BRITISH MINING No.55

MEMOIRS 1995

Claughton, P.F., 1995
"Notes on the Development of Bole Smelting"
British Mining No.55, NMRS, pp.127-138

Published by the

THE NORTHERN MINE RESEARCH SOCIETY
SHEFFIELD U.K.

ISSN 0309-2199

NOTES ON THE DEVELOPMENT OF BOLE SMELTING

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SYNOPSIS

An assessment of the bole (bale or bail) method of smelting lead and silver-lead ores from the 12th century through to the 16th century, and the introduction of ore hearth smelting, together with those processes used to complement the bole, primarily the blackwork furnace or oven, with the intention of dispelling some misconceptions which appear to be endemic in published articles on mining history.[22]

INTRODUCTION

Most works on the history of lead mining in the 16th century or earlier, if they refer to smelting at all, assume that it was done in a bole at a nearby hilltop site. That was not necessarily the case, however. The bole was not unique as a smelting method. Instead, it was supplemented by other methods often carried out remote from the mining site. Outside of 15th and 16th century Derbyshire and 14th century Devon silver-lead mines, evidence, both archæological and documentary, for the operation of the bole and the complementary processes is sparse and what there is is apt to be misinterpreted.

Pending further investigation, this paper seeks to put what is known in some order, perhaps thereby stimulating further comment and action.

THE ARCHÆOLOGICAL EVIDENCE

Early smelting sites have been identified on the ground throughout the Peak District and the Pennines, on Mendip and in Mid Wales. The term early is used because, as will become clear later, not all those sites, even the upland ones, are purely bole sites as has been suggested in the past. Only two are known to have been excavated, however. Beeley, in Derbyshire, and a structure on Winterings Edge, Swaledale, Yorkshire. The former is apparently a primitive early site utilising the remains of an existing cairn structure and the latter is almost certainly a blackwork furnace and not a bole, although unfortunately it is regularly used as an illustration of a bole structure.[1, 2] Neither are typical of upland bole smelting sites.

Barker has identified many bole sites in Swaledale and Wensleydale, obtaining a Carbon 14 dating from a charcoal heap adjoining one site on Calver Hill. Kiernan has made a close examination of a late bole site at Totley, to the west of Sheffield, and the search to identify further early smelting sites has been extended into Teesdale and the Alston Moor area by Pickin and Fairbairn respectively. However, none of the bole sites known to have been used at the Crown silver-lead mines in Devon have yet been positively identified.[3,4,5,6,7]

No doubt close examination of other lead fields will reveal similar sites. Whilst several early sites are already known in Mid Wales, none are boles. All are situated on the valley floor, close to water, but without strong winds.

Place names and the survival of slag scatter have so far provided the best evidence for early smelting sites. The latter, however, is no indication of the scale of activity on a site as much slag was removed for resmelting at various periods through to the late 19th century. On Mendip 19th century lead production relied almost totally on reworking slags and in the process removed much of the evidence from the Roman through to the early modern period. However, cursory examination of surviving slag, its categorisation by colour and texture, and subsequent comparison with the contemporary terminology can lead to confusion.

THE HISTORICAL EVIDENCE

The circumstances and date of the bole's inception are, as yet, uncertain, but it was probably in use in the lead industry from around the latter end of the 12th century, when the industry developed in its own right after the collapse of silver-lead working in the Alston Moor area (the Carlisle mines).[8]

Blanchard suggested that sterile lead (devoid of silver) made at the Carlisle mines in the resmelting of litharge resulting from the refining (cupellation) process would have been a cheap material for fabrication purposes, feeding the expanding construction industry, both lay and ecclesiastical. Only with the demise of the Carlisle mines were the base lead workings of the Pennines, working lead ores naturally low in silver, able to compete on a large scale outside their locality. Economies in smelting would have counted high in their ability to compete, and the bole provided a cheap, relatively efficient, method of reducing high grade galena to a lead of acceptable purity.[9]

