HISTORICAL METALLURGY

REPRINT EDITION

VOLUME 3 NUMBER 1 1969

Bulletin of the Historical Metallurgy Group

HMG

volume 3
number 1
1969

Refining silver. Agricola Book X

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The Furness Peninsula 1968

REPORT OF THE FOURTH ANNUAL CONFERENCE

The annual conference took place during the week-end 27-29 September and was centred on Barrow in Furness. The theme was "The Iron Industry of Furness and District". After a formal opening and a welcome by the Mayor of Barrow on the Friday evening, papers were read by Dr J.D. Marshall and Mr G.R. Morton on early iron working in Furness and district. After the papers, members attended a sherry party kindly given by the Mayor and Corporation.

Next morning, the party moved off to Newland, where they were shown over the remains of the blast furnace built in 1747 and blown out in 1891. After lunch at High Cross, members visited Duddon Furnace (1736-1866) where talks were given by Messrs Morton and Davies-Shiel. The party then moved on to Hodbarrow where they were shown round the Cornish Engine house, the mine head, and the sea walls of 1890 and 1905 by Mr D.R.G. Davies and his colleagues from the Millom Hematite Ore and Iron Co Ltd. After this, the Company invited the party to tea. The party then returned to Barrow by way of Askham and Roanhead.

In the evening Mr J. Cherry gave a paper on the 17th century bloomery at Muncaster Head, and Mr D.W. Crossley talked about his bloomery excavations. These papers were followed by a general discussion. Next morning, Sunday 29th, Mr Davies-Shiel gave members a very interesting summary of the state of industrial archaeology in the Lake District, with special reference to his excavation of the bloomery at Rusland. After this, Mr D.R. Wattleworth gave a talk on the West Cumberland iron industry in the 18th and 19th centuries.

About 65 members attended.

Group photograph taken during visit to Hodbarrow Mine.

Conference Paper

Some aspects of the Furness charcoal iron industry

J. D. MARSHALL, B. Sc. (Econ), Ph. D.

Slightly abridged version of paper read to the Historical Metallurgy Conference, Barrow-in-Furness, 27 September 1968

Much is known about the economic history of the Furness charcoal iron industry, and few comparatively small areas can boast of the lavish historical treatment given in Fell's "Early Iron Industry of Furness" (1908), now very properly reprinted as an industrial classic. Many of the documents which Fell used have either disappeared or become scattered, although the work of W. H. Chaloner, B. G. Awty, and other investigators has shown that it is still possible to add important details to Fell's story. However, thanks to agencies like the Historical Metallurgy Group, it has now become clear that significant information cannot be garnered without disciplined and technologically informed fieldwork.

This is not to suggest that the devoted Fell was ignorant in matters of iron technology. He went to immense trouble to inform himself about the practices of early iron manufacture, and his imaginative reconstructions of forge and furnace working provide enough solid information to make possible detailed checking in the light of increasing general knowledge. Often, however, he seems to have drawn general concepts from earlier knowledge, and related them to scattered details in manuscript account and other books; only rarely does he refer to "evidence on the ground" at given sites—although it is reasonably clear that he knew his territory intimately—and it is not clear how thoroughly, if at all, he investigated the earlier forge sites in Furness and its region. On the other hand, two important charcoal furnaces of the locality, those at Newland and Backbarrow, were working during his lifetime, and he had every reason to generalize confidently about some aspects of the industry.

It is not the purpose of this paper to repeat the story told in such detail by Fell; but, rather, it may be worth while to draw attention to certain aspects of the subject which still call for examination. His detailed account of bloomery sites in southern Lakeland is now providing a basis for considerable further study of an archaeological and metallurgical nature, and it is now clear that he did not list more than a modest proportion of such sites and their exact locations. Neither Fell, nor even the more exacting Collingwood, found much evidence of a kind which would aid confident dating of the various stages of bloomery operation. That there were such "stages" is at least a useful working hypothesis, for a "hearth" receives mention in Furness Abbey records in 1271, and some form of primitive smelting was continued at least until the establishment of blast furnaces in the district in 1711-12.

Fell evidently refused to believe that the iron technology of the district could remain static during the whole of this long period, and he distinguished stages in manufacture, or its small-scale organization, which do in fact indicate a progression: from the simple bloomery to the so-called bloomsmithy and then to the bloomery forge. It is just at this point that historical metallurgists will become properly concerned, for, allowing full weight to Fell's wealth of local scholarship, there is (as far as the writer knows) no clear historical evidence of any very regular evolution of techniques. The documentation is thin, and the evidence stimulates conjecture. Archaeological examination, of the kind pursued at Muncaster Head, Cumberland, and more recently at Stony Hazel in High Furness, is therefore of the utmost importance.

The greatest pre-18th century development, if any there was in any marked sense, was probably in the sphere of forge practice. Whereas the bloomery sites do not appear to have been invariably chosen with the use of water power in mind (and here a careful survey and census would eventually yield essential information) there is some evidence that the 17th century Furness forges used such power, sometimes lavishly. That is to say, the forge-hammers were powered by water-wheels, and considerable capital was expended on the cutting of leets and the making of earthworks. A deposition of 1638 reported that "Arthur Benson of Skellwith had 1 timber tree cut down and sold same for a forge hammer shaft or beam"; and about the same time William Wright built a forge at Hacket, not far away, where the remains of water channels can still be discerned. There was an iron forge at Coniston in 1674, in a locality which had earlier been utilized by the Company of Mines Royal for technologically advanced ore-crushing activities, and at Cunsey in 1675. In about 1677 the trade of Force Forge, High Furness, owned by the Quaker family of Fell, extended to Lancaster, the Fylde, and even to Cornwall.[1] This had been built some time before 1658, and in 1681 a deed relating to this forge recites "all that Iron Furnace or Iron house comonly called Force Fordge... And all Harthes Bellows Hammers Anvills Wheeles Work tools Broken Iron and Implements Dams Water Forces Weares Sluices Floodgates Channels Races Weights Weighes both at the said Fordge and elsewhere..."

The reference to the "Iron Furnace" may or may not be significant, but has to be seen in the light of a description of Milnthorpe forge in the Philosophical Transactions (1693-4), describing the latter forge in 1675 and making clear that among its equipment was a small water-powered furnace evidently of the Catalan type.[2] But terminology in deeds or other documents may be misleading, for early deeds relating to the Stony Hazel site, near Force Forge (for 1718 and years following), refer to a "bloomery" as part of the site.[3] Although investigations here are as yet far from conclusive, it is possible that the smelting performed here was not of the most primitive kind, although this site was, of course, used after the larger charcoal blast furnaces had been erected.

During the 17th century, meanwhile, the market for Furness hematite ore and iron undoubtedly grew. Technological development, even of the most basic kind, does not proceed without the stimulus of trade. Furness hematite was known outside its region in the mid-17th century, and in 1664 Stainton (Low Furness) ore was sent to Holmes Chapel and possibly to other places in Cheshire.[4] The so-called bloomery iron was bought and sold by the Lancaster Quaker merchant Henry Coward in competition with Swedish iron (1689). This connection with Cheshire is of the greatest importance, because Lawton furnace in that county came into the hands of the Cotton family, which had an incidental Cumberland connection, and Vale Royal furnace, also apparently in the hands of this family at one stage, used Cumberland and Furness ores extensively in the late 17th century. Early in the following century the Cottons and their immediate associates, the Halls of Cranage and Warmingham forges, followed their lines of supply by setting up a furnace at Cunsey, near Lake Winder-

[1] Isabel Ross, "Margaret Fell" (1949), pp. 267-8, which corrects Alfred Fell in the matter of the ownership of this forge, and which adds further details concerning it.

[2] Members of the H.M.G. will be familiar with this description, which has been given in full by Dr H. R. Schubert in his "History of the British Iron and Steel Industry", pp. 149-152.

[3] In the Archibald MSS (Lancs. Record Office).

[4] B. G. Awty, Trans. Hist. Soc. Lanc. and Ches., vol. 108 (1956)

mere, in 1711. Already, before this time, the Cheshire ironmasters were raising ore at Crossgates (Low Furness), and an association had begun with the Kendalls of Austrey, Warwicks, and Stourbridge, who were ultimately connected with the Duddon furnace (1736). The Halls and Cottons were evidently interested in supplying markets for hematite pig and bar iron, as distinct from the supplying of intermixtures of phosphoric and tough (or the so-called "cold-short") iron which was provided for the nail industry of South Lancashire and the Midlands.

It is therefore unlikely that these experienced ironmasters moved into Furness simply by virtue of fuel shortages elsewhere, although Fell hinted that this latter was a major reason. Lancashire hematite pig was sent (1716-17) by the Cunsey partners to Wildon forge and to Bewdley, and was probably used to supply specialized West Midland markets with superior bar iron.

This invasion by outside investors, assisted by existing trade lines and dynastic intermarriages, makes a pattern which is not uncommon in Furness and Cumbrian history. Meanwhile, established local families, at first represented chiefly in the Backbarrow Company, took action in their own defence (1711), and were able to act effectively for the following reasons. First, landownership and local influence had strengthened their relationships with woodowners and ore suppliers; the Rawlinsons were local gentry turned Quaker, and the Machells, their partners, also established gentry. Secondly, both families had had trading experience in the region for a generation or longer, and had owned or operated forges. Thirdly, three of the Backbarrow partners were Quakers, and were enabled to reach western and Midlands markets through other Quaker merchants. Both the Backbarrow and the Cunsey partners used established forge sites at Cunsey, Backbarrow, Coniston, and Hacket, and, despite the establishment of blast furnaces and the probable re-equipping of the forges, the developments of 1711 were as much evolutionary as revolutionary.

The Backbarrow partners were, perhaps fortuitously, in touch with "revolution" at one stage, for, as is now well known, Abraham Darby I seems to have offered the coke-smelting process to William Rawlinson as early as 1712.[1] There are no indications in the remaining Backbarrow MSS (which, as regards this period, can still be consulted at Barrow Public Library) that the offer was taken up, or that experiment followed. Small quantities of coal were imported for other purposes, but the commitments to local landowners and wood-cultivators were probably much too extensive to permit the company to be interested. (The Darby advice would have been more useful when the company began casting and moulding on a large scale). Cumberland ironmasters, who had fewer coppice woods at hand but much more coal (there were no workable coal seams in Furness), experimented more boldly during the period: abortive attempts to smelt with coke, on the part of Patrickson of Ennerdale perhaps and "Coiner" Wood at Frizington, were followed by successful ones at Maryport and Seaton in the middle of the century. Furness ironmasters remained firmly committed to charcoal and (occasionally) peat fuel, despite periodic shortages and problems in the control of prices and supply.

The shipping figures for Piel[2] show that the Furness charcoal iron industry, increasingly busy after 1736, boomed up to about 1756, by which time eight furnaces had been built to meet south-western and Midland demands for tough pig. In addition, the Halton, Conway, Dovey, Goatfield, and Lorn furnaces were all probably using Furness or Cumberland hematites. After that time, the growth of coke-smelting forced the local industry to cut its losses, and the number of furnaces rapidly declined to five, and, in the early 19th century, to three—Newland, Backbarrow, and Duddon. These furnaces were enabled to meet specialized markets, but continued to have some difficulty in obtaining fuel supplies. Despite systematic coppice growth in the area, the Backbarrow furnace was still experiencing difficulty in getting adequate supplies of fuel in 1898! "An enormous supply is required", lamented the Westmorland Gazette of 1 October in that year. Even when the industry was in its peak period of elaborate and careful organization, the problem of fuel must have been immense, involving the services of an army of charcoal burners, scores of packhorses, and large barns loaded with the characteristic long sacks sold to the companies by the "dozen".

The last survivor of the old regime, the Backbarrow furnace, continued to use charcoal until about 1920, thereafter turning over to coke smelting. It was blown out for the last time in 1966. The industrial uses of the last century have been responsible for much transformation of the Backbarrow site, whereas those at Newland (which closed in 1891) and Duddon (blown out in 1867) are still of much archaeological interest.

The case of the Furness charcoal iron industry is not without interest to the historical metallurgist, and will be instructive to him in one important respect. Understandably, specialists in the field are, much of the time, concerned with the precise nature of processes and the occurrence of technological innovation. Here is a local industry which survived —if in weakened form—for two centuries, with very little in the way of technological development once a certain point had been passed. There are, of course, a few developments even in 18th century Furness that are worthy of note: the adoption of Wilkinson-type blowing cylinders at several furnaces, and the establishment of a rolling mill at Newland in 1799. Other cases may yet be found.

A very important consideration in the success of the local industry—as Mr Morton indicates in the following paper—was the richness and nature of the local hematite. But there were geographical and economic factors of no less weight: an indented coastline and excellent lake waterways, abundant water power supplies, plenty of cheap land for furnaces, forges, and coppice woods, moneyed yeomanry and gentry anxious to develop existing trade channels, and, of course, existing industrial dynasties with an interest in the development of specialized lines of trade. The coastal position of Furness played a great part in its history.

Although economic historians and historical geographers can make their contribution in drawing attention to factors of this kind, the more specialized knowledge offered by the H.M.G. now has a vital part to play in adding significant details to the story.

[1] W. H. Chaloner, Economic History Review, II, No. 2, 1949.

[2] Brit. Mus. Addl. MSS 11255.

Conference Paper

Technical aspects of the early iron industry of Furness and district

G. R. MORTON

THE NATURE OF THE IRON ORE

The term "red hematite" was commonly used by British ironsmelters for all minerals consisting of anhydrous ferric oxide. The group included the micaceous scaly varieties of South Devon, the kidney ores of Furness and Cumberland, the red ochre varieties, and the titaniferous ores of the Forest of Dean. In the middle of the 19th century the most important deposits in the United Kingdom were those in the Furness district and the Cumberland side of the Duddon estuary. About three-fifths of the entire quantity raised was of a hard rocky nature, of uniform quality, and contained about 60% of metallic iron. The second largest quantity raised was a bright red, fine granular ore found in the neighbourhood of Ireleth, and large amounts were shipped up the Duddon estuary to supply the charcoal furnace at Duddon Bridge. Another class, chiefly raised in the North Lancashire district, was a hard, red, fine ore containing about 55% metallic iron, and was occasionally mixed with sufficient manganese to make it of value in other parts of the country.

