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# BALE SMELTING SITES AT CALVER HILL, SWALEDALE, YORKSHIRE

By Richard Smith and Samuel Murphy


## Synopsis

A field study of bale sites on Calver Hill, Swaledale, Yorkshire and examination of their smelting residues has been carried out. This showed that bales could be classified into three main types on the basis of SEM analyses of their smelting residues:

Type A - small amounts of residues, mainly stones splashed with lead silicate and some lead prills;

Type B - barytes or other non-silicate slags with galena and usually very little lead;

Type C - black silicate slags, usually in copious amounts.

The upper sites, which were of type A or type B, had mine-workings nearby and are therefore considered to have smelted local ore. This is noteworthy as the history of mining on Calver is virtually undocumented and the area has been regarded as unimportant in the context of lead mining in Swaledale. Some larger lower level sites may have treated ores from other mining grounds. The B and C sites smelted less pure ores than the A sites. The two main type C bales have been surveyed and reported in detail; they had copious slag residues together with pits and charcoal deposits.


## Introduction

The smelting of lead ores before the introduction of the ore hearth around 1575 AD was carried out in England using open fires known as ‘bales’ in Yorkshire and the Northern Pennines, and as ‘boles’ in Derbyshire and the Mendips.

In 1927, Raistrick published an account of a site at Winterings, Swaledale, which had been discovered several years previously.[1] This was followed, many years later, by the pioneering work by Barker reporting the location of 32 sites in Swaledale, increasing later to 53.[2,3] A paper on the mines of Downholme Moor, Swaledale by the same author described a further three sites.[4]

Working independently over a period of twenty years or so, Murphy and Baldwin[5] located over 70 sites, mainly in Swaledale with a very few in neighbouring Wensleydale, some of which were those described by Barker. Since then, the present authors have located further sites in Swaledale and with the help of Lawrence Barker have rationalised discrepancies in the positions of certain previously reported bales.

In addition to identifying bale sites, Murphy and Baldwin also drew attention to the importance of the underlying geology? Although many of the sites are in predominantly limestone areas, the bale smelters appear to have sought out sandstone or chert outcrops for their work, presumably with the aim of avoiding the problems of smelting on limestone. These would include the hazards of generating quicklime during smelting and the loss of lead and slags through fissures, which are common in limestone. Nevertheless, a few bales were found on limestone, which was protected by either a heavy over-burden of soil on the site or rough flagging with sandstone. Murphy and Baldwin also drew attention to the presence of small pits at a minority of sites, which they referred to as ‘pit bales’, and postulated that these were primitive wind-blown furnaces analogous to those used in Carniola or Bolivia.[5,6,7] They also reported some X-ray fluorescence (XRF) analyses and scanning electron microscope (SEM) studies on residues, although they stated that this work was at an early stage. This supplemented earlier work on the analyses of slags from Spout Gill and Fell End bales which had been published by Murphy.[8]

The current understanding of bale sites in North Yorkshire was reviewed by a group, mostly comprising members of the Northern Mine Research Society, at a NAMHO conference held in Bradford? At that time, Murphy and Baldwin had just published their paper, but the information had not been widely disseminated, and the status of the subject could be summarized as follows

(a) Although many sites had been identified in Swaledale and a few in Wensleydale, none were known at the time in the neighbouring mining fields of Wharfedale, Grassington or Greenhow. Several possible bale locations had been inferred from place names, and other sites in the Northern Pennines had been reported, but not studied (Beadle[10], Pickin[11] and Fairbairn[12])

(b) Very little work had been carried out on the sites, other than reporting their locations with brief descriptions of the residues found. At the time, only two SEM studies and Barker’s radiocarbon dating had been published.[2,5,8]

(c) The organization of the smelting part of the early Swaledale lead industry was not understood—it was not known who the smelters were or what were their relationships with the mineral lords, landlords, owners of woodland, miners or the lead traders.

(d) Following reports of excavation and historical research on Derbyshire boles by Kiernan and Van der Noort and Kiernan, a model for boles had emerged.[13,14] This appeared to be relevant to late Derbyshire boles but did not seem to be applicable to the Swaledale sites.

Attempts to undertake a more systematic study of bales by the NMRS were foiled by the foot-and-mouth disease epidemic of 2001 which effectively ruled out fieldwork during most of that year. Once access restrictions were lifted, the authors started the first part of this work by conducting a more detailed study of one area, that of Calver Hill near Reeth, in Swaledale. Figure 1 is a map of the area and shows Calver Hill as a prominent feature separating Swaledale to the south from Arkengarthdale to the east. This particular area was chosen because the known bales exhibited the range of features and slag types to be found on sites throughout Swaledale. Also there were significant differences between the larger and smaller sites and, importantly, access to the area was easy. In carrying out this work some hitherto unreported sites were found, although it is probable that others remain undiscovered.

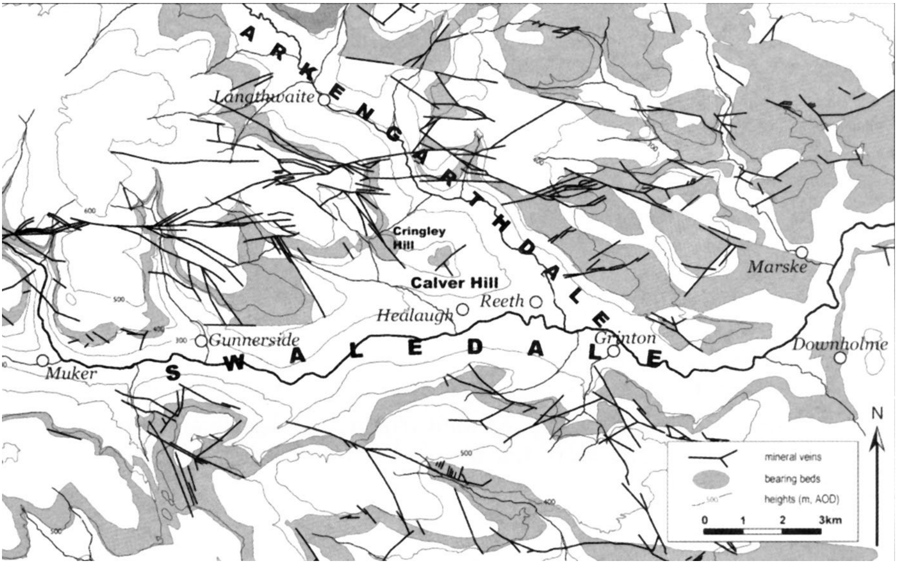


**Figure 1. Map of the Swaledale/lower Arkengarthdale area, showing locations of Calver and Cringley Hills and the bearing strata and veins in which lead ores occur. (Geological data based on Sheet 40 Kirkby Stephen (1997) and Sheet 41 Richmond (1997) by permission of the British Geological Survey IPRI44-260).**

## Survey procedures

As a preliminary exercise, aerial photographs of Calver Hill and other areas with known bales were examined to see if it was possible to detect bale sites in this way. In practice, it proved very difficult to identify even the larger sites which are very obvious from the ground. As an example, the photograph shown in Plate 1 is a monochrome vertical shot which includes the large bale site at the grouse butts. Although the site appears as an irregular grey area, there are many similar features which are not bales. Oblique colour photographs were also examined with little success; although again very large sites could be recognized. Thus at least on this landscape, aerial photography has not been found to be useful for detecting bale sites.

