Symposium on the Significance of Smelting Experiments for the History of Ferrous Metallurgy, Schaffhausen November 1970

The International Association of Prehistoric and Protohistoric Sciences was founded before World War II and has been organizing international conferences at roughly four-year intervals which have been attended by many archaeologists, prehistorians, anthropologists, and historians of technology. At its Congress in Prague in 1966 it set up a Committee for the investigation of early iron metallurgy, the so-called 'Iron Committee'.

This committee held its first full meeting at Schaffhausen, Switzerland, between 9 and 12 November 1970. The work of the symposium was devoted to the results of smelting experiments in various types of early furnaces. Scholars from nine European countries discussed their work on this subject. The chairman and host of the symposium was Professor W.U. Guyan of Schaffhausen; Dr R. Pleiner from Prague acted as secretary. The following took part: Herr G. Bauhoff (Düsseldorf, Germany), Dr K. Bielenin (Kraków, Poland), M J. R. Maréchal (Bénerville, France), Dr B. Osann (Wolfenbüttel, Germany), Dr A. Rjazancev (Jesenice, Yugoslavia), Dr Inga Serning (Grängesberg, Sweden), Dr H. Straube (Kapfenberg, Austria), Ing. R. Thomsen (Varde, Denmark), Dr R. F. Tylecote (Newcastle), and Dr O. Voss (Aarhus, Denmark).

The attempts of historians, metallurgists, and archaeologists to obtain definite information on early methods of bloomery processes, in order to verify results obtained in other fields, led to experiments of smelting in furnaces based on those found in excavations. In the course of these experiments many problems have been solved and the significance of archaeological finds have been clarified, so that we have now a clearer idea of the processes involved. Some questions still remain open such as the mechanism of the reduction of ore with carbon, which has always been a difficult problem in ferrous metallurgy. Although the results of most of the experiments have been published, the discussion of the problems by written communication proved unsatisfactory. Two years ago suggestions were made for a joint discussion to air the different views and to try and solve some of the problems.

The Committee has been collecting and disseminating information on iron working since 1966, and gladly accepted the offer of the Swiss authorities to bring about this meeting.

Scholars with practical or theoretical research to their credit were invited to lecture on their results with slides and to discuss the various problems. This was followed by a general discussion from which conclusions could be drawn.

All lectures and discussions were held in the committee room of the Museum zu Allerheiligen in Schaffhausen. The following papers were read:

R. F. Tylecote:	'The mechanism of the bloomery process'.
J. R. Maréchal:	'Experiments on smelting with peat and its significance for the history of metallurgy in the north'.
K. Bielenin:	'Smelting of iron in a bloomery furnace with a sunken hearth'.
R. Pleiner:	'Effect of furnace construction on the carburization of iron in the bloomery furnace'.
H. Straube:	'New views on bloomery processes'.
B. Osann:	'A direct process in the bloomery or via cast iron? What do we learn from smelting experiments and other facts?'
R. Durrer:	'Iron working in the past, present, and future'.
P. Fuchs:	Film on 'Erection of furnace and smelting of ore by the Balen tribe in the S. E. Sahara', with an introduction by Herr Bauhoff.
R. Thomsen:	'Experiments in iron refining in the forge'.
O. Voss:	'Danish smelting experiments in slag-pit furnaces'.

The papers were followed by discussion. On the Tuesday evening the group were entertained to dinner by representatives of the Schaffhausen iron industry, which was followed the next morning by a visit to the foundry of Georg Fischer A.G. During the Wednesday afternoon they made an excursion to the forests in the hills surrounding the Canton of Schaffhausen under the guidance of Professor Guyan, where they saw iron-ore pits in the vicinity of Neunkirch. On the way they visited the remains of iron-smelting activities on the site of the medieval village of Berslingen.

Discussion on steel production in bloomery

Historical and ethnographical evidence for the production of carburized iron in the bloomery is confirmed by finds of unworked blooms and a series of metallographic results of iron objects of different periods and from various areas. According to the evidence, carburization of iron in the bloomery was rare. This tends to be confirmed by the many experiments made in various types of furnaces. Nevertheless, carburization occurred in some of the experiments that have been carried out, and this requires revision of current theories of the bloomery process. Straube emphasized that, at least in the Carinthia-Styria area, conditions showed that the carburization potential of reduction gases was high enough, at relatively low temperatures, to produce cast iron from the partly reduced metal; but in most cases this material became decarburized later in the process. Other experiments produced a completely carbon-free iron, so that a carburization process can not be generally assumed (Osann). By varying the conditions, it was possible to obtain carbon-rich metal, homogeneous or unhomogeneous. The production of usable steel obviously depended on the choice of raw material, and on the experience and practice of the smiths.