Bole smelting was quite simple. It relied on the wind, so an exposed hilltop site was chosen and an open topped, roughly rectangular structure was built with the windward side left open, either totally, as suggested by Kiernan's late Derbyshire model, or partially to allow air flow to the fire.[23] Within this structure was a foundation of logs on which was spread a layer of slags from an earlier smelting and, above this, layers of brushwood and ore. Once lit, the ore near the top was roasted to form an oxide which then reacted with the unroasted ore giving off sulphur dioxide. The lead thus released fell through the fire to collect in specially formed hollows or channels below the foundation of logs. This can be expressed in chemical terms as:-

$$2PbO + PbS = 3Pb + SO_2$$

Once the process was complete, the metallic lead was removed and some of the residues or slag retained for use at the next burning, the rest being discarded. The log foundation was relatively unaffected and was retained for the next burning.[9,10]

ORE PROCESSING IN THE DEVON SILVER-LEAD MINES IN THE LATE 13TH CENTURY

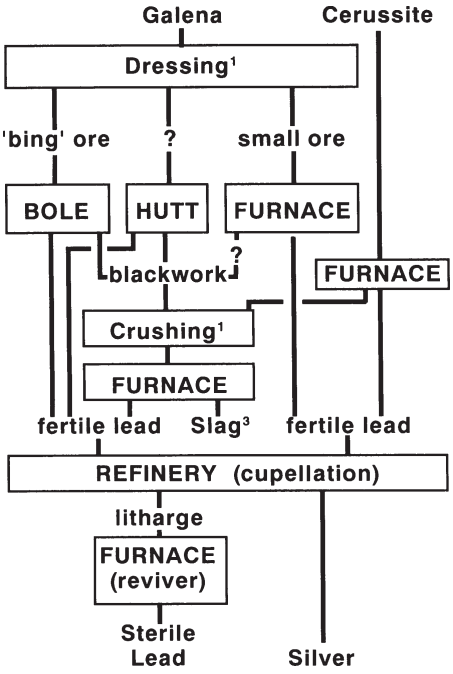

Figure 1.

Few, if any, boles from this early period have been examined, but Beeley, in Derbyshire, and Tag Bale, at Gate up Gill, near Hebden, Yorkshire, which are both apparently primitive hilltop sites, could fit the pattern for that period.

The precise structure and size of early boles can only be surmised from documentary evidence, but they were clearly much smaller than the late 15th - early 16th century structures described by Kiernan in Derbyshire.[11] Of these, the Totley bole (SK291798) is given as a typical example. There a prominent hilltop site was developed. It was well placed to take advantage of the prevailing winds and, although well clear of the mining field, had good access to transport routes towards the river ports. The hearth there can still be discerned, being an approximately rectangular structure measuring seven metres by three metres, with its long side to windward, and with some stones still in place along its back wall.[4] Such sites were capable of producing up to 16 fothers (of 2100 lbs each) of lead at each burning and operated in 'campaigns' at a time of the year when the prevailing winds were strongest.

Such a large produce perhaps reflected the nature of the smelting organisation in Derbyshire, here it was on an 'industrial' scale, with the smelters buying in ore over a wide area and having the ability to take advantage of economies of scale not available to smaller seigneurial units.

A move to 'campaigns' was evident in the silver-lead industry by the 1340s. Boles in south Devon were fired for a week at time, generally in autumn, early spring and, only once, in July.[26] However, by that period the output of the mines had fallen and there was less ore suitable for bole smelting.

Some bole sites, as at Beeley and Tag Bale, appear to have utilized existing boulder scatter and, in the former, part of an earlier cairn. Masonry, tiles (bricks ?) and earth walls were used in early 14th century silver-lead boles. Late Derbyshire structures were probably of similar construction, perhaps with much greater emphasis on the use of stone, as at Totley.

Normally the bole relied on wind for its draught, but there is an isolated reference, at Baxenden, in Lancashire, in the early 14th century to the use of bellows to supplement the draught.[18] The practicality of such an arrangement is suspect, however, as the use of bellows on a bole in low wind conditions would have caused considerable discomfort to the operators.

