Early lead smelting sites in the Swaledale area of Yorkshire

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ABSTRACT: Many bale smelting sites have been located in the Swaledale area. Their locations were influenced by several factors, principally a position within a few kilometres of lead mines, with ready access to the valley floor and sufficiently elevated to catch the prevailing winds. The site topography was very varied: many bales were at the head of a scar, preferably with an open aspect, but sloping ground was commonly used. The ideal was a ridge or a rounded hill projecting from a fellside, allowing operation under a wide range of wind directions. An additional geological factor was a position with a refractory silicious base rock underfoot. Sandstones were imported where necessary. In some areas there are many more bale sites than elsewhere and possible reasons for this are discussed. Most bale sites had no associated pits or structures and little slag, indicating batch smelting of small quantities of pure galena. Possibly larger quantities were smelted in shallow pits with a forward opening, set on a slope at the head of a brow. A few sites had charcoal dumps and slags which indicate higher temperatures were attained, and the technical implications of this are considered.

Introduction

The Swaledale area is a high plateau region of bedded strata dipping to the east, but intersected by the deep flat-bottomed valleys of the Swale and Arkle becks and their tributary gills. Geologically this area is a region of Carboniferous rocks of the Brigantian and Pendleian periods, consisting of cyclic deposits of sandstone, shale, chert and limestone. The succession of strata with different resistances to weathering has given rise to a step-like series of cliffs or scars along the valley sides. There are many mineralized veins in this area, a high proportion of which contained workable deposits of lead ore. The important deposits were located in the Main Limestone and overlying cherts, termed the 'bearing beds'. In most cases the workings were richest over a comparatively small vertical range of 30-60m (Dunham and Wilson 1985, 9, 10, 51-3, 85). The moor tops at elevations of around 350-500m AOD frequently expose the bearing beds under a light surface cover of peat or clay, and the river valleys provide sections through the strata which would have facilitated the finding of the mineral veins. Figure 1 shows the principal features of Swaledale and part of Wensleydale, and the lead-bearing veins in their geological context.

The mines

There are indications that lead mining was carried out here, albeit intermittently, for the best part of the last two millennia. On the high plateau at Hurst a group of rich veins in the bearing beds was exposed at surface, and the discovery of a lead ingot of Hadrianic date (117-138AD) is evidence for working as far back as the Roman period (Speight 1897, 207; quoted in Raistrick and Jennings 1965). Virtually nothing is known about the next thousand years, but when the Benedictine priory for nuns was established at Marrick in about 1165, the roofs were made from local lead from the Hurst mines, which were said at that time to have existed 'from time out of mind' (Tyson 1989, 13).

During the 12th century, and in particular from 1130 to 1170, large quantities of lead are thought to have been produced as a by-product of silver mining in the border county workings known as 'the minery of Carlisle', and Blanchard (1981, 72) has argued that lead mining in other areas was not viable until the former were stopped by the Scots invasions of 1171-72. This cannot be entirely true however, for there were lead mines at Hurst long before 1165, others at Grinton and Arkengarthdale in 1145, and some in Wensleydale before that time (Raistrick and Jennings 1965, 31). The interruption of supplies from the Carlisle mine evidently did spur lead mining in Yorkshire, for from 1179 to 1183 at least 100 tons a year of lead were exported from Swaledale (Pipe Rolls 26-30 Henry II, quoted in Raistrick and Jennings 1965, 25-6). This high output was possibly short-lived, for some of the Carlisle mines re-started in 1180 and continued until 1212 (Blanchard 1986, 30).

Lead mining in the Swaledale area probably continued on a small and declining scale from the 12th to the 14th centuries. A brief resurgence in the Marrick and New Forest areas of Arkengarthdale in the late 14th century preceded a collapse to virtually nothing in 1490 (*ibid*, 82).

During this time, much of the wastes or pasture lands in Swaledale and Wensleydale belonged to the Crown or the great monastic houses, who seem to have encouraged mining by small groups of entrepreneurs. A list of 12 lead merchants of 1307 includes seven men from Arkengarthdale, and five from Redmire and Preston-under-Scar in Wensleydale (Raistrick 1927, 84), whom Raistrick and Jennings (1965, 30) argue were probably owners of or partners in small mines. Mention of lead from Swaledale and Wensleydale is made in an Act of 1499, good evidence that contrary to Blanchard's data, these areas were then significant lead producers. In the early 16th century lead was mined at Marrick Moor near Hurst for the nuns of Marrick Priory. These mines were governed by ancient mining laws similar to those applying in Derbyshire, which themselves suggest a lengthy history of lead mining (Tyson 1989, 13-4).

The leasing of the lead mines to small partnerships continued after the Dissolution, but powerful landowners then took an interest in the mining fields. In 1546 Lord Scrope was searching for lead mines near Bolton Castle in Wensleydale (Leland 1546, 96), and in 1558 Henry Lord Scrope and Arthur Phillips leased the mines of Grinton and Fremington. Thereafter these east Swaledale mines were worked more or less

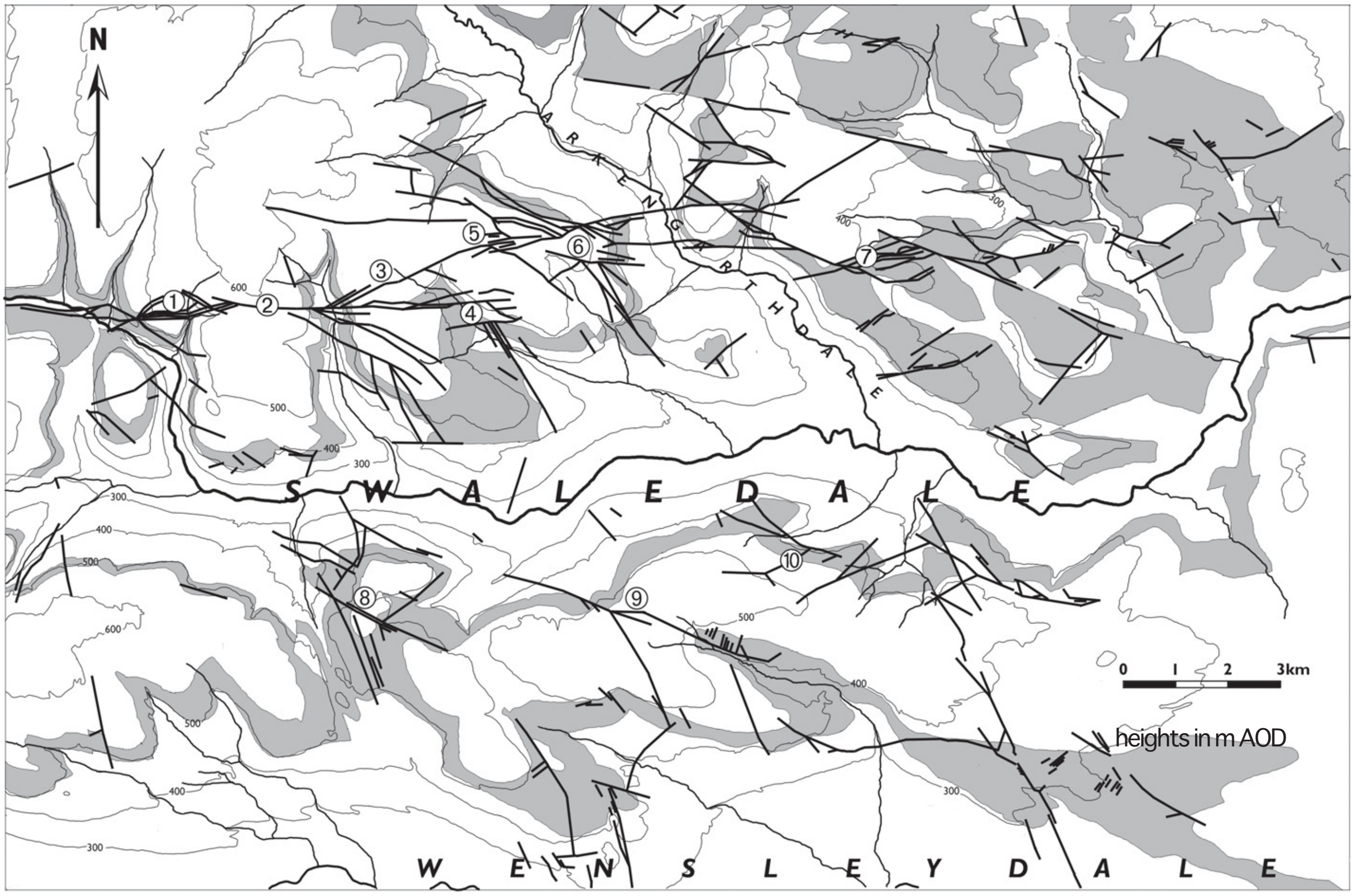

Figure 1: The steep-sided valley of the river Swale and its tributaries. The numerous lead veins, especially to the north of the river, are marked by black lines. Their most productive parts were in the bearing beds, whose surface exposures are shown in grey. Some of the important mining areas are: (1) Beldi Hill-Swinnergill, (2) Lownathwaite, (3) Friarfold, (4) Old Gang, (5) Surrender, (6) Moulds, (7) Hurst, (8) Spout Gill-Summer Lodge, (9) Whitaside-Apedale Head, (10) Harker-Grovebeck-Grinton. Contours show heights AOD in metres (Geological data based upon maps 40: Kirkby Stephen (1997) & 41: Richmond (1997) by permission of the British Geological Survey, IPR/11-8C. Topographical detail is reproduced from same sources, Ordnance Survey copyright permission No. NC/1285/00).

continuously until late in the 19th century (Raistrick 1975b, 43-5).

In 1544-56 Sir Thomas Wharton purchased the manors which comprised much of upper Swaledale (Cooper 1948, 17). By 1601 his grandson Philip was actively encouraging working of his mines by small partnerships of independent miners, and this continued until the 1670s, when the Whartons took control themselves (Dunham and Wilson 1985, 5). The Wharton mines passed into the hands of the Draycott/Denys family and mining continued until it petered out in the late 19th century. The mines of the eastern end of the north Swaledale mining belt were also controlled by a powerful family from 1656, when John Bathurst bought the Arkengarthdale royalty, and were developed into the biggest producers of lead of the northern belt, the last mine closing in 1912. The mines of the Surrender field, which lie between these two larger properties, were in operation before 1680, and though small in extent proved very rich and were intensively mined.