The following possibilities are indicated for the simple process, which is historically attested and is known as the bloomery process:

(a) There are considerable obstacles to the production of other than soft metal

(b) The conditions are favourable for carburization, i.e. for the reduced metal to absorb considerable amounts of carbon up to that required for the formation of cast iron; this is followed by oxidizing conditions, which tend to cause the final product to decarburize partly or completely and thus to produce low-carbon iron or inhomogeneous steel

(c) The efficiency of the carburizing factors and other favourable conditions not only to decide whether carburization will occur but whether it will be maintained. Under such conditions steel would be produced in the bloomery (as is known from written sources, from the archaeological record, and from some of the experiments that have been carried out).

Discussion on slag formation in bloomeries

The experiments have shown that iron smelting presents no particular problems, even under the most primitive conditions. The most difficult part is the separation of metal and slag by means of the production of a free-running slag. This influences the productivity of the smelt and the quality of the iron as regards forgeability and carburization. Archaeological finds of large furnace bottoms (100 kg or over) still in situ in slag-pit furnaces show that the La Tène and Roman smiths in some parts of Europe were able to remove the slag from the sinter zone of the iron sponge and let it run (by the use of special techniques) into the slag-pit below the furnace.

More or less horizontal tap-holes served the same purpose in other types of furnaces. Although tap-slag was obtained in some of the experiments with a certain amount of difficulty, none of the experiments succeeded in producing large furnace bottoms filling the whole hearth.

The reason for this is not yet understood. This problem, important for the history of iron production in Europe as well as Africa, will be studied further.

Suggestions for uniform recording of smelting experiments

To date about 100 smelting experiments have been carried out by 20 people in 13 countries, and all have been documented and published. Publications are widely scattered and often do not contain the details necessary for comparing results. Dr Pleiner suggested that the Committee should circulate a questionnaire to all workers in the field in which questions should be answered in a uniform way so as to aid comparison. A similar procedure should be followed for future experiments. Agreement was reached on this point by all present, and the questionnaire will be published as an appendix to the proceedings of the symposium.

Minutes of the Annual General Meeting 1971

Held at 2.30 p.m. in the Arts Tower, Sheffield University, on Saturday, 1 May 1971, 22 members being present.

Apologies for Absence were received from H. F. Cleere, D. M. Headworth, G. R. Morton, N. Mutton, Professor H. O'Neill, G. Raphael, S. N. Russell, D. G. Tucker.

Minutes of the A.G.M. for 1970, being published in the Bulletin, Vol. 3, No. 2, pp. 85-6, were taken as read and signed as a correct record.

Matters Arising: None were raised.

Chairman's Report: Mr Barraclough outlined the changes taking place in the administration of the Group consequent upon the departure of Henry Cleere from the staff of The Iron and Steel Institute. He first thanked Mr Cleere, and his Secretary, Mrs Goddard, for the great amount of work they had put into the management of the Group's liaison with the Institute, circulation, and the production of the Bulletin. The Treasurer had now taken over the circulation duties, and Mr Cleere had agreed to remain as Assistant Editor, with oversight of production of the Bulletin. It was, however, desirable that someone be found to assist the Treasurer, who, the Chairman felt, now carried an enormous burden, and leave was sought to make enquiries among suitable persons. This was granted by the meeting, and the Chairman went on to refer to enquiries at present in progress regarding the degree of assistance the Group could in future expect to receive in the production of the Bulletin. The Group would be kept informed of the result.

Secretary's Report: The latest membership figures were announced. Of a total of 382 (an increase of 48 in the year), 190 were members of The Iron and Steel Institute or The Institute of Metals, 12 were honorary, and 180 were independent members of the Group.

The annual conference had been held in Swansea, and about 50 members and friends were present. A report of the proceedings had appeared in the Bulletin, Vol. 5, No. 1, pp. 1-11.

A link had been arranged with the Royal Anthropological Institute, who were to send a representative to the Committee of the Group. This step indicated a revival of interest on the part of the Institute in matters once covered by its lapsed Ancient Mining and Metallurgy Committee. This development was approved and welcomed.

