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SMELTING MILLS OF THE WEST PENNINES: KNOCK SMELT MILL

by Samuel Murphy and Richard Smith

INTRODUCTION

This small Cumbrian lead smelting mill stands on the south bank of Knock Ore Gill, a small beck which has cut deeply into the high fells which form the west-facing extremity of the Pennines in this area. The mill is well up on the ancient commons above the enclosed lands at NGR NY697299 and at altitude of approximately 365m OD and is shown in outline, with no annotation, on both the lst Edition (1/10560) and current OS maps. Thomas Hodgson's map of Westmorland of 1828 shows it as Old Smelt Mill.[1,2] The London Lead Company plans in the Northumberland County Record Office show mineral ground in the manors of Knock, Murton, Dufton, Milburn etc, belonging to the Earl of Thanet and leased by the company. One of these shows the mill as Old Smeltmill. This plan is undated, but has some mine workings dated 1820.[3] Another undated plan, with mine workings marked 1872, shows several mills, but the Knock mill is absent.[4] The ruins of this mill and its ancillary buildings are considerable and in a relatively complete state to a few feet above ground level, and the layout of watercourses and buildings is clear. The mill is believed to be at least 250 years old.

HISTORY

The mill lies in the parish of Long Marton, in the manor of Knock Shalcock, which was anciently purchased by the Cliffords and passed into the hands of the Earls of Thanet Island on the marriage of Margaret Clifford to the Second Earl of Thanet, Sir John Tufton, in 1629. The manor of Knock is a narrow strip of land, running north-east from the upper Eden valley almost to the river Tees. It is bounded by the manor of Milburn to the north where Knock Ore Gill forms the western boundary, and Dufton to the south where the western boundary lies along Swindale. The Earls of Thanet owned both of these contiguous manors, but they were acquired much later than Knock by Sackville Tufton, the Eighth Earl, who purchased the manor of Dufton from Edward Milward Esquire in 1785 and the manor of Milburn from General Philip Honeywood in 1780.[5,6] Although the manor of Knock is small, in the late 18th century, and probably from the time that the Earls of Thanet came into possession, the Lordship of Knock included the whole of Milburn Fell, a large upland area which contained some of the richest lead mines.[7]

The date of construction of the mill is unknown. It almost certainly did not exist in 1703, when the Earl's duty ore was weighed at *Blyhopp Smelt Mill* (Bollihope), but stood in a furnished state in September 1739, when Edmond Ellwood, a blacksmith of Dufton, was charged with stealing *"an iron pot and some other goods out of the House or Smelting Miln at Knock, belonging to the Right Honourable Sackvill Earl of Thanet"*. This accusation is revealed by an Appleby Crown Court record of the Christmas Session held in January 1740, where Thomas Eliot and Ann Rain, both of Knock, were required to