Historical evidence of lead smelting

Early lead smelting in Britain was carried out on silver-rich ores in small furnaces, but bole smelting was introduced late in the 12th century in Yorkshire and Derbyshire and continued until the ore hearth was developed towards the end of the 16th century (Blanchard 1992, 11). Blanchard (1981, 77-9) propounds the view that the bole was the mainstay of lead production for much of this period, with modest use of the turnbole in some parts of the north as a scarcity of wood grew during the period 1360-1520. The blackwork *ofen* he claims was introduced to smelt old bole slags as rich lead ores suitable for bole smelting were exhausted. Claughton (1995) has more recently reviewed the development of lead smelting technology and suggests that simple bole smelting was followed by variants which, prior to the introduction of the ore hearth, replaced or supplemented the simple bole. These include the turnebole, the blackwork *ofen* and the (high) furnace.

Lead smelting was certainly being carried out in Swaledale in the period 1179-83, when the Carlisle mines were in abeyance, but at that time either furnaces or boles may have been used. All later smelting was conducted using the simple bole (known in Yorkshire as the 'bale'), and bale smelting, or one of its derivatives, continued in the Swaledale area until after the Dissolution, although documentary evidence for this is extremely sparse. The earliest record of wood-fired bale smelting is at Marrick in 1502 (Tyson 1989, 13). Lead smelting is reported in Swaledale in about 1540 but the wood needed was imported from other parts of Yorkshire and Durham (Leland 1546, 32). A post-Dissolution map of *c* 1592 shows four bales along the south end of Fremington Edge and another site called the 'Priores Bale' on the SE-facing fellside to the east of the Edge (Tyson 1989, 12). The Fremington Edge bales, with others, were later stripped of their waste slags for re-smelting in ore-hearth furnaces, *eg* in the period 1660-63 925 horse-loads of slags were removed from Fremington Edge and 158 from Skelton Moor for re-smelting in the Marrick smelting mill (*ibid*, 23).

The date of the introduction of ore hearth smelting into the Yorkshire Dales is uncertain, but a smelt mill of some sort equipped with bellows was operated by Fountains Abbey at Brimham, just outside the Nidderdale orefield, as early as 1445. In Swaledale the change from bales to ore hearth smelting seems to have started towards the end of the 16th century, when the first historical references are found. The first of the cluster of smelting mills at Clints was constructed at some time before 1589 and were used to smelt lead from all the mines worked by the Conyers family in the manors of New Forest and Arkengarthdale. A few miles to the west of Marske, the Marrick smelt mill referred to earlier was present in 1592; its name the 'Newe Mill' suggests that it was a replacement for an earlier one, and this was in turn replaced by two others on or near the same site (Raistrick 1975b, 37). These 16th century mills are the earliest known, but a mill at Sleigill below Fell End in Fremington Manor dates from before 1628, the four Wharton mills on Old Gang Beck in Healaugh from before 1670, and Raistrick (*ibid*, 18) lists another eight 17th century mills. Bales may well have continued in use until the mid-17th century, especially where mining was under the control of small groups of miners, but dozens of smelting mills, mostly using ore-hearth technology for primary smelting, were built in the Swaledale area and used during the period to the end of the 19th century.

Based on the rather scanty evidence summarized here, it is concluded that bale smelting was the principal means of smelting lead ore in the area for perhaps 450 years from *c* 1200AD, the first and last centuries of the range being the least certain. Given the abundance of lead ore and the long period of mining prior to the adoption of the smelt mill, Swaledale is a particularly suitable place to study the development of bale smelting technology.

Survey of lead smelting sites

Barker carried out the first survey of early smelting sites in the Swaledale area (Barker 1978), and produced a map showing 32 known sites, which are there described as bales. Another was presented in 1992 which showed 53 (Barker and White 1992), and an unpublished updated version of the latter (Barker 1999 pers comm) shows further discoveries, mostly in Fell End/Slei Gill and Calver areas, which has raised the total to 74.

Working independently, but with reference to Barker's maps from 1992, the authors have located over 70 early smelting sites during systematic fell-walking excursions over the last fifteen years. An attempt was made to search areas which were not necessarily probable sites, but practical difficulties such as field enclosure and limited access meant that most of the work was carried out on the high moorland. In the following descriptions the term 'bale' is used in a generic sense for all smelting sites which were not smelting mills, but recognizing that in some cases the variants noted earlier may have been employed.

Identification of bale sites is not always simple. Initially bare ground was the principal search criterion, but experience showed that this is often due to factors other than lead pollution, and that many (possibly older) sites are completely covered by turf. Similarly, bright green turf amongst a heather cover was another useful but unreliable indicator of lead pollution. Where bale sites are associated with bare ground, smelting debris may be very thinly scattered. Slags, the indicator expected early in the project, were in fact rather uncommon, but pieces of heavy black chert, which closely resemble one type of slag, were not. The most certain visible identifier of a smelting site is the presence of pieces of metallic lead, but a more common indicator is a scatter of pieces of fire-reddened sandstone with spots or coatings of slag or lead.

The sites we have located are shown in Figure 2 and listed in Tables 1-4. Only unambiguous sites were

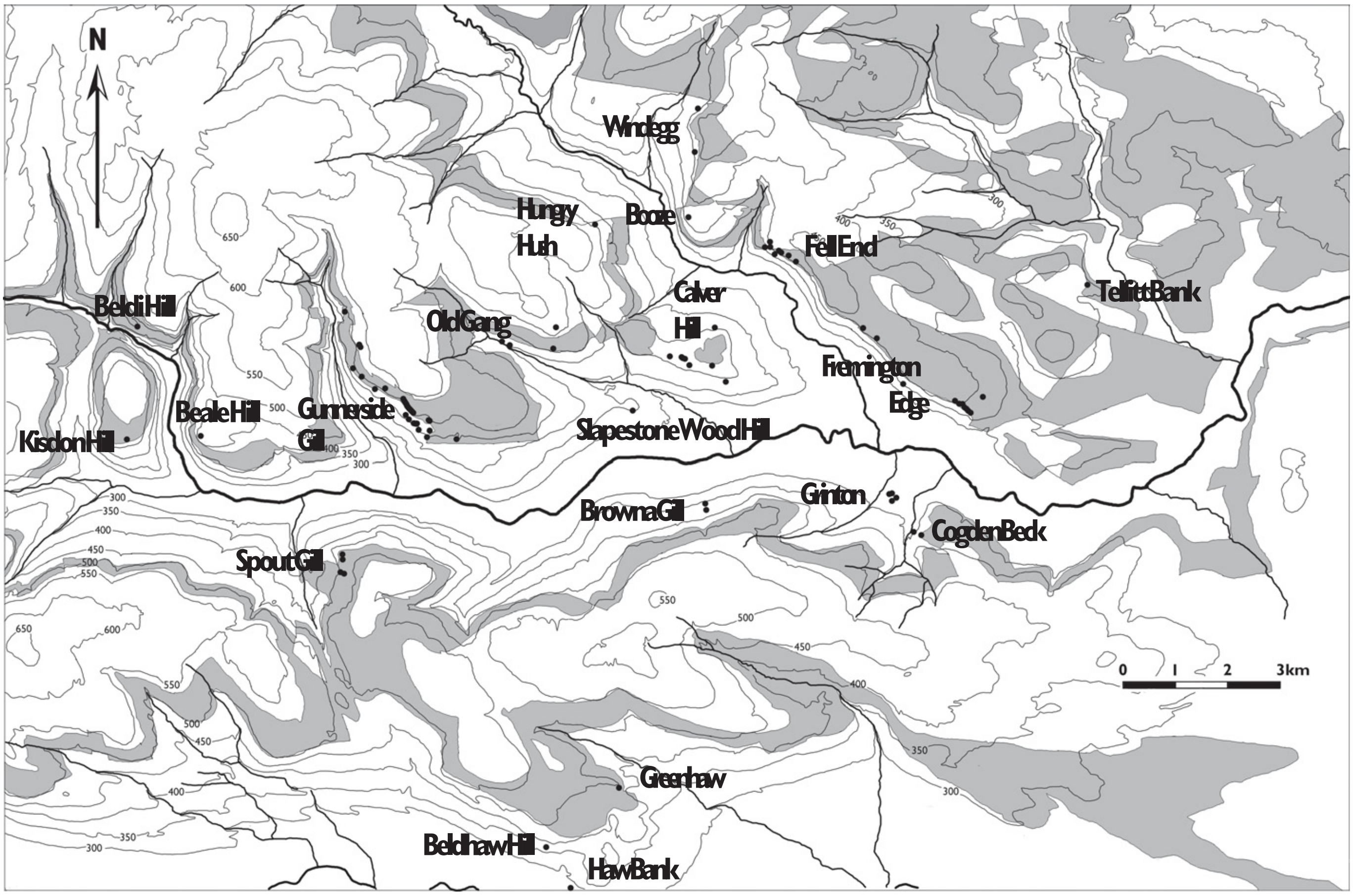

Figure 2: Locations of bale smelting sites in Swaledale area. The bearing beds are shown in grey; contours show heights AOD in metres (Geological data based upon maps 40: Kirkby Stephen (1997) & 41: Richmond (1997) by permission of the British Geological Survey, IPR/11-8C. Topographical detail is reproduced from same sources, Ordnance Survey copyright permission No. NC/1285/00).

Table 1: Bale sites of the Western Swaledale area

Identity	Location (NGR)	Height (m) AOD	Size	Description								
				Bales	Aspect	Pits	Smelting debris					Surface rocks
							rs	rs/sl	l	m	sl	
KDH1	SD89959888	490	S	1 on edge of scar	S	0	-	-	tr	sp	tr	ML
BDH1	NY90200104	410	S?	? on SE flank of rounded hill	SE	0	-	-	-	tr	-	TFG
BLH1	SD91389895	470	M	2? on edge of scar	S	0	md	sp	md	sp	sp	sandstone over ML
BUN1	NY94050129	490	M	2 along apex of low ridge.	SW	0	sp	-	-	md	md	sandstone over ML
WDB1,2	NY94430063	530	M?	2 80m apart along edge of scar	W	0	tr	-	tr	tr	-	TFG
WNS1	NY94310021	480	S	1 on edge of scar, sloping hillside above.	SW	1	md	-	sp	tr	tr	sandstone over ML
WNS2	NY94460000	480	S	1 on edge of scar, sloping hillside above	SW	0	sp	sp	-	-	tr	sandstone over ML
WIN1	SD94749981	480	S	1 on steep slope of projecting spur	SW	0	md	sp	md	sp	sp	ML
WIN2	SD94929982	500	M	2 on sloping fellside above steeper declivity	SW	1	md	-	md	sp	sp	sandstone over ML
PTS1	SD95289930	470	S	1 on S side of a mound at NW end of scar	SW	0	-	-	tr	tr	-	sandstone over UL
PTS2	SD95359923	465	S	1 on edge of scar with very gentle slope above.	SW	0	-	-	tr	tr	-	sandstone over UL
PTS3	SD95489913	465	L	Several sites along 100m length of scar close to edge, very gentle slope above.	SW	1	md	sp	sp	sp	sp	thin mudstone or sandstone over UL
PTS4	SD95539901	450	S	2 on edge of low N-S scar, about 50m apart.	W	0	tr	tr	-	-	-	UL, or thin mudstones & sandstones over UL
WHS1	SD95389940	480	VL	Multiple sites along edge of scar from 95329953 to 95459920, moderate slope above	SW	2	cp	sp	sp	sp	sp	sandstone over ML
KIN1	SD95729919	490	S	2 on forward slope of small grassy hill	SW	2	cp	md	tr	md	tr	MC over ML
KIN2	SD95759917	490	M	2 on short knoll protruding from the S shoulder of the fell	S	2	cp	md	sp	md	tr	MC over ML
MEL1	SD95739907	465	M	1/2 on flat ground at edge of scarp	SW	0	tr	-	tr	-	-	sandstone under ML
MEL2	SD95709920	460	S	Probably 1 on sloping fellside	SW	0	sp	-	-	-	-	AG strata under ML
MEL3	SD95689909	455	S	Probably 1 on sloping fellside	SW	0	sp	-	-	-	sp	AG strata under ML
MEL4	SD95619895	445	VS	Probably 1 on sloping fellside	SW	0	-	-	-	-	tr	AG strata under ML
MEL5	SD95699887	430	M	2/3 on bulge on steeply sloping fellside	S	2/3	cp	md	md	md	md	AG strata under ML
FFH1	SD96279882	450	S	1/2 on summit and NW side of narrow projecting ridge	S	0	md	sp	tr	-	-	TFG