The famous kidney ore was perhaps the richest of all British ores, and produced iron of the highest quality. In addition a compact greasy micaceous variety, known as "puddler's ore", was found in veins of limestone rock in the neighbourhood of Lindal-in-Furness. This ore was exclusively used for lining the hearths of puddling furnaces. In 1840 Henry William Schneider obtained a lease of the ancient workings of the Park mines near Askham, and later in 1850 he discovered in the area a great bed of ore which laid the foundation for the town of Barrow-in-Furness. This ore became the raw material for the production of acid Bessemer steel; in earlier days it had been extensively mined for the bloomeries of High Furness. Comparative analyses of Furness ores with those from other iron-producing regions are given in Table I. The high purity of the red hematites of Furness is equalled only by the Forest of Dean ores. In both these areas the bloomery process of ironmaking was extensively used, and and examination of the quantity of slag produced from these ores confirms several important points. Morton and Wingrove (1) have shown the bloomery slags consist mainly of three mineralogical constituents: anorthite ($CaO.Al_2O_3.2SiO_2$), fayalite ($2FeO.SiO_2$), and wustite (FeO). Whereas for a particular ore analysis the proportions of anorthite and fayalite are fixed, the FeO content might vary according to the degree of deoxidation of the sponge iron reduced from the ore. If this is assumed as constant at 10% in all districts, the ability to use ores from the various regions can be compared. The percentage iron lost to the slag has been determined after all the volatile matter has been removed from the ore, i.e. after calcining. An examination of the iron available per 100 lb of ore (Table 1) gives a measure of the efficiency of the process in the various regions.

The small quantity of slag per 100 lb of ore produced from Forest of Dean ores and the enormous quantities of slag left after the Roman occupation show the vast extent of the bloomery process in that region. In a similar manner the ores of Furness produced little slag, and they were so easily reduced in the bloomery that the change to the indirect process of the blast furnace and forge did not take place until 1711, some 220 years after the first introduction of the blast furnace in the Sussex Weald. The quantity of iron produced from the ore was high and therefore it was not until the introduction of the blast furnace that the ore was extensively mined. Indeed, it was not until the discovery by Schneider and the setting up of the iron and steel works at Barrow-in-Furness that the greatest use was made of local deposits.

BLOOMERIES

The earliest bloomeries in the area were itinerant, moving from district to district as the charcoal, or in some cases the ore, became extinct. A large number of these sites is already known and yet greater number is expected to be traced. Later bloomeries were permament and housed in substantial buildings associated with a good water supply. The ore and charcoal were brought in, often over considerable distances. Three stages of the development of the bloomery process can be identified in the area, and these can be related to the use of water power. In the earliest type as seen at Stone Star, although the site is near a beck, insufficient water appears to have been available for driving the bellows or operating a water wheel, and the question that must arise is, was the furnace blown by natural draught or were hand or foot-operated bellows used? In this position the use of a power-driven hammer can be discounted. The slag clearly shows flow markings and it was therefore tapped from the furnace in the molten condition. At the 14th century site at Throng Moss, Torver Low Common, a large pool near at hand could have provided sufficient power for both bellows and hammer. The site being far from any recognised route suggest that the ore or fuel supply was the reason for its remote setting. Tylecote (2) has stated that the Catalan hearth-type furnace (Fig. 1) was used exclusively in Britain for the later medieval bloomeries, and this is probably so in the case of the later furnaces of the Lake District. Both the bellows and the hammers were operated by water power and the effeciency from ore to metal was much higher than in the early period. This can be seen from calculations on a table given by Percy (3) (Table II) which gives a balance sheet for a Catalan forge in the Pyrenees in 1840 from which a comparison may be drawn. It will be noted that the free FeO has been replaced by free SiO_2. The calculation for available iron for reduction was based on there being 10% free FeO present in the slag, and the increased efficiency obtained by the ability to operate the furnace with a slag containing no free FeO would result in a larger quantity of iron being available for reduction. Thus the probable reasons for the late introduction of the blast furnace to the Furness district can be seen.

THE CHARCOAL BLAST FURNACE

State of knowledge by 1700

During the 200 years between the introduction of the blast furnace at Buxted, in the Sussex Weald, and the establishment of the furnace at Backbarrow and Cunsey in 1711, considerable advances in technique had taken place. Water was still the motive power, and the shortage of charcoal in the Midlands had led to the introduction of coke smelting by Abraham Darby at Coalbrookdale in 1709. Whereas charcoal was still available in the Lake District generally, supplies were not over-abundant, and in 1730 the Furness ironmasters sought additional supplies in Scotland.

Furnace lines had become established and the number of cams on the water-wheel shaft had increased from two to six, giving an output of about two to three tons of pig iron per day. Refractory materials in the form of manufactured firebricks from the Stourbridge area were brought by coastal vessels, and these tended to replace the silica stone of the earlier furnace hearth, sidewalls, and bosh. Thus by 1736, when Duddon furnace was built, full advantage was made of these technical developments. This can be seen in a letter

TABLE I Comparison of iron ores for use in the bloomery (analyses after Percy)

District	Cumberland	N. Lancs.	F. of Dean	Northants.	Lincs.	Durham	Yorks	Derbys	S. Staffs.	N. Staffs.	Salop	S. Wales
Fe_2O_3	95.16	94.23	90.05	52.86	55.46	49.57	2.39	3.49	3.75	3.11	0.53	
FeO				trace		10.77	41.77	39.55	49.04	46.35	48.28	45.22
SiO_2	5.66	4.90	0.92	13.16	19.65	6.64	8.93	10.22	7.94	5.78	7.36	9.46
CaO	0.07	0.05	0.06	7.46	0.70	5.69	2.55	3.38	0.79	1.93	2.34	1.63
MgO		trace	0.20	0.68	1.15	1.21	3.85	2.88	0.66	2.24	1.83	3.24
MnO	0.24	0.23	0.08	0.51	0.95	3.06	1.13	1.50	0.79	1.61	0.82	1.05
Al_2O_3	0.06	0.63	0.14	7.39	7.70	0.84	4.79	5.65	3.76	1.52	4.17	4.78
P_2O_5	trace	trace	0.09	1.26	0.42	0.01	0.75	1.12	0.18	0.67	0.26	0.38
S	trace	0.05	trace	0.03	0.16	0.03	trace	0.05	0.11	0.15	0.20	0.71
Total %	101.79	100.09	91.54	83.35	86.19	77.82	66.16	67.84	67.02	63.36	65.79	66.47
CO_2						14.49	31.39	28.63	30.80	32.46	32.98	31.58
C							0.86	1.14	0.60	2.95	0.62	0.64
H_2O		0.56	9.22	11.37	13.11	8.44	1.70	1.75	1.03	1.43	0.86	0.66
Alkali									0.42	0.18	0.10	0.56
Total Fe %	60.60	65.98	63.04	37.00	38.65	43.02	34.16	33.20	40.81	38.29	37.92	35.48
Weight of slag per 100 lb of ore, lb												
	23.23	20.40	4.02	54.25	100	37.37	45.15	49.52	44.60	34.27	34.91	53.10
Iron contained in 100 lb roasted ore, lb												
	59.54	65.98	68.87	44.39	44.84	55.29	51.64	48.94	60.89	60.43	57.62	52.16
Iron lost to 100 lb roasted ore, lb												
	12.78	10.95	2.27	18.41	63.24	24.80	20.12	21.05	32.60	24.34	14.84	33.92
Available iron for reduction per 100 lb ore, lb												
	46.76	55.03	66.60	29.98	nil	20.49	31.52	27.89	28.29	35.09	42.78	18.24

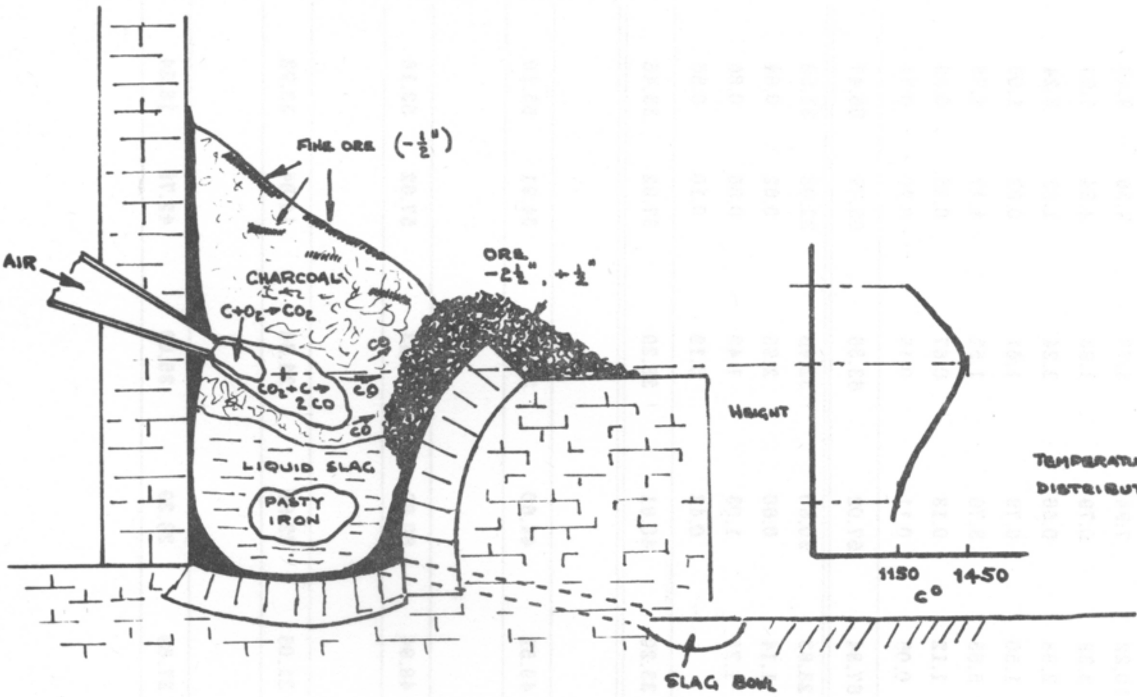

Fig. 1 — **Catalan hearth**

TABLE II Balance sheet for Catalan hearth (after Percy)

%	Ores 1	Ores 2	Ores 3	Slags 1	Slags 2
Fe_2O_3	63.47	65.50	64.00		
FeO				41.77	39.87
SiO_2	14.72	11.40	10.50	33.54	33.00
CaO	2.79	5.00	3.50	8.54	7.20
MgO	0.55	0.45	0.80	1.32	2.35
MnO	6.21	3.00	6.20	12.31	13.00
Al_2O_3	1.01	1.30	1.20	1.91	3.65
Total	87.75	86.65	86.20	99.39	99.07
H_2O	12.11	13.20	14.50	0.61	
Loss	0.14				
Total Fe	43.75	45.87	44.82	29.66	28.31

	1	2	3		1	2
Weight of slag per 100 lb of ore, lb	73.64	56.84	54.14	Mineralogical composition of slag, %		
Iron contained in 100 lb roasted ore, lb	49.86	52.94	52.00	Anorthite	6.66	12.68
Iron lost to 100 lb roasted ore, lb	39.19	34.36	32.57	Fayalite	75.66	71.99
Available iron for reduction for 100 lb ore, lb	10.67	18.58	19.43	Free SiO_2	17.67	15.32

to Sir Joseph Pennington from his steward Joseph Herbert,[(4)] dated 20 February 1736, which reads:-

> "As hinted in my last Mr. Hall & Company are (as I hear) already begun to Erect a new Furness & other comodious Buildings at Dudden Bridge. And it's Reckoned to be made one of the most beneficial works of ye sort in England".

Ore

The ores used were those obtained from the Furness peninsula, and were transported to the furnace sites either overland by cart, or by water up river estuaries to wharves near the furnaces. For example the ore for Duddon furnace was carted from Crossgates and Lindal Moor to Ireleth, and up the Duddon estuary to the wharves just below Duddon Bridge.

Calcining (roasting) by burning the ore in heaps with charcoal, opened up the structure, made it easier to break and gave better access to the reducing gases in the furnace. The process, however, was not general and, whereas it was carried out at Backbarrow and Leighton, there is no evidence of roasting at Duddon. One disadvantage of roasting was the production of large quantities of fines, which if used tended to choke up the furnace. In later years, fines briquetted with peat formed part of the charge at Backbarrow.

The ideal size range of the ore for efficient furnace operation was $-2\frac{1}{2}" +\frac{1}{2}"$, and it was broken into this size fraction by hammering—thus in Leighton accounts for 14 May 1717:-

"To Wm. Brown for Breaking Iron Ore .... 5s 0d"

In small furnaces with little blast, wet ore would be a source of considerable trouble, and care was taken by the provision of an ore store on the highline near the furnace charging platform. The ore stores at Duddon, Backbarrow, and Newlands are quite sound, and the red oxide pigment on the walls reveals the height to which the ore was stored. By keeping the ore dry the possibility of charcoal wastage in drying off any moisture in the furnace was reduced.

Fuel

Before the rise of the ironworks at Barrow, Askham and Millom, etc. in the middle of the last century, the main fuel used in the furnaces was charcoal. In order to obtain maximum heat with the limited air flow from the leather bellows, it was again necessary to keep the charcoal free from moisture. Since vast quantities of charcoal were needed, the charcoal store buildings occupied a much greater space than the ore stores. Spontaneous combustion of the charcoal in the storehouses was not uncommon, and evidence of such a fire can be seen by the slagging of the walls in the Duddon store.