With the resumption of silver-lead working in the late 13th century at new sites in Devon, at Bere Ferrers (Birland) and Combe Martin, the bole was found wanting as the primary method of smelting. Whilst it was effective in smelting a large part of ore's the lead content, too much silver remained in the slags for these to be discarded as waste. The bole also suffered from its inability to deal with the smaller pieces of galena (less than ½ inch), cerrusite (lead carbonate) and the silver-rich tetrahedrites. Whilst this was not a problem in the lead industry, where fresh sources of the larger galena (bing) could readily be opened up, with a restricted resource like the silver-bearing ores any smelting operation had to be capable of treating all the ore mined. Consequently, within four years of opening up the mines in Devon, the bole was supplemented by the furnace. This was a closed structure, charcoal fired and with a forced draught provided by manually operated belows, and was probably based on the process which had been the mainstay of production at Carlisle and elsewhere prior to the end of the 12th century.

FURNACE SMELTING

The furnace was used to treat the smaller galena, cerrusite and other ore which could not be dealt with in the bole. In addition the same, or similar, was used to resmelt the blackwork (*opus nigrum* - slags produced during initial smelting) from both boles and furnace. The oxidisation of the blackwork during earlier smelting accelerated the reduction process. With the ores some initial oxidisation at low temperature would be required to initiate the reaction, although there is no reference to this as a separate process until the 15th century. In 1480/81, at Bere Ferrers, the ore was roasted prior to smelting at the '*fynyngmyll'*, while the mid 16th century procedure in Derbyshire involved roasting on an open wood fire.[11,17] Once the lead ores were oxidised, they could react with the carbon in the fuel (charcoal) to release carbon monoxide and carbon dioxide as gas, allowing the lead to sink to the bottom.

$$PbO + C = Pb + CO$$

or

$$2PbO + C = 2Pb + CO_2$$

Furnaces had a major disadvantage in that their high temperatures resulted in the loss of a larger proportion of the lead through volatilisation. However, where the silver content was high this loss was acceptable, the temperature at which silver evaporates being much higher than that for lead. There was also experimentation with other forms of smelting, eg. the '*hutt*,' in an attempt to maximise returns from the silver-rich ores, with little apparent success. The bole/furnace complex remained the prime smelting method through the late mediæval period.

There were those who would have preferred to rely entirely on the furnace as is evident in the following advice on proposed activity at Barristown by Clomine, co.Wexford, in 1557:-

> "*III. The order and charges for the melting of ore into lead in a bole with the wind, after the manner of the bollars in Derbyshire in England.*
>
> *Two men of good knowledge in that work are sufficient, one a bollare and the other a smelter, after it be burned; each to have 12d a day.*
>
> *These men must have divers workmen, to cut great timber and divers sorts of wood for the boyle; and labourers for the carriage of the said timber both by water and land to the boyle hill. It is not only painful and tedious, but also chargeable; it is uncertain to make an estimate thereof. The cause is, the workmen must patiently abide for a south-west wind for the burning and melting of the ore into lead by the said boyle. Other wind will none serve, for this wind is most steadfast. There may be made and molten in one boyle in two days and two nights, if the wind serve, six fother lead, and every fother is 20 hundred in weight; but yet, in mine opinion, it is better and the less labour and pain, and also more for the profit of the surveyor who shall have the great burthen and charges thereof, to melt in a close furnace; for I have the knowledge and practice in both kind of meltings.*
>
> *IV. The order and charges for the melting of ore into lead in close furnace, and for fining of the same into fine silver.*
>
> *If you will melt your ore into lead in a close furnace, it must be blown with very great bellows, and by violence of water by the means of a certain instrument called a sleagyll, for which instrument all the timber and stuff is in a good readiness made and lying in the King and Queen's Majesties' storehouse at Rosse. And this instrument will not only serve to blow bellows for the melting of the ore into lead, but also*

it will serve to stamp and break the grove ore, and wash it also, and it will serve to blow the bellows for the fining; which is not only very commodious and great ease for the melters and finers, but also profitable for the head and chief officers or general surveyors of the mines.

Six men of good knowledge will serve this work, both for the melting of the ore into lead in the close furnace, and also for fining; and one carpenter with his man will keep the mill in good temper, and the sleagyll in reparations, and also will also break and wash the ore in the said mill. This is a necessary instrument, which of necessity must be had and made.

These six men will be chargeable in wages, for the labour is both great and painful, by reason of the much occupying of the fire. Wherefore the master and head workman, if he will take the charge both of the melting of the ore into lead, and the fining of the same into fine silver, will have 2s. a day. Two other workmen at 12d.; and three at 10d. 2 colliers to make charcoals for the melting, one of them at 10d., the other at 8d. The carpenter at 12d., and his man at 6d.