Note: Positions and heights are estimated from OS map or measured GPS data; sizes (S=small, M=medium, L=large VL=very large) are estimates based on extent of visible debris scatter; pits are those thought to be bale-related; smelting debris amount: tr=trace, sp=sparse, md=moderate, cp=copious; smelting debris type: rs=reddened sandstone, rs/sl=reddened sandstone with spots or streaks of slag, l=lead, m=galena matte, sl=slag; rock: UL=Underset Limestone, ML=Main Limestone, MC=Main Chert, TFG=Ten Fathom Grit, AG=various strata of Alston Group.

included in the tables. This compilation is not intended to be a definitive list. Many of the sites listed by Barker are the same as those we found, allowing for ambiguities in precise position, but some have not been visited and others which were examined did not meet our identification criteria.

Western Swaledale

Twenty-two sites were found in this area and their features are listed in Table 1.

Kisdon Hill

The Kisdon bale is an anomaly, as this high isolated hill is separated from the main mining grounds by deep valleys. The single bale KDH1 was on the south side of the hill on the edge of a high cliff. It is probable that ores from Beldi Hill or other mines on the either side of the river Swale were brought here.

Beldi Hill and Swinnergill

Beldi Hill is a sandstone-capped hill close to an ancient mining ground of the same name on the main fellside. There are no lead mines on the hill itself, and no overt indications of lead smelting. The presence of bale site BDH1 was revealed by a heavy growth of lead wort (*Minuartia verna*) over the whole of the SE flank almost from top to bottom. Two small pieces of galena matte in earth from rabbit burrows confirmed the identification. The bale is possibly large and served the adjacent mines.

Swinnergill ore may have been brought down to Beldi Hill for smelting, but more probably was smelted at a group of bales above Ivelet Wood. Barker (1978, 16) shows a bale site on Beale Hill, some 300m back from the scar, but no evidence for smelting was discovered during our examination. Two other sites identified by Barker in enclosed fields at SD 917986 and SD 918915 were not visited, but bale BLH1 was discovered on the SW edge of the uppermost scar where smelting debris was found over a distance of *c* 20m.

Gunnerside Gill

Extensive mining took place on both sides of the river, but bale sites were restricted to the east side. The bale site nearest to the top of Gunnerside Gill was found in the heart of the mining ground above Bunton Level, on a peat-covered sandstone bench some way below the main plateau. Figure 3 shows a view of the area from the south. Two areas of thin black peaty soil (BUN1, BUN2) containing smelting debris and reddened sandstone were located at the north end of the ridge on the crest and backsloping ground, a common topographical feature of bench bales.

To the south there is a scatter of small bales at increasing distances from the mines. At Windy Beale there were traces of lead-smelting residues at both ends of a sandstone scar, 80m apart (WDB1, WDB2, Barker 1978 No.10), but any sites in between may have been destroyed. This site is close to the Lownathwaite/ Friarfold mining ground.

Winterings Scar is much farther from the mines, grass-covered and apparently devoid of bales but had a number of shallow hollows along its edge, a common erosion feature. One of these (WNS1) was a particularly symmetrical turf-covered hollow about 2m across, opening forwards towards the edge of the scarp. A metal detector produced a strong response at a point 4m from the lower edge of the hollow and a large piece of metallic lead with entrapped sandstone pebbles, weighing 1.84kg in all, was recovered. This find is discussed below. Further to the south on the same scar another bale (WNS2) was found under a thick soil and turf cover, but there was no hollow in the vicinity.

Two bales occurred at similar altitudes on sloping ground just above the Winterings field enclosures. Bale WIN1 was on a projecting spur with a SW exposure, where a very minor erosion feature near the head of the grassy area appeared to be the source of the debris. Another bale (WIN2, Barker 1978, No.11) on sloping ground to the south of WIN1 was more extensive, with a shallow pit with raised edges, some 2m in diameter. In the lower rim of this pit an approximately hemispherical mass of lead and entrapped sandstone pebbles was found, weighing 0.74kg. Both bales are well connected by fell tracks to the mines. Barker's bale (1978 No.12) was not found.

About 1km SE of WIN1 and WIN@ is the most extensive cluster of bales in the area, set at different heights and with different features, but all within easy reach of the track to Gunnerside village, and connected

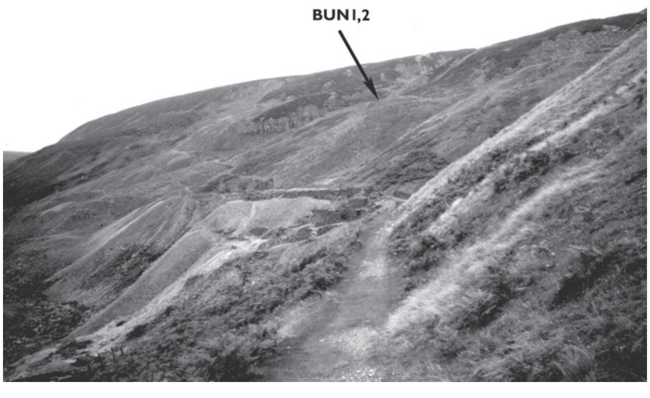

Figure 3: Hushes on east side of Gunnerside Gill, where veins of the northern mining belt cross the gill. Bunton bales (arrowed) are on the edge of the bench above the Bunton Level (foreground)

Figure 4: View from north of Winterings High Scar showing excellent exposure over Gunnerside Gill. The bales start at the summit (left centre) and continue south for 350m to the end of the cliff.

by moor roads to the Lownathwaite/Friarfold mines and others. The highest, and seemingly the most heavily-used bales (WHS1, Barker 1978 No.13) are typical scar-top bales set along Winterings High Scar for a distance of 350m from the highest point on the scar to its southern extremity, with two shallow pits. This impressive cliff, exposing the Main Limestone, is shown in Figure 4. There was a marked absence of sandstone on the north end of the scar where no bales were found. To the west of the High Scar is a broken series of low scarps: Winterings Low Scar to the north and Potting Scar to the south. No bales were found on the former whose top is a bare limestone with earth cover, but Potting Scar, capped with thin shaley sandstones, has several bale sites. PTS1 was on a mound at the highest point of the scar, and PTS2 nearby. PTS3 (Barker 1978, No.14) was a much larger site set along a 100m stretch of the scar edge. One 2m pit near the south end had an opening towards the scarp. It was noticeable that the bale working stopped at a point where the surface rocks changed to limestone. Potting Scar East is a N-S extension of Potting Scar below Melbecks Ridge. The surface rocks are limestones, apart from a small region in the middle where two small bale sites PTS4 were located about 50m apart on thin sandstones.

Bales KIN1 and KIN2 (Barker 1978, No.16?) lay on a low hill protruding from the shoulder of the fellside above the Kining mine. KIN1 on the grassy forward (SW) slope of the hill had two shallow pits 1.5m and 2m wide, set side by side, each with an opening towards the valley. Figure 5 shows the positions of these and neighbouring bales. KIN2, a south-facing area on the same spur has two pits, one 2m in diameter at the head of the slope, with a lateral trench behind it and another 1.5m in diameter halfway down the slope. Nearby is a group of bales on and below Melbecks Ridge, a flat-topped sandstone spur jutting from the general fellside. One bale site (MEL1, Barker 1978, No.17) consisted of a flat boulder-free bare area along the top edge, and MEL2 and MEL3 were scatters of smelting debris on sloping ground below. A fourth possible site, MEL4, further downhill in the hollow of the valley, was simply a long streak of short green turf where a few fragments of black slag were found.

MEL5 (Barker 1978, No.18) is the lowest and most southerly of this group, comprising three pits at the head of a steep debris-covered slope with a prominent exposure over the main Swaledale valley. One pit in the sandstone boulder tumble does not look like a viable working area; another, just at the head of the slope, was 3m in diameter with a raised rim and the third, close by, was a 2m pit with square edges cut into a thin limestone.

Just over 0.5km due east of MEL5, and at a similar elevation, an isolated site FFH1 was discovered on Friar Folds Hill, a long narrow NE-SW ridge jutting out from the main fellside, formed by an outcrop of the Ten Fathom Grit. Bare stoney areas with smelting debris on the summit and halfway down the NW slope of the ridge, suggest one or possibly two bale sites.

Old Gang Beck

Eleven sites were found in this area, all but one on the north or NW side of the valley. Their details are listed in Table 2.

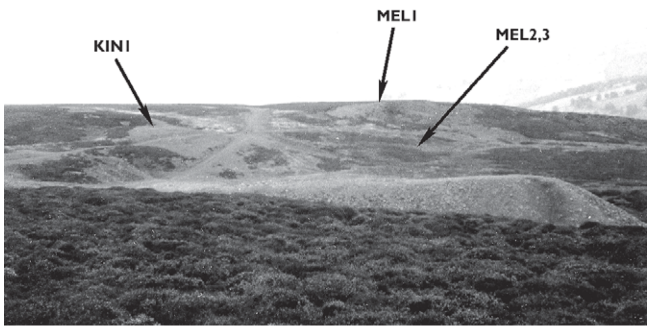

Figure 5: Kining mine and Melbecks Ridge areas; the bale positions are arrowed. KIN2 is behind the hill beyond KIN1.