The practical work commenced by field walking the whole area of Calver Hill and the adjoining area of Cringley Hill to the NW, to firmly locate known bales and search the ground thoroughly for others. Considerable difficulty was experienced in locating bales whose positions had been estimated and/ or reported earlier on the basis of three-figure National Grid References (NGRs), ie ±100m. Although this was frustrating, it had an unexpected

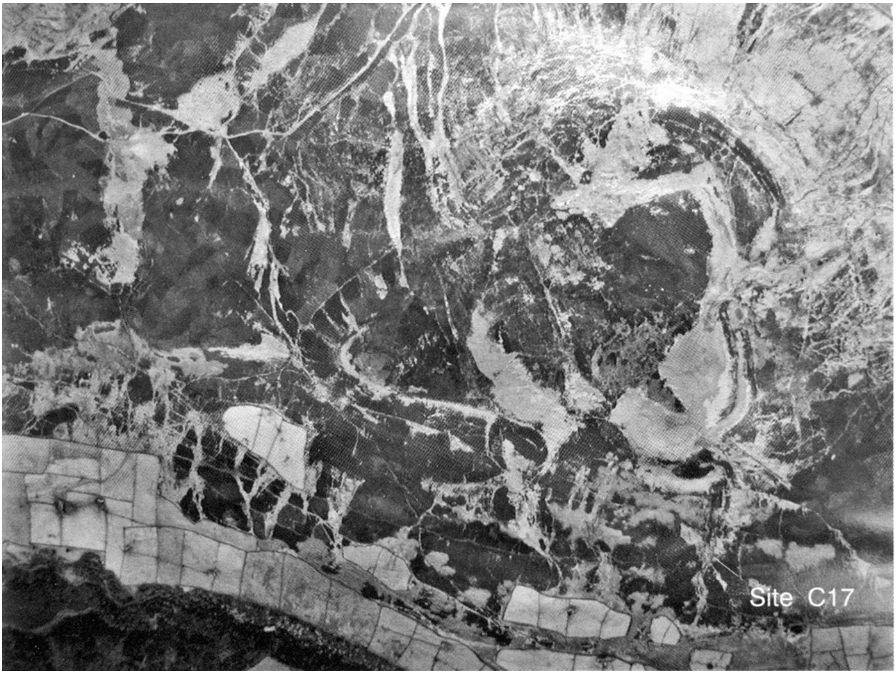


**Plate 1. Vertical aerial photograph of Calver Hill showing summit plateau to right of centre.**

advantage in that several new sites were found as a result of these searches. Hand-held Garmin Etrex GPS receivers were used to determine the positions of the sites with an indicated accuracy of il0m or better. Heights above Ordnance datum (AOD) were obtained by either using the GPS satellite system or with one GPS receiver with a built-in barometer which required a correction for pressure drift during the course of the day. The first method is relatively inaccurate, the second is much better but decidedly fiddly. Therefore, the heights quoted here are those determined by one or other of these methods or interpolation from O.S. map contours, whichever was considered to be most suitable, and are estimated to be accurate to 12m. The positions and brief descriptions of the new and previously known Calver bale sites are described below and listed in the table of Appendix l.

A difficulty arose over the definition of site limits. Usually the smaller bales were well-defined patches of ground that could be reasonably delineated, but the larger sites had widely-scattered satellites, probably indicative of several distinct smelting points. In other cases, large patches existed where several bales were close enough to have blended together. Where widely scattered satellites existed, they have been given separate reference identities.

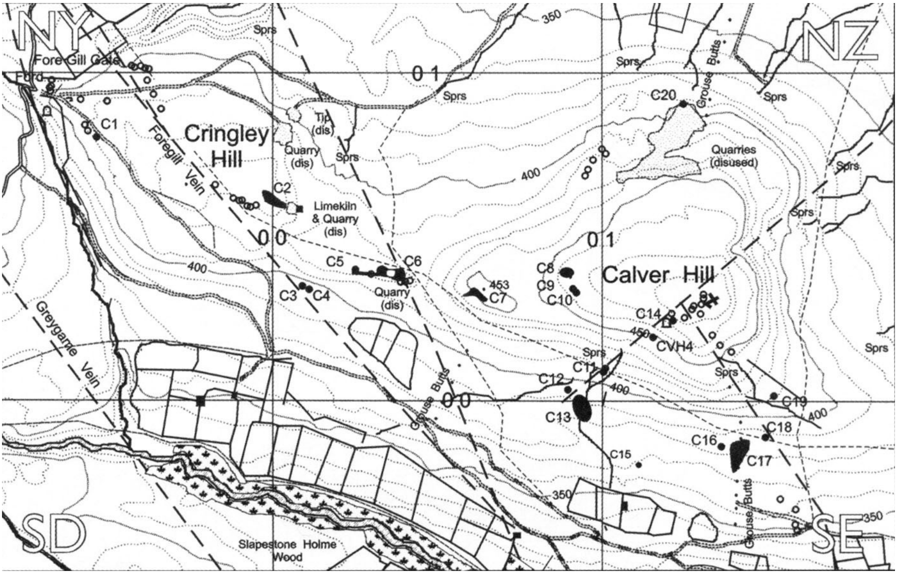


**Figure 2. The locations of the bales, mines and mineral veins on and near Calver Hill (by kind permission of Ordnance Survey © Crown Copyright NCl03I18199).**

**The smaller bale sites**

The sites which have been located are described briefly; their positions are shown in Figure 2.

Site C1 lies on Cringley Hill on the SW slope of a ridge above Bleaberry Gill and beside a small group of shallow mine-workings. These workings and the bale are on the Richmond Cherts.

Site C2 (Limekiln site, Barker[2] site 19) is a large site on the crest of Cringley Hill above a prominent limekiln which served a small quarry in the Main Limestone. The bale site is situated on the Main Limestone, above and to the E of a group of shafts that worked the Foregill Vein; both ore and fuel would have had to be taken uphill to this site. There are signs of a track running NW from this site, connecting the bale with a group of shafts in the Richmond Cherts in the NW corner of the area.

Sites C3 and C4 are unusual in that they are situated on a large flat area at the foot of a slope near the E end of Cringley Hill. Site C3 is a flat patch of bare ground with a scattering of grey non-silicate slags straddling a small stream, and may have been a slag dump or sorting place. C4 is a collection of sandstone boulders on a distinct small hillock which suggests a possible structure. C4 also has some grey non-silicate slags. Both sites are near a major track leading to the valley and by the side of a small stream but they are not on an exposed edge or slope. Although close to the Foregill Vein, there is no evidence of local mining activity. The sites lie on an area of till overlying the mixed limestone/sandstone strata of the Wensleydale series, at the foot of a steep slope of Underset Limestone.

Site C5 lies on the crest of the tail end of Cringley Hill, just above a trench-and-shaft working and very close to the C6 site. C5 lies on thin soil cover over the Underset Limestone.

Site C6 (Barker[2] site 20, Murphy & Baldwin[5] site CVH1) is a large extended site near C5 but appears to have been severed by subsequent quarrying. A group of small shafts lie immediately SE and worked a major vein. The main residues are grey slags. Coal was found at the E end of site at NZ 00364 00385, but this could be associated with subsequent limestone working. C6 lies on a thin sandstone platform of the Wensleydale series which lies immediately above the Underset Limestone into which the quarry has been dug.

Site C7 (Barker[2] site 21, Murphy & Baldwin[5] site CVH3) is situated in a rock-strewn area and consists of a scatter of residues over a large area on the south-facing downward slope of the western ridge of Calver Hill. Residues consist of cream-coloured splashes of lead silicate on sandstones, with lead prills. Small amounts of grey slag were also found. It is likely that these were residues which had tumbled down from one or more sites lying on the ridge at the 450m contour. This area lies on the Underset Chert but the summit ridge where smelting probably took place is on sandstones of the Wensleydale series.