The carriage of coals and also wood by land and water to the melting house, and fining, will mount every year 100l. Howbeit the lead will bear the charges, and the silver clearly reserved, with some more advantage to the surveyor.

The whole charges thereof will amount yearly to 272l. 13s."[12]

The silver-lead ores found at Barristown were, however, not easily smelted and do not appear to have yielded their best until shipped to Combe Martin, in North Devon, for reduction by the new (ore hearth) technology in the late 1580s. However the above proposal in many ways reflects developments in the silver-lead industry in the later part of the mediæval period when the furnace was combined with the cupellation hearth in a '*fynyngmill*'.

We are as yet unsure as to the nature of the structure of these later, water-powered furnaces, but they were probably of the shaft type, similar to the Almain furnace used by Kranich in Derbyshire in the 1550s and illustrated by Kiernan and others.[11] They were evidently inefficient when used on the lead ores found in Derbyshire, and were only practical for the more complex silver-bearing ores.

THE TURNBOLE (*BOLAS TURNELLAS* OR *BOLAS VERSATILIS*)

One adaptation of the bole itself proved successful, however. Unlike later practice, the silver-lead industry provided a steady flow of fertile lead (that is lead containing silver) to the refinery. This left the bolers to cope with shifts in wind direction, while using multiple bole sites without the advantages

of prominent high ground sites available to their contemporaries in the Pennines. By at least 1296 a bole structure had been mounted on a moveable platform which was capable of being rotated about a central vertical axle to face the wind. These became a permanent feature in smelting on the Devon mines. As smelting activities were moved around the Birland area, and across to Calstock, in response to the availability of wood for fuel, the substantial timber base of the turnbole was uprooted for transfer to the new site. At Buckland Monachorum in 1302, it took seven men a whole day in '*removing the post and timber of the said bole from the ground.*' For this they were paid 4d each, twice the normal rate for labour at that date, suggesting it was heavy work indeed. The development in Europe of the post mill provided an ideal model on which to base the construction of the turnbole, although confirmation of this must await the identification and archæological investigation of specific sites.[13]

Blanchard has suggested that the turnbole was adopted in Durham in the 15th century, but Drury's examination of the Bishop's accounts has failed to substantiate this and there would seem to be little economic advantage to its use outside the silver-lead industry.[9,14]

THE BLACKWORK OVEN

Whilst the silver-lead industry was quick to introduce further treatment of blackwork in the furnace, it appears to have been up to 130 years before the technique was adopted in the lead industry. The economics of lead smelting were such that, whilst metal prices were low, there was no incentive to treat slags using a process which resulted in high lead losses. But with price changes, and as ore suitable for bole smelting became scarce, the lead remaining in the blackwork was increasingly attractive. The indications are that this situation was reached in some areas in the early to mid 15th century. With static or falling lead prices in the first half of the 15th century, Blanchard suggests that scarcity of high grade ore was the leading factor in the introduction of blackwork ovens. This was perhaps particularly relevant in Weardale where production at that time was geared to the demands of the bishopric rather than responding to market forces. Here Drury has provided evidence from the Bishop's accounts in Weardale for the use of the blackwork oven in the period 1425 to 1431 and for the use of waterpower in the operation of the bellows there.[19,14]

Barker has obtained a Carbon 14 dating of 1439 to 1469, for charcoal found on a site at Calver Hill. As this dating relates to the fuel for the blackwork furnace or oven and not to the bole itself, however, there is no evidence that the boles there were active at that date. There is in fact field evidence in that area that slags (blackwork) were moved from some bole sites to central points, where water was available for washing, and resmelted there in the blackwork oven. Charcoal heaps and a scatter of vitrified slags can be seen at those sites. Further archæological investigation is needed to establish the sequence of activities.[15]