Excavations by members of the Group had continued: Mr Cleere had completed excavations at the Roman site at Bardown (Sussex) and had been concentrating on the nearby furnaces at Holbeanwood. The Secretary's work at the 16th-17th century Furnace and Forge sites at Chingley (Kent) had continued.

Editor's Report: Two issues of the Bulletin had been published, and material satisfactory in quantity and quality continued to be received for the future. The response to a circular to members seeking those willing to prepare abstracts had been satisfactory, although there was still a lack of volunteers able to deal with Russian material.

Treasurer's Report: The accounts were presented in unaudited form, owing to shortage of time on the part of the Honorary Auditor. These showed a credit balance of £293, although as a number of subscriptions of I.S.I. members were temporarily held in the Group's account, the true balance would be less, though still substantial. The adoption of the accounts was proposed by Mr Batty, seconded by Mr Raper, and passed unanimously.

The Treasurer reported that he had taken over the circulation files and address plates from Mr Cleere's office, and was at present reviewing the state of the records and mailing lists. He drew attention to the Group's future liability to postage formerly paid by the I.S.I., and recommended that an increase of subscription be discussed to cover this increasingly heavy item. The Chairman proposed and the President seconded a motion to raise the annual subscription to £1 from January 1972; this was passed unanimously. The Treasurer was asked to prepare a note for the Bulletin to this effect and to make arrangements for overseas members' payments to realise a satisfactory net amount in the U.K.

Election of Officers:

The following were nominated by the Committee:

President and Hon. Editor	Dr R. F. Tylecote
Chairman	K. C. Barraclough
Hon. Secretary	D. W. Crossley
Hon. Treasurer	C. R. Blick
Hon. Asst. Editor	H. F. Cleere

Committee:

M. M. Hallett	J. G. Rollins
Dr N. Swindells	J. W. Butler
W. K. V. Gale	B. M. Hardman
Professor H. O'Neill	(representing The Institute of Metals)
G. R. Morton	(representing The Iron and Steel Institute)
B. Fagg	(representing the Royal Anthropological Institute)

Hon. Auditor Dr W. Pumphrey

These names were proposed by Mr Doncaster, seconded by Professor Beaver, and passed unanimously.

The Chairman expressed the appreciation of the Group to the outgoing President for his notable services.

Annual Conference: The Chairman reported that Professor J. Nutting's invitation to hold the Conference in Leeds, emphasizing the Yorkshire lead industry, had been gratefully accepted, and that plans for a meeting on the weekend of 24-26 September 1971 were well advanced.

Other business: The Chairman expressed the appreciation of the Group to Messrs W. H. Bailey, J. G. Timmins, and C. A. Turner for acting as guides on visits to Abbeydale Works and cutlery workshops during the morning, before the A.G.M.

Members then dispersed for visits to Wortley Forge and Abbeydale.

Book Reviews

Radomir Pleiner: 'The Beginnings of the Iron Age in Ancient Persia' (publ. in the Annals of the Naprstek Museum, 6, Prague, 1967, 63 pages, 14 plates)

Pleiner discusses briefly the various influences which led to the beginning of the Iron Age in north-west Persia. In spite of a long metallurgical tradition and all the necessary material available, (i.e. iron-ore deposits and fuel), as well as technical knowledge, the conclusion reached is that the first iron objects were imported. The only site which produced iron and some slag is dated to the last third of the 3rd millennium BC; this is Geoy Tepe, west of Lake Urmia, and production does not appear to have continued. The metal was a white cast iron and may have been produced by accident.

The first wrought-iron objects that appear in graves are daggers and small objects at various sites with dates varying from just before 1000 BC (Tepe Giyan, Sialk A, Geoy Tepe etc) and are thought to have come from civilizations further west (i.e. Assyria, Babylonia, and Urartu). Pleiner discussess in great detail the problems of dating the Luristan bronzes; there is considerable disagreement amongst scholars as to the origin of certain types of daggers with inscriptions from this area. By about the 9th century BC iron becomes more plentiful, especially at Hassanlu IV and in the Sialk B cemetery, the latter having been in use from the end of the 9th to the beginning of the 7th century BC; in one grave alone 90 iron objects were found.