Sites C8, C9 and C10 (Barker[2] site 22) consist of three main areas with copious quantities of predominantly grey non-silicate slags, on a flat bench to the W of Calver Hill summit. There are no mines nearby but the bales are on a natural downward route from the main concentration of mines on the summit of Calver; nevertheless these sites are not conveniently situated for supplying fuel. They are situated on sandstones of the Wensleydale series.

Site C14 lies on the edge of the Calver summit plateau surrounded by shallow mine workings. A trench and a series of shallow shafts lie immediately to the N, and a run-in level to the SW just below. The main evidence for smelting consisted of cream-coloured splashes of lead silicate slags on sandstone, some had inclusions of lead and matte (melted lead sulphide), together with prills of lead. Quantities of both were fairly sparse and they were found on the downhill slope, although they appear to originate from the scarp edge where there is some evidence of a wall-like structure. It is possible that the single piece of slag found by Murphy and Baldwin[5] (their site CVH4 is on the ridge below) came from this bale. Although this is the nearest site to the fairly extensive mines on the summit of Calver, the amount of residues is small and suggests that it served only the workings in the immediate vicinity. The geology here is complicated as the summit consists of the Main Limestone, but the strata are displaced vertically and laterally by two intersecting mineral veins. Although unclear, the rocks underlying the bale site are probably Wensleydale sandstones, with the adjacent mine workings in the Main Limestone.


Plate2. View of site C13 from the south, showing bare patches with slag in foreground and on scarp slope. The charcoal dump is to the left of the EDM station.

Site C15 (Barker & White[3]) is an occurrence of grey slags on a minor hillock. Most of the residues are buried and have been exposed by erosion and rabbits. This is a fairly isolated site which may have treated ore from shaft workings in the SE corner of the area.

Site C19 consists of flat bare patches with traces of grey slags, low down on the SE end of Calver Hill. There are some small streams here and in this respect it is somewhat similar to C2. It is uncertain as to whether this is a bale site, slag washing/sorting area or merely transport spillage. It is situated on thick till.

Site C20 (Barker[2] site 24, Murphy & Baldwins site CVH6) is very small, much disturbed by subsequent quarrying and extremely difficult to locate. This bale is unique in being the only one of this group lying to the N of the Calver Hill/Cringley Hill Watershed. The site lies to NE of and downhill from a group of shafts and is on Wensleydale sandstone, just above the Underset Cherts.

**Survey of the large bale sites**

The two large sites with their associated bales were surveyed in the summer of 2002. The site near the grouse butts (C17, Barker & White[3], Murphy & Baldwin[5] site CVH5) was surveyed using a hand-held GPS receiver and the results plotted on the contours of the O.S. map. The second (C13, (Barker[2] site 23, Murphy & Baldwin[5] site CVH4), further north was surveyed using an EDM theodolite; contours were determined using the EDM. This is the site from which a piece of charcoal was taken and radiocarbon dated[2] to 1439-69 AD. The survey proved interesting in that obvious features could be easily placed but others such as slag scatters and distressed vegetation were difficult to delineate. No attempts were made to map residues under the surface vegetation.

**Site C13**
**(with C11 and C12)**

Site C13 and satellites C11 and C12 is on thick till. Starting from the south, this site has a general slope upwards to the N, with a shallow marshy valley containing a small stream running down to the SE at its lower end. A general view of the site is shown in Plate 2, and a plan in Figure 3. A tributary, running through the central part of the area of interest, joins the stream from the N. Over its lower part, the tributary has areas of bare ground on both sides with variable amounts of slag. It was not possible to determine if these were the positions of bale fires or areas where slags have been scattered after smelting. At the N end of the area is a more steeply rising scarp, beyond which the ground declines gently to a flat area. Most of the northerly part of the site consists of rising ground at the foot of the hill.

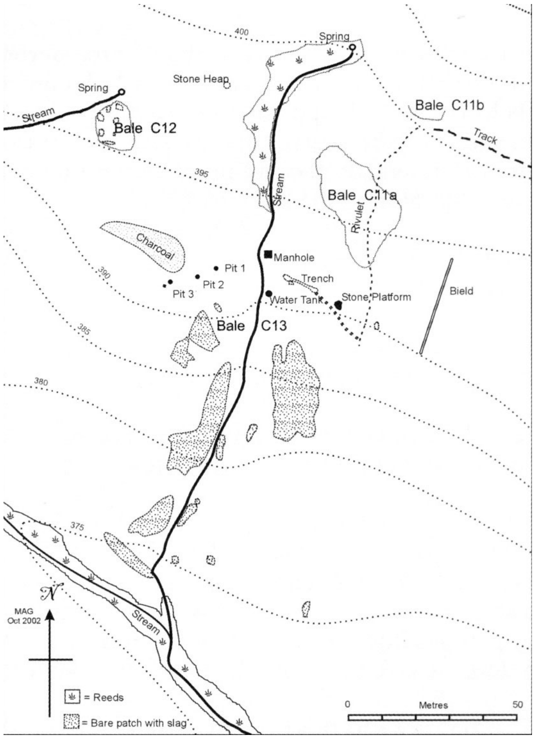


**Figure 3. Plan of the Calver site C13**

The region around the scarp edge has some interesting features which are described in detail below.

From the W, there is an area on the gentle back slope of the scarp, with a thick surface deposit of charcoal covered by grass and distinguished by the lushness of the vegetation. This curved area is approximately 30 x 15m in size and a small trial hole found fairly large pieces of charcoal (some 100 x 75 x 75mm). No slags were found in this area and it is reasonable to infer that this area was the site of a charcoal store.

To the E of the charcoal area is a line of three small pits about 1m in diameter and 0.5m or less deep, with forward openings to the downhill slope.

Immediately E of the stream is a large plastic tank with an associated manhole about 25m to the N. These are recent and part of the arrangements for the water supply to Five Intakes Farm.

A trench runs from close to the stream, across the slope in an approximately SE direction. This is deeper at the NW end and became much shallower over its lower half. It appears to have directed water from the stream eastwards to the edge of the scarp. The eastern end of this trench terminates at an indistinct channel (dotted in Figure 3) running parallel to the stream from a point some 50—60m to the N.

By the side of this trench is a circular area which appeared to have been purposely paved with sandstones.

Beyond the paved area to the E is a small patch of ground relatively densely covered with slag, which may be the position of a bale fire.

A bield wall (linear sheep shelter) running NNE-SSW lies beyond, and represents the eastern limit of the site.

Other significant features were found at the northern end of the site. The large flattish area above the edge of the scarp has a cover of fairly short grass. At the NW end is a sparse occurrence of slags (C12) on the S side of a small stream, running WSW from a spring to the N. The feature has a series of patches having little or no vegetation and is shown on Figure 3 as a single patch. A circular stone heap to the E appears to be the ruins of a building. The flat area to the E of the stream is marshy with much high grass. This disguises a number of possible channels which may have been the result of stream meanderings. Sparse amounts of slag were found over a wide area here but because of the vegetation, the limits of the slag distribution were difficult to determine with any precision. This has been given the designation C11.

The northernmost part of the site consists of progressively rising ground with another slag occurrence on a knoll at its foot. This bale appears to have been situated at the side of a now dried-up spring from which water formerly flowed S through the channel described earlier and shown as a dotted line in Figure 3. A track from the E appears to terminate at this point. This has been also included as Site C11.

**Site c17 (with C16 and C18)**

Site C17 with satellites C16 and C18 is on thick till. A general view of this site from the lower, south end, is shown in Plate 3 and the results of the survey are shown on the plan of Figure 4.