On 6 May 1712 Abraham Darby wrote a letter to Wm. Rawlinson of Kendall (a partner in the Backbarrow furnace), wishing to discuss with him the new method he had developed of smelting iron ore with coke, thereby overcoming the problem of the ever dwindling charcoal supplies. No action appears to have followed this letter, and by 1730 the Newland Iron Company began to buy woods in Scotland and erect storehouses for charcoal awaiting shipment to Furness. Attempts to replace charcoal with peat met with only partial success, and by 1717 it was used as a substitute for part of the charcoal needed at Leighton furnace.

Fluxes

By the time of the establishment of the industry in Furness fluxes were normal additions to the charge and, whereas the general practice was to use limestone, reference is made in the various accounts of Backbarrow, Leighton, and Duddon to catspaule, Forest cinders and Harrington stone. Catspaule was an iron-bearing limestone collected from the beaches and was considered an excellent flux. This type of flux was in later years superseded by Harrington limestone, which was an iron-bearing magnesian limestone. Bloomery slags from the Forest of Dean (Forest cinder) was also considered an excellent flux and large quantities were shipped, possibly on return voyages from pig iron delivery to Chepstow. Why these were considered better than local bloomery slag cannot be ascertained.

Furnace operation

The introduction of the blast furnace to the area in 1711 did not effect any major increase in the efficiency of iron extraction in terms of iron produced per 100 lb of ore. It did however increase the overall output. The new method involved the two-stage process of smelting to obtain pig iron, followed by refining the pig iron produced and hammering the product into bar. The former operation was performed in the blast furnace and the latter in the finery forge. Since the main object of the process was the production of malleable bar, the manufacture of castings was of secondary importance only, although mention is made in the Duddon accounts of the Duddon Castmetall Company.

Before a new campaign started the hearth, sidewalls, and bosh of the furnace would be removed, the necessary repairs made to the stack, and the hearth, sidewalls, and bosh rebuilt. Special shaped refractory bricks were used to rebuild the lower sections, several of which can still be seen in the beck near Duddon furnace. A period of drying out, called "seasoning", followed the reline, during which time the structure was brought near to the working temperature. Details of the materials used for this operation at Leighton furnace can be seen from the accounts for 22 December 1716,(5) which indicate that considerable quantities of peat were use to conserve the charcoal supply:

LEIGHTON FURNACE DEBTOR

1716 From December 22nd Till
Decem 30th of Ditto Att 10 a clock
30th—at Night. To Sunderys for heat
= ing . . . . viz .

		£.	s.	d
Do.	To peats for 140 cart Load at Ld: Sa 9½ p load	5	10	10
Do.	To yard for coale at 30d p id. 2 3	3	7	6
Do.	To Thomas Strickland for stock Taking at 5s 4d p week . . .		5	4
Do.	Furnace Debtor To Sundery	9	3	8

Because the charcoal pig iron industry in Furness and district began late (1711 Backbarrow and Cunsey) it likewise finished late, hence the remains which still exist at Backbarrow, Duddon, Newlands, and Nibthwaite represent the finest collection of this type of industry in the country. Charcoal pig iron was in demand even into the present century, and the furnace at Backbarrow survived in its somewhat antiquated form to produce iron highly favoured by chilled-roll manufacturers.

Although the size and shape of the furnaces was similar, they were somewhat larger than those in other districts. Small differences in furnace engineering and operation were introduced at various periods: in 1790 the leather bellows at Duddon were replaced by iron blowing cylinders and in 1871 Newlands was converted to hot-blast when the fuel used was 4/5 charcoal and 1/5 coke.(6)

In areas where ironstone from the coal measures was used for smelting several grades of iron from tough to cold short were made, the grades being dependent mainly upon the phosphorus content of the ore. On the other hand, the high purity of the ore in Furness and the limited blast volume and pressure permitted only tough iron to be made. It was only when hot blast or greatly increased blast volume and pressure were adopted that tough pig iron could be supplied within a range of analyses to suit the customer.

The total time of continued operation between relines, i.e. the campaign, varied considerably, but an average of nine months is a reasonable figure to accept. When a furnace was blown out, the amount of charcoal in store was usually very small and the furnaces often lay idle until vast quantities of charcoal had been taken into store. The continued supply of charcoal was always a problem and it is surprising to note that, whilst at Leighton peat was used at a ratio of one peat to two of charcoal, this practice did not spread to the other works. The successful use of peat at Leighton must have prompted John Wilkinson to carry out a series of experiments at Wilson House. The experiments failed and Wilkinson was obliged to fall back on charcoal.

Another problem which the ironmasters had to consider in later years was the production of large quantities of fines from ore preparation. Other than from a brief quotation by Stockdale that fine ore briquetted with peat was successfully smelted at Backbarrow, very little is known about the utilization of fines. Fortunately several of these briquettes are preserved in the museum at Barrow-in-Furness and the writer has been able to carry out some experimental work on one. Details of the dimensions and appearance are given in Fig. 2.

The colour is the red typical of kidney hematite ore, and pieces as large as $\frac{1}{4}$-$\frac{1}{2}$ in are embedded in much finer material. Since the briquette consisted of ore, peat, and some

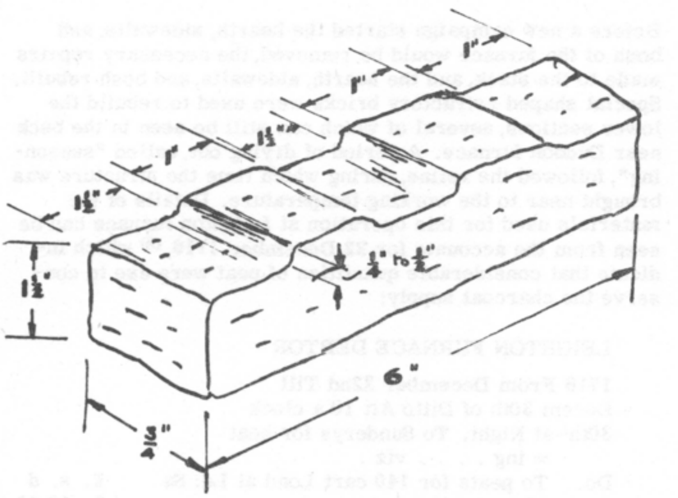

Fig. 2 – Details of ore-peat briquette

form of bond, analyses of the whole briquette, the larger hard particles, and the soft matrix were compared with typical ores of the district. From these analyses (Table III) it will be seen that the $SiO_2 : Al_2O_3$ ratio in the Lindal Moor and Duddon ores is of the order of 8 : 1. If it is assumed that the same ratio was present in the ore used in the briquette, then for an Al_2O_3 content of 0.6% (i.e. approximately similar to the Lindal Moor ore) the silicon content would be in the order of 4.8%. If these values are now subtracted from the quantities in the complete briquette, excess silica and alumina contents of 3.27% and 2.70% suggest that an aluminium-silicate bond (i.e. clay) was used.

Experimental work also showed that, whereas the amount of peat added to the briquette was sufficient to reduce the oxides to the metallic state, it was not sufficient to melt the reduced metal. Thus it would be necessary to add charcoal to the furnace charge when smelting the briquettes.

The products

The products of the furnaces were pig iron and slag, the former being sent to the forge for conversion into bar iron, and the latter discarded on the slag heap. When castings were made, the molten iron was ladled from the open forehearth of the furnaces and poured into prepared moulds on the casthouse floor.

The slags produced are glassy in nature and vary in colour from bottle-green to creamy-green and blue. Since they are acid and as such unable to carry much sulphur it was necessary to keep all sulphur-bearing minerals in the charge to

TABLE III Analyses of briquettes and typical ores (% by wt).

	Lindal Moor	Duddon	Hard pieces from briquette	Matrix of briquette	Complete briquette
SiO_2	4.90	0.48	9.44	7.28	8.07
CaO	0.05	3.03	2.00	1.80	1.87
Al_2O_3	0.63	0.06	3.30	3.30	3.30
MgO	trace	0.69	0.30	0.50	0.43
MnO	0.23	–	–	–	–
Na_2O	trace	0.12	–	0.12	0.12
K_2O	trace	0.20	–	0.25	0.23
P_2O_5	–	0.006	–	–	–
Fe_2O_3	94.23	90.30	80.80	28.50	47.64
L.O.I.	–	1.29	3.92	58.40	38.46
H_2O	–	3.12	–	–	–

an absolute minimum. Therefore the ores used contained only a small amount of the element, whilst the charcoal was practically free from it. Morton and Wingrove[7] have shown that the melting point of such slag was in the order of 1250-1350°C, at which temperature it would flow quite freely.

Three pigs of iron have been found, two at Duddon and one at the Nibthwaite site. The analyses are given in Table IV with, for purposes of comparison, the analysis of special quality iron made at the works of the Millom Hematite Ore and Iron Co. Ltd. The very low silicon content of the charcoal pig

TABLE IV Analyses of pig, "refined", and wrought metal

%	Nibthwaite Pig iron	"Refined metal	* Wrought iron
Graphitic carbon	2.43	0.01	} 0.028
Combined carbon	1.43	2.93	
Si	0.85	0.173	0.23
Mn	0.05	0.05	0.13
S	0.029	0.037	0.024
P	0.11	0.16	0.31

* Analysis of a bolt from Nibthwaite furnace structure

irons can be accounted for by the low temperature at which the cold-blast charcoal furnace must have operated, and in a similar way this accounts for the acid nature of the slag. It will also be seen the irons contain about one-half of the total carbon in the combined form. This would result in good mechanical properties, and low-temperature operation would give a fine grain size. Microstructures of pig No. D1763 confirm the good mechanical properties (Fig. 3), and it will be seen that the carbon is in a reasonably fine form even though some kish graphite is present. The structure also shows a well defined pearlite with small areas of free cementite and patches of phosphide eutectic. The structure of the Nibthwaite pig suggests that some reheating had taken place, possibly in the finery during the refining operation in the manufacture of bar.

THE FORGE

In the bloomery process both smelting and refining took place in the same furnace, smelting being effected in the region of the tuyere, and refining by slag-metal reactions in the

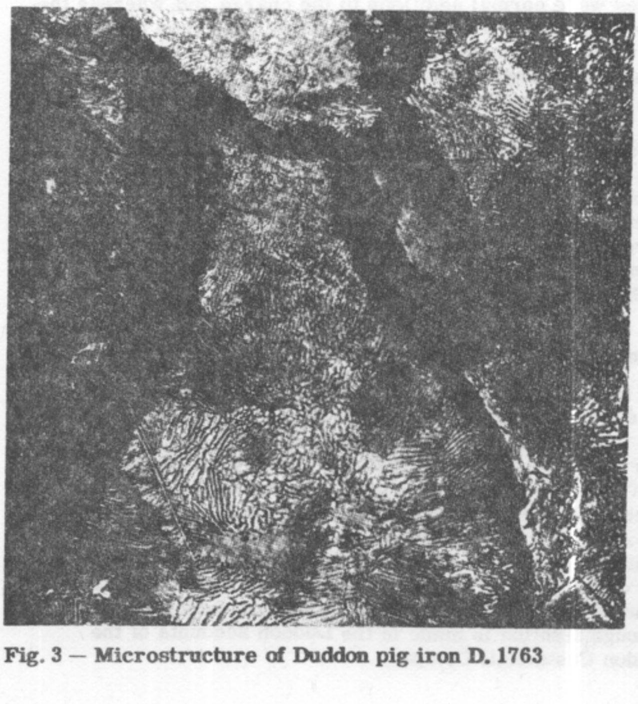

Fig. 3 – Microstructure of Duddon pig iron D. 1763

hearth. Production was exceedingly low, however, and to produce a large quantity of iron a great number of bloomeries would be required. On the other hand, the purpose of the finery forge was to refine pig iron previously reduced from the ore in the blast furnace. Therefore the availability for increase output could be readily provided, and high-quality tough iron bar was produced in sufficient quantity to supply the demands.

The forge therefore comprised three essential units: the refining hearth (known as the finery), a fire for reheating preparatory to hammering (the chafery), and the hammer. In design the finery was similar to the Catalan bloomery hearth, but the bellows were driven by a water wheel. In simple terms, the chafery was a crude muffle furnace heated by the combustion of charcoal within its walls, and a detailed description of its design is given by Fell. A painting by Hillestrom shows a similar type of furnace in a Swedish forge at Forsmark (Fig. 4) and an examination of the appearance of the iron taken from it for forging suggests a temperature of 1450°C.

The conditions in the hearth are reproduced in Fig. 1. During the meltdown stage gradual fusion of the metal took place

Fig. 4 — Interior of the Walloon forge at Forsmark in Sweden, in 1793, by Peer Hillestrom. By courtesy of Jernkontoret, Stockholm.

and, under the influence of the oxidizing blast, silicon and some graphitic carbon were readily oxidized. With the removal of the silicon some carbon went into solution with the iron, and the product in the hearth was a brittle white metal with no uncombined carbon and very little silicon. At this stage the iron was said to be refined, and complete fining was achieved by raising the pasty lump into the tuyere zone and remelting, when further deoxidation would take place. When the metal was satisfactorily fined it was taken in a pasty condition from the furnace and hammered into a half-bloom, after which it was reheated in the chafery and forged into the form of bar. The writer (8) has reproduced these conditions and the analyses at the various stages are given in Table IV.

From the foregoing it will be seen that two types of slag-finery and chafery-were produced at the forge. Finery slags approximate to the composition of fayalite ($2FeO.SiO_2$) and frequently exhibit "runnels" on the exposed surface. Chafery slags, often termed "mossers", comprise two layers, the lower layer of which is a compact mass, and the upper layer a porous cindery material.

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Conference Paper

The 17th century bloomery at Muncaster Head, Cumberland

R. F. TYLECOTE AND J. CHERRY

There have been many reports about the existence of bloomery slag beside the Esk at Muncaster Head Farm in Eskdale (Nat. Grid Ref. SD 141989). Excavations were carried out on this site in 1967 and 1968, and as a result there is no doubt that this is the site of the bloomery mentioned in an agreement of 1636.