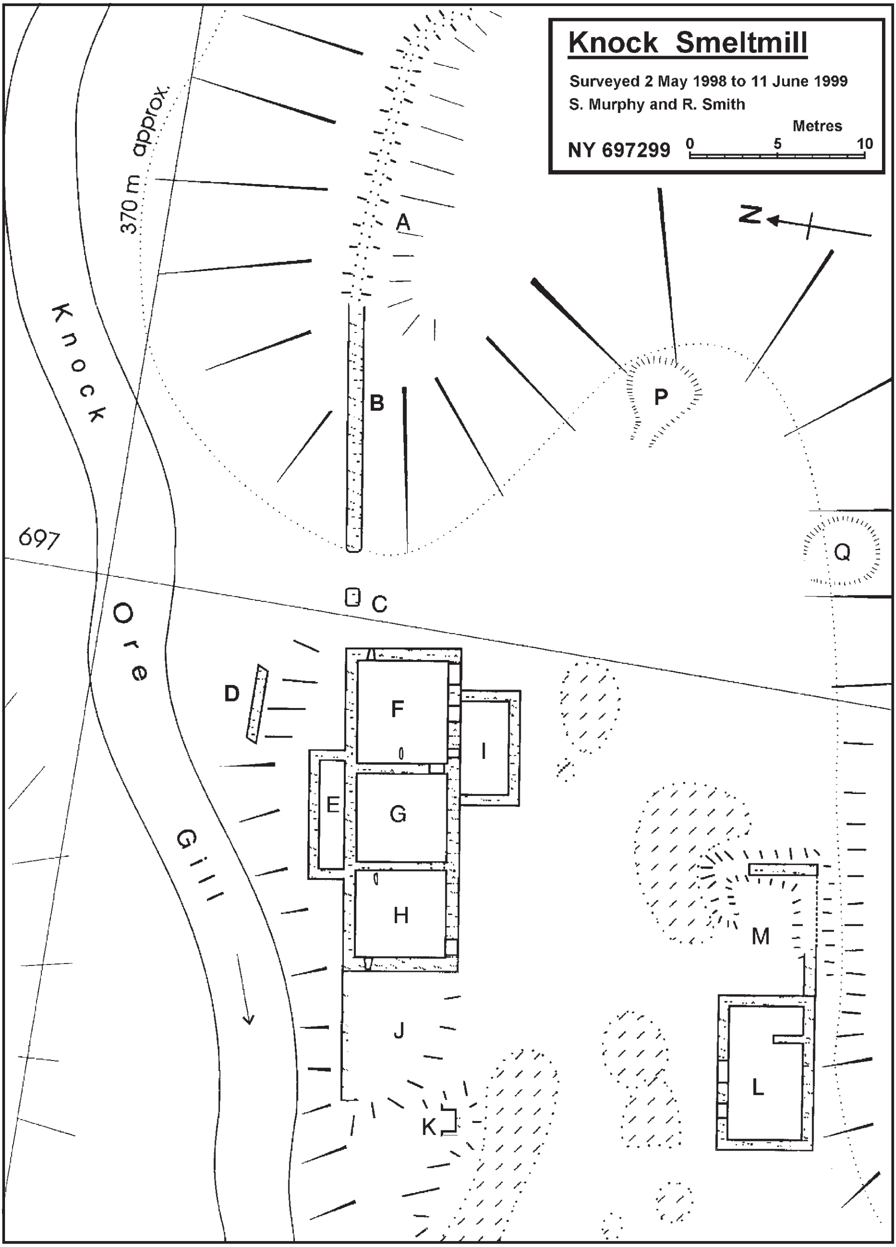

Fig.1 Survey of Knock Smeltmill - overall site

attend to give evidence against him.[8] Ellwood was also indicted for the theft of a prayer book valued at eleven pence from a lady at Dufton, but

Plate 1 Site photograph from leat (R. Smith, 1998).

disappeared at about Michaelmas 1740, leaving his wife and three children to be supported by the parish.

This early date supports the conclusion that Knock mill was built to smelt ore from the Thanet mines within Knock Lordship, which included the mines of Knock and Milburn fells, but not those of Dufton, which was then owned by another Lord. The mill is conveniently placed for the lead mines at the head of Knock Ore Gill (1 km NE) and Over Hearth (4 km ENE) in the Knock manor, and at Silverband (2 km NNE) and Dunfell (3-4 km NE) in Milburn manor. It would be less convenient for the mines of Nether Hearth near the Tees (6 km ENE), whose rich veins passed through all three manors almost exactly at the point where they touched. Mining took place in this area from at least the 17th century: Silverband and Dunfell mines were at work in 1689 and the Knock mines were sufficiently important at that time to merit the employment of a "*Bayliffe of the Lead Workes at Knock.*"[9]

How long the mill continued to work is uncertain, but it was probably used intermittently, whenever the Dunfell mines were being worked. Minor repairs, totalling £2 7s 4d, were made at a Knock mill in 1765, 1767 and 1768, and, since there is no known corn mill at Knock, these must have been repairs to the smelting mill. The Dunfell mines were not working from about 1772 to 1779, but Dunfell duty lead appeared in the accounts in 1780. In 1782 the lead duty was reckoned up "*exclusive of a Road to the Smelt Mill*", which indicates that a mill road was constructed within a year or two of that date and that the smelting mill was then in use.[10]