**Plate 3. View of site C17 from the south, showing grouse butt No. 6 in centre.**

The site lies on ground which sloped gently upwards to the N, with small hill with a wall to the W. A small but currently vigorous stream issues from a spring at the upper end of the area and passes southwards approximately parallel to a line of grouse butts (GB4—8). Two other streamlets issue from springs in boggy ground to the E of the main stream and flow S before angling SW to join it. The latter streams are weak or ephemeral; traces of their channels exist in several places and they have clearly taken different courses at different times. At the northern end of the site is a low-lying marshy area with more springs and where water discharges into a sink-hole at the E.

The central part of the site to the E of the stream consists of slag scatters with copious amounts of black slag and some brown barytes slags. A gulley starting near GB7 has been cut to divert water from the middle stream SE towards the eastern stream but this gully no longer carries water. Two depressions and a stone shelf lie on the S bank of this dry gulley.

At NE corner of the area is a small knoll where small amounts of slag were found (C18). There is a pit on the SW end of the knoll and a buried charcoal heap at its E end. The charcoal which was examined consisted of fairly large lumps similar to those found at the other main site (C13), although the quantity here was much less.

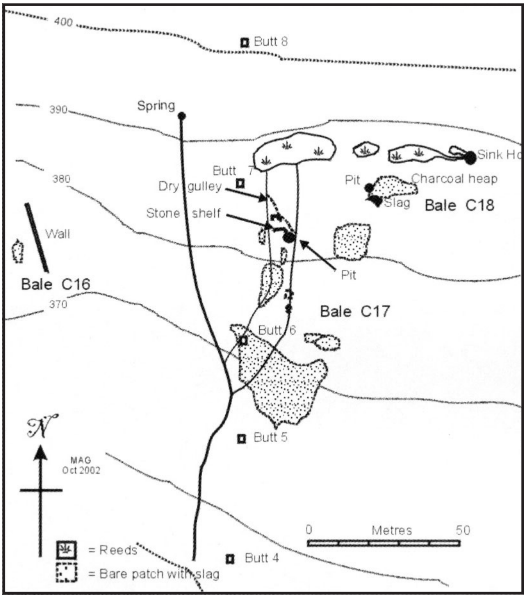


Figure 4. Plan of the Calver site C17.

Traces of slag were found on the small hill at the NW corner of the area and this has been designated as a separate site (C16).

It is presumed from their published photograph that this is the site which was surveyed by Hamilton et al.[15] by magnetometry, using a fluxgate gradiometer. Unfortunately they give no grid reference or other means by which the site may be identified. It would have been helpful if their survey could have been used in conjunction with the results of Figure 4 but unfortunately no details have been published which would allow this.

**Smelting residues and classification of slags**

Over thirty Calver slag samples have been examined by scanning electron microscopy (SEM) using the backscattered electron mode, with semi-quantitive analysis carried out using energy-dispersive X-ray spectroscopy (EDS). In the main, the analyses were sufficiently accurate to allow identification of the atomic ratios of the elements present. Because of the overlap of the Pb-M series and S-K series peaks, analysis for sulphur was not always possible, although the EDS peak analysis software enabled good atomic ratios to be obtained on samples and inclusions of lead sulphide (galena). In all cases lead was determined using the unambiguous Pb-La peak. Samples were cut with a diamond wheel, polished and coated with carbon before examination in the SEM at a beam potential of 25kV. Examples of slag microstructures are shown in Plates 5-12.

As a result of this work and more extensive studies of bale slags from Swaledale and elsewhere, distinct patterns have emerged which have subsequently enabled quite easy identification of slags to be made in the field. For the purposes of this paper it is convenient to divide the slags into three main groups and to classify the sites at which they predominate accordingly.

**Type A slags**
At several sites, the main evidence for smelting consisted of pieces of reddened sandstone with small splashes of cream-coated lead silicate slag, sometimes containing traces of lead or matte (see Plate 4). Lead prills could usually be found at these sites, even though they were only 1—3mm in size, as they have a conspicuous coating of white cerussite. They can be distinguished easily from other lead-rich residues in the field as they can be deformed with a hammer or scratched with a finger nail. At some sites, prills may be the only evidence of smelting. Pieces of galena or matte are usually scarce, although small traces may be occluded within slag.

**Plate 4. Splashes of lead silicate slag and lead on stone, typical of Type A slag and pieces of grey barytes slags typical of Type B**

Lead silicates are formed by the reaction of molten lead oxide with silica. The latter occurs locally as chert, sandstone or siliceous soil and may arise from gangue within the ore or from the base upon which the bale is built. Lead oxide melts at approximately 890°C and forms silicates having the general formula $(PbO)_n.SiO_2$ (where n = 1, 2 or 4). These silicates and their mixtures with lead oxide have very low melting points in the range 720-770°C. For silica contents above 30%, the melting point rises sharply. Plate 5 is an SEM photograph of a sample of lead silicate slag. It is typical of others examined by the authors in that it consists of a fusion of needle-like crystals. In this work, it has not been possible to detect or resolve different lead silicate phases, if they exist but this is a feature which will be sought in future samples.

At Calver, the sites tend to be on upland situations with relatively long distances to sources of wood. Because of the low-melting composition and scarcity of residues it is reasonable to postulate that these were bales Where relatively little smelting activity had taken place and where locally mined ore was ‘tried’ for a short period. In these remote sites, the smelters would have wanted to economise on the use of wood, perhaps supplementing it with peat or ling (heather). Smelting temperatures would therefore have been low and the absence of gangue residues indicates that the ores smelted were pure galena.

**Type B slags**

The most widespread type of slag consists of irregular rounded lumps of up to 75mm diameter, sometimes showing signs of superficial softening and which are internally light to mid-grey or occasionally green or brown (see Plate 4). In this paper they have been termed 'grey slags', although this does not imply that they are similar to the slags of that name produced in ore hearths. They are relatively soft and analysis showed them to be gangue materials, predominantly baryte, but also fluorspar and rarely calcium compounds. Frequently, inclusions of charcoal, galena, matte, lead or small amounts of Type C slags (see below) are present. The gangue materials have very high melting points (baryte melts at over 2400°C) and yet their crystalline form has been transformed. The inference is that these residues were formed by smelting impure ores which were relatively free from silica.

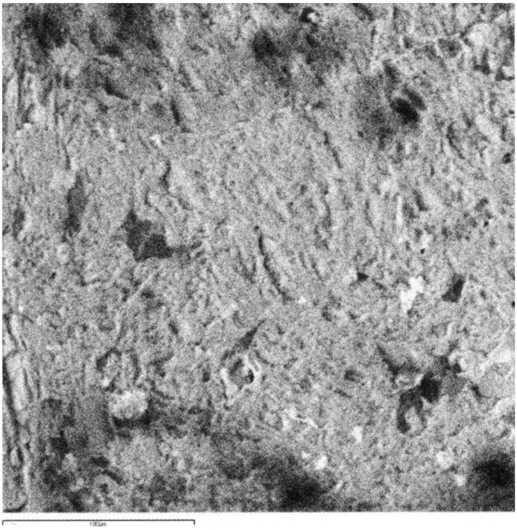

**Plate 5. (C6, sample 2, scale 100mm) Backscattered electron micrograph showing a matrix of needle-like lead silicate crystals (mole ratio $1.5Pb:SiO_3$). White inclusions of Pb or PbS occur. The dark shadows are carbon used to induce conductivity and black irregular areas are pits within the crystalline matrix. In the hand specimen, the area shown was moderately hard and dark green.**

Galena was often found at these sites, usually as unchanged ore but sometimes with signs of being affected by heat or by reaction at the surface. Distinct prills of lead were less common at these sites. Silicate slags could be found but these were generally small amounts occluded in pieces of gangue or seen as glazing on stones. It is fairly clear that the ores smelted at these bales were less well-dressed than those giving rise to Type A slags. Such sites are located throughout the area; the large bale above the limekiln on Cringley Hill (C2) and on the higher slopes of Calver Hill (C6, C8, C9 and C10) are good examples.