The site lies on a low terrace a few feet above the flood plain of the river Esk (Fig. 1). At present it is approached by an estate road which leaves the public road from Boot to Bootle at Forge House, and which crosses a bridge built in 1818 and then contours the base of the hill to Muncaster Head Farm. The bloomery is reached about 150 yards before the farm and can be recognized by the uneven nature of the ground due to slag and charcoal heaps that have resisted levelling. Soon after crossing the bridge, in the wood to the south-east of the road, can be seen the remains of the millrace that supplied water to the bloomery. Like the road, this contours the hill-side until it reaches the bloomery about 300 yards after the bridge. Here it is temporarily lost, but it soon reappears along the southern edge of the bloomery terrace. After leaving the bloomery it flows away by rather devious routes, collecting water from small streams and drainage ditches, back to the Esk.

To the north of the bloomery terrace a modern drainage ditch has been dug and the spoil used to increase the height of an earthen bank which was undoubtedly first raised at the time of the building of the bloomery. This is perhaps the most prominent feature on the site, although the digging of the race along the south-east side of the bloomery has left some signs of embanked spoil.

Eskdale has many sites of importance to the history of iron-working which are now remembered by place names, but near Muncaster Head itself, besides the name Forge House, the hills above are called Forge Hills.

HISTORICAL

According to an agreement(1) dated 24 September 1636, between William Pennington of Muncaster and William Wright of Brougham, a forge or ironworks was to be set up on a parcel of Pennington's land called Tyson's Holme adjoining the River Esk, being part of the demesne known as Bank End. This was for the purpose of making bar iron and was to be working before 29 September 1637. By this time the timber, one hammer, one anvil, one hirst together with boits and gudgeons, three bloomery hearths with bellows, iron gear, tools, and all implements were to be brought to the site. There was to be also one dam or pond to control the water, ditches and water courses for carrying away the water from the forge as well as for bringing it out of the Esk, and floodgates and all other necessaries. Pennington was responsible for finding as many oak trees as were necessary to build the forge and make the dam, ground-work, weir, and floodgates. The Stanleys of Dalegarth were to supply 25 of the necessary trees. In addition, Pennington had to provide gravel, tough clay sods, earth, stones, and other building materials for making the weir, dam, ditches, and races. From convenient ground nearby, but not the meadow, was to come oak wood for stakes and withies for making the weir across the Esk to divert the water to the forge.

Within one month of Wright finishing the forge, Pennington had to make available at his pits at Egremont or elsewhere 150 tons of well dressed ore or ironstone. When the forge was completed, Wright and Pennington were to become equal partners until 3, 200 cords of wood were used: 1600 cords were to be bought by Gavin Braithwaite from the Stanleys and the other 1600 were to come from Wright's woods. The iron was to be equally divided between them, or sold, after every 4 tons had been made. After the 3, 200 cords of wood were used, iron was to be divided in the proportions one-third to Pennington and two-thirds to Wright, unless Pennington wished to leave the partnership, in which case Wright would be free to carry on by himself for five years but must keep the equipment in good repair.

It was also agreed that Wright was to set up a coalhouse for charcoal near and convenient for the work, and that Pennington was to supply the timber for it. Pennington was to allow the ironworkers the use of a dwelling house standing at Bank End for a term of five years.

The witnesses to this agreement were Samuel Rutter, Robert Copley, Clement Nicholson, Thomas Jackson, and William Tubman. It is interesting to note that an Edward Tubman was a lessee of the Maryport blast furnace in 1752.

RESULTS OF THE EXCAVATION

The mill-race and its controlling sluice gate

The race left the river about 150 ft south of the bridge of 1818, and after continuing for 160 ft was interrupted by a sluice gate or regulating weir. This was excavated and found to consist of a masonry slot in which was fitted a permanent wooden sill about $1\frac{1}{2}$ in thick which was supported by stakes driven into the ground on either side. The masonry was found to extend for about 5 ft north and south of the slot, but it is very likely that originally it went much further to the north than this so as to line the return channel or by-pass, which would have returned the surplus water to the river.

A sherd found in the clay at the base of the sluice gate near the wooden sill has been dated to the late 16th to early 17th century.

The amount of water entering the sluice would have been regulated by means of a permanent weir across the river that would have been sufficiently high to produce a reasonable head of water at the gate during dry seasons. The amount of water going through the gate would be controlled by putting 9 in square timbers in the slot to the necessary height and removing these as the amount of water in the river varied. The sluice gate was at least 4 ft high and would contain at its highest as many as five timbers.

No sign of the by-pass was found. Since the river gravel has been piled up to form an embankment to prevent flooding in recent times, any traces near the river itself would have been obliterated. The river runs over a series of rapids and has quite a fall where the dam could be expected to have been.

After leaving the sluice gate, the water ran in an earth and stone channel about 10 ft wide, contouring the side of the hill a little above the level of the flood plain. This channel disappears just before the bloomery; in order to find where it crosses the present flood plain to connect with the stone lined wheel pit, a trench, (YY) was dug in a west-to-east direction across the corner of the flood plain, as shown in Fig. 2. A channel about 15-20 ft wide and 3 ft deep from the present ground level was located in the fine gravels and silts of the flood plain, and it is now clear that the race cut off the corner and came into line with the wheel pit as shown.

The present surface configuration makes it clear that the race followed the south-east edge of the bloomery terrace and that it must have skirted the edge of the high bank very closely. Excavations in the area of Q3 and Q4 located the two sides of the race and showed that these had been revetted with stone;

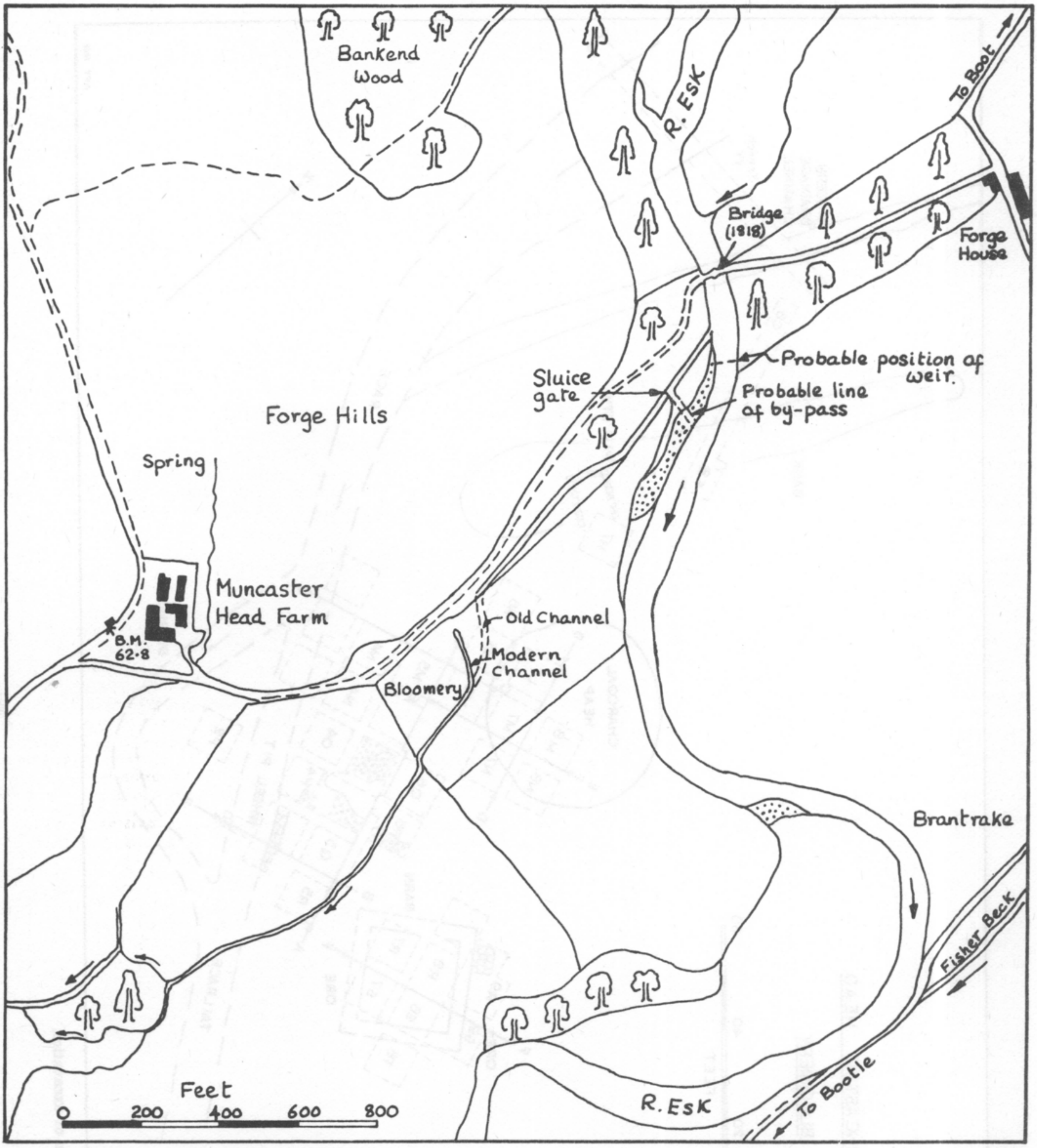

Fig. 1 — Location of Muncaster Head site

but there were no signs of revetting in other areas excavated along the likely line of the race, i.e. L3, M3, and N3. Either this area had not been revetted or else the stones had been robbed. The contours show clearly that there was a by-pass channel to the south-east of the race proper. This would have been intended as a diversionary channel so that the water could be stopped from flowing in the main race when the wheel was out of use or repairs were necessary. The diversion would be controlled by placing some sort of gate or shuttle in the main channel.

In the revetted part of the race the remains of what appears to have been a wheel were found. These remains and the depth of the race itself at this point suggest that the wheel was about 15 ft diameter. The width of the channel would be about 8 ft at the top and about 6 ft at the bottom. Owing to the low fall on this site (there is not more than 7½ ft difference between the level of the river in July at the point where the return channel enters it and the bottom of the presumed wheel-pit), it is almost certain that the wheel was of the undershot type. Indeed, the remains would suggest this type rather than a breast wheel. Calculations for both these possibilities based on a 6 ft wide wheel give the same order of power available i.e. between 15 and 19 hp. This would be ample for three pairs of bellows and a tilt hammer or belly helve.

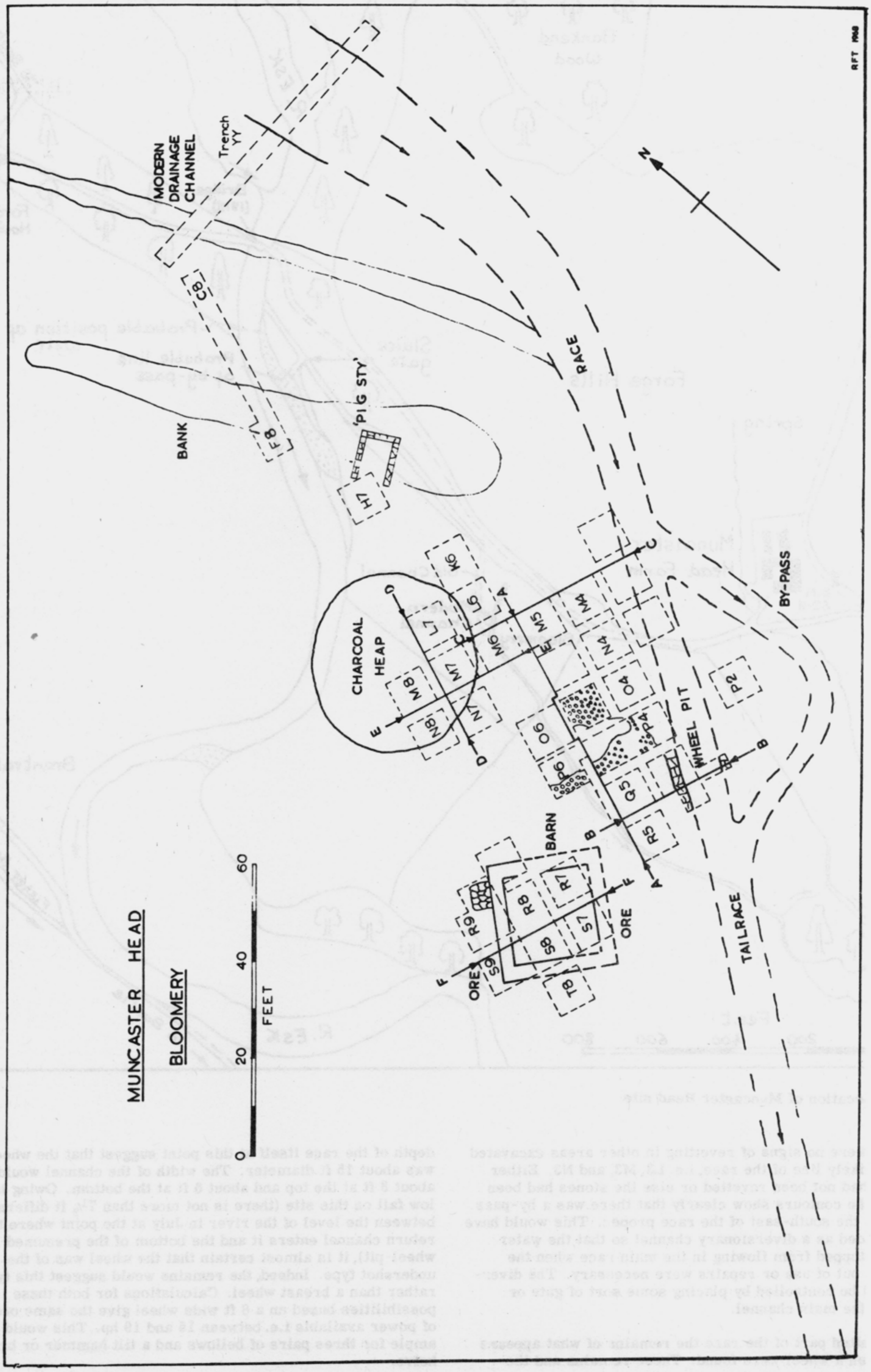

Fig. 2 — Muncaster Head: general plan of excavation

It is, of course, possible that the remains of the wheel are not in their original position and have been swept downstream. However, this is very unlikely as there is not much room before the by-pass channel is reached, and other indications on the site suggest that the hammer at least was positioned on the working floor above. It is, however, very unlikely that the hammer and the bellows would be driven from the same wheel, since the space required to give access to several pieces of equipment is so great that a complicated linkage or gearing would be required. It was therefore felt that the wheel and the revetted race gave the position of the hammer, but the position of the hearths and the bellows would be elsewhere and that the bellows, if powered, would be driven from a smaller wheel or wheels.