Table 2: Bale sites of the Old Gang Beck area

Identity	Location (NGR)	Height (m) AOD	Size	Description								
				Bales	Aspect	Pits	Smelting debris					Surface rock
							rs	rs/sl	l	m	sl	
OLG1	NY 97160071	415	S	2 on E edge of low hill	NE	0	-	-	-	tr	-	AG over UL
OLG2	NY 97160071	415	S	probably 1 on sloping fellside	SW	0	sp	-	sp	md	-	AG over UL
OLG3	NY 97300063	415	M	3 on sloping fellside	SW	0	md	-	-	sp	sp	AG over UL
BAT1	NY 98180095	520	M	? on gentle slope near top of ridge, steep fellside below	SE	0	md	-	sp	md	md	cherts over CL
SMH1	NY 98130054	475	M	? on top of bench	S	0	cp	sp	sp	md	md	sandstone over ML
SWH1	SD 99649933	345	M	2/4 on flank of isolated hill	S	0	cp	cp	md	md	md	sandstones over FYL
CVH1	NZ 00360034	420	L	? on S edge of flat-topped ridge	S	1	cp	-	md	md	cp	sandstones over UL
CVH2	NZ 00600025	440	VL	? along summit of projecting bench	SW	0	cp	-	-	-	sp	sandstones over UL
CVH3	NZ 00910002	395	M	? on front of backsloping bench, also on fellside above	S	0	sp	-	-	-	cp	geology uncertain, strata over FYL
CVH4	NZ 01150020	450	L?	? on edge of flat-topped scar	SW	0	-	tr	-	-	-	cherts over UL
CVH5	SE 01429985	380	L	4? on moderate slope	S	0	cp	-	tr	sp	cp	geology uncertain, strata over FYL

Note: Positions and heights are estimated from OS map or measured GPS data; sizes (S=small, M=medium, L=large VL=very large) are estimates based on extent of visible debris scatter; pits are those thought to be bale-related; smelting debris amount: tr=trace, sp=sparse, md=moderate, cp=copious; smelting debris type: rs=reddened sandstone, rs/sl=reddened sandstone with spots or streaks of slag, l=lead, m=galena matte, sl=slag; rock: FYL=Five Yard Limestone, UL=Underset Limestone, ML=Main Limestone, CL=Crow Limestone, AG=various strata of Alston Group.

Healeugh Side

The most northerly bales OLG1-3 are distinguished by their position close to the valley floor in the Old Gang mining field. OLG1 was on the NE slope of a small shoulder of land with a thick heather cover, where probably two bales are represented by small grey patches 6m apart with a bare slope below and a few flattish sandstones above (Fig 6). Just below the bales is a rivulet and on its opposite bank was a tiny site OLG2. The thick heather in this area may conceal further sites. OLG3 was a larger site on sloping ground just below the east end of the vast peat store of the Old Gang Smelt Mill. There was probably a cluster of three bales here, serving the adjacent Old Gang mines.

Bales BAT1 and BAT2 were in much more exposed positions, BAT1 close to the top of a prominent ridge and BAT2 on a lower bench. Both were on limestones, but many sandstones were amongst the smelting debris. Faint traces of an old track running up from Old Gang beck passed just below BAT1 and another track could be traced for a distance of nearly 1km from just below BAT2 to a point near Surrender Bridge. Both bales could have served the Old Gang or Surrender mines.

Slapestones Wood Hill

On the SW side of the beck 1km south of Surrender Bridge is a low sandstone hill with a thick grassy cover. It has no name, and for the purposes of this report was called Slapestones Wood Hill. A large bale site, SWH1, was located on the SE slopes of this hill, beside the road from Surrender Bridge to Healaugh, with an elevation of only 345m AOD but a good southern exposure over the main Swaledale valley. There were probably two sites with different types of smelting debris, separated by a track from the road.

Calver Hill

The bales further down the valley were on the north side in the region of Calver Hill and were mostly large.

CVH1 (Barker 1978, No.20), was on the summit of a small flat-topped E-W sandstone spur joining Calver Hill to Cringley Hill. There were traces of what might be one or two shallow pits near the west end, and a scatter of coal on the east end. The smelting debris was unusual as it included heavy run-slags.

About 200m further to the east is a nearly flat-topped sandstone bench projecting from the west extremity of Calver Hill. A major bale site CVH2 (Barker 1978, No.21) occupies much of the hilltop for a length of *c* 130m, with most smelting debris at the upper eastern end.

Bale CVH3 (Barker 1978, No.23) was on a steep slope below the main scar. 50m uphill from a prominent bench, a single piece of heavy slag with a white coating and green vitreous interior was recovered from earth from a rabbit burrow. On the top of the bench was a bed of charcoal under a thick turf cover, and a 40m spread of smelting debris lay on the steep forward downslope. To the east, in the bottom of a shallow valley, was a long spread of dull yellow-grey coated run slags.

CVH4 was represented by a series of large apparently polluted areas on the flat ground above a high scar, extending in total for 200m. The only positive evidence for smelting was a single piece of thin sandstone with a green-yellow slag spatter.

The most easterly bale site on Calver Hill, CVH5 (Barker 1978, No.21), lay near a line of shooting butts on a moderately sloping fell which continues to the steep brow above Healaugh. This large site had a thick scatter of yellow-coated, generally lightweight run slags amongst the debris and clusters of larger sandstone cobbles indicating possible structures. Several more bales have been reported in the Calver Hill area (Barker 1978, Barker and White 1992) but these were not confirmed by our examination.

These Calver bales differed from those higher up Old Gang beck in that there are no large mines nearby, but tracks run past the bales from the Surrender and Old Gang mining fields to Healaugh in the Swale valley, giving excellent means of communication. The bales chiefly faced towards the south or SW, and although their altitude varied, all had a good exposure over the valley.

Arkengarthdale and Marske

The 22 bale sites found in this eastern end of the area are listed in Table 3.

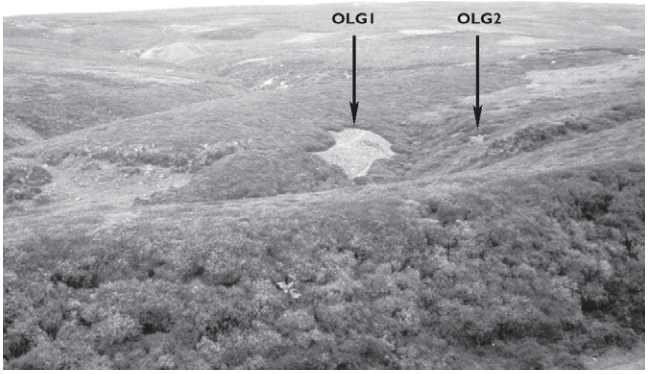

Figure 6: The low bales OLG1 and OLG2 among the mines at Old Gang; the low height above the valley floor and northeast orientation are unusual.

West Arkengarthdale

Only two bale sites were found on the west side of the long valley of Arkengarthdale, both very small and in ground much disturbed by mining and quarrying. HUH1 was in the Hungry Hushes region on a sandstone outcrop. Near the bottom of the dale on the north side of Calver Hill was a tiny site (CVH6, Barker 1978, No.24) in a tumbled area below a quarry.

Bales are much more prolific along the east side of Arkengarthdale, especially where the tributary gills join Arkle beck.

Windegg

The most northerly are three bales set on the high fellside above Shaw Beck. WEG1 and WEG2 were small sites on a ledge of sandstone rocks beside a fell road along Dry Gill Edge. Both bales were situated below the ancient and rich flot mines which lie between the Windegg and Little Windegg veins on the high moor to the east. Barker (1978, 52) shows three other bales between WEG1 and WEG2, but these were not confirmed. BZE1 was a small bale just below the moor fence wall, about 200m west of the moor track to Booze. Barker (1978, 52) places four bales in this area, none of which coincide with BZE1, although No.28 may coincide with an unconfirmed site discussed later.

Fremington

Fell End is a shoulder of high ground in the southern corner of the intersection of Slei Gill with the east side of Arkengarthdale, in an area of intensive mining (Fig 1). Smelting activity appears to have been extensive in this area, with bales along the edges of the upper and lower scarps overlooking Arkengarthdale, and on the

Table 3: The bales of Arkengarthdale & Marske

Identity	Location (NGR)	Height (m) AOD	Size	Description								
				Bales	Aspect	Pits	Smelting debris					Surface rock
							rs	rs/sl	l	m	sl	
HUH1	NY 990030 *	320	S	probably 1 on sloping fellside	E	0	sp	tr	-	tr	tr	geology uncertain
CVH6	NZ 01230090	395	S	probably 1 on sloping fellside	W	0	sp	-	-	tr	tr	geology uncertain
WEG1	NZ 00930504	440	S	1 on top of bench	W	0	md	sp	-	sp	sp	sandstone over UL
WEG2	NZ 00880421	465	S	1 on top of bench	W	0	md	sp	sp	sp	sp	sandstone over UL
BZE1	NZ 00730300	425	S	1 on sloping fellside	W	0	sp	-	-	sp	sp	TFG
FLE1	NZ 02370227	350	S	1 on edge of backsloping bench	W	0	sp	-	md	-	-	sandstones over UL
FLE2	NZ 02380226	350	S	1 on edge of backsloping bench	W	0	-	-	sp	-	-	sandstones over UL
FLE3	NZ 02370248	390	L	3? along sloping front of flat-topped brow	W	0	cp	sp	tr	sp	sp	CC
FLE4	NZ 02300250	400	VL	? on flat top of brow	W	0	-	-	-	-	cp	CC
FLE5	NZ 02200240	370	S	1? on moderate slope	W	0	-	-	-	-	cp	CC
FLE6	NZ 02440235	420	L	2/3 on top edge of scarp	W	0	tr	-	md	sp	tr	RC
FLE7	NZ 02500231	425	M	2/3 on top edge of scarp	W	0	tr	-	tr	sp	sp	RC
FLE8	NZ 02650225	430	S	1 on slope at head of brow	W	0	sp	tr	tr	sp	-	RC
FRE1	NZ 02790213	410	S	1 on summit of small scarp	W	0	md	sp	tr	md	tr	RC
FRE2	NZ 04060084	405	S	1? on sloping fellside	SW	0	md	sp	tr	md	md	RC
FRE3	SE 04809980	355	S	1 on top of bench	SW	0	cp	sp	-	-	sp	WND over FYL
FRE4	SE 05799945	400	M	2? on sloping fellside	SW	0	-	-	-	-	-	ML
FRE5	SE 05909940	392	M	1? on sloping fellside	SW	1	cp	sp	sp	-	-	ML
FRE6	SE 05949938	388	M	2? on sloping fellside	SW	0	cp	md	-	-	-	ML
FRE7	SE 05969933	387	VL	4? on sloping fellside	SW	1	cp	md	tr	tr	-	ML
PRB1	SE 06349951	388	M	on low hill projecting from sloping fellside	S	0	sp	tr	-	tr	tr	RC
TLB1	NZ 08350165	320	L	on low hill near edge of scarp	NE	20	md	sp	sp	md	sp	TFG over RC

Note: * approx. Positions and heights are estimated from OS map or measured GPS data; sizes (S=small, M=medium, L=large VL=very large) are estimates based on extent of visible debris scatter; pits are those thought to be bale-related; smelting debris amount: tr=trace, sp=sparse, md=moderate, cp=copious; smelting debris type: rs=reddened sandstone, rs/sl=reddened sandstone with spots or streaks of slag, l=lead, m=galena matte, sl=slag; rock: FYL=Five Yard Limestone, WND=Wensleydale strata, UL=Underset Limestone, ML=Main Limestone, TFG=Ten Fathom Grit, CL=Crow Limestone, CC=Crow Chert, RC=Richmond Chert

level ground back from the upper scarp edge.