Plates 7, 11 and 12 are examples of heterogeneous Type B slags. They are typified by having large fractured pieces of gangue materials, usually barytes or more rarely fluorspar. Inclusions of galena are often evident as irregular pieces, matte is normally identifiable by its shape which shows evidence of flow and penetration into broken fragments of gangue materials. Lead metal is usually identifiable by eye in the polished specimen or as spherical prills where amounts are small. Inclusions of mixed silicates, similar to those in Plate 6, can often be found in Type B slags. With practice it is fairly easy to identify constituents within Type B slags by inspection of a cut surface.

**Type C slags**

In contrast, slags found on the two very large sites on the lower slopes of Calver (C13 and C17) were relatively homogeneous. Externally they had a white or light grey coating and internally they varied from a black shiny glass-like material to a dull black or very dark grey (see Plate 9). The shiny, vitreous examples were hard and brittle and tended to shatter like glass on cutting. Analysis showed them to be mixed silicates containing lead, barium and calcium but with lesser amounts of potassium, sodium, iron and aluminium. Plate 6 shows an SEM photograph of a typical vitreous black slag of Type C. It is featureless and the majority of samples have shown a general molecular formula: $M.SiO_3$ where M is a metallic element. It should be stressed however, that the samples examined have contained mainly divalent metals such as Ba, Ca, Fe and Pb. Only small amounts of other metals such as Al, K and Na were present in the samples examined and the general formula reported here is subject to this limitation.

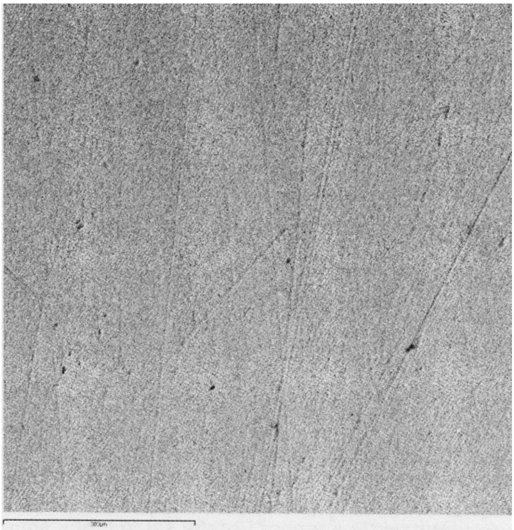

**Plate 6. (C17, sample 1, scale 300mm) Backscattered electron micrograph showing a featureless matrix of mixed silicates of approximate composition (0.17Pb, 0.23Ba, 0.09Fe, 0.51Ca)$SiO_3$. This is typical of brittle, black shiny vitreous slags of Type C.**

The dull examples were hard, tough and much less brittle than the vitreous slags. Like the vitreous slags, they are mixed silicates containing the same range of elements. They differ in that high melting crystals of calcium silicate, barium silicate, mixed calcium/barium silicate or more rarely calcium fluoride have precipitated within the glass matrix. Their melting points have not been determined but are expected to be higher than those of the simple Type A lead silicates. Plate 8 shows an SEM photograph of this type of slag. It consists of a light grey matrix of mixed silicates such as that shown in Plate 6.

Large mid-grey inclusions of mixed calcium/barium silicate — approximating to $Ca_2Ba(SiO_3)_3$ — have precipitated as a mid-grey phase together with black elongated crystals of $Ca_2SiO_4$ having an hexagonal cross-section. It is fairly clear that the presence of elongated crystals will impart toughness and give a duller appearance compared with the brittle shiny black slag typified in Plate 6. Plate 10 shows a somewhat similar case where there is a light grey matrix of mixed silicates having an approximate general formula $M.SiO_3$ with black crystals of $Ca_2SiO_4$ present. In this sample, however, very tiny crystals of $CaF_2$ have also precipitated within the light grey matrix. Examples similar to those shown in Plates 8 and 10 have been found at bale sites elsewhere in Swaledale; the precipitation of $Ca_2SiO_4$ is relatively common in black slags but the precipitation of smaller crystals much less so.

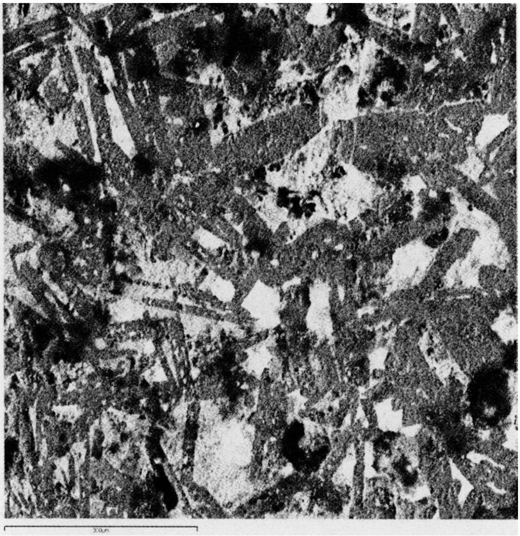

**Plate 7. (67, sample 1, scale 300mm) Backscattered electron micrograph showing dense laths of dark $Ca_2SiO_4$, in a surrounding matrix of light PbO or $PBCO_3$, with round white spots of Pb; the small black spots are fragments of $BaSO_4$. The area shown was a dark grey silicate inclusion in a Type B slag. The hand sample was heterogeneous with hardness varying from fairly hard to soft. Areas of galenalmatte, dark grey slag and brown stony material (shown to be $BaSO_4$) could be seen by eye.**

The presence or otherwise of silica is a major distinction between Type B and C slags. In nearly all cases, fire-reddened sandstones are present and it is reasonable to infer that these have not provided a significant source of silica for slag making. The large bales (C13 and C17) are situated on sandy soil which would have reacted much more readily with gangue materials than compact sandstones. This may help to explain some of the considerable differences shown by these sites.

Calcite and limestone could be expected to be major gangue materials occurring either in the ores or introduced inadvertently into the smelting process. However, as these become converted to quicklime on roasting above 900°C, it is not surprising that calciferous residues exist only where silica is present and the reaction to form calcium silicate has taken place. In some rare cases, calcium compounds (probably carbonate or basic carbonates), have been found as inclusions in Type B slags but these are very soft and would not survive weathering if on an exposed surface. In general, the only significant appearances of calcium are as silicates in Type C slags.

**Relationship of bales with underlying geology**

It has been suggested by Murphy and Baldwin[5] that bale smelters avoided placing their fires on limestone for the reasons outlined above. However, superposition of the Calver bale site locations on a geological map suggests that this was not necessarily the case at Calver, as shown in the site descriptions above. Half of the bale sites were on acidic rocks, usually sandstones of the Wensleydale Series or chert. The majority of the remainder were situated in places which had a thick soil cover and where the underlying geology was unimportant. The best example of this is the large limekiln bale C2 which, although sited on the Main Limestone, was in fact on a heavy soil overlay. Another good example is site C6 which is on a very thin sandstone over the Underset Limestone, which has been quarried in the centre of the bale site.

It is evident that the conclusion of Murphy and Baldwin[5] is still valid, in that limestone was avoided as a foundation for smelting and that sandstone was preferred wherever possible. This is particularly evident for those sites located on the alternating limestone/sandstone/mudstone rocks of the Wensleydale series where sandstone bases were chosen and where reddened sandstones were a characteristic feature of such sites.