Although there is no direct evidence to support it, the most probable date for closure is 1785, when the Earl of Thanet purchased the adjacent Dufton Manor with its flourishing mines and a smelting mill. This smelting mill was located in a convenient position in the lowlands near Dufton village, and would easily have been capable of handling the ore from the Milburn and Knock mines as well as those of Dufton. Financial records for 1787 and 1788 contain entries in the Dufton Estate accounts of payments for the smelting of duty lead by John and Christopher Gelder, who worked at the Dufton Mill, with no mention of any separate payments for the smelting of Dunfell duty ore, which was also being produced at that time. This suggests that the Milburn and Knock produce was smelted at Dufton after 1785, with each group of mine lessees renting the smelt mill from the Lord of the Manor and hiring the smelters to process their own ore, and the Earl likewise paying the smelters for dealing with his duty ore from both sources.[11] A firm date for the abandonment of Knock Mill can be deduced from the Earl of Thanet's accounts, as the bellows were removed from Knock Mill in 1791 and used in a new smelting mill which was built in Dufton in 1791/2.[12]

SITE SURVEY

Knock Mill is set beside a fast flowing gill, on a broad platform about two metres above the stream. The fell rises steeply just above the mill site to the east and south. Upstream the gill is contained in a narrow V-shaped valley, but there is an open flat-bottomed hollow downstream to the west of the mill. This change in topography appears to be due to geological factors, as the mill is on the extreme western edge of the gritstone which forms the

Plate 2 Smelting room F, showing hearth keeper stone. (R. Smith, 1998).

Plate 3 Smelt mill and wheelpit area from NE. (R. Smith, 1998).

gentle lower slopes of the fell, while a few yards to the east of the mill a hard limestone outcrops, forming the steep edge of the higher fells. The mill is on the Knock commons, several hundred metres away from the nearest fenced pastures which were enclosed in 1815. A rough track from the Knock Fell road branches off near some modern sheep pens and curves down in an easy gradient to join an older road which leaves the mill site and runs uphill in a straight line in a south-westerly direction as far as the fence wall of the 1815 enclosures, beyond which it vanishes. This old road is marked on the 1st Edition OS map, and must be part of the road constructed in 1782.[1] It is 2.4 metres wide, well-metalled with gritstone cobbles and black slag, and is still in an excellent state of repair.

The smelt mill occupies a position which satisfies the criteria of easy access to a road from the valley, a suitable distance from habitation or pastures, and near to a beck with a sufficient flow of water and rising ground above to give a good head for the wheel.

The ground plan of the smelting site is shown in Figure 1. The main building (Figure 1 and Plate 1) was a three-room smelting mill set along the edge of a platform adjacent to the gill, and its northern wall was the principal retaining wall for the platform. It was a long, symmetrical building, with a central bellows room, G, single hearth rooms, F and H, at either end, and a walled yard or store, J, of the same width attached to the western end. A small annex, I, adjoins F and G to the south and was probably used as a lead store. One side of a tapered window in the gable wall of F gave some light to that room, and another narrow, tapered window opening in the western gable wall of H suggests that the walled enclosure, J, was a later addition.

The two smelting rooms, F and H, each have one 0.8 m high hearth keeper stone standing. Smelting room F, with a hearth keeper stone *in situ*, is shown in Plate 2. This room had been paved with gritstone flags, about 200-400 mm in size and 30 mm thick, in front and to the left of the keeper stone. The exposed part of the paved floor has an area of about $3m^2$, and has a pronounced slope away from the furnace area and towards the beckside wall. Numerous pieces of coke and some black slag were found in this room. The second smelting room, H, is covered with tumbled stone and its floor is not exposed. The bellows room, G, was between them, with the wheelpit on the north side, parallel and close to the gill, and now substantially filled with tumbled stone. A doorway through the south end of their common wall connected the smelting room, F, with the bellows room, G, and a similar doorway probably connected G and H. The need to leave an unobstructed passage through the door may be the reason for the hearth units being offset from the centre line of the mill towards the north.