The lower bales (FLE1, FLE2) are typical bench bales set on the very edge of a low scarp. FLE2 appeared to be no more than a bare patch of earth, but FLE1 had a small area crudely paved with sandstone. Figure 7 shows these bench bales viewed from above.

The high bales (FLE3, FLE4 and FLE5) are on cherts and thin flaggy strata above the Crow Limestone. FLE3 was a group of three or more smelting sites on a moderate slope where some natural benches were formed by the strata. In one place a crude terrace some 3m long had been formed by a line of sandstone cobbles but there were no definite structures. FLE4 was a large area of thinly-scattered crushed black slag on mostly level ground extending for *c* 100m along the scar edge. FLE5 was a smaller patch of similar slag on the gentle forward slope of the fell near the track down to the valley. Figure 8 shows this area viewed from the high scarp to the SE. Barker's latest map (1999) shows several sites along Slei Gill and on the sandstone ridge

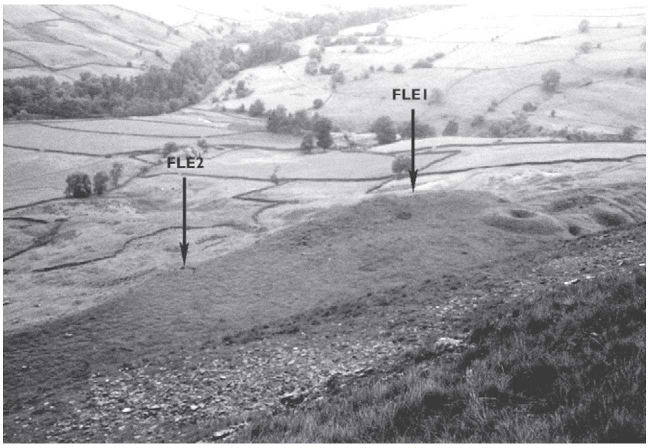

Figure 7: Two small bales on a low bench beside the Fell End mine. The pit (centre right) is a small mine shaft.

near FLE4, but a careful search did not confirm any of these bales.

On the top of the scarp SE of the vein, at a point marked by a cairn, there were two or possibly three bales (FLE6) on the edge of the scarp on bare cherty bedrock. The ground continues to rise to the SE and two more bales were located on the edge of the scar, which by then had diminished to a low cliff above a steep grassy bank. FLE7 was an interesting bale site 63m SE of the cairn, and on similar strata to FLE6. Here on a mostly heather-covered fell was a large area of short turf extending 30m back from the edge, with bare earth patches. The remains of a walled rectangular structure *c* 3.5m wide by 3m deep were set close to the edge (Fig 9). It was made of the same material as the underlying rocks, a hard silicified mudstone/limestone. On either side of it was a downhill scatter of smelting debris on bare stoney ground. FLE8, the last bale of this group, was a small bare patch on a gentle grassy slope at the head of a steep bank. Immediately beyond was an old track which zigzagged up from Heggs House in the Arkengarthdale valley bottom to join the cliff-top medieval wain-way from Marrick to Fell End.

To the south of the track, Fremington Edge forms a 4km continuation of the Fell End scars dividing the manors of Fremington from Marrick. Unusually, the cliff top is not flat but generally slopes upwards with a moderate gradient. There are small groups of bales along Fremington Edge on the edge of the highest scarp and on the lower scarp. FRE1 was a small bench bale 15m from the track from Heggs House, on the steep fellside. A deep hollow 16m x 3m lay uphill of the bale. Barker (1978, 52) shows two bale sites on the lower bench in enclosed land to the SE of FRE1 at NZ 030018 and NZ 031016, but these were not visited.

No bales were found near the track from Castle Farm to the moor, but 200m to the NW of a moor track from High Fremington to Hurst, another bale (FRE2) was located on the highest point on the main scarp with a wide exposure over the valley. Some 400m south of Copperthwaite vein a small bale site (FRE3) was located on the highest point of the lower scarp which featured a pile of sandstone cobbles, some reddened, with drips and coatings of slag and a scatter of pieces of pure galena up to 35mm in size.

On the tail end of Fremington Edge, above Hagg Farm, is a series of bales FRE4-FRE7 on sloping ground above a steeper bank, the Main Limestone scar having dwindled from a few metres to nil in height at this end. These bales were all in two fields within the boundary

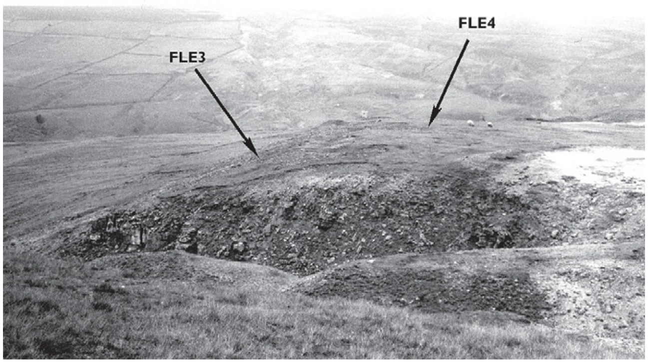

Figure 8: Fell End, where the largest bales are on the slope and flat top of a high scar. The rich Fell End lead vein cuts through the scar in the middle foreground, washing floors are to the right.

Figure 9: View south along Fell End scar, showing a rectangular stone structure on the edge and areas of pollution on level ground. The structure is unique but bale position is typical of those on scars.

walls of Fremington (with one possible exception), and terminated in an area of intense activity at the SE boundary. They have been surveyed and reported as part of a detailed archaeological study of Hagg Farm (Dennison 1997).

The northern-most site FRE4 consisted of a low platform with a central mound and a shallow level area above, close to the boundary wall. No debris was located here, but the magnetic gradiometer survey reported in Dennison shows two sizeable areas of magnetic noise, one to the north and the other to the south of the mound.

About 120m SE of FRE4 was bale site FRE5, a small semicircular pit some 2m in diameter on the sloping edge of the banking and opening forwards towards the valley. Some 60m further along the edge was FRE6. Here two small quarries may have obliterated some of the features, but pieces of reddened sandstone and lead prills were visible on a 2m bare patch to the north, and on another larger one to the east of the quarries. Near FRE6 was the wall which separates this field from the next, and 20m SE of that wall was the beginning of another site FRE7, which extended almost continuously for 170m to the field end. There were probably at least three bale sites here, represented by bare earth and areas of sandstone cobbles, many of which were reddened. At the north end was a pit 2m in diameter, with two others nearby which were probably not bale pits. About 35m from the end wall and on the Marrick side of the NW-SE boundary wall was a 2m bare earth patch with reddened stone fragments, but no other visible debris to confirm a bale.

These bales, with FRE3, are part of the group shown on the map of 1592, and served the mines of Fremington Edge and Hurst (Tyson 1989, 12).

Marrick Moor

The Prioress's bale (PRB1) was on a small heather-covered NNW-SSE hill sticking out from the general SE-trending slope of Marrick Moor. The hill, *c* 100m long and only 5-10m high, is composed of thin flaggy strata of the Richmond Cherts, with a last remnant of a former sandstone capping on the summit. A large bare area covers most of the southern apex of the hill and there were several bare patches with slag-coated sandstones on the west flank. Near the crest of the hill at its midpoint two large pieces of galena matte/slag/sandstone aggregate were found in the heather; other than this the hill was largely devoid of smelting debris. On the summit at the north end were the foundations of a sandstone wall or structure, and the foundations of a 6m-long wall project east from the base of the hill. A line of flat flags heading across the low land towards Marrick might be a former path. This bale is known to have smelted the Priory duty ore from the Hurst field to the north (Tyson 1989, 12).

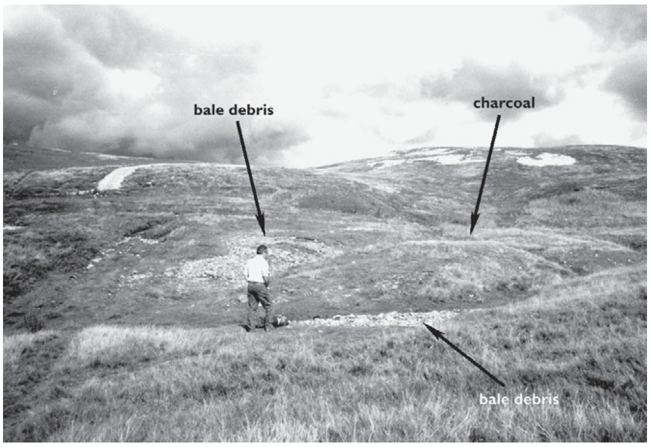

Figure 10: Part of the group of bales set in the shallow valley of Spout Gill. SPG1 comprises the flat-topped mound with charcoal layer and smelting sites to the left and right.

Telfitt Bank

A large bale site (TLB1) occupies a low sandstone hill set a short distance back from the scar forming the west side of Marske valley, beside a moor road from Hurst to Marske. The hill is 120m long and a metre or two high above the moor top, but close enough to the scarp to give a good exposure to the east. About 20 unusually small pits only 1 to 1.5m in diameter were scattered on the summit ridge and both flanks of this hill. There are no important mines in the vicinity, but the site is well connected with the mines of Hurst to the west and others to the north.

South Swaledale and Wensleydale group

The bales in this area tend to be fewer but more extensive than those described above. Their details are listed in Table 4.

Spout Gill

There are two groups of bales near Spout Gill. The upper bales were located above Satron Side. STS1 was on gently rising ground set back from a scar edge and STS2 was located where the scar curved round to the SW to form a steep brow. Two large shallow depressions were set on the edge of the brow and two smaller ones, very similar to those at KNG1, to the west of the large ones and lower on the slope.