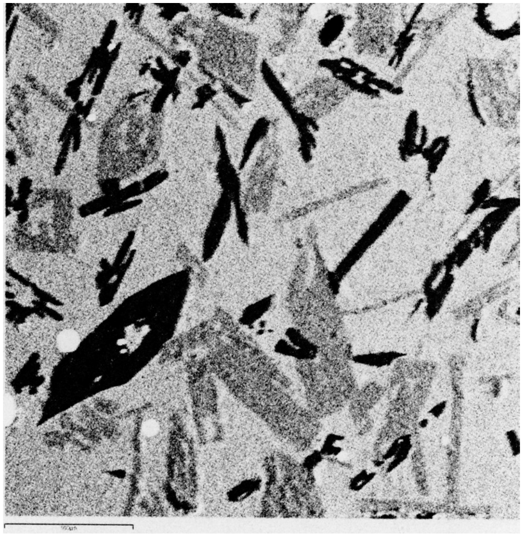

Plate 8. (C3, sample 5, scale 100mm) Back-scattered electron micrograph showing a matrix of (0.5Ba, 0.1Fe, 0.4Ca)$SiO_3$ with large grey precipitated inclusions of $Ca_2Ba(SiO_3)_3$ and black elongated crystals of $Ca_2SiO_4$. The round white spots are Pb prills. The hand sample was hard, tough, dull, very dark grey with a cream-coloured outer surface.

**Site features and bale smelting technology**

The absence of visible excavations and structures at most of the Calver sites accords with Murphy and Baldwin's[5] suggestion that smelting was mostly conducted on simple bonfires with little or no foundation or structure. Nevertheless, unusual features were observed at some sites, particularly at the larger ones, which are worthy of discussion and further work.

Old texts (Agricola[6], Barba[7] Biringuccio[16], and Ercker[17]) refer mainly to lead production by roasting the sulphide ore and then smelting it in small blast furnaces. Barba's description of lead smelting in South America in the mid-

17th century shows that bale smelting of unroasted galena worked even at the very high altitudes of the Andean Altiplano, but only Agricola shows examples of how bale smelting was carried out in different parts of Europe a century or more earlier. His woodcut[6], shown in Figure 5, offers an explanation of some of the features observed in the Calver area and is discussed below.

**Sandstone platforms**

At site C4 there is a heap of sandstones, suggesting that smelting may have been carried out in a circular low-walled enclosure (as described by Raistrick[1]) or on a raised platform arrangement, similar to that described by Agricola[6] for the Polish hearth (V in Figure 5). The former suggests that this could have been a site for re-smelting of slags from other bales, although no superficial evidence of charcoal dumps was apparent. In the case of the Polish hearth, the upper surface of a stone-walled bed is plastered with lute or clay, then a layer of heavy wood is laid on top, followed by another layer of lute and then wood shavings. Pure lead ore is placed on top of the shavings and covered with large pieces of wood. The size of the hearth shown by Agricola can be assessed relative to the height of the smelter. It appears to be fairly small considering the various layers which were placed upon it but is consistent with the size of the mound at site C4. With a hearth of this type, at least some the wood could be replaced by other local fuels such as peat or ling. Site C4 is interesting in this respect and merits further examination.

**Plate 9. Typical Type C slags at site C17. They are characterized by their grey irregular exterior; sometimes showing flow marks and gas vesicles.**

**Charcoal dumps**

A significant feature of the two lower-level sites C13 and C17 is the presence of large pieces of charcoal in what appear to be special storage areas. A large charcoal dump has also been found at Spout Gill[5]. In all cases, the charcoal was found at some distance from the area where slags were found and consisted of large pieces which do not appear to have been the remains from a fire but appear to have been awaiting use in some way. Two possibilities are suggested for the presence of charcoal, based on contemporary metallurgical parallels:

(a) secondary slag smelting took place using small charcoal-fired 'blackwork' furnaces. In the absence of excavation, no evidence of structures suggesting that this took place at Calver has been found, other than the mound at site C4. Nevertheless, charcoal would have been the fuel of choice for such a process.

(b) charcoal was used for the smelting of ore and/or slags using bale fires at sites C13 and C17. In Continental Europe charcoal was definitely used for bale smelting. Agricola[6] shows an example of Westphalian practice (Figure 5, hearth P), in which a large heap of charcoal was covered with straw and lead ore placed on top. It is possible that it was used here too in this way. Charcoal would offer some advantages over smelting with wood as it has a higher calorific value and would be expected to allow more control over smelting. In Swaledale the charcoal heap would be covered with heather instead of straw to prevent the ore falling through too quickly and hence being inadequately roasted. There would be less flame than with wood and the progress of smelting could be observed more closely. Because ore would be well-supported on top of the heap, roasting would take place in a very oxidizing atmosphere, provided there was a reasonably strong wind. Reduction to lead would take place very readily in the hotter, lower parts of the fire.

A sample of charcoal from the dump at site C13 was shown[2] to have a radio-carbon date of 1439-69 AD, showing that charcoal-firing was in use in the latter part of the bale-smelting period.

Charcoal is bulky, friable, mechanically weak and therefore difficult to transport on horseback without severe fragmentation. It is not surprising therefore, that where charcoal dumps exist they and their associated bales are sited on convenient routes as near as possible to woodland but sufficiently distant to avoid the pollution of grazing land.

**Pit structures**

Small pits, about 1.0m in diameter by 0.3m deep, were found at both of the large sites C13 and C17. Similar structures have been described elsewhere in the Yorkshire Dales[5] and it has been proposed that these were employed for smelting ore using an alternative technology. Murphy and Baldwin[5] suggested that the process was analogous to that shown by Agricola for the Austrian Carniolan process (Figure 5, hearth A), where green-timbers are laid across a pit to form a grate. Dry wood is placed over the grate and ore on top; during smelting molten lead trickles into the pit beneath.

However, another explanation is offered by Agricola in his description of the Polish method of smelting, when he says that the metal from primary smelting is collected and remelted by means of a wood fire laid over a pit, the slabs of lead to be remelted being laid across it. Since the melting point of lead is only 328°C, little or no wind would be needed to liquify the lead and allow it to trickle down into the pit. The result would be a round 'bun ingot', which may have been remelted elsewhere. Whatever methods of bale smelting were used, it is highly probable that at least some of the lead would require remelting, either because the shape was irregular or because the lead was in small pieces or contained inclusions such as stones. Murphy and Baldwin[5] recovered exactly such pieces from the vicinity of pit bales above Gunnerside Gill in Swaledale. A small pit, sunk into the ground is the most likely evidence to be expected from such a melting operation but would leave few other traces of metallurgical activity.

Some of the pits at C13 were similar to those found elsewhere in Swaledale in that they were cut into the ground at the head of a steep brow or cliff, and had openings in the direction of the prevailing wind. Others, however, were on flatter ground, such as those at the site C17 at Calver, and would offer little advantage over a simple fire other than better draught and more convenient collection of the smelted lead.

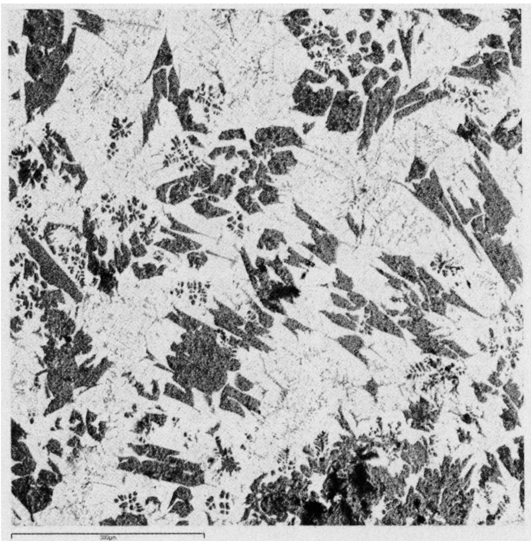

Plate 10. (C13, sample 4, scale 300mm) Backscattered electron micrograph showing a matrix of (0.42Pb, 0.07Ba, 0.12Zn, 0.12Fe, 0.27Ca)$SiO_3$ with black hexagonllaths of $Ca_2SiO_4$ and fine leaf-like crystals of precipitated $CaF_2$. Large inclusions of $CaF_2$ such as that in the bottom of the image were also present. The hand sample was hard, tough, dull, very dark grey with a light grey outer surface.