The Working Area

A working floor was found in Q5 at a height of 6 ft above the level of the bottom of the race (Fig. 2). This is composed of pebbles and sand and probably represents the original upcast from the digging of the race with some additional pebbles. Charcoal has spread over half the area and later (probably after the demise of the bloomery) the channel has been cleared and further upcast has been dumped on the charcoal and working floor. After this, slag and furnace bottoms were either spread over the area to level up the field or had slid down from a nearby slag heap. The charcoal produced a number of pipe stems and bowls which have been dated from c. 1650 to 1710.

The working floor extended in a northerly direction for about 15 ft (Fig. 2) through trenches P5 and O5 and finally disappeared in N5. There must have been a gully in the area of O5 and O6, and this has been levelled up to the height of the working floor with a great deal of slag, clay, and other debris. The floor over this section was a reddish-yellow and extremely hard, so much so that it was penetrated with a pick only with great difficulty. It seemed that the slag, ore, and clay were capable of making a concrete, a situation that has been found elsewhere. There is little doubt that originally the hard working floor extended to the edge of the race, but that with time the edge crumbled away, probably aided by the removal of the revetting stones.

In the area of M4 and N4, and M5 and N5, the contours show that the levels are a good deal lower than on the working floor itself. It was thought possible that the hearths might have been located in this area, since with their smaller power requirements they could have been driven from wheels of small diameter, which could have been placed lower in the race. An examination of this area gave rather ambiguous results. The subsoil slopes gradually to just before the race itself, where it drops suddenly to the old channel, now filled with large water-worn pebbles to an undetermined depth. It is clear that in this area there has been no dumping of spoil arising from the cutting of the race. On the other hand, there are signs of a sudden change in level, suggesting a well-cut channel. This could have been stone-lined but, if so, the stone has been entirely robbed.

After such robbing it would seem that care had been taken to maintain a gradual slope down to the old bed of the race in order to provide a crossing place or drinking area for cattle. Gradually, slag and soil covered this slope. What does seem important and indicative of this being the smelting area is the fact that there were a large number of furnace bottoms in the race and also some pieces of cast iron that might have formed part of the furnaces themselves. It is suggested therefore that near the line of the revetted race, only two or three feet above the bottom, were situated the smelting hearths driven by a small wheel or wheels placed in a channel with a fast flow of water. The most efficient arrangement would be for these wheels to be undershot and for the water leaving them to fall a few feet down a stone-lined sluice to impinge upon the hammer wheel, either undershot or low breast.

Charcoal Heap

Although the agreement refers to the setting up of a timber building for charcoal, no sign of such a building came to light. On the other hand, there was no doubt than an enormous heap of charcoal had existed to the west of the supposed smelting area (Fig. 2). This charcoal heap was about 35 ft in diameter; in some places it was 18 in thick and at the time of cessation there must have been left something like 5 tons of charcoal. What was left was rarely more than ½ in in size and seems to have represented the smaller sizes. The inference therefore is that the workers favoured the larger sizes. In the course of removing the charcoal from the heap they had left a number of hard floors, which probably represented the shovelling surfaces. As would be expected, in the course of time charcoal was tipped on to, and shovelled off, the same places. On its southern edge it was later overlaid by the extension of the slag bank, thus forcing the heap to the north and acting as a boundary to it.

On the eastern edge of the heap was found a sherd dated to the late 16th to early 17th century. The rest of the pottery on the site is 17th century or later. A large number of pipe stems and a few fragments of bowl were found on this part of the site, and these all belonged to the 17th century.

Agricultural Buildings

The southern and western parts of the bloomery field are heavily impregnated with hematite, and it seems that this was connected with the remains of a building at the southern end of the excavated area (Fig. 2). It was therefore thought that this building might have been used as an ore store. However, after excavation it was clear that this was not the case and that it was a later agricultural building, probably a barn, built over or near to the original ore storage area. This building measured 18 ft square internally, had a wall thickness of about 2 ft 6 in, and was roofed with green "slate". The walls were made from granite boulders with little if any dressing, a type of masonry which is quite common in the area. While there was much hematite all around, particularly on the west side, there was hardly any inside and a section showed that the construction trenches cut through layers of hematite.

It is clear that the barn was built by removing the turf and topsoil from the whole area of the building, so leaving the inside free of all but scattered patches of ore and charcoal. The walls were then built directly upon the pebbly subsoil without foundation trenches. Later the building was robbed, leaving in some places two or three feet of the walls. The barn was entered from the west side over a wide step made from granite boulders laid with their flat side uppermost and looking rather like crazy-paving. On this step was found a triangular-shaped piece of cast iron about 2 in thick and weighing 22 lb. It was clearly cast to shape and was thought to be part of a plough but, if so, it is difficult to see how it could be drawn, since it had no holes for attachment. It would appear to have been scrap that might have been used for some purpose by the crofter who used the barn. It could have originated from the bloomery and, if so, might have been used for the hearths. This point is discussed later.

Outside the building, particularly to the south and west, substantial deposits of hematite remain. One such, on the south side, is on a level with the bottom of the wall and is covered by upcast from a later deepening of the race nearby to form a pond. On the west side and to a slight extent elsewhere, greenish patches are visible in the hematite soil. These were found to consist mainly of weathered greenstone pebbles, and it appeared that the presence of the hematite had accelerated the weathering process, since such pebbles were common on the site and this form of weathering was not found elsewhere.

At the north end of the site, built into the high bank, is another building of agricultural purpose. This is made of granite boulders and measures internally 8 ft × 10 ft. It has been paved with square red sandstone slabs and covered with the same green slate as the barn. This building could have housed animals such as pigs or horses and has been termed, for convenience, the "pig-sty". There is no doubt that it postdates the bloomery, since its south-west end rests on an extension of the bloomery slag heap. Its NE corner rests on the toe of the bank into which it has been built for support. It could not have been free-standing and therefore postdates the bank.

EXAMINATION OF THE PRINCIPAL FINDS

Metallurgical material

Large amounts of hematite ore and charcoal had been left, together with large furnace bottoms consisting of slag and charcoal. In addition there was a certain amount of small tap-slag. One find, surprising for a presumed bloomery site, was three pieces of cast iron.

Iron Ore—The only iron ore found on the site was high-grade hematite. The analysis of this material is given in Table I, together with data for Eskdale hematite for comparison. There is little doubt that its origin was local, either from higher up the valley where there are many mines or from the mine on Brantrake Crags on the opposite side of the valley.

TABLE I Analysis of ore from Muncaster Head and Eskdale (%)

	Muncaster Head	Nab Ghyll (Kendal) (2)
Fe_2O_3	91.7	92.6
MnO	0.02	0.026
SiO_2	2.9	2.05
Al_2O_3	1.0	0.88
MgO	0.1	0.08
CaO	0.6	0.50
TiO	0.01	n.d.
H_2SO_4	n.d.	0.01
P_2O_5	n.d.	0.03
H_2O	3.7	3.7

n.d. = not determined.

The agreement mentions the possibility of getting ore from Egremont, and this is certainly a possible source. Egremont is also near the Cumberland coalfield and could therefore have been a source of nodular ore. However, no such ore was found and one must therefore assume that the ore that was smelted here was exclusively hematite.

Slag—The slag consisted of large furnace bottoms and smaller pieces of tap slag. Four of the furnace bottoms (A, B, C, and D) were weighed and gave figures of 48, 31, 35, and 39 lb respectively. These all consisted in the main of a mixture of porous slag or "cinder", and charcoal. The tap slag was of the usual type, consisting mainly of fayalite with some wüstite, silica, and iron and was non-magnetic. The composition is given in Table II. It will be seen that it has an appreciable phosphorus content which is absent from the ore. One of the furnace bottoms (D), weighing 39 lb, was therefore checked for phosphorus and the result gave 0.43% P_2O_5.

TABLE II Analyses of slags from Muncaster Head (%)

	Tap slag	Furnace Bottom (D)
FeO	62.3	
SiO_2	23.9	
Al_2O_3	5.5	
CaO	4.5	
MgO	0.7	
TiO_2	0.2	
MnO	0.1	
P_2O_5	0.65	0.43
S	0.01	

One of the furnace bottoms was examined petrologically and found to contain partially reduced iron ore particles (i.e. Fe_3O_4), and there is no doubt that it was a smelting product and not a "mosser" or product of a forge. It therefore seems that the tap-slag and the furnace bottoms came from the same process. The main problem is the source of phosphorus, which could not have come from the hematite ore found on the site. Either a phosphorus-bearing ore such as that from the Cumberland coalfield was used or else there must be some other source. There could have been contamination from organic phosphorus from animal excreta on the field, which has been used for feeding stock for some time, or, more likely, it came from the wood used for charcoal. Peat can also contain phosphorus. Table III shows the composition of cast irons from the Furness-Cumbrian blast furnaces. As expected, the coalfield irons have higher phosphorus contents, but the Duddon and Nibthwaite irons have phosphorus contents of the same order as those found in the slags at Muncaster Head.

TABLE III Composition of Furness and Cumbrian cast irons (%)

	C	P	Si	Mn	S
Nibthwaite	3.73	0.11	0.85	0.05	0.029
Duddon	4.3	0.12	0.65	0.10	0.023
Duddon	4.11	0.09	0.93	0.036	0.019
Maryport	2.6	0.06	3.26	0.4	0.12
Bareport	3.8	0.36	2.10	2.45	0.15
Clifton	3.36	0.37	1.54	0.71	0.16
Maryport	2.72	0.22	2.49	1.10	0.073

G. R. Morton believes that one source could be limestone flux known as "catspaule", which can be found in the vicinity of Eskmeals. Fluxes were not generally used in bloomeries, although Scrivenor (3) does mention their use in this country.

One clue to the origin of the phosphorus may lie in the fact that Muncaster slag also contains Al_2O_3 and lime. While hematite does not usually contain much alumina, that from Lindal in Furness can contain 2%. Aluminous shale has also been used as a blast furnace flux and can contain as much as 1% P_2O_5.

Other comparable slags are those reported from Nibthwaite, where there was a finery and forge, and from Sparke Forge and Penny Bridge, where "mossers" of chafery slag were found (Table IV). From the high sulphur content it is clear that the mossers were made with the help of coal, and this could account for the alumina content. However, the alumina content in the finery slag could not be due to this cause, nor of course could that from Muncaster, since it has only 0.01% S. Clay linings to the furnaces could provide this, and it is possible that the clay is also the source of the phosphorus at Muncaster. So there are three possibilities: charcoal ash, shale or limestone as flux, and clay furnace lining. Slagged furnace lining from Camerton, Somerset, (4) was found to contain 16-19% Al_2O_3 and 0.4-1.2% P_2O_5. Even here, the P_2O_5 probably came from charcoal ash.

TABLE IV Slag analyses, %

		Mossers			
	Finery, Sparke Forge	Nibthwaite	Sparke	Penny Bridge 1	Penny Bridge 2
SiO_2	8.16	16.16	21.32	11.04	14.58
Al_2O_3	4.65	4.30	2.52	4.30	12.45
CaO	2.60	2.10	5.68	4.34	5.16
MgO	0.54	1.20	1.77	3.14	3.00
FeO	33.60	65.53	33.10	29.3	40.63
Fe_2O_3	50.4	9.43	27.6	31.4	9.70
P_2O_5	0.57	0.23	0.12	0.05	0.05
S	—	0.47	—	3.69	4.67

Furnace bottom A

This consisted mainly of charcoal and slag. The remains of a slag runner could be seen on the bottom and those of a tuyere on the top at one side. A magnet showed that most of the bottom was non-magnetic but there were some mildly magnetic regions, and the central boss on the top was strongly magnetic. For this reason it was detached with a cold chisel and found to have a very high metal content. It weighed 2.9 lb and was in fact the remains of the bottom of the bloom. The separation was relatively easy owing to the presence of a considerable amount of charcoal between the bloom and the slag. The metal was porous and a hardness test gave 142 HV5, showing that carbon was present. The microstructure consisted of coarse ferrite with coarse angular pearlite grains which were easily resolvable at low power. The ferrite-pearlite distribution was Widmanstätten and this shows it to have been fairly rapidly cooled from a high temperature. But the coarse spheroidized pearlite indicates that it had remained for some time in the range 600-700°C. The carbon content averaged about 0.2%.

Hemispherical shell (Embryonic furnace bottom E)

If smelting had continued this would have become the same as the above. Magnetic testing showed that the edges were highly magnetic and it was found that pieces of metal could be detached from them. This had the same structure as the above, except that the pearlite was not quite so spheroidal. The carbon content was about 0.2% and the hardness in the area tested was found to be 192 HV5.

Small furnace bottom (broken top surface)

This was the bottom half of a bottom of the same sort as A. It was almost entirely non-magnetic and no iron was found in it.

Furnace Lining

There was not much of this on the site, but one piece was found to consist of clay, slag, and charcoal and seemed to have come from near the tuyere. The inside was found to be highly magnetic in places and this suggests that the clay had been exposed to reducing conditions.

Some furnace bottoms had granite pebbles sticking to them with a small amount of clay between the pebbles. It would seem that the lower parts of the furnaces just above the hemispherical bottoms were not very regular in structure and generally rather crude.

Slag runners

Like the tap slag, these also were non-magnetic.