CHANGES IN ORE PROCESSING IN THE LEAD INDUSTRY

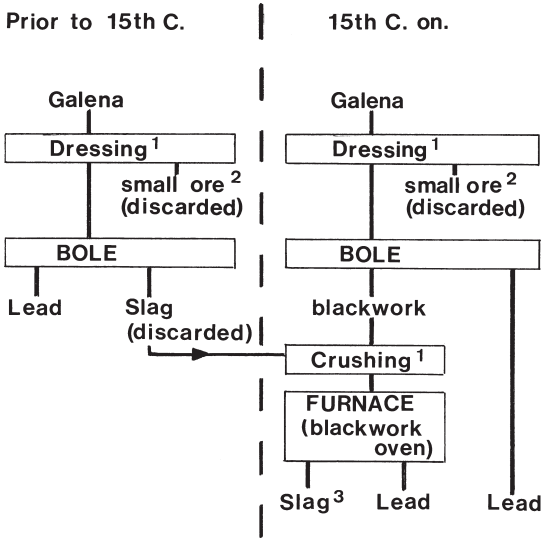

Figure 2.

Key to Figures 1 and 2

1. Including the separation of waste matter by washing.
2. Later recovered and smelted in the ore hearth.
3. As techniques improved these slags would be re-smelted, a procedure common at 18th/19th century lead smelters, but begun as early as the 14th century in the Devon silver-lead mines.

Blackwork ovens, similar in fuelling and operation to the furnaces used in the silver-lead industry, were erected alongside existing boles and perhaps on some old bole sites where large amounts of blackwork remained, although it was probably easier in most cases to remove the blackwork to an active site and resmelt it there. Later Derbyshire bole sites incorporated the oven as a matter of course, two being associated with that at Totley.

Documentary evidence from the 16th century in Derbyshire points to the blackwork oven being a low circular structure, blown by manually operated bellows, and identical in many respects to that structure excavated by Raistrick at Winterings Edge in the 1920s.[11,2] What form the furnace took when adapted for water power in the lead industry, as in Weardale in the 1420s, is unclear. It may have evolved as a form of shaft furnace, such as the Almain furnace referred to above, but, based on the evidence of the 16th Derbyshire experience, it was probably confined to blackwork smelting. Early references to smeltmills, such as that to a '*smeltmyln*' in the Fountains Abbey accounts, 1446 to 1458, are probably to such water-powered blackwork furnaces used to complement the bole.[21]

The efficient operation of such smeltmills may be responsible for the apparent absence of field evidence for bole smelting in some areas of mediæval mining activity, as all available blackwork may have been gathered in for reworking. Conversely, at a purely subjective level, the physical evidence for bole/blackwork smelting in areas like Calver, Swaledale, has the appearance of an ad hoc and perhaps wasteful local operation.

Pickin has provided tantalising field evidence of what could be dedicated blackwork smelting sites in the Eggleshope valley, Teesdale, an area where archæological investigation should reveal a wide range of early smelting activity.[5] Dedicated blackwork smelting would also probably account for the large deposit of residues at Smeltings, near Grinton Lodge in Swaledale (SE047976).[16] This site appears to be topographically unsuited to bole smelting, but I am assured by those more familiar with the area that it is a very exposed place and that there is evidence for bole smelting at other sites of a similar altitude on that side of the dale. Having seen some of those sites displaying evidence of blackwork only, the suggestion would be that Smeltings was chosen as a central point for the treatment of residues from a number of boles in the area. Similar sites appear on Fairbairn's list for the Alston Moor area, but there, particularly in the areas around Fletcheras, Sheldon and other mines in the Firestone Sill, the possibility of evidence from earlier 11th/12th century (pre bole) silver-lead smelting should be borne in mind.[6]

The combination of bole and blackwork oven, or furnace, was to remain the standard arrangement for smelting in the lead industry until the gradual introduction of the new, ore hearth technology developed on Mendip in the mid 16th century. That same period in Derbyshire is well documented by Kiernan.[11] The silver-lead industry on the other hand, whilst continuing to use the bole, was increasingly reliant on the furnace as its ore resource was reduced to marginal deposits and deeper workings. By the early part of the 15th century at Bere Ferrers the operation of the furnace, for both initial and blackwork smelting, had been rationalised with that of the refinery at a centralised '*fynyngmill*' located at Maristow. It was not until the advent of the ore hearth and the opening up of new deposits in Mid Wales that that industry saw any upturn in production. Even then, some of the old furnace techniques lingered on well into the 17th century.