Other shallow pits found by the side of dried-up watercourses probably served different purposes from those described above and are likely to have been used for slag-washing and separation of metallic lead.

**Black slags**

The presence of large amounts of black slag suggests that the materials treated at these two sites were very different from that at many of the smaller, higher-level sites. Of the upper sites, those with Type A slags appear to have been treating clean galena at a relatively low temperature and generated little or no waste. Many of the other sites (those with Type B slags) had copious amounts of slag, but silicates were rare, suggesting that these were treating dirtier ores with an absence of silica. The presence of black silicate slags at the two main Type C sites (C13 and C17) can be explained in at least three ways:

(a) Some of the ores being treated contained large amounts of silica or silicates, in which case they almost certainly came from more distant mines.
(b) The large two large bales are situated on fine sandy soil which would react more readily to form silicates than would the sandstones found elsewhere.
(c) Higher temperatures were generated at the two large bales, probably through the use of charcoal as discussed above.

It is likely that factors (b) and (c) applied and were sufficient to create the differences found.

**Relationship with the lead mines, fuel supplies and water**

**Lead mines**

Little is known of the mines on Calver when compared with those elsewhere in Swaledale (Dunham and Wilson[18] and Gill[19]), and they have generally been regarded as fairly unproductive trials of low significance.

The lead-bearing Calver Vein strikes NE/SW across the summit of Calver and is intersected at right angles by an unnamed vein. The former has a large number of apparently shallow shafts and trenches, the latter has several shafts on the SE flank of the hill. The most intensive mining activity appears to have taken place on these two veins.

The Foregill Vein strikes NW/SE across the western half of the area and has several closely-spaced shafts and surface workings along its length, although none of these have large spoil heaps. A major fault strikes NNW/SSW across the centre of the area between Cringley Hill and Calver Hill. This intersects the Foregill Vein just above Bleaberry Gill in the south of the area and has some shafts between the two, near the point of intersection.

Although the Calver area displays evidence of low activity, this must be taken in the context of pre-seventeenth century mining when annual production levels of a few hundredweights of ore were normal and many workings were shallow to avoid the problems associated with water and ventilation. The area is close to Reeth and Healaugh and would have been prospected at an early stage.

As part of this work, the more obvious signs of mining were surveyed using hand-held GPS receivers. The remains were indeed small but more extensive than anticipated. Appendix I shows that the remote bale sites on high ground had mine workings close by, except for the groups C7 and C8—10.

It was first thought that the Calver bales had served the Moulds mines to the N of Foregill Gate. These are some of the most significant in the mining field and were known to be productive in the mid-eighteenth century, although their importance before the sixteenth century is not known. Some of the lower bales on Calver are ideally placed for treating ore from these mines, however, it is now apparent that most of the sites could well have treated only ores from workings on Calver and Cringley.

Apart from one Type A site (C14, there were no bales on the edge of the summit plateau of Calver that could be associated with the intensive mineworkings there. Sites C8—10 do not have mines nearby but are on natural routes leading down from the summit plateau; these are well-defined, major Type B sites and would have treated ore from the summit only. It is very unlikely that the smelters would have carried ore from elsewhere and fuel up to these. Site C7 is widespread with fairly sparse residues mainly of Type A but some Type B and because of this it is difficult to assess the level of smelting activity. The site is conveniently placed to take ore from Calver summit and from mines on Cringley Hill, or from further afield.

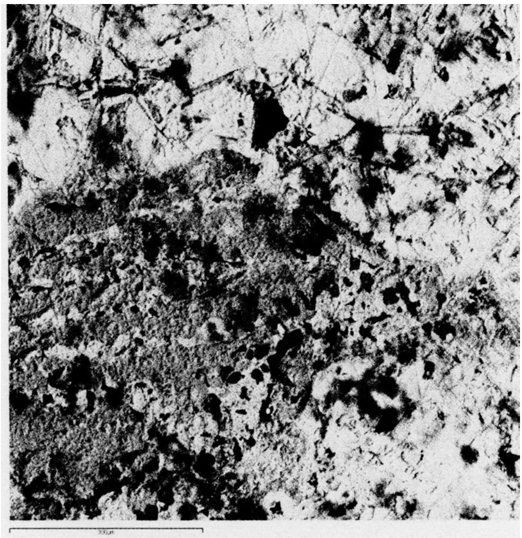

**Plate 11. (C6, sample 1, scale 300mm) Backscattered electron micrograph showing a light matrix of PbS with a mid-grey fractured inclusion of $BaSO_4$ in the centre and a darker inclusion of $CaF_2$ at the bottom left hand corner. The hand sample was soft and heterogeneous with PbS showing as streaks.**

The two large bales (C13 and C17) on the lower slopes of Calver are situated on what are now clear tracks down to the valley and to settlements at Reeth and Healaugh. Their size and the amount of slags are indicative of major smelting activity and possibly secondary slag smelting took place here also. They are situated close to current sources of wood and it is possible that these may have been more extensive in mediaeval times. As lead ore is compact and easier to transport than fuel it is not surprising to find bales sited at the lowest possible point compatible with the constraints of obtaining sufficient wind and avoiding pollution of grazing land. It is possible that these sites treated ore from Calver, Cringley and possibly Moulds or other mines to the north. Sites C3 & C4 are similar in that they are close to downward routes and by the side of a stream but differ in the amount of residues present. It is reasonable to suggest that these were sited with similar intentions but were not persisted with.

## Fuel supplies

There is good evidence that ore was often transported considerable distances for smelting at large bales situated on convenient routes and as near as practicable to supplies of fuel. The surviving bales in the Old Gang area are relatively small but a major site exists on a natural downward route to Swaledale along the E side of Barney Beck (Murphy and Baldwin's[5] SWH1). This is in an exposed position near to supplies of wood and has similarities with the Calver Type C bales on the opposite side of the beck. It has black slag as well as the other debris, much of it buried. There are no mines anywhere near this bale so it must have smelted ores from far afield. Other examples include the large bale on Telfit Bank (Murphy and Baldwin[5] TLB1) which appears to be at a collection point for some of the Hurst and Marrick mines. The bales at Winterings and Potting Scar appear too extensive for local supplies of ore from Kinniside and probably smelted ores from higher up Gunnerside Gill and Merryfield.

It is very probable that peat and/or ling was also used to supplement wood as a bale fuel. This is perhaps because wood would have had to be purchased from landowners and subject to formal arrangements for a regular supply, whereas peat and ling could be obtained more easily from the high fells by the smelters themselves. The form of these fuels would make them ideal for supporting pieces of ore which would tend to fall through to the bottom of a wood fire. Ling would burn very quickly, creating much flame which would be ideal for inducing air flow through the fire and creating conditions conducive to roasting. Peat or wood in the lower parts of the fire would burn more slowly and provide the higher temperatures and conditions necessary for reduction to lead. The presence of charcoal dumps at the two large sites C13 and C17 has been discussed above.

Plate 12. (C2, sample 3, scale 50mm) Backscattered electron micrograph showing mid-grey pieces of $BaSO_4$ in a light grey matrix of (0.33Pb, 0.02Ba, 0.70Ca)$SiO_3$ with some black crystals of $Ca_2SiO_4$. The hand sample was a soft, light brown stony material ($BaSO_4$) with a few minor inclusions of dull-grey silicate slag of the above composition. The area shown shows the boundary between the gangue material and a slag inclusion.