Cast Iron

Considering that this site was undoubtedly used for the purpose of making bloomery iron, it was interesting to find upon it three pieces of cast iron. The largest was a piece of white cast iron weighing 22 lb, which was found on the step of the barn. It is triangular in shape and about 2 in thick with one corner pointed. From its position it would seem to be post-bloomery, but of course it might have been found on the site and used during the period of use of the barn or for its destruction. At first, it seemed that it might have formed part of a plough but it is difficult to see how it can have been drawn as it has no holes for bolting on to the body; if used as a share it must have been very makeshift. Possibly it has been used for the demolition of the barn.

If these three pieces were made in the Lake District they would have been made after 1711, the date of the start of the first blast furnace in the area at Backbarrow. However, it is possible that they were brought up to the site from other parts of the country where cast iron was being produced at an earlier date.

The other two pieces were found in the SW corner of L3. There was a good deal of scrap material in this area of the race, but these two pieces appear to be early in date; they are about 1 in thick. The smaller of the two was again white iron and appeared to be broken, but it still has a straight side. The larger has no straight sides and was originally mottled iron, i.e. white iron with some flaky graphitization. However, it now contains a considerable amount of nodular graphite which has formed, since it was cast, at a temperature of about 800-900°C. There is little doubt that it has been exposed to such temperatures during use and this invites speculation as to its purpose. We know that during the 17th century iron plates were used in bloomery, finery, and chafery hearths and, indeed, Sturdie refers to the use of iron plates in a bloomery at Milnthorpe, Lancs, in 1675 (Phil. Trans., 1964, vol. 17, p. 698). In Sussex in 1573 and in 1582 iron plates were used in the forges and fineries (Schubert, p. 277-8).

Although the bulk of the iron on this site appears to have been made in more primitive furnaces than those mentioned above, it is possible that at a later period during the period of use of the bloomery more sophisticated hearths were used which employed cast-iron plates. White cast iron would be used for two reasons: first, it is more resistant to cracking due to "growth" (i.e. graphitization of pearlite and oxidation along the graphite flakes), and secondly, a good deal of early charcoal iron was white owing to its low silicon content and the fact that most of it was intended for conversion to wrought iron. Grey cast iron was generally only made in thick sections or by slowing down the rate of cooling.

TABLE V **Properties of Pieces of Cast Iron.**

	A 2 in thick	B 1 in thick	C	
Hardness, HV30	493	481	177-212	
Graphite	slight mottling	none	Flaky and nodular	
Composition, %				
Total Carbon	3.81	3.46	3.69	3.76
Silicon	0.58	0.17	0.18	
Manganese	0.56	0.68	0.66	
Sulphur	0.07	0.091	0.121	
Phosphorus	0.49	0.75	0.72	

The chemical composition is given in Table V. There is no doubt that these are cold-blast charcoal iron. The phosphorus content is very typical of that being produced in the Cumberland coalfield in the 18th century. The figures for Barepot and Clifton are 0.36% and 0.37% respectively, while Maryport has given figures of 0.22% for its product and 0.12-0.15% for iron in its structure.

Alternatively, this could have been produced from a blend of hematite and Staffordshire tap slag which was used in the 18th-19th century. The formation of nodular graphite during use was also noted in a piece of iron in the structure of the Maryport furnace (1750).

DATING

The pipe fragments and pottery sherds fix the first period of use of the site as being from the early 17th century to the early 18th century (c. 1710). Then there is a gap until the 19th century. Whereas this evidence effectively dates the life of the site as a bloomery, it poses a problem for the dating of the barn, which postdates the bloomery. Since there is no late 18th century pottery on the site, the barn can hardly have been built before the beginning of the 19th century, when the bloomery had been out of use for nearly a century. If this is so, the barn would have been destroyed by the middle of the 19th century when Muncaster Head farm was probably enlarged, no doubt with the help of stone from the barn and the bloomery. This seems an unusually short life for such a building.

The "pig-sty" with its flagged floor and walls made with the help of pieces of concrete and fire brick was undoubtedly late 19th century work.

The existence of the flat plates of cast iron suggests a sophisticated type of bloomery furnace, perhaps built later in the

17th century. These plates would have been made outside the area, as the cast-iron blast furnace did not appear in the area until 1711 at Backbarrow. It would seem that this bloomery was not converted to a forge for making wrought iron from cast iron, perhaps because it was too far away from the nearest blast furnace and there were other more convenient sites for this purpose.

ACKNOWLEDGMENTS

It is with great pleasure that we acknowledge the help of the following: Mr I. McWilliam for allowing us to excavate on his land; Brathay Field Studies Centre and Exploration Group for providing most of the labour in 1967 and the Charlotte Mason College for providing it in 1968; the Cumberland and Westmorland Antiquarian and Archaeological Society and the Committee for Archaeology of the University of Newcastle upon Tyne for making grants towards the cost of the work; the U.K. Atomic Energy Authority for providing some of the equipment and for allowing their apprentices to help; Mr B. J. N. Edwards for his examination of the pottery and the clay pipe fragments; and Dr H. T. Angus of the British Cast Iron Research Assn. for examining the cast iron.

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1. Papers in County Record Office, Carlisle.
2. J. D. Kendall: "Iron ores of Great Britain and Ireland", London, 1893.
3. H. Scrivenor: "History of the Iron Trade", London, 1841.
4. W. J. Wedlake: "Excavations at Camerton, Somerset", Camerton Excavation Club, 1958.

Conference Paper

The industrial archaeology of the Lake counties

M. DAVIES-SHIEL, B.Sc.

Note: this paper was illustrated throughout by about 200 coloured slides taken in the area in the last ten years, and is therefore only the gist of the matter covered.

The purpose of my talk today is to provide the setting against which the various metal industries of the area developed, blossomed and are now unfortunately, though inevitably, dying.

Fortunately, Lakeland does not depend entirely on the robber industries based on mining, for many of her raw materials can be cropped at regular intervals. Her varied resources depend upon geological and geographical chance, for the rocks that have been a source of many minerals have also by their hardness caused the mountainous features and climate and vegetation, and the accident of a westerly position has produced abundant potential waterpower.

The earliest industries to which our researches have led us are those common to almost all parts of Britain at some time or another. They are mining, woodland industries, the fulling of wool, and cornmilling, in that order for Lakeland.

The initial settlers of Lakeland were reduced to a very small number by the Romans, and only the Solway and Low Furness Plains were to any degree inhabited by Saxon times. The Irish-Norse invaders were, from about AD 960, the first true settlers in that they began the clearance of the forested valleys. After them came the Norman-French barons who from about 1150 bequeathed large areas of wild country to several monastic Orders. The monks opened out the larger valleys, established sheep-runs, folkii or farm schools, and initial industries of charcoaling, iron-mining, wool and cornmilling.

By the very nature of the terrain, the woodland industry was the first to begin. It was truly an industry since the various trades involved hundreds of able-bodied men working in the woods to provide thousands of men in domestic and small manufactories with raw materials, which in their final state were exported by the shipload to all parts of Britain and the world. Even in early monastic times timber was carefully controlled, although they probably never dreamt that the endless trees might ever be decimated. Only dead wood could be used for fuel and even then it was more usually "coaled" Miners of copper and lead needed it for shafting and roof-props, for tubs and tools and for charcoal to concentrate the ores. Enormous quantities of charcoal were made in the woods for the early monastic bloomeries and gradually the forests shrank. After the Dissolution, the shipping industry had the best oaks allocated "for the King"; other calls were for oak bark for tanning, staves for barrels and basketry, and twigs of birch for ashes (of potash) for the fulling mills. A very early reference of 1476 mentions the prohibition of indiscriminate taking of spelks (small sticks) and of the "cropping of butt ellers and Birks there", in Troutbeck near Windermere[1]. By 1574, the practice of coppicing had spread across the whole of southern wooded Lakeland[2] and charcoaling for the bloomeries was so rampant that a special edict from Elizabeth prohibited all smelting for one hundred years. As a result, most Lakeland ore was packed out to the Rossendale Forest to be smelted there. (I shall refer to this in more detail when considering something of the bloomery trade).

In later years, the bark from oak coppice was supplied to nearly 60 hand tanneries in Lakeland, but by the later 19th century better barks from overseas and mechanical innovations caused these hand tanneries to close. Small twigs of birch were esteemed for their high potash content. They were roasted in stone cisterns built into the hillsides of the more wooded valleys. The ashes were mixed with lime and water to produce caustic potash and tallow was then added to make a soft brown soap. This was used locally by the ton to wash and "full" the woollen yarns and cloths of the area in well over 200 fulling mills. "Ashburner" was already a common name in High Furness by 1600 A.D. In the heyday of the mid-19th century timber-container boom, millions of small sticks and lathes were cut and shaped to make spelk baskets, grommets, barrel hoops, staves, and box pieces. Pill boxes for "pale people" were turned at Spark Bridge by the hundreds of gross per week, and bobbins and reels of all shapes and sizes, to the tune of over thirty million a year, were turned out from semi-hand-operated lathes for the textile trades. Several hundred coastal brigs and schooners were built in various ports around the coast, from Maryport round to Greenodd.

Although, chronologically speaking, the corn mills and kilns were contemporaneous with the fulling mills, they are however common to all parts of Britain, and their main value to us is to be found in details such as the milling families, mill distributions, and gearing mechanisms. This last aspect is of value in that the complex gears used to drive the top runner stones were later applied in principle to other machines in gunpowder mills, textile and bobbin factories.

The next major group of industries were those concerned with the iron trade, i.e. mining, smelting, exporting, and smithy work. Dr. Marshall and others have already spoken of the first two, especially in the regions well known to us all here, but I should like to draw your attention to other areas that also had their part to play in the inter-development of the region as a whole. There were outcrops of iron ores in Dunnerdale, Wasdale, Eskdale, Ennerdale, Langdale and by Grasmere. All were mined briefly during the latter part of the 19th century, by various companies from Cleator or Egremont. They are of more interest to me, though, in helping us to locate a wider spread of the early bloomery sites. Many of these latter are indicated by such names as Smithy Brow, Blomery Beck, Red Nab, Cinderhill and Forge Wood. A team of local enthusiasts, together with Mr Morton's analytical and field researches, has at present located or found detailed reference to 98 bloomeries, with a further 42 under inspection. Forty of the total lie within Hawkshead parish and 33 more in adjacent parishes. A second major group of 23 has to date been located in the Wasdale-Eskdale area. All the bloomeries lie in an area stretching southwards from Bassenthwaite to Morecambe Bay.

The bloomeries of Hawkshead and adjacent parishes are all contained in the lake basins of Coniston and Windermere and appear to have been worked in monastic times if large and from c. 1559 if small. The latter date is that of a Decree of the Customs of Furness Fells[3] which closed the only three smithies that had worked iron for sale since the Dissolution, but did however allow the tenants of the parish to make iron for their own use, since they were so far removed from the normal iron trade of England. The earliest known of these "bloomeries", "smithies" or "forges" was 1150 and they finished some time shortly after 1711. A large number of water-powered forges were built from 1690 onwards, and many of these were later rebuilt into true chafery forges once blast furnaces had begun.

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[1] S. H. Scott: "A Westmorland Village", App B, p. 254–Some royal decrees.
[2] Elizabeth's Customary Allowances with the Richmond Fee. p49. 1558.
[3] Decree of the Customs of Furness Fells 1-7 Elizabeth vol. 13 Fol. 705.

Although the Halton group are not strictly in Lakeland, I should like to mention them as they include a group of 15 or more furnaces, forges, and bloomeries stretching from Halton-on-Lune northwards to Milnthorpe and Sedgwick near Kendal. They were not mentioned much by Fell[4].

I shall omit reference to the charcoal furnaces of Lakeland since they have already been described by others, and we have all seen Backbarrow, Newlands, and Duddon. Yet the wealth gained from the sale of furnace iron must have influenced others to try their hand at other types of industry. Most of the ironworks were owned by Quakers, and another Quaker, John Wakefield, turned to the making of gunpowder in 1764. Eventually there were six powder works making a total of over 10,000 tons of powder a year for blasting, sporting, and military purposes. The makers imported their sulphur and saltpetre, got local charcoal that had been specially refined and used up to 400 hp per site to make the final product. Most of the powder went overseas to Africa and India, but some served most of the coalmines of northern England; 2000 tons were used to help build the Lancaster to Carlisle Railway in 1846. Other products were railway fog signals, minute-gun powder, and that for fireworks. Although the valuable machinery has long since gone for scrap (the last works were closed by I.C.I. in 1938), there are still some vast earthworks, weirs, wheelpits, runner stones, and building shells. We also have a few rail vans, retorts, kegs, labels, and photographs of working machinery.

Most of the local iron mines were worked using Lakeland powder. The bulk of the iron was shipped out to the Carron works in Scotland, to South Wales, and to Sheffield. Little was retained for local smelting until the 19th century. Copper concentrates were sent to St Helens for refining; lead went to Newcastle. Other shipping took slates to London and Ireland from the Broughton area, coal to Ireland from Whitehaven, and granite out from Shap and Eskdale.

Textiles, especially wool, were of early importance in Lakeland. Kendal's motto—"Wool is my Bread"—has only slowly become untrue within the last 90 years. Kendal, Stainton, and Keswick were all woollen centres from the late 18th century onwards. Kendal, however, had already become famous for its cheap green-coloured woollens as far away as France by the 14th century. Most of the people of Lakeland were involved in the woollen trade in some way or other. The farmer bred his sheep, factors bought it, pack-men carried it to the mills where it was spun into thread. Domestic weavers by the hundred turned it into cloth, the cloth being then returned to the mills for fulling, friezing, and cutting into clothing. Waggoners then took the finished product to the ports of Whitehaven, Ulverston, Greenodd, Milnthorpe, or Lancaster for shipment to London or Liverpool. Whitehaven's pre-eminence in the trans-Atlantic trade of the early 18th century grew from her Irish coal trade. Thus woollen goods went out to the West Indies and the new colonies, and cotton, sugar, tobacco and rum returned. Flax and timber came in from the Baltic. As a result, flax industries grew up near the ports or shipyards, linen-making nearby, and cotton spinning for cloth and lace wherever there was enough water power to drive the many spinning jennies and mules. Many of these latter factories started before the bulk of the south Lancashire concentration got going and only began to close after about 1820 when competition from steam engines and coal proved too severe. The major cotton centres were Carlisle, Wigton, Cockermouth, and Ulverston. The major flax centres were at Milnthorpe, Egremont and near Workington.