The next section contains a discussion on Luristan and iron. Nothing is known about the cemeteries that were plundered in the late 1920's. Between 1928 and 1930 the 'Luristan Bronzes' began to appear in Teheran and other capitals. Pleiner divides the objects into three groups. The first group consists of cast bronze daggers (some of which have iron blades), halberds, and axes. The second group consists of bronze and iron objects 'without exact analogies', daggers, pins, and bracelets of bronze. Only the third group consists wholly of iron, i.e. daggers, axes, arrowheads, and various ornaments. The fan-shaped hilted daggers have parallels in Azerbaijan and South Russia. The Luristan material consists of ornaments and decorated axes with crouching animals. Several examples of iron daggers are known with human heads and with crouching lions on both sides of the hilt. Pleiner discusses the various theories as to the originators of these motifs, whether Cassite, Hittite, or even the Chalybes which he thinks is too 'imaginative'. Metallurgical examination established that some were made of wrought iron while others were made of inhomogeneous carbon steel. Full structural details are given with hardness measurements.

The dating of the Luristan material is mostly from the 11th to the 7th century, but weapons with iron blades are assigned to the period from the end of the 9th to the beginning of the 7th century BC.

Evidence of iron working by the Achaemenids from Passargadae, where iron clamps were used in building, is given. The total used for this purpose must have amounted to about 5 tons, but hardly any of it now remains as most of it was robbed in antiquity. Metallurgical examination of an iron clamp shows it to be heterogeneous carbon steel, and there is no doubt that this was direct bloomery steel and not the product of intentional carburization. By the 6th-5th century BC the industry was well established, and we are in the full Iron Age. Pleiner makes the best of the evidence on the structural aspects. The full Iron Age is indicated by the use of iron for ploughshares and spades.

The limited material is supplemented by recourse to written sources. In a short section on the Avesta, Pleiner comes to the conclusion on the basis of linguistic evidence that the Indo-Iranians were not acquainted with iron until their arrival in Iran.

Some of the evidence given in this booklet is the result of personal experience obtained on expeditions in 1966 and 1968 sponsored by the Smithsonian Institution. The author has made a valiant attempt to summarize the scanty and conflicting evidence. More than 150 references are given, and the plates give a lot of useful detail and some microstructures.

Elizabeth Tylecote

W. F. Schuster: 'Das alte Metall- und Eisenschmelzen' (Technikgeschichte in Einzeldarstellungen, No. 12, VDI, Düsseldorf, 1969, 124 pp. £1. 75).

A discussion on the development of smelting from the earliest times with an emphasis on iron, it starts with statements on the properties of iron ores and charcoal and describes some primitive ironsmelting experiments conducted by the author using forced draught. It goes on to discuss the technology of early induced- and forced-draught furnaces using data obtained from well known graphic representations and excavations. It then traces the medieval development of furnaces, taking examples from China and Sweden. The reproduction of the copper smelting furnace from the archives of Stora Kopparberg is particularly useful and shows the change from the Agricolan conception. It concludes with a discussion on the development of the Stucköfen and the blast furnace, showing the progressive increase in the dimensions of the latter over the period 1771 to 1802 and the improvement in fuel rate.

This booklet is rather expensive for what it appears to give. But it deals with the subject with the eye of a scientist and it presents an original and fresh view of what is by now a fairly familiar scene. It contains a good bibliography of 75 references.

R. F. T.

Abstracts

GENERAL

Art, Technology and Science. Notes on their Historical Interaction. C. S. Smith (Technology and Culture, 1970, II, (4), 493-549). A study of the interplay of the three, giving some examples of the techniques used and the products produced.

Tin in the History of Science Technology and Art. (National Technical Museum, Prague, 1970: 2 vols). These two volumes contain the papers read at the conference held in Prague in September 1969. The original papers were in Czech or German, but the printed versions all have English summaries. The contents of the first volume are as follows: -

1. Bitfried Wagenbrecht: 'Saxon tin ore deposits and their importance in the history of geology'.
2. Hans Prescher: 'A number of Bohemian ores of tin in the collection of J. W. van Goethe in Weimar; the results of new researches'.
3. R. Pleiner: 'Tin and early civilizations'.
4. V. Moncha: 'The use of tin in the Early Bronze Age in Bohemia'.
5. I. Pleinerova: 'The problem of the Ore Mountains in the use of tin in the Early Bronze Age'.
6. O. Kyticové: 'The importance of bronze in the Late Bronze Age from the evidence of hoards'.
7. A. Beneš: 'Prehistoric colonization in the Ore Mountains'.
8. J. Koran: 'The history of mining, dressing and smelting of cassiterite in the Ore Mountains and Schlaggenwald'.
9. P. Vitouš: 'The importance of tin in the history of mining'.
10. E. Henschke: 'On the organization and finances of mines at the beginning of modern times (16th century); the Oberharz silver mines and the Saxon tin mines in the light of mining laws'.
11. L. Nemeškal: 'Tin coins in Bohemia'.