The lower Spout Gill bales, SPG1 and SPG2, were

Table 4: Bales of South Swaledale and Wensleydale

Identity	Location (NGR)	Height (m) AOD	Size	Description								
				Bales	Aspect	Pits	Smelting debris					Surface rock
							rs	rs/sl	l	m	sl	
STS1	NY 94039668	490	L	probably 3 on scar top	W	0	sp	tr	sp	tr	sp	sandstone over ML
STS2	NY 94029661	490	M	3 on brow and sloping fellside	SW	4	sp	tr	-	-	-	sandstone over ML
SPG1	NY 94089630	465	M	2? on slope in valley	W	1	sp	tr	sp	tr	sp	MC
SPG2	NY 94099631	455	M	1 on slope in valley	W	1/2	-	-	tr	tr	cp	MC
BRG1	SE 01029756	365	M	several on projecting hill	N	1	cp	md	tr	-	-	sandstone over FYL
BRG2	SE 01049743	375	M	2 on sloping fell, 4? on projecting hill	N	6	md	-	tr	tr	cp	sandstone over FYL
GRN1	SE 04589775	260	M	2 on sloping fell, 1 in valley	NE	0	tr	-	tr	tr	cp	geology uncertain
GRN2	SE 04609765	275	S	5 on small hillock on sloping fell	NW,SE	5	sp	-	-	-	tr	geology uncertain
GRN3	SE 04689763	265	M	4/5 on sloping fellside	NE	4/5	tr	-	-	tr	sp	geology uncertain
GRN4	SE 04619759	320	S	1? on sloping fellside	NE	1	-	-	-	-	tr	geology uncertain
CGD1	SE 04989700	290	M	2 on sloping fellside	NW	0	tr	-	tr	sp	sp	WND strata under UL
CGD2	SE05129696	310/320	L?	2/3 on sloping fellside	NW	0	tr	-	-	tr	sp	WND strata under UL
BHH1	SD 97929109	385	S	1 on bench	SW	0	-	-	tr	tr	-	UL
KNT1	SD 98359030	275	S	1 on scarp top	SW	0	sp	-	tr	-	tr	ML
GHB1	SD 99319223	445	M	several on projecting spur	SE	0	md	-	md	-	md	MC

Note: Positions and heights are estimated from OS map or measured GPS data; sizes (S=small, M=medium, L=large VL=very large) are estimates based on extent of visible debris scatter; pits are those thought to be bale-related; smelting debris amount: tr=trace, sp=sparse, md=moderate, cp=copious; smelting debris type: rs=reddened sandstone, rs/sl=reddened sandstone with spots or streaks of slag, l=lead, m=galena matte, sl=slag; rock: FYL=Five Yard Limestone, WND=Wensleydale strata, UL=Underset Limestone, ML=Main Limestone, MC=Richmond Chert

distinctive in topography and residues, set one above the other in the bottom of a shallow valley at the head of Spout Gill, a former tributary of Oxnop Gill, now dry, where an old fell road leaves the Satron-Wensleydale road on its way to the high moor. The Spout Gill lead vein which runs through the site has been worked extensively by hushes and shafts in the fellside below and there are lead prospecting pits beside the bales.

The uppermost site, SPG1 shown in Figure 10, had two bale sites and a charcoal dump on a flat-topped mound. SPG2 was a downhill continuation of SPG1, starting 16m from the end of the upper mounds as a 3m diameter pit. Below the pit an extensive area of bare polluted ground was covered with a light scatter of thin flaggy stones and many pieces of black slag, most of which were at the upper end of the bare area. There were no reddened sandstone fragments nor any other smelting residues. At the bottom of the bare patch was a small deep pit.

Harkerside and Grinton

On the south side of Swaledale and opposite Calver Hill is a steep fellside with a sandstone spur projecting northward, beside Browna Gill. The spur is divided into two parts by a major fell track, and extensive bales were located on both parts, shown in Figure 11. The bales BRG1 were on the top and possibly both flanks of the lower spur. For 40m along the ridge was a scatter of reddened sandstone, many pieces with slag or lead encrustations. On the west side were disturbed areas, including a possible pit near the summit and an arc of reddened sandstone boulders part way down the slope which can be seen in Figure 11.

The bales BRG2 were on both sides of the upper spur. Two pits shrouded by very thick heather were located on the summit ridge. Bare earth patches on the forward slope revealed an extensive scatter of greenish-black vitreous slags and other smelting debris. To the east of the ridge line and just below the track were two shallow pits each 2m in diameter. All these bales are within 500m of the extensive Harkerside lead veins, and straddled by the above-mentioned track which leads down to the valley floor.

About 3.5km to the east are the well-known bales of Grinton Smeltings. Here several bales are on a gently sloping hillside above a steeper drop to the river Swale. GRN1 is a pair of bales on sloping ground on the west side of the Redmire road. Further to the west is a long patch of ground in the bottom of a small valley, covered with small sandstone cobbles and much black vitreous slag. GRN2 is a group of five small pits on a hillock in the angle between a track linking the Redmire and Leyburn roads opposite Grinton Lodge. GRN3 is a group of at least four bales set in a line along the middle to east end of the same stream, two on each bank, with possibly a fifth on the north bank at the east end. South of these bales and close to the track linking the two roads was GRN4, a single shallow pit some 2.5m in diameter. This was heavily grassed over and concealed in the thick heather, but a bare patch beside it revealed small pieces of black vitreous slag.

Some 700m to the SE, on the east bank of Cogden Gill, is a line of bales starting at the head of the river bank and spreading up the fellside to the SE for a distance of about 180m. Site CGD1 was two patches of polluted earth one above the other amongst disturbed ground between the river and the field wall. Two more bales, CGD2, lay within the field enclosure, and a fifth possible bale was represented solely by a piece of soft white slag in a molehill higher up the hillside. Traces of an old track were found passing across the field just below the second site of CGD2, and the modern road may have obliterated part of this group of bales. The Cogden and the Grinton bales served the adjacent Grinton mines and others to the east.

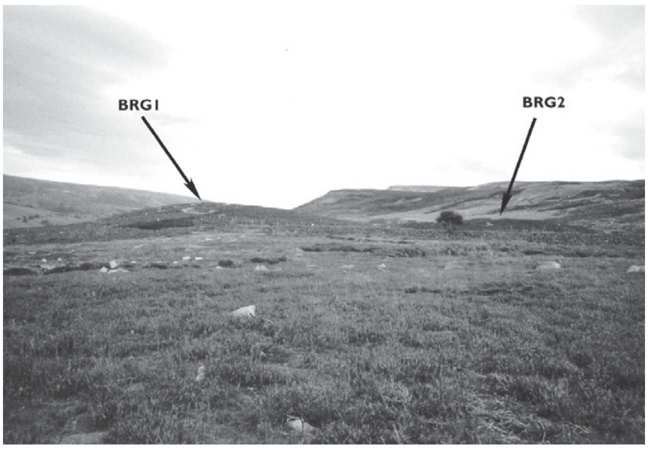

Figure 11: The lower sandstone ridge at Browna Gill which carries the bale BRG1 is clearly outlined against the sky in this view from the west. The bale BRG2 on the upper ridge is arrowed.

North Wensleydale

These bales are below Carperby Moor about 4-5km west of Bolton Castle. Bale site BHH1 was on the SE end of a bench with a gentle backslope to the north and a long steep downslope to the south. A fell road from Woodhall up to the mines on Carperby Moor passes the site. The bale KNT1 was a small site on the edge of a vertical limestone scar, opposite an ancient and extensive lead mine in large rock known as the Knott and probably smelted the ore from there. The Oxclose road, a high level track flanking the north side of Wensleydale, passes within 50m of the site with short links to the valley bottom on either side.

Some 2km to the north of KNT1 is GHB1, set on the SW slopes of Greenhaw Bank, a low east-west spur projecting from the hillside, whose summit is now occupied by a shooting hut. This bale site has a good open aspect to the east where Wensleydale shifts to the north. It is positioned to serve the mines of Brownfield 1km to the west and a small group of mines 300m to the south-west.

This is the eastern limit of the area investigated, but Barker (1993) has described bales on Thorpe Edge near Downholme, and the 1:25,000 OS map shows a 'Bail Hill' in a military area nearby at SE 09339655, none of which were visited.

Examination of smelting residues

Samples have been collected from almost all of these sites, and the second part of this research programme is to characterize these by metallographic study and SEM analyses. This work is at an early stage, but some data on residues from Spout Gill and Fell End have been reported (Murphy 1992).

The materials found during our present survey fell into several distinct categories: lead prills, galena ore, galena mattes and three types of slags. Lead prills ranged in size from a few millimetres to more than 150mm and all had a white coating due to weathering.

Galena ore was present at some sites. It was identical to recently-exposed galena apart from the heavy grey-blue patina and etched surface appearance, a consequence of weathering. A distinctive feature was the large size and lack of attached or intergrown gangue minerals. Pieces were almost always at least 15-20mm thick and often 30-50mm wide or long. At one site on the high scar above Windegg (not listed, as a bale could not be confirmed) a patch of bare ground had around 20 pieces of galena of these dimensions on it, only one of which had a piece of spar attached.

Galena which had been melted or reduced from sulphates in the bale is called galena matte. Mattes were widespread, typically 25mm in size and often irregular and knobbly in form with a white surface coating. Occasionally much larger pieces with a flowed surface were found. Matte was usually fine-grained, but occasionally coarse-grained matte (*c* 10-15mm grains) was found which was indistinguishable from galena ore but for its smooth surface and white coating.

Three types of slag were identified. Type 1 was typically a very dense dark-green vitreous slag, mechanically weak, and with a thick yellowish coating. It was found very frequently as a spot or coating on reddened sandstones, and less commonly as discrete lumps about 20mm in size. Type 2 was a strong black or greenish-black slag, often with gas pores and usually with a thin white or yellow/white coating. It was occasionally vitreous, but usually had a very fine crystalline appearance with some gas pores and often small galena matte inclusions. Some were agglomerated lumps with surface impressions of sticks or charcoal, but many had flowed surfaces and were fragments of larger pieces. Sizes ranged up to *c* 100mm. Comparison of slags from many sites suggested that these two types were end limits of a continuous series.

Type 3 was a light-coloured slag, externally white or grey with pale brown/yellow patches and often very variable in texture and colour internally. Many contained disseminated or attached particles of galena matte. Some were distinctly flowed slags but others showed little signs of melting and none were vitreous. They were very variable in hardness, ranging from a soft almost earthy material to very hard, and density also varied greatly.

Samples of crystalline and vitreous forms of Type 1 and 2 slags were selected for qualitative XRF analysis, and the elements present (omitting Si and lighter elements) are shown in Table 5 with an indication of their relative amounts. Type 3 slags have yet to be analysed.