As competition closed the textile mills, so the premises were turned over to the production of bobbins. This latter trade is now on its last legs. Competition from Norway began about 1860 and the invention of plastics has caused the closure of all but three mills out of a one-time grand total of 68 mills.

About 1830, several other industries of a somewhat specialized nature came to the fore from quiet beginnings. Paper was made from cotton and flax waste and most mills are still to be found near the early textile centres on the coast. Snuff was manufactured at Penrith and Kendal, "marble" from local hard limestones in eastern Lakeland, combs from local horn, shoes from leathers, and bleaches and dyes from various local products. There were many edge-tool manufacturers too, who concentrated their mills and forges near the iron-ore mines, in which the bulk of their shovels were used. Mill-wrighting, in a district that could boast nearly 2,000 water power sites and a known "make" of well over 30,000 hp, was always a strong trade, and it is not surprising to learn that turbines were made here too from as early a date as 1856. Other machine trades were associated with the vast mill industry and included lathe making and wood-lathe tool making, pumps, laundry machines, and shipbuilding at Barrow.

Today there is still a woollen industry at Kendal and in Carlisle. Kendal still makes turbines, snuff, and also rum butter and mint cake. Workington still produces Bessemer steel and iron mining continues at Beckermet. But, in the final analysis, the industrial past has died yet has not left a visible corpse and the ingenuity of the local people lives on.

[4] A. Fell: "The Iron Industry of Furness (to 1800)", 1908.

Conference Paper

The West Cumberland iron industry: its origins and development

D. R. WATTLEWORTH

My story begins where that of Dr Marshall and Mr Morton left off. West Cumberland is near enough to the Furness district for the knowledge of what was happening there to spread northwards. The conditions in Cumberland were, however, quite different. A known coalfield had been worked extensively since the middle of the 17th century.

Lack of inland transport facilities had led to the development of overseas trade (mostly to Ireland) and port facilities came into existence, particularly at Whitehaven. Iron ore of similar quality to that found in Furness was mined and small bloomeries and forges were operating, Egremont being the centre of such industry. The port facilities however provided the opportunity of exporting ore to other parts of the country, notably Chester and South Wales.

Both mining and shipping created demands for iron in one form or another, and it was almost inevitable that sooner or later efforts would be made to produce it locally from the indigenous raw materials. This became a possibility with the successful smelting of ore with coke. Knowledge of Darby's success at Coalbrookdale in 1709 appears to have spread fairly rapidly for those days, and as early as 1723 a blast furnace was operating at Little Clifton about half-way between Workington and Cockermouth. This furnace had quite a long life, operating until 1771.

Another furnace was erected at Maryport in 1752 and a third at Barepot near Workington in 1763. There is evidence that coke was used at both places.

Gabriel Jars in his "Voyages Métallurgiques" tells of his visit to both Little Clifton and Barepot in 1765 and particularly describes the making of coke in heaps at the former place. I explored the site some 40 years ago and was able to trace the site of the Meiler heaps by the tar-saturated sandstone blocks on which they had been built.

Whilst Little Clifton apparently continued to operate satisfactorily over a long period, the Maryport furnace was continually in difficulties owing to insufficient water power, a fact which probably accounted for the furnace being in comparatively good state of preservation when it was demolished some three years ago.

There is little evidence to indicate how the iron from these two furnaces was used. Some refining may have been done at Maryport, otherwise castings for use in mining operations, water pipes and domestic ironware appeared to have been the principal products.

The Barepot project was a more ambitious scheme, and over the years developed into what we would now call an engineering works. It was here that the Heslop engine had its origins and from there that the Heslops extended their activities to Lowca. The Barepot story is sufficiently interesting to make a paper on its own and it still provides opportunities for research into its early history. Actually it survived operationally in one form or another and under various ownerships until 1862.

These three early ironmaking establishments cannot, however, be regarded as the foundation of what was later to become the major industry of West Cumberland. Almost 100 years had to elapse before there were serious ahd substantial developments. Much had happened in the meantime as the Industrial Revolution gathered force. Mechanical means gradually supplanted manual operations. Steam replaced the water-wheel and removed the necessity for siting adjacent to rivers. The demand for iron received an impetus from these developments which at the same time provided the means for meeting the demand.

Cast iron did not, of course, fully meet these demands and it was not until Cort introduced his puddling process that wrought iron with its superior tensile properties could be produced in quantity. From then only did blast-furnace pig iron production begin to move.

It is perhaps difficult in these days of bulk production to realise what an important part the puddling furnace played from its inception in 1784 until the end of the 19th century. The small reverberatory furnace (6 ft × $4\frac{1}{2}$ ft) had 4-cwt charges and used 5 to 6 tons of coal per ton of finished wrought iron. Working 6 or 7 charges per 12-h shift, their operations required the most strenuous manual effort of any manufacturing process (before or since).

In 1880 J. S. Jeans wrote that "the puddling furnace had been condemned as crude, barbarous and wasteful, yet it continued to enjoy a measure of vitality and appreciation to which its merits did not entitle it". But the production of wrought iron by this crude process provided the needs of industry not only until bulk steel was produced by the developments of 1856 and onwards, but well afterwards: as late as 1889 the annual production of wrought iron was $2\frac{1}{4}$ million tons with the peak of 3 million tons having been reached in 1872/3. This has been somewhat of a digression but it has a bearing on the story, in that we are looking at the features which influenced the demand for iron. A major influence in the early 19th century was the introduction of steam locomotion and the growth of the railways.

The quickening pace of both industrialization and transport brought a tremendous impetus to the iron industry. Clifton, Maryport, and Barepot furnaces were too early to benefit. The two former closed in 1771 and 1782. Barepot changed hands in 1837 and a blast furnace was rebuilt but does not appear to have resulted in any great activity.

From 1840 onwards, however, things began to move. In that year a blast-furnace plant was erected at Cleator Moor. In 1857 and 1858 similar installations appeared at Harrington and Workington, and in 1863 the West Cumberland Iron Company built five furnaces at Workington, which were later increased to seven. This latter company added to their blast-furnace plant by erecting 32 puddling furnaces and in 1865 were rolling 400 tons of wrought-iron plates per week in sizes up to 7 ft × 2 ft.

Smaller companies operated in the area buying the locally produced pig iron and converting it into wrought iron. In the mid 19th century, railway expansion in Britain proceeded apace and the demand for rails continued to stimulate the iron trade. Overseas countries were also turning to mechanical locomotion and were buying their rails from Britain, where the earlier industrial lead had provided the "knowhow" and ability to supply. The rails were however still being made from wrought iron, at that time the only suitable material for the purpose.

This was the position in 1856 when Henry Bessemer introduced his steelmaking process which was eventually to result in the wrought-iron rail being completely superseded. Hitherto, steel had been produced in crucibles by melting down wrought iron which had been impregnated with carbon by prolonged heating in contact with charcoal (cementation process—crucible steel). The process was lengthy and costly and the product measured in hundredweights rather than tons.

Bessemer's process had its teething troubles and it was some time before the chemistry of steelmaking was fully understood, but from the outset it became fairly obvious that "Bessemer steel" was to be a superior material to wrought iron for many purposes. Trials of steel rails in the track were soon to confirm this.

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The Barepot project was a more ambitious scheme, and over the years developed into what we would now call an engineering works. It was here that the Heslop engine had its origins and from there that the Heslops extended their activities to Lowca. The Barepot story is sufficiently interesting to make a paper on its own and it still provides opportunities for research into its early history. Actually it survived operationally in one form or another and under various ownerships until 1862.

These three early ironmaking establishments cannot, however, be regarded as the foundation of what was later to become the major industry of West Cumberland. Almost 100 years had to elapse before there were serious and substantial developments. Much had happened in the meantime as the Industrial Revolution gathered force. Mechanical means gradually supplanted manual operations. Steam replaced the water-wheel and removed the necessity for siting adjacent to rivers. The demand for iron received an impetus from these developments which at the same time provided the means for meeting the demand.

Cast iron did not, of course, fully meet these demands and it was not until Cort introduced his puddling process that wrought iron with its superior tensile properties could be produced in quantity. From then only did blast-furnace pig iron production begin to move.

It is perhaps difficult in these days of bulk production to realise what an important part the puddling furnace played from its inception in 1784 until the end of the 19th century. The small reverberatory furnace (6 ft × $4\frac{1}{2}$ ft) had 4-cwt charges and used 5 to 6 tons of coal per ton of finished wrought iron. Working 6 or 7 charges per 12-h shift, their operations required the most strenuous manual effort of any manufacturing process (before or since).

In 1880 J. S. Jeans wrote that "the puddling furnace had been condemned as crude, barbarous and wasteful, yet it continued to enjoy a measure of vitality and appreciation to which its merits did not entitle it". But the production of wrought iron by this crude process provided the needs of industry not only until bulk steel was produced by the developments of 1856 and onwards, but well afterwards: as late as 1889 the annual production of wrought iron was $2\frac{1}{4}$ million tons with the peak of 3 million tons having been reached in 1872/3. This has been somewhat of a digression but it has a bearing on the story, in that we are looking at the features which influenced the demand for iron. A major influence in the early 19th century was the introduction of steam locomotion and the growth of the railways.

The quickening pace of both industrialization and transport brought a tremendous impetus to the iron industry. Clifton, Maryport, and Barepot furnaces were too early to benefit. The two former closed in 1771 and 1782. Barepot changed hands in 1837 and a blast furnace was rebuilt but does not appear to have resulted in any great activity.

From 1840 onwards, however, things began to move. In that year a blast-furnace plant was erected at Cleator Moor. In 1857 and 1858 similar installations appeared at Harrington and Workington, and in 1863 the West Cumberland Iron Company built five furnaces at Workington, which were later increased to seven. This latter company added to their blast-furnace plant by erecting 32 puddling furnaces and in 1865 were rolling 400 tons of wrought-iron plates per week in sizes up to 7 ft × 2 ft.

Smaller companies operated in the area buying the locally produced pig iron and converting it into wrought iron. In the mid 19th century, railway expansion in Britain proceeded apace and the demand for rails continued to stimulate the iron trade. Overseas countries were also turning to mechanical locomotion and were buying their rails from Britain, where the earlier industrial lead had provided the "knowhow" and ability to supply. The rails were however still being made from wrought iron, at that time the only suitable material for the purpose.

This was the position in 1856 when Henry Bessemer introduced his steelmaking process which was eventually to result in the wrought-iron rail being completely superseded. Hitherto, steel had been produced in crucibles by melting down wrought iron which had been impregnated with carbon by prolonged heating in contact with charcoal (cementation process—crucible steel). The process was lengthy and costly and the product measured in hundredweights rather than tons.

Bessemer's process had its teething troubles and it was some time before the chemistry of steelmaking was fully understood, but from the outset it became fairly obvious that "Bessemer steel" was to be a superior material to wrought iron for many purposes. Trials of steel rails in the track were soon to confirm this.

now regularly achieved (from 250 tons per week per furnace to 5, 000). The early stone-built furnaces had open tops and cold blast. Nielson's introduction of hot blast (350°C) in 1828, resisted because of its suspected effect on iron quality, was later adopted at the Old Side furnaces of the Workington Iron Company, the stoves being heated by coal fires (until 1879). Closing the furnace tops and using the gas for heating the blast came later, as did the regenerative type of hot-blast stove. More powerful blowers led to bigger hearth diameters and higher outputs. Ore preparation, improved coke quality, and sintering of fine ore all made their contribution, as did the mechanical aids such as skip charging, pig-casting machines, taphole guns, etc. A major step in the final concentration of iron and steel manufacture at Workington was the building of coke ovens in 1936, permitting a degree of integration which had not previously been possible.

I suppose what I have been telling you can be classed as "historical metallurgy" and it may be of more interest in 100 years time than it is to-day. I am afraid there are few remains to be found of the plants I have mentioned, but plans do exist and should be worth preserving. One point worth making is that West Cumberland offers a striking example of the effects of technological change on the well-being and prosperity of an industry and of the people dependent on it for a livelihood.

Going back to the building of the first furnaces at Workington in 1857/8 the town had a population of 6, 000. As more works were established there were not enough locals to man these and people were recruited from Scotland and Ireland. Later, Cammells brought their own people from Dronfield and in 1891 the population of Workington was 25, 000. There were sorry times for some of these people in the '80's and there were many who emigrated, but for those who stayed the soup kitchen, the pawnshop, and the workhouse featured all too prominently in the local scene.

Fortunately, the area is no longer solely dependent on coal mining and iron and steelmaking, and there is sufficient variety of industry to provide a stability that did not exist in the bad old days.