Figure 5. Agricola's illustration of European lead smelting practices in the mid-16th century: *A* an indoor system of the Carni which uses a crucible under a green wood grate; *K* a Saxon variant which uses a crucible with a tap hole; *P* the Westphalian charcoal bonfire with straw cover and pure lead ore on top; *V* the Polish hearth: a stone bench on which wood was piled and lead smelted on top.

**Water**

The association of four sites (C3, C4, C13, C17 and C19) on the lower slopes of Calver with water from a line of small springs is definite but difficult to explain. Several other bales in Swaledale[5] and Cumbria[20] are situated alongside small watercourses. Water would be useful for quenching fires, washing slags or metal and for refreshing the smelters. There is no evidence that water was used to granulate slags which were then broken up to recover lead; indeed the large pieces of slag found at the two Type C sites suggests that this was not done. Water may have been used to wash first-run slags which have been subsequently reworked and there is evidence particularly at sites C13 and C17 that this may have taken place. However, it may be that running water simply acts as a natural focus and that the smelters sited their bales alongside a rivulet rather than in the middle of a featureless landscape.

## Conclusions

This study has shown an emerging pattern relating the location of smelting sites to the type of residues to be found and the availability of fuel. This is consistent with observations of sites elsewhere in Swaledale:

(a) High upland bales were situated close to the mines and remote from supplies of Wood fuel. It is proposed that smelting activity at these sites was small and that they were used mainly in the early life of the mine. Fuel would have been carried to them each day as the miners went to work and smelting would have been carried out infrequently and almost certainly by the miners themselves. It would have been quite practicable for a pair of miners to have carried sufficient wood to work each day for smelting the small amounts of ore they produced. The difficulty of transporting wood dictated that this was used as economically as possible and that it was perhaps supplemented by ling. The residues suggest that only low temperatures, typically less than 800°C, were achieved and that the ores which were treated were almost pure galena with little gangue.

(b) As the mines became more productive, it became usual to reduce the distance over which fuel had to be carried. Bales were situated lower down the fell sides and on what are now clear routes linking the mines, woodland and centres of population. The residues suggest that ores containing significant amounts of gangue were treated at these sites and that temperatures around 1,000°C were obtained. It is very possible that there was a clearer division of labour and that specialist wood carriers using pack horse may have been contracted. As supplies of wood became available with less personal effort, the smelters tended to use hotter fires and maximized lead production by smelting more impure ores. These sites would have been used repeatedly over a period of years.

(c) Finally, very large smelting sites were established, which treated ores from several mining areas. These were set up as near to supplies of wood as possible, consistent with avoiding the pollution of grazing land. Smelting of bale slags from other bales probably took place at these sites and novel fuels such as charcoal were tried either for smelting or reworking slags. It is likely that the division of labour was fairly complete with miners, carriers and smelters being employed as specialists and setting patterns which would persist after the introduction of ore-hearth smelting.

It is possible that all three models were contemporaneous and merely reflected the level of productivity of the mines concerned.

The patterns emerging from this work point to the need to investigate these sites and other sites more fully and to correlate the observations more closely with technical and sociological information from other sources.

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## Appendix 1: Summary of bale sites

| Area & ID | Grid Ref. | | | Ht (m OD) | Size | Aspect | Pits | Red stone | Slagged /stone | Lead | Gal | Grey slag | Black slag | Fuel | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | NY | 99467 | 00810 | 418 | M | SW | 0 | sp | sp | tr | - | - | tr | | One patch below top of ridge. Limestone present, SE of small surface working. |
| C2 | NZ | 00038 | 00595 | 434 | L | SW | 0 | cp | md | sp | md | cp | - | - | Large site on hill above lime kiln. SW of track going through site to mines at Foregill gate. Immediately N of workings. |
| C3 | NZ | 00080 | 00346 | 406 | M | S | 0 | - | tr | | | | | | Slag scatters by side of dry stream on flat ground. Not associated with nearby mine workings |
| C4 | NZ | 00092 | 00350 | 410 | S | S | 0 | - | tr | | | | | | Cairn/pit on flat ground. May be secondary smelting area or circular bale. Not associated with nearby mine workings. |
| C5 | | | | | | | | | | | | | | | Scattered slags on stones at W end of trench & shaft mine workings. |
| C6 | NZ | 00306 | 00388 | 434 | L | S | 0 | md | sp | - | sp | md | - | md | Along ridge of scarp with small quarry through middle of site. Coal at E end of site at NZ 00364 00385 439m. Situated at E end of trench & shaft mine workings. |
| C7 | NZ | 00649 | 00286 | 457 | M | SW | - | sp | md | sp | sp | - | - | - | Top of slope with traces over a wide area down slope. A path goes through richest part. No associated mineworkings. |
| C8 | NZ | 00897 | 00375 | 461 | L | SW | 0 | sp | sp | md | cp | cp | - | - | Several on nearly level ground overlooking steep slope. No associated mineworkings. |
| C9 | NZ | 00905 | 00344 | 458 | S | S | 0 | sp | sp | md | md | cp | - | - | Single patch on level ground above steeply sloping fellside. No associated mineworkings. |
| C10 | NZ | 00906 | 00343 | 457 | M | S | 0 | sp | md | md | md | cp | - | - | Single patch on level ground above steeply sloping fellside. No associated mineworkings. |
| C11a | NZ | 00994 | 00034 | 388 | L | S | 0 | sp | - | - | tr | cp | md | md | Grass covered. Slag scatter over extensive area of grass-covered flat ground N of C13. No associated mineworkings. |
| C11b | NZ | 01007 | 00070 | 392 | S | S | 0 | tr | tr | tr | tr | tr | - | - | Grass covered mound above C13. No associated mineworkings. |
| C12 | NZ | 00910 | 00052 | 400 | S | S | ? | - | - | - | sp | md | - | - | Four small patches on flat area by side of spring NW of C13. No associated mineworkings. |
| C13 | SE | 00949 | 99984 | 391 | VL | S | 3+ | sp | md | - | md | cp | - | - | Major site with large scatter on down slope of scarp. No associated mineworkings. |
| C14 | NZ | 01211 | 00241 | 476 | M | SW | 0 | md | sp | sp | sp | - | - | - | W end of summit plateau of Calver. Adjacent to mineworkings. |
| C15 | SE | 01073 | 99324 | 373 | M | S | 0 | | | | | | | | Side of flat-topped protruding bench, most slags are buried. No associated mineworkings. |
| C16 | SE | 01352 | 99855 | 384 | S? | S | 0 | tr | tr | - | tr | - | - | - | On slope of green hill to W of C17. No associated mineworkings. |
| C17 | SE | 01400 | 99846 | 380 | VL | S | 2-3 | sp | - | - | tr | cp | md | - | Major site at grouse butts No associated mineworkings. |
| C18 | SE | 01446 | 99888 | 388 | S | S | 1 | - | - | - | - | md | - | cp | Satellite above C17 with pit and charcoal deposits. Ponded water above. No associated mineworkings. |
| C19 | NZ | 01511 | 00016 | 413 | VS | SE | - | - | - | - | - | tr | - | - | Open level ground with distressed vegetation. Traces of grey slag on either side of rivulet. No associated mineworkings. |
| C20 | NZ | 01230 | 00900 | 395 | S | W | 0 | Sp | - | - | tr | tr | - | - | Difficult to find in subsequent quarry workings. Downhill from mine shafts. |

Abbreviations: tr=trace, sp=sparse, md=moderate, cp=copious.
Slagged stone=reddened sandstone splashed with cream lead silicate slags of Type A.
Grey slag=Type B slag
Black slag=vitreous Type C slag.