Table 5 shows that all the samples contained lead and many a little zinc, the latter from zinc blende commonly intergrown with galena. Iron gangue minerals occur in the flot deposits of south Swaledale, and significantly the slags from Spout Gill and Browna Gill bales were rich in iron. Type 1 slags were almost entirely lead silicate, although some contained a small amount of iron, and were usually glassy. Those from Fremington Edge were mostly crystalline, evidently due to slow cooling, as the

Table 5: Qualitative XRF analyses of some Types 1 and 2 slags.

Identity		Description				Element				
		Type	colour	vitreous	crystalline	Pb	Fe	Ca	Ba	Zn
Winterings	WIN1	1	dark green	x		4	-	-	-	1
Calver Hill	CVH3	2	dark green		x	4	1	3	3	1
Fell End	FLE5	2	black	x		4	1	3	3	1
Fremington Edge	FRE2(a)	1	green/black	x		4	1	-	-	-
	FRE2(b)	1	green/black		x	4	-	-	-	-
Spout Gill	SPG2(a)	1	green/black	x		3	1	-	-	1
	SPG2(b)	2	black		x	3	3	-	-	-
Browna Gill	BRG2(a)	2	green/black	x		4	3	-	3	1
	BRG2(b)	2	green/black		x	4	3	-	3	-
Grinton	GRN1(a)	1	black	x		3	-	tr	1	-
	GRN1(b)	2	black/green		x	1	tr	3	4	3

Note: Analyses are non-quantitative. Intensity of elemental peaks in XRF spectrum is expressed numerically in this table on a scale of 1 to 4 and provides only a guide to the relative amounts of the elements in each sample. Silicon could not be analysed.

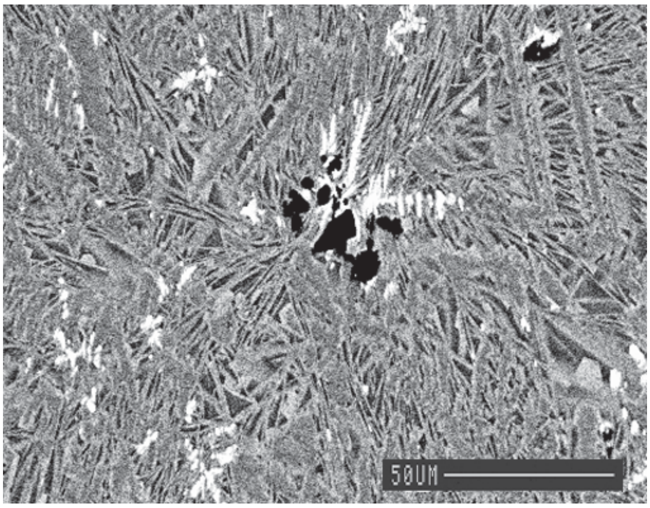

Figure 12: SEM (BSE) image of green devitrified Type 1 slag from Winterings bale WIN1, showing galena dendrites (white), baryte (black), lead silicate laths (grey) and residual glass (dark grey).

compositions are the same as the glassy type. Type 2 slags from Calver Hill, Fell End and Grinton had large amounts of calcium and barium, those from Browna Gill iron and barium, and those from Spout Gill iron only. Most were crystalline, but some with similar compositions were vitreous, indicating that cooling rate was an important factor.

So far only some Type 1 slags from Winterings and Greenhaw Bank have been studied metallographically. A sample from Winterings WIN1, typical of slag from many bales, was polished and examined in the SEM in atomic number contrast (BSE) mode, Figure 12. The glassy matrix contained minute dendrites of galena and many tiny spherical particles of metallic lead. However the glass had almost completely devitrified to form feathery crystalline structures of different but high atomic numbers. Semi-quantitative analysis showed that these were all lead silicates, with small amounts of barium-rich material left in the glassy interstices. A similar sample from Greenhaw was structurally identical. The yellow outer coating appeared in cross-section to be a mass of tiny interlocking crystals in three concentric layers. Analysis showed only lead, so weathering had leached the lead oxide from the silicate glass which had precipitated on the surface and progressively altered into different lead compounds.

Discussion

In this study as much ground as possible was covered so that the observed distribution would reflect as closely as possible the true distribution of smelting sites in the Swaledale area. However difficulties of access, especially to the military area at Stainton and Ellerton on the SE side of the dale, and to others which lacked any form of public access, means that the survey was unavoidably incomplete. A comparison of Figure 2 with the previous maps showing bale sites in this area (Barker 1978; Barker and White 1992) shows many similarities, but some Barker sites were not visited, and others which were, yielded no conclusive evidence of smelting activity.

The broad scatter of identified sites reveals that the lead ore was smelted locally, unlike Derbyshire where large boles were set up at considerable distances from the mines. This difference is probably because the known Derbyshire boles were used towards the end of the bole-smelting period, when mining activity was high. Some small boles in the Derbyshire ore field have been located which may relate to an earlier period, but no systematic large scale search has been carried out (Kiernan and Van de Noort 1992, 19). In contrast, in the Swaledale area during the period when bales were used, the mining was carried out by small partnerships with limited resources and the scale of lead production from each mine was possibly quite small, so that the simple bale was adequate to smelt small parcels of ore as they were produced.

Location of bale smelting sites

The selection of a particular site for a bale depended on a number of factors. One was clearly the presence of an ancient mining ground within a range of a few kilometres, shown by a comparison of Figures 1 and 2. This also shows that some extensive mines have few or no nearby bales, for example the Moulds mines in Arkengarthdale. Ores from these mines may well have found their way to the south side of Calver Hill or Fell End for smelting as the west side of Arkengarthdale has a modest slope and unfavourable aspect for westerly winds. Other mining areas lacked bales, either because they were not worked during the bale-smelting period or because bales have yet to be found there. Whitaside and Apedale veins for example have no associated bales but may have used the Browna Gill or Greenhaw bales. Cobscar and Chaytor Rakes also have no nearby bales, but the survey in this area was incomplete.

Another important factor was good communication routes. Moor tracks usually connect the bales with the mines, but more significantly almost every bale is located immediately adjacent to a track from the valley floor, implying that sites were chosen with ease of transport of fuel in mind. The limited historical evidence indicates that wood was the fuel used in the bale, possibly supplemented by peat or heather in this area. It is known that by the end of the bale-smelting period Swaledale was almost completely deforested (Leland 1546, 32), and considering the large number of bales now identified here, it is probable that lead smelting had played a significant part in this deforestation. Gledhill (1992) has discussed this and presented evidence that coppicing was practised in Swaledale towards the end of the bale-smelting period, with modern woodlands still in existence near known bale sites.

With the favoured position of a bale determined by proximity to mines and communications, the next major factor was a position that allowed a good exposure to wind. Figure 2 and Tables 1-4 show that most bale sites are at elevated positions on a bench, ridge or a vertical scar, or on a sloping fellside, although there are exceptions. Heights varied from 260-530m AOD, with 75% in the range 375-499m. Generally a wide angular exposure was preferred, for example in Arkengarthdale the biggest bale sites are located at both ends of Fremington Edge with few overlooking the narrow part of the valley between. For the same reason another preferred position was often one on a projecting spur or low hill on a sloping fellside.

The geological context of the bales was clearly important: 42% were located on beds on or directly overlying the Main Limestone, with others on strata overlying the Underset, Five Yard and Crow Limestones. Much of this has to do with the effect of geology on the topography of the fellsides, the hard limestones tending to produce the preferred steep slopes or cliffs on which the bales were commonly located. However the tables show that 60% of all bales (or 72% of those on identifiable strata), were on sandstones or other silicious rocks such as the Richmond or Main Cherts, signifying a strong preference for those as a bedrock for bales. Where the top of an apparently suitable limestone scarp had no superficial cover of silicious rocks it was often avoided. The reason for this aversion is evidently that smelting involved intense local heating of the fire base, evidenced by the reddened sandstones found at almost every bale site. Limestone, which is readily cracked and even decomposed on heating, would be unsuitable for a base or stone structure, and if quicklime were produced it would make the work of the smelters in recovering the lead from the remains of the fire positively dangerous. Nevertheless, some bales were on limestone, and lead glazes on fragments of limestone rock found at several sites show that some attempts were made to smelt there. It is probable that this was soon abandoned and where the base rock was unsuitable, sandstones were brought in from elsewhere and used to provide a sound working base.

Migration of bale sites

These factors determined which sites were suitable for bale smelting, but pose the question as to why so many different sites were used, especially in Gunnerside and to a lesser extent Old Gang. One explanation is that once local wood supplies were exhausted, the smelting point was repositioned closer to another source of fuel. This would probably result in a shift towards the main valley and ultimately towards the east whence supplies came once Swaledale was almost denuded of trees. Early bales should thus be near the mines and later ones closer to the main valley. The bales cannot be dated at present, but the largest bale sites are clustered at the furthest distance from the mines at Gunnerside and Old Gang, and if size is equated with a later date this fact supports the explanation.

A plausible alternative is that different sites were used according to the strength and direction of the wind at the time, low bales used when the wind was strong to save the effort of hauling wood to a higher one, and sites with different directions of exposure chosen according to the prevailing wind. This notion is strongly supported by the bales clustered at the lower end of Gunnerside Gill, where high and low bale sites were extensively used.

Finally it might be that if several mines were being worked at the same time by different groups of miners, then sites were selected so that the smelting operations of one did not hinder the others. Each mine might even have had its own bales, so that one might speculate whether the bale at Friar Folds Hill was specific to the mines on Friarfold Vein. In practice it seems likely that the choice of a site was governed by a combination of all these factors.

Some thoughts on lead smelting technology

Without archaeological excavation it is not possible to come to any definite conclusions as to how lead smelting in the bale or its derivatives developed, but this study has identified some distinctive features which give clues as to how bale smelting was carried out in this area.

Lead smelting in a bale probably took place by the roast-reaction process in which molten lead is produced by a chemical reaction between lead oxide (or sulphate) and lead sulphide, with the evolution of sulphur dioxide gas. Galena (PbS) was the main or only lead ore recognized by early miners, hence partial oxidation was needed prior to smelting. Ideally roasting should be controlled to produce the appropriate quantity of oxide or sulphate needed to react with the remaining sulphide.

Clough (1962, 37) suggested that in Yorkshire the ore was roasted as a separate process to smelting, but there is no evidence for this unless the heap of galena found at Windegg (possibly that reported as a bale by Barker 1978, No.28), was a roasting charge. Practically, a separate roasting should not be necessary before bale smelting. A bale was a heap of dry chopwood with brushwood or heather on top on which the lead ore was placed. When lit, the ore, exposed to a strong cold wind, was gently heated for a relatively long time by the slow-burning wood fire, the wind also sweeping away reducing gases and providing the necessary oxygen. The temperature needed to roast galena is only 500-700°C, and could easily be generated near the top of a log fire, aided by the strongly exothermic nature of the roasting reactions. The roast-reaction process requires an exact proportion of reactants for complete reduction to lead, 65wt% for oxide or 56wt% for sulphate, and it may be that considerable skill (or at least experience) would be needed for efficient smelting in a bale. The frequent occurrence of solidified matte among bale debris confirms that roasting was sometimes insufficient.