The second volume contains:

1. Jiří Majer: 'The main outline of Bohemian tin mining technology in the 16th century'.
2. Jiří Schenk: 'Technological methods of working and dressing tin ore deposits from the 13th to the 17th centuries'.
3. O. Wagenbreth: 'On the construction of a water pressure engine in Freiberg in Saxony (in 1816)'.
4. H. Wilsdorf: 'Tin in the culture and life of the Stanneries in the metalliferous ranges of Bohemia and Saxony (in English)'.
5. F. Kirnbauer: 'The tin ore miners' slang, proverbs, and songs'.
6. L. Kubatova: 'The sources of the history of Bohemian tin'.
7. G. Reinheckel: 'The collection of tin in the Museum of the History of Art at Dresden'.
8. O. Wagenbreth: 'The surviving technical monuments and culture of the tin mining areas in the Saxon Ore Mountains'.
9. V. Machovič: 'The use of suitable activators and depressants in the floatation of cassiterite and tungsten minerals'.
10. C. J. Thwaites and B. F. Müller: 'Tin in spheroidal graphite irons'.
11. Karel Vetejska: 'New ways of using tin'.

The papers are of varying length and, judging by the summaries, of differing quality. One detects certain disagreements between authors and there is no record of any discussion. This is certainly the most comprehensive series of papers on the history of Central European tin that has yet appeared and a good supplement to the history of tin in Cornwall as written by A. K. Hamilton-Jenkin, J. Barton, J. H. Trounson, F. B. Michell, and many others.

British Isles

The Romano-British Industrial Site at Bardown, Wadhurst. An interim report on excavations 1960-1968. H. F. Cleere. (Sussex Arch. Soc. Occas. Paper No. 1, 1971: Price 6s (30p), 23 pp.) The detailed report of the excavation of the remains of an iron smelting settlement at Bardown and the neighbouring satellite sites. Ore roasting furnaces were found at Bardown and smelting furnaces at Holbeanwood. The sites are believed to have served to supply the needs of the Roman fleet (Classis Brittanica) in the 2nd century AD.

The Roman Gold Mines at Dolaucothi. P. R. Lewis and G. D. B. Jones. (Carmarthenshire Antiq., 1970, 6, no pagination). A short description of techniques of mining and dressing supposed to have been used according to the surface evidence.

The Dolaucothi Gold Mines; (1) The Surface Evidence. P. R. Lewis and G. D. B. Jones. (Ant. J. 1969, 49(II), 244-272). A lengthier treatment of the same theme with a brief reference to more recent working; the processes discussed are mainly hydraulic processes, such as hushing, hydraulicing etc. This work is to be followed by an underground survey and excavation of an associated settlement.

Early North Worcestershire scythesmiths and scythegrinders 1541-1647. J. A. Roper. (W. Midlands Studies, 1969, 3, 73-88) The evidence of wills and probate inventories, chiefly among six or seven families, is examined to provide an outline of the local industry and its organisation.

Four hundred years on. G. B. Callan. (Steel Times, 1970, 198, Nov., 791-798) A brief account of iron and steelmaking in Sheffield from the 17th century precedes a history of Sanderson Bros. and Newbould, founded in 1776 as Naylor and Sanderson. The company merged with Kayser Ellison in 1960 and a brief description of the Darnall Works is given.

The Low Moor Ironworks, Bradford. C. Dodsworth. (Industrial Archaeol., 1971, 8, (2), 122-158). The history of the works is described from the foundation in 1789 of the partnership of Hird, Jarratt, Dawson (Rev. Joseph Dawson, 1739-1813, Unitarian minister), and Hardy, which had taken over local colliery interests and cast the first iron in 1791. The account, illustrated with photographs of surviving buildings and remains and citing contemporary documents, is taken down to the present day, when alloy steel is produced by the Samuel Osborn group.