Water was supplied to the wheel from a leat, A, which was carried over a short bridge, C, the stone pillars of which are quite distinct. The leat started from a flat area beside Knock Ore Gill, well upstream from the mill, which may have acted as a reservoir. It continued along the south bank in a gentle gradient to a sluice gate, then descended sharply for a distance of 14 metres to a stone embankment, B, which carried it for a further 14.3 metres to the head of the bridge, C, and thence to the water wheel. The small fragment of wall, K, is covered with tumbled stone and may have been another wheelpit or the outlet of a drain leading to the gill.

The building, L, on the south side of the platform had two rooms and a courtyard or open-fronted shelter, M, on its eastern side. It may have been a shop where miners and smelters lodged. If so, it would also have served as a storage area and general administrative centre for this remote site. The courtyard walls are low and fragmentary and appear to be much older than the adjacent building, L.

All the buildings were neatly constructed of the local gritstone. The walls of the eastern smelting room, F, stand higher than the rest, up to about head height, and had been dry walled originally, but the upper eastern part of its streamside wall and part of the east wall have been rebuilt at some time, using lime mortar. The south wall of F, G and H is dry walled, but lime mortar has been used for the streamside wall of H and J, and the annex I. This suggests that originally the main mill FGH was dry-walled, but that the eastern streamside retaining wall was extensively rebuilt and I and J added later. Large pieces of burnt gritstone, with a characteristic vivid red coloration, have been used for some of the rebuilding work, especially near the chimney area of smelting room H. There are many fragments of burnt gritstone, some with partially glazed faces, and also pieces of hand-made brick scattered amongst the tumbled stones which cover most of the mill, especially at the western end and at J. A scatter of small pieces of red gritstone lies just outside the entrance to smelting room H, suggesting that these are fragments of the masonry of an ore-hearth. The beck runs at the base of the wall at I.

An interesting feature of this mill is the presence of two shallow hollows, P and Q, scooped out of the steep banking at the west end of the site. There is a good deal of burnt gritstone at the mouths of the hollows, especially the smaller northern one, and a short piece of the stem of a thick clay pipe lay on the surface. All the early lead smelting mills in the Thanet properties appear to have been mainly fuelled with chopwood from the Earl's woods, mostly that at Fleakbridge, so these pits were possibly chop-wood kilns, set into the banking and used to dry the wood for the ore-hearths. They resemble similar hollows at Marrick and at Sutton Clough in Yorkshire.

SMELTING RESIDUES

There are considerable quantities of slags over most of the site, which have restricted the growth of vegetation. The main exposures are shown on the ground plan of Figure 1. All were lumpy black slags, with occasional gas vesicles and many lead prills, and were typical lead smelting products derived from a slag hearth. There was some metallic iron, generally in pieces up to 1-2 kg in weight and other iron-rich material, especially in the heaps in front of the store building (M). Many small lead prills in sizes up to 30 mm were scattered amongst all of the slag heaps.

The biggest heaps were the two at the east end of the platform which were made up of large fragments, around 20-50 mm in size, and some with a superficial rusty coating. When tested in depth, the coarse stuff persisted to a depth of about 200-300 mm, and below this, to a depth of over 450 mm, was a fine grey powder, or ash, with numerous small fragments of heavy black slag. The other heaps, towards the west end of the platform, were much thinner, with large lumps only at the edges, and most of the material had a grey powdery appearance similar to that in the deeper part of the larger heaps. Small test holes showed that these western scatters were generally about 100-300 mm deep. The widespread occurrence of slag over most of the working part of the site suggests that it had been used as a surfacing material.

Just inside the east corner of the old building, M, was a heap of quite different material, consisting of large, heavy, porous aggregates of metallic iron and oxidised ferrous material, some with pieces of entrapped coke, lead and minerals. The largest of these was a triangular piece, 130 mm thick with a base 280 mm long and height of 230 mm, which weighed 13 kg.