FIELD EVIDENCE FOR BLACKWORK SMELTING

As mentioned above, the presence of charcoal heaps is an indication of a blackwork smelting site. Slags can also provide clues. Under normal operating conditions the bole would not reach temperatures high enough to vitrify the slag. The slag would have been heavy with entrapped lead and varied, according to documentary evidence, from yellow through to dark grey/black in colour. This was the blackwork (*opus nigrum*) referred to in mediæval documents.

It is the vitrified slag which appears black on sites today and that is the product of the higher temperatures in blackwork smelting. It is generally glassy and light, being low in lead content. The original blackwork, where it survives, is today coloured a light grey through oxidisation, the result of weathering over at least four centuries. Sites displaying only light grey, generally fragmented, heavy slag and with no evidence of charcoal heaps can be assumed to have not been the site of blackwork smelting.

THE ORGANISATION OF SMELTING IN THE MEDIÆVAL PERIOD

The smelting of silver-lead ores, and the subsequent refining of the silver content, was the responsibility of those working the mines on behalf of the Crown and throughout the mediæval period it was an integrated industry from the working of the vein through to the production of its metallic content. The same may have been true of the early base lead industry, but the evidence is that in the latter part of the mediæval period smelting was divorced from mining and ore preparation.

By the 15th century bole smelting in Derbyshire was in the hands of the 'brenners,' a discrete group of smelters comprised at various periods of men of estate and merchants involved in the lead trade, and was increasingly carried out remote from the mining field, at sites adjacent to the routes towards their markets.[9,11] Fairbairn has noted what could be a similar development in the northern Pennines, with bole sites found far to the east of the mining field, but with good access to Newcastle and the Tyne/Wear river ports.[6]

In Weardale smelting had become a separate activity in the second decade of the 15th century, but was taken into the hands of the bishop and operated at a central point in the lower dale.[19] However, it is not clear that the seigneurial control found elsewhere was so tight as to allow for more effective collection of dues. On Mendip, which is divided into four liberties and where smelting was apparently in the hands of the mineral lords, a miner was free to take his lead ore to the most convenient '*minery*.' These were centred on sites with adequate water for washing and combined both dressing and smelting.[24]

At Marrick and Marske in Swaledale, bole smelting was in the hands of the mineral lord by the early years of the 16th century. This situation was accentuated in Swaledale from the end of that century, with the introduction of ore hearth smelting, with the early ore hearth mills being built in the eastern part of the dale. Overall, the available published evidence for the areas without strong customary laws and practices, like Swaledale, suggests that increased seigneurial control was a feature of the early modern period. It perhaps reflected the increased control exercised nationally by the Tudors?[20,25]

CONCLUSION

Whilst the silver-lead industry developed a complex of smelting processes at an early date (Fig.1), the base lead industry initially relied on the bole alone, supplementing this with the blackwork oven (Fig.2) by the first half of the 15th century. As yet, however, little is known about the introduction of other forms of smelting into the lead industry during the mediæval period. It is evident that much more archæological, as well as documentary, investigation is needed to determine the size and structure of the early bole, the sequence and dating of the introduction of the blackwork oven into the lead industry, and the development of the early water-powered furnaces.

The mining historian working on the lead industry should bear in mind the variation in smelting processes available prior to the late 16th century. Observation of the documentary and physical evidence for those processes will bring forward our understanding of their development. In the meantime it should be noted that:-

a) Not all upland sites were purely bole sites. Carbon 14 dating of charcoal heaps is related to the blackwork oven and not the bole.

b) The site excavated by Raistrick on Winterings Edge, Swaledale, was probably a blackwork oven and should not be used as illustrative of a bole.

c) Kiernan's Totley site is probably typical of the late bole/blackwork oven arrangement in Derbyshire, but it should be remembered that such sites were capable of producing much larger quantities of lead than the early boles.

d) Finally, the 'smelt mill' occasionally evident in documents prior to the 16th century would appear to have been a form of furnace employing water-powered bellows and probably confined to blackwork smelting.

ACKNOWLEDGEMENTS

I should like to thank Mike Gill for constructive comments on the early drafts of this paper.

REFERENCES

1. Radley, J. "A triple cairn ... on Beeley Moor" *Journal of the Derbyshire Archæological and Natural History Society*, Vol.89 (1969), pp.1-17.