Swedish view of the West Midlands in 1802-1803. W. A. Smith (W. Midlands Studies, 1969, 3, 45-72) An English translation is presented of the travel diary of E. T. Svederstierna, whose narrative was published in Sweden in 1804 and in Germany in 1811. The editor has added an introduction, maps, and illustrations, and notes. Among the places and works described are Coalbrookdale, the Calcutt works at Broseley, the Lightmoor Works near Ironbridge, Bilston New Mills at Wolverhampton, and the Bradley Works of John Wilkinson, near Wednesbury.

The first and last foundry in England. K. J. Morton (Found. Trade J., 1971, 130, Jan. 14, 49-53). An account is given of the early beginnings and subsequent history of Holman's Foundry at St. Just in Cornwall. The foundry, founded in 1834 by Nicholas Holman, made a substantial contribution to the prosperity of the area before its eventual decline due to changing economic circumstances, Some pictures of the old foundry, which is now demolished, are shown.

Old Swan Foundry, Langley, Warwickshire. M. K. Stammers. (Industrial Archaeol., 1971, 8, (2), 165-174). An account is given of the foundry, which was established by William Troth in the 1840s and run by his descendants until it closed in 1965. Its speciality was a single-furrow horse-drawn plough.

Alfred Hickman Ltd, 1866-1932. G. R. Morton and M. LeGuillou (W. Midlands Studies, 1969, 3, 1-30) An account is given of the history of the company which, purchased in 1866 by Alfred Hickman (1830-1910, knighted 1891), had become the largest integrated works in S. Staffs. by 1895. Descriptions are given of processes, equipment, and production throughout the history of the company. Many of these are drawn from unpublished records.

Blaenavon iron works preservation project. (Brit. Steelmaker, 1970, 36, Oct., 23). A brief account is given of a project to restore the works which existed from 1789. The old Blaenavon plant was phased out around 1860 and a new plant named Forge Side was built on the other side of the valley. It was here that Thomas and Gilchrist, helped by Blaenavon general manager E. P. Martin, made the first series of successful blows in a small converter using the basic steelmaking process. A larger Bessemer plant was later developed at Forge Side.

Level New Furnaces. W. K. V. Gale. (Acorn, 1970, Winter, 2-8) An illustrated historical description is given of the Level New Furnaces, Brierley Hill, blown out in August 1954 and dismantled in 1957 to make way for extensions to Round Oak Steelworks.

Funtley Iron Mill, Fareham, Hants. M. D. Freeman. (Industrial Archaeol., 1971, 8, 63-68. The history of the famous site where Henry Cort is said to have developed his puddling process which he patented in 1784. The works were in use until about 1857, and the author discusses the significance of the details that can be seen today.

Henry Cort at Funtley, Hants. R. C. Riley. (Industrial Archaeol., 1971, 8, 69-76). Further details of Cort's mill—mainly water supply and layout of machinery. These are based upon excavations carried out in 1964-65 in the building which the author claims to have been used to house the rolling mill.

Beehive coke ovens at Whinfield, Co. Durham. B. McCall (Industrial Archaeol. 1971, 8, 52-62. A description of one of the few groups of beehive coke ovens remaining in this country. They were built in 1861 of local brick to make coke from coking coal from Garesfield Victoria Colliery on the western edge of the Durham Coalfield near Rowlands Gill. These were the last beehive ovens to operate and are scheduled as an ancient monument. Only five now remain of the 193 ovens at Whinfield. The article discusses their construction, their manner of working and the tools used. The coke was mainly used for the local iron industry.

Europe

John Cockerill. A Vanhemelryck. (Cockerill-Ougrée-Providence, Bull. d'Inf., 1970, (164), 36-42) [In Fr.] The history of the Cockerill family, skilled mechanics in wool carding and spinning machinery, is traced from the first emigration of William, the father, and two of his sons, to Sweden during the industrial depression in England in the 1790's, to the final death of John Cockerill, the youngest of William's sons, in Warsaw in 1840. In this period, the Cockerills, and John most of all, had transformed the industrial scene in the Low Countries, and had become manufacturers of steam-engines, steamships, rails and locomotives; their own basis for this was the intensive use of local ore and coal and the construction of all their own plant. However, Cockerill production remained diversified, including spinning mills, cotton-printing works and zinc mines in various parts of Europe, as well as a sugar-mill in Dutch Guiana. It was on his return from Russia, after an attempt to enter the market there in compensation for over-production at home which had brought a financial crisis upon him, that he died of cholera. His body was brought back to Seraing, 27 years later, when management had passed out of Cockerill hands.