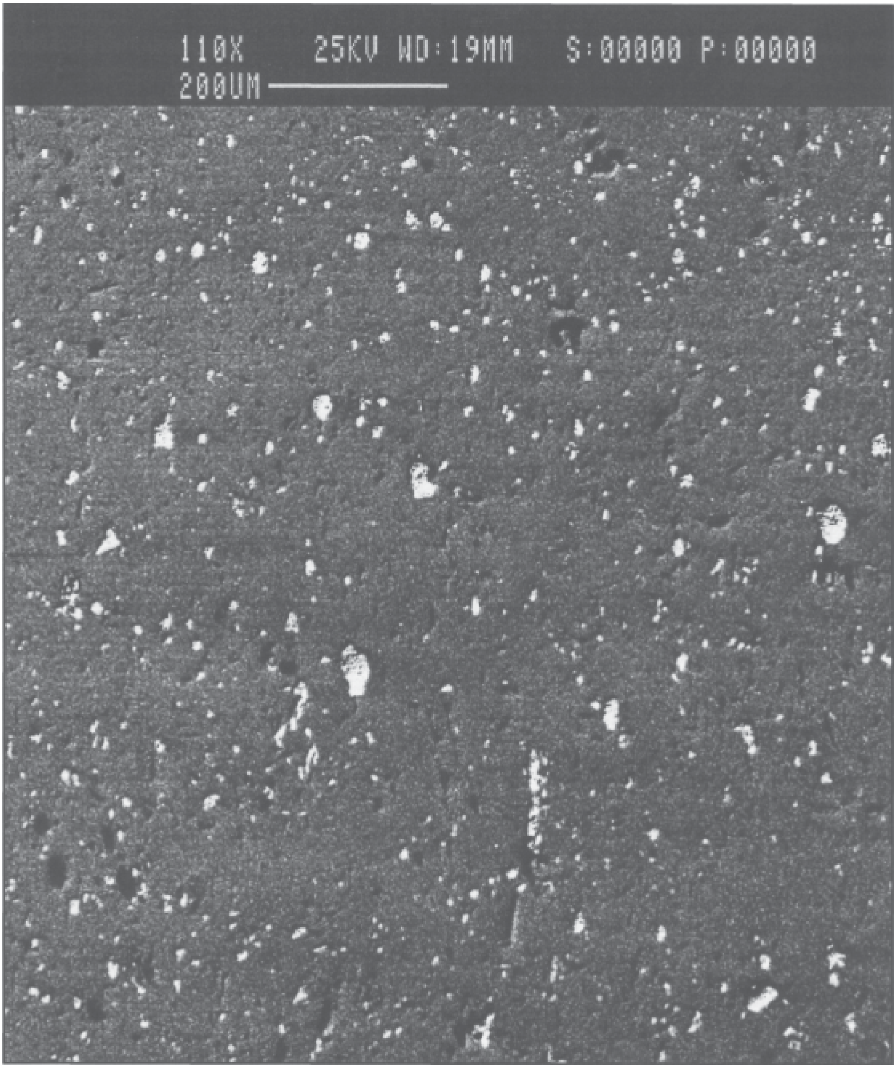

Plate 4 Scanning electron micrograph (BSE contrast) of black slag, showing numerous round white lead particles and irregular dark porosity in the grey silicate matrix (S. Murphy, 1998).

Small quantities of crushed black slags, 5-6 mm in size, were also found to the west of the mill, near one of the rivulets which runs north into Knock Ore Gill, suggesting that some of the material may been washed to recover the metallic lead.

A representative sample of slag was weighed and was shown to have a bulk density of 1460 kg/m^3, which leads to an estimate for the slag present on site as 40 tonnes. For ore of 75% Pb, 11.6% S and 13.4% gangue and a final slag of 5% Pb, the slag present equates to a quantity of ore of 373 tonnes, with a contained lead content of 280 tonnes. This is lower than might be expected for a mill with a long operating life, but, as some slag can be found exposed in the banks of Knock Ore Gill, it is clear that some has been removed by the beck and that some of the slag on the site is buried and has not been included in this survey. It is also possible that slag has been removed either for further treatment or for road making.