2. Raistrick, A. "Notes on lead mining and smelting in West Yorkshire" *Transactions of the Newcomen Society*, Vol.7 (1926-7), pp.81-96. Despite the best efforts of a number of people, the exact site of Raistrick's excavation has not been rediscovered. If and when it is, a reassessment of the evidence can be made.

3. Barker, J.L. "Bale hills in Swaledale and Arkengarthdale" *British Mining*, No.8 (1978), pp.49-54; and "The mines of Downholme Moor and Thorpe Edge, Swaledale" *British Mining*, No.48 (1993), pp.22-30.

4. Kiernan, D. and Van de Noort, R. "Bole smelting in Derbyshire" pp.19-21, in Willies, L. and Cranstone D. (Eds) *Boles and Smeltmills* (Matlock Bath: Historical Metallurgy Society, 1992).

5. Pickin, J. "Early lead smelting in Teesdale" *Boles and Smeltmills*, op cit, pp.25-27.

6. Fairbairn, R. "Bales of Alston Moor, South Northumberland and Weardale" *British Mining*, No.50 (1994), pp.93-99.

7. Claughton, P. "Medieval silver-lead smelting in Devon" *Boles and Smeltmills*, op cit, pp.12-15.

8. Blanchard, I. "Technical implications of the transition from silver to lead smelting in twelfth-century England" *Boles and Smeltmills*, op cit, pp.9-11.

9. Blanchard, I.S.W. "Lead mining and smelting in medieval England and Wales" pp.72-84, in Crossley, D.W. (Ed.) *Medieval Industry* (Council for British Archæology, Research Report No.40, 1981).

10. Gill, M C. "An outline of the chemistry of lead smelting" *Boles and Smeltmills*, op cit, p.3.

11. Kiernan, D. *The Derbyshire Lead Industry in the Sixteenth Century* (Chesterfield: Derbyshire Archæology Society, 1989).

12. Public Record Office (PRO), Calendar of Carew papers in the Lambeth Library, Vol.I, pp.268-72.

13. Claughton, P F. "Silver-lead, a restricted resource; technological choice in the Devon mines" pp.54-59, in Ford, D.T. and Willies, L. (Eds) *Mining Before Powder* (Matlock Bath: Peak District Mines Historical Society and Historical Metallurgy Society, 1992).

14. Drury, J.L. "Leadworks in Weardale, County Durham 1425-1431" *Durham County Local History Society Bulletin* No.38 (May 1987), pp.3-10.

15. Barker, L. and White, R. "Early smelting in Swaledale and Arkengarthdale: a further look" *Boles and Smeltmills*, op cit, pp.15-18.

16. McDonnell et al. "Geophysics and slag analysis at Grinton Smeltings" *Boles and Smeltmills*, op cit, pp.48-50.

17. PRO E101/266/25

18. Gill, M.C. *The Yorkshire and Lancashire Lead Mines* (Sheffield: British Mining No.33, 1987).

19. Blanchard, I.S.W. "Seigneurial entrepreneurship: the bishops of Durham and the Weardale Lead Industry 1406-1529" *Business History*, Vol.XV (1973), pp.97-111.

20. Gill, M.C. "Yorkshire smelting mills, Part 1: The northern dales" *British Mining*, No.45 (1992), pp.111-150.

21. Gill, M.C. "Yorkshire smelting mills, Part 2: The southern dales and Lancashire" *British Mining*, No.48 (1993), p.133.

22. Bole is the term used in Derbyshire and in the Devon silver-lead mines - "*bolem*" or "*bolas*" in mediæval latin documents. Bale or bail are the common terms in Yorkshire and the Northern Pennines (See Barker ref.15 for possible origins).

23. Such simple structures were also used in central Europe and there are also some similarities with the wind-blown hearths used by aboriginal miners in the upper Mississippi valley area of the U.S.A. See Gill, M.C. "The diffusion of ore-hearth smelting techniques from Yorkshire to the upper Mississippi valley lead region" *British Mining*, No.43 (1991), pp.118-128.

24. Gough, J W. *The Mines of Mendip* (Newton Abbot: David & Charles, 1967) p.99.

25. Tyson, L.O. "Mining and smelting in the Marske area, Swaledale" *British Mining*, No.50 (1994), pp.24-40.

26. Public Record Office E101/263/7; 10.

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