Röchling-Burbach and the Saar canalization after one hundred years. -. Stockart. (Hüttenmann Röchling, 1971, 25, Mar.-Apr., 16). [In Ger.] The recent association between Röchling and ARBED-Burbach is shown to have antecedents going back to 1856. Similarly, the canalization of the Saar is traced back to 1853 and is shown to have served French and German interests, although restrictions on the size of boats severely limited the usefulness of the Rhine-Saar waterways to the iron and steel industry.

The development of the iron foundry in Diosgyör. T. Nyizsnyanszy and J. Vagner (Bany. es Koh. Lapok Koh. Ontode, 1970, 103. (7), 145-149 [In Hung.] From original sources, the history of the almost 200 years old iron foundry is described.

Development of the steel foundry in Diosgyör. J. Toth and Z. Nagy. (Bany. es Koh. Lapok Koh. Ontode, 1970, 103, (7), 153-155) [In Hung.] The history of development of steel casting production in Diosgyör since its beginning in 1844 is briefly described.

Roman Gold-Mining in North-West Spain. P. R. Lewis and G. D. B. Jones. (J. Roman Studies, 1970, 60, 169-185). An examination of the mines in the Asturias in the light of the author's earlier work at Dolaucothi. Attempts to answer problems relating to the origin and development and exhaustion of the sites, techniques used in the extraction of the ore, and the character of the social and economic organization. This paper has a map showing the sites of mines for base metal ores, and has an Appendix in which quotations from the Elder Pliny on gold mining, dressing, and smelting are discussed.

Asia

An Egyptian Temple of Hathor discovered in the Southern Arabah (Israel). Beno Rothenberg. (Bull. No. 12 June, 1970: Museum Haaretz, Tel Aviv). This is the report of the excavation of a temple used by copper workers in the Timna area in the Late Bronze Age—Early Iron Age period (14-12th cent. BC). The mining and smelting installations were operated by the Egyptians using the local Midianite-Kenite labour. A large number of small votive offerings of copper-base alloy were found which have not yet been metallographically examined.

Japan's original steel making and its development under the influence of foreign technique. K. Kubota. (International co-operation in History of Technology, Pont à Mousson, March 1970, 8 pp.) Describes the Japanese 'Tatara' process, which was originally a direct reduction process using an efficient box bellows system like the Chinese but foot-driven. This process was modified by foreign influence in the 17th century to produce cast iron and steel. The author describes the construction of the small blast furnaces, which had 30 radial tuyeres. Under normal operation, both cast iron and steel are produced in the same furnace. Greater fuel/ore ratios are used initially and cast iron is tapped, but gradually the ratios are reduced and a solid bloom is produced, rather like the Stückofen. The magnetite sands used as ore before dressing contained as little as 1—2%Fe, but they were dressed to give a concentrate of 55—60% Fe, and this gave a steel containing about 1.3% C. The cast iron contained 3.0—3.9% C and was low in silicon, phosporus, and sulphur. A low-carbon product could be separated from the bloom.

In the 19th century, reverberatory and European-type blast furnaces were installed. The former were primarily for cannon casting. The article concludes with a section on the birth of the modern iron and steel industry.

History of steel in Japan-1: Foundation for the development of modern steel technology. K.-I. Iida. (Nippon Steel News, 1971, Apr., No. 12, Suppl., 2 pp.). A brief illustrated account is presented, stressing the influence of some important Japanese publications: 'Notes on Iron Mines' (1784) by S. Shimshara (1783-1821) and 'A Study of the Seven Metals of the West' (1854) by S. Bata (1787-1822).

Iron-working slags from Eski Kahta (Vil. Adiyaman), South-East Turkey H. G. Bachmann. (Arch. Eisenh., 1970, 41, Aug., 731-736) [In Ger.] From the analytical results of slags excavated in this village in Turkey it must be assumed that they were slags from forging furnaces rather than ironmaking furnaces. Details of the analytical results are presented and the reasons for this assumption are demonstrated. (12 refs).