Most of the black slags had a dull crystalline appearance with an iridescent vitreous surface, and many had the corded surface of a run slag which had been quite fluid on passing out of the furnace. Most of the larger pieces had solidified in a cake up to 50 mm thick and had pieces of coke trapped in the upper part, with prills of lead attached to the lower surface, indicating gravity segregation of entrapped lead prior to solidification. There was almost no external evidence of weathering of the surfaces, but the lead prills were heavily coated with a white powdery substance. A few slags were porous and light, and had a rusty surface appearance.

Pieces were broken off four of the samples and mounted in conducting bakelite for metallographic examination and X-ray microanalysis in the scanning electron microscope. When examined in atomic number contrast, the structure consisted of a slag matrix with dark pores and very large numbers of white lead particles (Plate 4). Semi-quantitative analyses were carried out in the SEM, without ZAF corrections. General areas on three samples produced very similar results. These were major iron (~40%), with substantial barium, calcium, silicon and oxygen, minor aluminium, lead, potassium and manganese, and trace zinc.

Four samples of metallic iron were also prepared, two from each of two pieces recovered from the slag heaps. Small pieces about 10 mm in diameter were sawn off and mounted in bakelite for metallographic examination, then ground, diamond polished and etched in nital. All samples were essentially similar, being made up of equiaxed grains of carbon-free ferrite, with varying amounts of porosity, many small slag particles, a few isolated lead particles, and areas of corrosion. Microhardness measurements, using a 10 gf load on the matrices of two parts of the two samples (1 and 2), gave the following results: 1A: 129.7±9.2 VPN; 1B: 170.3±50.2 VPN; 2C: 114.8±32.5 VPN; and 2D: 117.3±9.2 VPN. These are slightly harder than would be expected from pure iron, but are consistent with a degree of solid solution strengthening. Semi-quantitative microanalysis in the SEM of the hardest sample, 1B, showed that the iron matrix contained 2-3%Sb, about 0.2%S and a trace of silicon. Plate 5 shows the metallurgical structure of this sample, and the slight dark/light contrast within the ferrite is almost certainly due to variations in the amount of dissolved antimony.

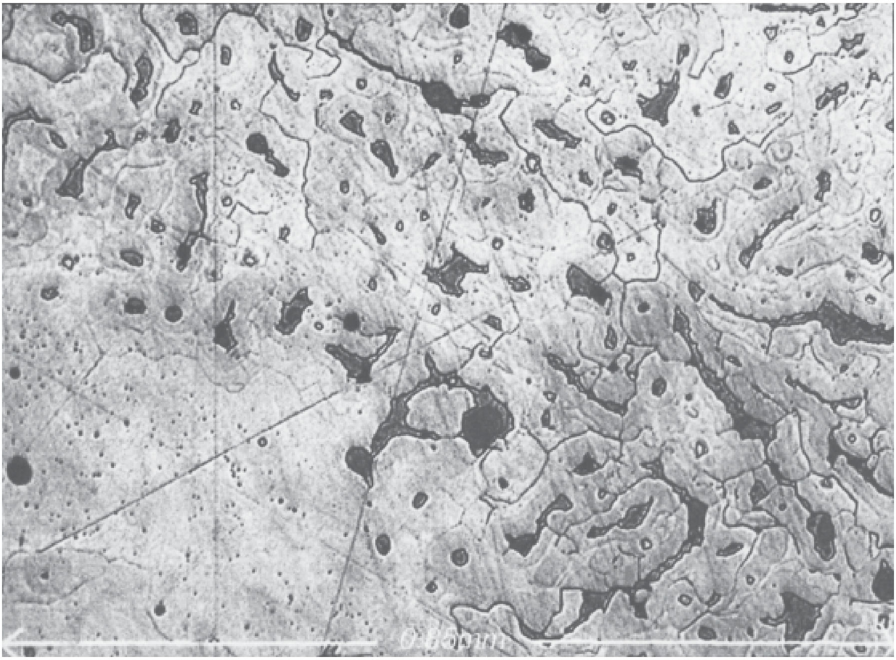

Plate 5 Light optical micrograph of a piece of ferritic iron from the slag dumps, which contained 2-3% dissolved antimony, showing carbon-free equiaxed ferritic iron matrix, small rounded particles of slag and irregular porosity. The ferrite shows a slight dark/light contrast, probably due to local variations in antimony content. The horizontal dimension of the micrograph is 0.85 mm (S. Murphy, 1998).