Smelting is achieved by raising the temperature high enough to allow at least partial melting of the reactants, allowing the reaction products, sulphur dioxide gas and liquid metallic lead, to escape from the reaction interface, without which the chemical reactions would be stifled. Pure galena melts at 1113°C, PbO at 886°C and $PbSO_4$ at 1170°C, but mixtures generally melt at lower temperatures than the pure compounds, so temperatures in the region of 900-1100°C would probably be sufficient and could easily be generated in the heart of the fire. Thus, as the wood burned away and the ore gradually descended, it would reach the necessary temperature to allow the smelting part of the process to proceed. Experience of the windy nature of many of the sites, investigated over the years, suggests that for much of the year sufficient draught could be obtained even at a fairly low altitude.

The piece of lead recovered from the Winterings pit-bale (WNS1) provides some important information on bale smelting. The lead had pooled in a V-shaped hollow between some stones to form the main mass of the piece, but the last dribbles of lead falling into the pool

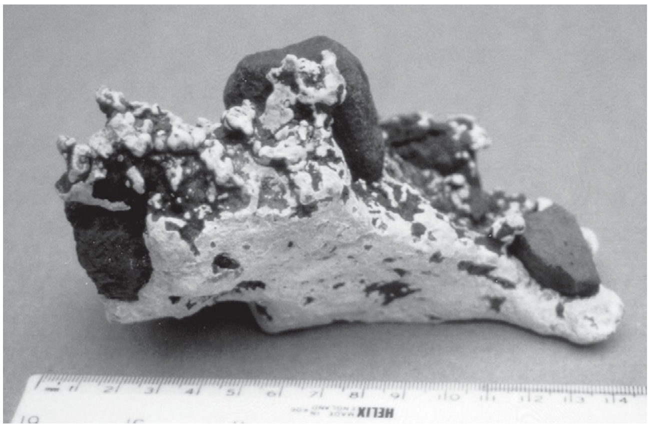

Figure 13: The large piece of lead with embedded sandstones from Winterings Scar pit-bale WNS1.

had solidified as irregular masses on the surface (Fig 13). Clearly the ambient temperature was below 327ºC, the freezing point of lead, when the last trickles arrived, and the hollow was underneath the bale with some space overhead. The open space suggests that in this pit-bale the fire was supported over the hollow in some way. Agricola (1556; trs Hoover 1950, 390) describes windblown Carniolan furnaces which used greenwood timbers as simple grates and this may well have been done in Yorkshire too.

The Winterings pit-bale had a forward opening to the scarp edge, but no room there for collecting lead, which must have remained in a hollow under the fire. The shape of the piece and the presence of rounded pieces of sandstone which had floated on it while molten, suggest that the hollow had been crudely partitioned by placing sandstone rocks in the bottom, so that the lead trickling down gathered into a number of separate cavities. The lead lump we found represents the contents of one such cavity. The hemispherical piece of lead from bale WIN2 may be another example. This segmentation would allow the product to take the form of a number of pieces, each of convenient size for transportation.

Support for this deduction comes from a description of Bolivian pit furnaces, used at Las Chichas for smelting galena (Barba 1640; trs Douglass and Mathewson 1923, 195) which had clay bottoms hollowed out into a number of moulds. The principle is directly transferable to bale smelting, where, if several hundred kilogrammes of ore were smelted at a time, the product could not be removed from the smelting place as a single piece.

If the front opening was not for draining lead, it must have been to admit an air blast to the base of the fire, presumably using low walls to shield the lower part of the log pile. Directing the air blast into the bottom of the fire through a grate would greatly lower the base temperature, thus reducing volatilization losses, cooling and preserving the wooden grate so that slags and other debris could be filtered out, and allowing better temperature control. We await an archaeological excavation of one of the pits with interest to see if the Bolivian/Carniolan solution was indeed used in Swaledale.

It is evident from the many finds of fire-reddened sandstone that bales were floored or partially walled with sandstone or some other refractory stone. Evidence of structures is sparse and definite structures were found only at Fell End (FLE7) and the Prioress's Bale (PRB1).

Our findings and Barba's (*ibid*) description of smelting technologies may even provide a glimpse of how lead smelting developed in Swaledale. Tables 1-4 show that there were few or no discernible pits at 73% of bale sites, and even large sites had only a few (the bale TLB1 is the sole exception). This suggests that mostly small parcels of ore (weighing perhaps tens of kilogrammes) were smelted on a simple fire set on flat ground or a shallow slope so that the lead trickled out randomly and was collected at the end of the operation. The many finds of lead prills near the bales, some large, confirms that lead losses were common. Larger amounts of ore, possibly in parcels weighing hundreds of kilogrammes, could be smelted in bales with divided bottoms.

If bigger quantities had to be smelted in campaigns of several days as in Devonshire or Derbyshire (Claughton 1995, 129-30), the lead accumulating in the base would have to be removed either continuously or by periodic tapping, and again a greenwood grate would be useful. Pits located on the edge of a scarp would need a back or side opening through which the lead could be drained, but those with a convenient working place in front would allow lead removal through the air blast opening, and Barba (*op cit*, 195) describes such a system in Bolivia.

A bale using a separate drain system in the Winterings area of Gunnerside Gill was excavated by Raistrick in 1919 (Raistrick 1927, republished Raistrick 1975a, 31). This bale was a simple clay-lined hollow *c* 700mm in diameter surrounded by a circular wall *c* 1.5m in diameter. The pit had several openings at the front for air ingress and one opposite for the lead to drain into a collecting place outside the wall. The site of this bale is not now known, and none we found was of this type, so it is concluded that it was not a common one in Yorkshire. Blanchard (1981, 78) has reinterpreted Raistrick's archaeological results and concluded that the structure was not a bale but a blackwork *ofen*, bellows blown, and used to re-smelt slags from bale operations, as carried out in Durham. On our evidence this seems unlikely, as none of the Gunnerside sites carried more than trace amounts of black slags, the end product of blackwork smelting.

A significant result of this survey is that slags of any type are rare, most sites being devoid of slags except for small lumps of Type 1 slags. Table 5 and our other analytical results show that these are lead silicates which would form very easily when lead oxide came into contact with silica at temperatures obtainable in the bale. The lead silicates $2PbO.SiO_2$ and $PbO.SiO_2$ melt at 764°C and 743°C respectively, temperatures so low that they would be very fluid in the bale. If the silica was attached to the ore as a gangue mineral, the lead silicate would coat the ore and hamper its oxidation, as well as wasting lead. Other gangue minerals such as calcite or baryte could not be slagged effectively as their silicates have far higher melting temperatures, and if more than a little was present they would shield the admixed galena from the necessary reactions. The observed absence of slags at most sites thus indicates that bale temperatures were such that only virtually pure galena was smeltable.

Support for this conclusion is provided by Agricola's references to smelting pure ore in bales or bale-like furnaces (1556; trs Hoover 1950, 391-2), and the large lumps of pure galena ore found at some of the sites. A practical explanation is that fines or small pieces would fall through the fire too quickly for effective roasting, or be blown away, and is consistent with the observation that the tips of many small mine workings contain discarded pieces of galena up to 10-15mm in size.

Clearly a supply of large pieces of pure ore could not be maintained indefinitely, and as the mines exhausted their smeltable resources a lower grade of ore would have had to be accepted. Replacing wood by charcoal as the fuel in a windblown bale would substantially increase the temperature obtainable (if sufficient blast were available) and enable iron, calcium and barium-rich (Type 2) slags to be melted. Impure ores would yield much more slag, and significantly Type 2 slags were only found in quantity at a few sites: Fell End, Calver Hill, Spout Gill, Browna Gill and Grinton. Even there the sites yielded both Type 1 and Type 2 slags, suggesting re-use of the bales at different times. It is unlikely however that bales can be divided into early and late on this basis, as mines in different areas could have exhausted supplies of pure ore at very different times.

The possible use of the blackwork *ofen* to re-smelt slags must also be considered. The slags found at most bale sites were predominately lead-rich Type 1 lead silicates, abandoned by the bale smelters as waste. Probably only small amounts of such slags were produced, but the possibility exists that some slags were removed and re-smelted with fluxes in a charcoal-fired blackwork *ofen,* the higher operating temperature allowing the resulting slag to run freely.

We have no historical evidence for blackwork *ofen* re-smelting in Swaledale; indeed the records of slags being removed from the Fremington and Skelton bales in the 17th century for re-smelting in early ore hearth furnaces suggest that bale slags were not re-worked in the bale smelting period. Careful archaeological excavation will be needed to determine the furnace design, and whether the feedstock at sites yielding Type 2 slags was lead silicate slag or lead ore.

Conclusions

The location of an early lead smelting site was determined by a number of factors, of which one was a position within a few kilometres of the lead mines and another ready access to the valley floor whence the chopwood fuel would be sourced. The bales for the most part must have been windblown, for positions were chosen which were sufficiently elevated to catch the prevailing winds, usually from the south or southwest. A great height was not essential, sites ranged from 260m to 530m AOD, with an average of 412m AOD. The site topography varied enormously: some were simply convenient slopes, others the tops of sharp scarps, but a preferred configuration was a projecting ridge or a rounded hill sticking forward from the fellside. The particular geology of this area produced a series of steep cliffs and slopes, but an additional contribution was to provide a refractory silicious base rock of sandstone or chert for the bale and any bale structures.

At Gunnerside Gill in particular, and also in the lower reaches of the valley of Old Gang beck, there are many more bale sites than elsewhere. Possible reasons for so many in a localized area are: that the focus of smelting shifted as woodlands were depleted, different sites were selected according to wind strength and direction, different groups of smelters used different bales to avoid inconveniencing each other, or even that individual mines had their own allocated bale sites.

The majority of the bales appear to have been small affairs where a small quantity of pure galena was smelted as a single batch, the lead trickling freely from under the fire. Larger quantities were perhaps smelted in shallow pits set on the slope at the head of a brow, an opening towards the cliff allowing a strong draught of air to the base of the fire. The lead was retained in a hollow under the fire, and there is some evidence that this hollow was subdivided into separate cavities to produce lead ingots of handleable size. A few sites had charcoal dumps and slags which indicate that higher temperatures were attained. It is suggested that these were used to smelt galenas with admixed or attached gangue minerals as supplies of pure ore of smeltable size became exhausted, but re-smelting of slags cannot be ruled out.

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