Metallographic Examination

Examination of three steel spear tips of the 7th and 6th Cent. BC. G. J. Varoufakis. (Arch. Eisenh., 1970, 41, Nov., 1023-1026) [In Ger.] Results are given of metallurgical studies on three 6th and 7th Cent. BC steel spear points found at Mycenae, Greece, which are shown to have 0.65% C, 0.38% Si, 0.046% P, and 0.02 S and, in another instance, 0.13% C, 0.07 Si, 0.016% P, and 0.012% S. As iron-rich ores without Mn, As, Cr, Ni, and Pb are known not to have been available in Greece, it is believed that the tips were weapons imported from Asia Minor or were semi-finished products brought in from the Near East, It is conjectured that they were sacrificial offerings for the temple of Mars at the outer walls of which they were found together with ceramic vases of the same period.

Investigations on high-nickel steel in antiquity. J. Piaskowski. (Hutnik, 1970, 37, (2), 83-90) [In Pol.] Arguments on the meteoric origin of iron with a high nickel content in use in antiquity are discussed. The results obtained by metallographic examination of ancient products manufactured of such iron are described. The author presents arguments for the hypothesis that high-nickel steel of antiquity was man-made (among others by the Chalybes, the tribes of primitives in Asia Minor mentioned in classical literature) and not of meteoric origin.

An examination of fractures in the first iron bridge at Coalbrookdale. G. R. Morton and A. F. Moseley. (J. West Midland Reg. Studies, 1970, (2), 8 pp.) The bridge, opened on 1 January 1781, was the first iron bridge in the world. An examination of 53 observable fractures in its ironwork is reported.

Techniques

Non-Ferrous Metals, Casting, History and Forecast. J. W. Meier (Dept. of Energy, Mines and Resources, Ottawa Mines Branch Information Circular IC 239, Aug. 1970, 59 pp). A short comprehensive history of non-ferrous foundry metallurgy. The emphasis in the early period is mainly on the casting of statues, but by the medieval period the author discusses bells and cannon and large Buddhas. He concludes with a discussion on modern metals and techniques and a look into the future.

Contributions to the history of the heat treatment of steel (largely from the evidence of sword blades). H. Bartlett Wells. (J. Arms and Armour Soc., Dec. 1969, 6, (8), 217-240). The title is misleading; it contains little evidence on heat treatment but it is a good description of some medieval blade-smithing techniques and that of the Toledo process, which was reinstituted in the 19th century, based on the earlier traditions. This involved the welding of an outer steel casing to a wrought-iron core using Swedish steel. A quotation dispels the ridiculous idea that a sword that could be bent double (point-to-hilt) would have some value as a weapon.

Biography

Wilhelm Lueg (1792-1864). (Tradition, 1971, 16, Mar.-Apr. 49-71). [In Ger.] An account is given and an assessment is made of the life and influence of Lueg, director of the Gutehoffnungshütte concern, and of his family, social, industrial, and financial connexions. He was succeeded in the business by his son Carl (1833-1905) in 1873 following a period of direction by Ludwig Haniel (1817-1899) from 1864 to 1872.

Robert Forester Mushet. Metallurgist and inventor 1811-1891. (Iron Steel, 1970, 43, Oct., 311-312) A brief biography is presented.

John Weld of Willey 1585-1665. M. D. G. Wanklyn. (W. Midland Studies. 1969, 3, 88-89) An account is given, based in part on archival material in the Shropshire Record Office, of the activities of John Weld (1585-1665), an enterprising land owner and an epitome of the rising gentry who was active on his estates in agricultural improvement, coal mining, ironworking, and in operating a forge.

Miscellaneous

The incidence of forgery amonst archaic Chinese bronzes. N. Barnard. (Monumenta Serica, 1968, 27, 91-168). The vast majority of Chinese bronzes are not attested by scientific excavation and therefore could be forgeries. Barnard discusses the types of forgery and some of the techniques used in the distinguishing characteristics. The fact that most of the bronzes in collections are inscribed while the inscribed bronzes from controlled excavations are only a minority speaks for itself. It is clear that the forgery of Chinese bronzes has been going on for a long time—perhaps thousands of years—and that in some cases the forgeries are only partial, i.e. the addition of an inscription to suggest that the vessel belonged to an earlier period than that in which it was made. Barnard discusses 'ageing' techniques involving the production of an artificial patina and some of the criteria by which forgery and genuine articles may be distinguished. At the moment these do not make use of metallurgical analysis.