DISCUSSION & CONCLUSIONS

Knock mill has a layout similar to those of Spout Gill and the New Mill at Grovebeck, on the south side of Swaledale in the Yorkshire Dales. In addition to the two mills above, old plans show Cobscar and Apedale mills in Yorkshire to have this configuration.[15] These, too, had a central bellows room and single hearths at either end. The former is known from documentary sources, the latter can be traced as a ground plan. Knock Mill is an earlier mill than either of these, and is important as it is the best surviving example of this configuration.

The detailed development of mill configuration has been described elsewhere.14 Briefly, the first mills were single hearth units, with a separate bellows room behind the furnace and with an external waterwheel. Examples include Hoggett Gill in Cumbria, Buckden High Mill in Yorkshire, and some of the tin blowing mills on Dartmoor described and excavated by Greeves. The next stage of development appears as the addition of a second hearth room on the other end of the bellows chamber. While this isolated the two smelting units and made entry to the bellows area more difficult and dangerous, the arrangement was inexpensive in that long roof timbers were not required, as would be the case with two hearths arranged side-by-side.

In common with the single hearth units at Hoggett Gill and Buckden High Mill, there was no long condensing flue, the chimney of each hearth being simply part of the wall between the bellows and smelting rooms, with the front wall resting on a wooden lintel. At Knock there is no evidence of any form of support for the front wall of the chimney such as an arch. The lack of a condensing flue to a remote chimney was normal before about 1820, and there would undoubtedly have been some nuisance caused by the smoke, but the mill was built far from the nearest village and well above the early enclosed fields so that cattle would not be harmed. The fields produced by the 1815 enclosure terminate some distance from the mill, and this may be an unusual reversal of the normal case in that the enclosed fields distanced themselves from the smelt mill rather than *vice versa*.

The fact that the gill runs very close to the rebuilt wall, J, strongly suggests that erosion may have necessitated the extensive repairs observed in the western part of the mill. Originally the gill was a considerable distance from the mill, for, although the First Edition Ordnance Survey map shows one branch of the stream at the present position, another branch looping around to the north is the one followed by the parish boundary line, indicating that this was originally the main, or only, course of the gill. The northern branch, active in the mid-19th century, is now completely dry. It is interesting to speculate whether a change in the stream bed, taking it dangerously close to the mill, may have undermined the repaired wall and ultimately been a factor in its abandonment.

An unusual feature of the black slags from this mill was the presence of substantial amounts of iron, which, together with the silica, had formed iron silicates which would have been very fluid that at blast hearth temperatures. Barytes and calcite are the other common gangue constituents which gave rise respectively to the barium and calcium contents of the slags.

The iron in the slags may have been a deliberate addition, made to displace lead from silicates in the grey slags, or to partially remove antimony. It was more probably a naturally occurring constituent of the ore. Haematite and goethite were mined a few kilometres to the north of the smelt mill in the Elizabethan period, and in the late 19th century and iron minerals occur in some of the lead veins.[16,17] It is quite probable that the lead deposits at Dunfell and at the head of Knock Ore Gill contained appreciable amounts of iron minerals, which became a gangue constituent of the dressed ore.

The metallurgical structures of the large, rounded, porous iron pieces examined, ie carbon-free ferrite with numerous cavities and small slag particles, are consistent with solid-state reduction of iron ore. They are typical of hearth accretions produced in modern blast furnaces and are known variously as dogs, bears or sows. The presence of ca 2 - 3% antimony is a little surprising and prompts the question that strongly reducing furnace conditions were deliberately employed and that iron additions may have been made to remove antimony. Ercker refers to the addition of iron filings to eliminate the interference in the dry assay for lead.[19] He also says that old iron, hammer scale, iron-bearing slag or iron cinder is often added in lead smelting to remove antimony or sulphur. Ercker's method for smelting lead was by heap roasting, followed by smelting in a blast furnace. The binary phase diagrams show that iron and lead metals are immiscible in the liquid and solid phases.[20] That for the Fe-Sb system shows that, for low Sb concentrations, an a-phase, containing up to 8 % Sb in iron, separates out. Fe-Sb, having 2% Sb, has a melting point of approximately 1400^{o} C (pure iron M.Pt. 1528^{o} C).

The residues also give an insight into the way in which the slag hearth was operated. Coke-fired blast furnaces, with much greater column heights than would have been the case at Knock, do not reduce iron-rich slags to iron unless they are deliberately overcoked. Coke consumption depends principally on the blowing rate and, for a fixed rate, varies only slightly with feed composition. However, the amount of slag treated depends very much on the choice of the smelter. Slag:coke ratios of 2:1 by volume can easily be run in modern blast furnaces when it is necessary to clean out the furnace or prepare it for a stop. Sustained operation with very high slag:coke ratios of 3:1 can eventually put out the furnace. Nevertheless, slag smelting can be effectively carried out, if the composition is suitable, at such low temperatures that the coke bed, when viewed through the tuyeres, is a dull red in colour. In contrast, when low slag:coke ratios are used, the tuyeres glow white-hot and iron can be reduced from slags fairly easily, especially if they are high in elements such as calcium. When a furnace is run under such conditions, the outward appearances are that all is well: the slag runs freely and the taphole does not block, at least in the short term. Overall, however, the process of overcoking is unnecessary and completely uneconomic. Eventually, dogs or bears build up on the hearth and can cause the furnace to seize up. In high furnaces, the volatilisation and condensation of zinc compounds produces shaft accretions, which stop the furnace after a period of weeks. Even under excessively reducing conditions, much of the iron will be tapped out with the lead, from which it can be easily removed, either by skimming the furnace tapping pot or by remelting, when pieces of iron mixed with dross float to the surface of the molten lead.

These observations indicate that ore was smelted normally in the ore-hearth and the resulting grey slags were then run in a slag hearth to lead and black slag, perhaps with the addition of iron to remove antimony. The presence of iron pieces in the slag dumps is indicative of fairly high reducing conditions, obtainable only using a slag hearth. It is unlikely that these could have been achieved by simple modifications of an ore-hearth, as has been suggested for single-hearth mills such as Hoggett Gill and Buckden High Mill.[18] The fuel used in the ore-hearth was most probably chopwood, but coke may be found at various places on the site, and small pieces were entrapped in some of the iron masses dumped at M, so almost certainly there was a true slag hearth in operation at Knock. The presence of coke on the floor of the smelting unit, F, suggests that the keeper stone in this room was used to support a slag hearth rather than an ore-hearth. The distribution of black slag outside the mill lends credence to this deduction, for the slag heaps appear to start from close to the entrance of room F and form a rough arc around the south and central areas of the yard. Outside the entrance to room H was only general ore-hearth debris.

The combination of a single ore-hearth and a slag hearth creates an imbalance in that the latter would only have been used for one tenth of the time of the former.[13] The records relating to Grovebeck New Mill show that ore and slag hearths were installed. The most practical way of running the mill then would have been to suspend ore smelting when the slag hearth was working.[21]

The most striking feature of Knock Mill is that, despite its age, a considerable extent of the site remains. The remote location and the abundance of local stone quarries has no doubt saved it from the ravages of builders and vandals. Although the present buildings are reasonably stable, however, some protection against erosion by the gill would be beneficial.

ABBREVIATIONS

CCROK – Cumberland County Record Office, Kendal, Hothfield archive
NCRO – Northumberland County Record Office, Newcastle, London Lead Co. archive.
NYCRO – North Yorkshire County Record Office, Northallerton, Bolton Estate archive.

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