Reports on Work in Progress

Excavations at Panningridge Furnace, Sussex, 1968

D. W. CROSSLEY

The Background

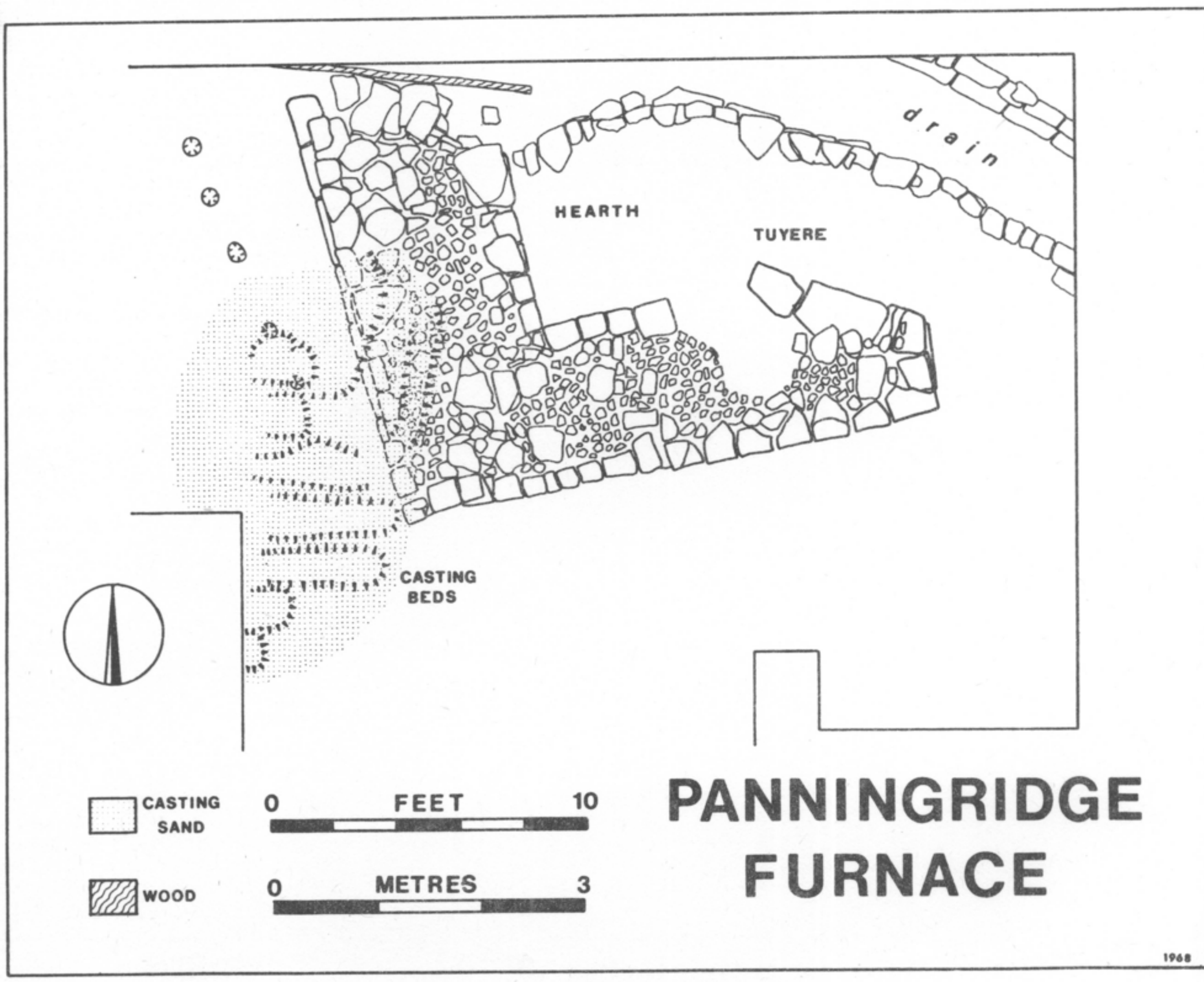
Documents in the De L'Isle and Dudley Collection show that Panningridge was built in 1542 for Sir William Sidney to smelt the ores of the Ashburn Valley, mined in the area now known as Pannelridge Wood. Pig iron was carried, probably along the existing holloway towards Netherfield, to be converted into wrought iron at the finery forge at Robertsbridge. Between 1542 and 1546 this forge was also supplied by a furnace near Robertsbridge, built in 1541, but this fell into disuse during 1546 and Panningridge was the sole supplier until 1563. After 1563, less is known of the furnace; in that year the Sidneys relinquished the lease of the site, and thereafter it was run by William Relfe and Bartholomew Jeffrey, two ironmasters with widespread local interests in the industry. The length of their tenure is not known, and by 1574 the site was in the hands of John Ashburnham, who is also recorded as holding it in 1588. Whether it was still in use at these dates is uncertain, but by 1611 its existence seems to have been no more than a local memory.

The Excavation

Fieldwork and trial trenching in 1964 and 1967 established the site of the furnace (Nat. Grid Ref. TQ 687175), which lies close to the west end of a dam, now breached, across the Ashburn valley. A wooden area of about $1\frac{1}{2}$ acres on the downstream side of the dam is covered with slag dumps and is severely waterlogged. The only traces of water-courses associated with the furnace are two channels, one at either end of the dam, which, using as a parallel the furnace site at Sheffield Park, Fletching, appear to have been overflow spillways for the pond.

The plan this season was to extend the trial cuttings made in 1967 at the base of what may be a charging ramp close to the west end of the dam. Unfortunately, heavy and prolonged rain in June and July made it impossible for a mechanical excavator to enter the site to remove the overburden of silt, and a restricted area had to be dealt with entirely by hand, although greatly aided by an engine-driven spoil-winch.

The excavation yielded the plan of the southern side of the furnace. The foundations of the south wall were intact; much of the west end, together with the working platform and the site of the forehearth, had survived, with the hard sand of the pig beds into which the molten iron had been run. It appeared that in the last campaign pigs 4ft × 6in × 6in had been cast. The west end of the furnace had been largely destroyed by an open water-course which had been dug through the structure soon after its abandonment; however the south side of the tuyère was clear, and its presence on the opposite wall to the



tap-hole is of major interest and completely at variance with surviving 17th century furnaces such as Rockley. The north wall of the furnace probably lay just outside the area of the year's excavation, but is unlikely to have survived the building of the water channel. The hearth had been removed from the furnace, but much of the internal stonework of the south and west sides of the furnace tower, against which the hearth would have been built, had survived.

After abandonment and the robbing of the upper stonework of the furnace, no doubt by the Ashburnhams to build their own furnace, the site appears to have been levelled and clay deposited. This appeared as a distinct platform of reddened clay, and its uses as an ore-roasting platform may be suggested. The clay seems to have been deposited at much the same time as the construction of the water-course, roughly built of furnace stones.

The entire site was covered with silt and slag, some of which appeared to have been levelled and consolidated as a platform sealing the red clay. No pottery was found to suggest that this deposit dated from later than the early 17th century.

Future work has two clear aims, to check whether any traces of the north wall of the furnace survived the construction of the later water-course, and to locate and examine the water channels serving the bellows' water wheel. Thus area excavation to the north and to the west of the 1968 cuttings will be required, and it is hoped to carry out some of this work in the summer of 1969.

Acknowledgments

Thanks are due to the owner of the site, Mr J. Spencer Wills, for permission to excavate; to the tenants, Messrs. W. and G. Rudman, for their continued help and interest, and in particular for allowing the cuttings to be fenced and left open until next season; to Mrs J. Stiles for her indefatigable help with local arrangements; to Messrs. Bush, Morse and Welling, the agents for the estate, for their interest and co-operation; to the Knoop Fund of Sheffield University and the Sussex Archaeological Society of financial support, and the Twenty-Seven Foundation for assistance with transport. I must thank particularly all those volunteers who helped to make this season such a success, despite weather and conditions worse than most of them had ever encountered; to those who provided accommodation and who were made only too aware of the conditions on the site, our particular gratitude and apologies are due.

Excavations at Chingley, Kent, 1968

D. W. CROSSLEY and D. ASHURST

A scheme is under consideration to dam the River Bewl, near Old Forge Farm, Lamberhurst, in order to create a reservoir for the provision of water for the Medway towns. This proposal threatens two iron-working sites, the late 16th-century blast-furnace at TQ 684327, and the 17th century finery forge at 682335.

Excavations began in August 1968 with the aid of a grant from the Ministry of Public Building and Works made through the Society for Post-Medieval Archaeology to attempt precise location of these sites as a preliminary to fullscale excavation.

The furnace

Only brief testing of the site was possible in the available time; the dam crossing the Bewl valley at 684327 may now be accepted as belonging to the furnace. A limited area downstream from the surviving bank is covered with blast-furnace slag, and tests disclosed building debris in a small part of the south-east corner.

The forge

Test-trenching confirmed that the site lies at the south end of a marshy strip running parallel to the Bewl between 682335 and 683337.

The hill-slope to the east, although covered by deposits of cinder and charcoal, did not appear to have been built upon and the meadow to the west was the site of scattered tips of cinder.

The main test-trench across the marsh disclosed a deep channel running beneath an accumulation of silt and humus. This cutting was extended southwards, and a partially culverted stone-lined channel, part of a building containing a hearth, and a complex of post-holes were stripped. The site had been damaged by stone field drains, one built on the capping-stones of the culvert, another cutting through the furnace.

The hearth lay against the north wall of a stone building which had been rebuilt on at least two occasions; it had been lined with iron plates in the way mentioned in contemporary descriptions of forges, and fragments of two of these survived. The position of the tuyère could be estimated, halfway along the back wall of the furnace. Whether the hearth was used as a finery or a chafery is not yet clear. Whilst superficially it resembles a finery, excavation of others on the site may allow overall comparisons to be made, showing detail differences between the two types.

A group of postholes lay outside the north wall of the hearth building, in significant relationship both to this and to an unculverted portion of the main water-course. It appears that upright timbers had supported the bellows, for which an undershot wheel in the adjacent channel provided power.

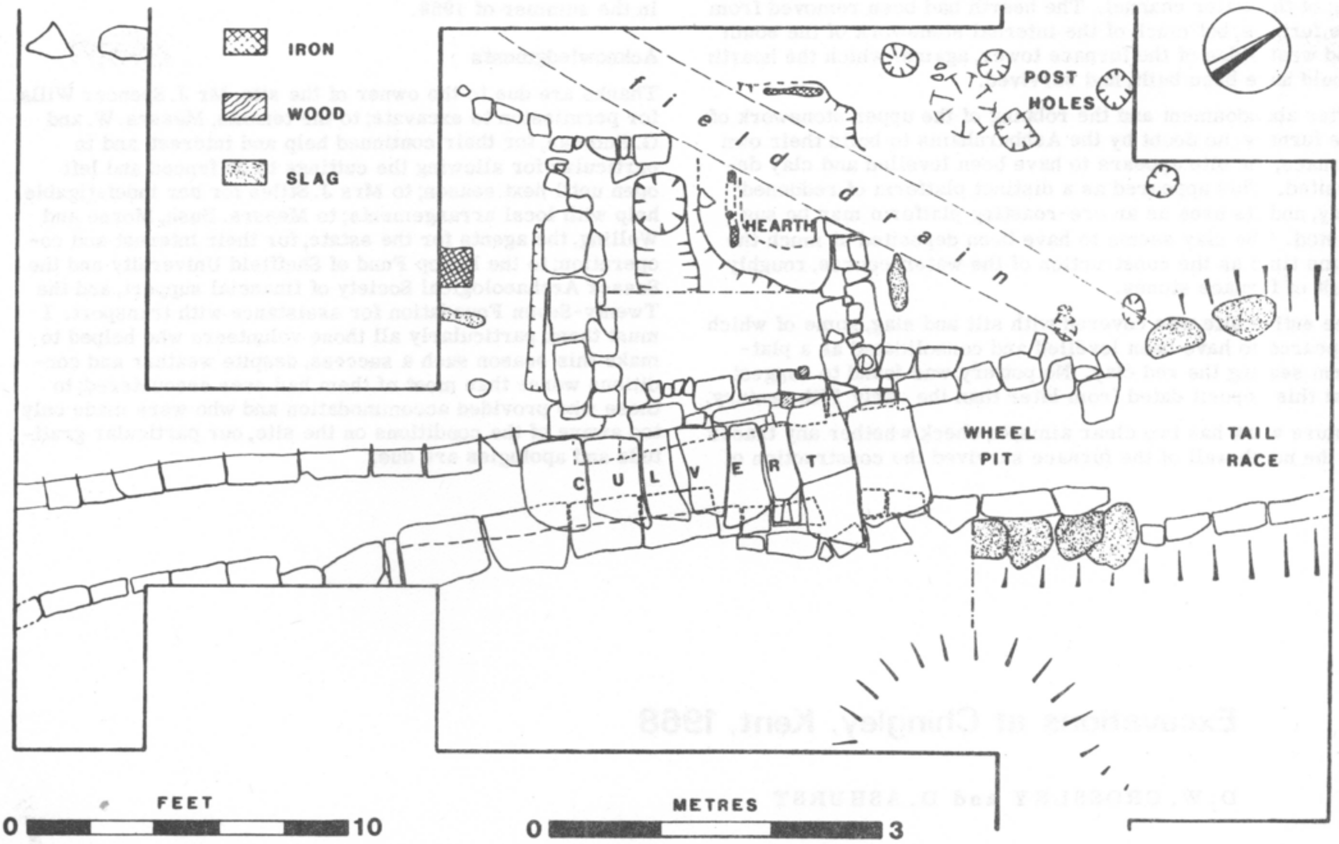
Future work on the site will be devoted to establishing the scale on which operations took place, to be judged from the number of finery and chafery hearths, the type of hammer and the character of the water-supply. This latter is a particular problem, for a machine-dug section of a slight bank across the valley failed to reveal clear indications of a dam, making the use of a leet from higher up the Bewl seem the more likely.

Further excavations are planned for Easter and Summer 1969.

Acknowledgements

Thanks are due to Mr Christopher Hussey, owner of Scotney Castle estate, for permission to excavate; to Mr G. D. Veitch, tenant of Bewl Bridge Farm, for practical help on numerous occasions; to the estate's agents, Messrs. Langridge and Freeman, for their interest and co-operation; to all those volunteers who helped to make the excavation a success; to the Ministry of Public Building and Works for financial help; to the Twenty-Seven Foundation and the Knoop Fund of Sheffield University for assistance with transport; and to those who provided accommodation for volunteers.

CHINGLEY FORGE KENT



Excavations at Bardown, Sussex, 1968

H. F. CLEERE

Excavation continued at the Bardown Roman industrial site at Wadhurst, Sussex (Nat. Grid Ref. TQ 663294) from 29 July to 18 August 1968, and for two subsequent weekends.

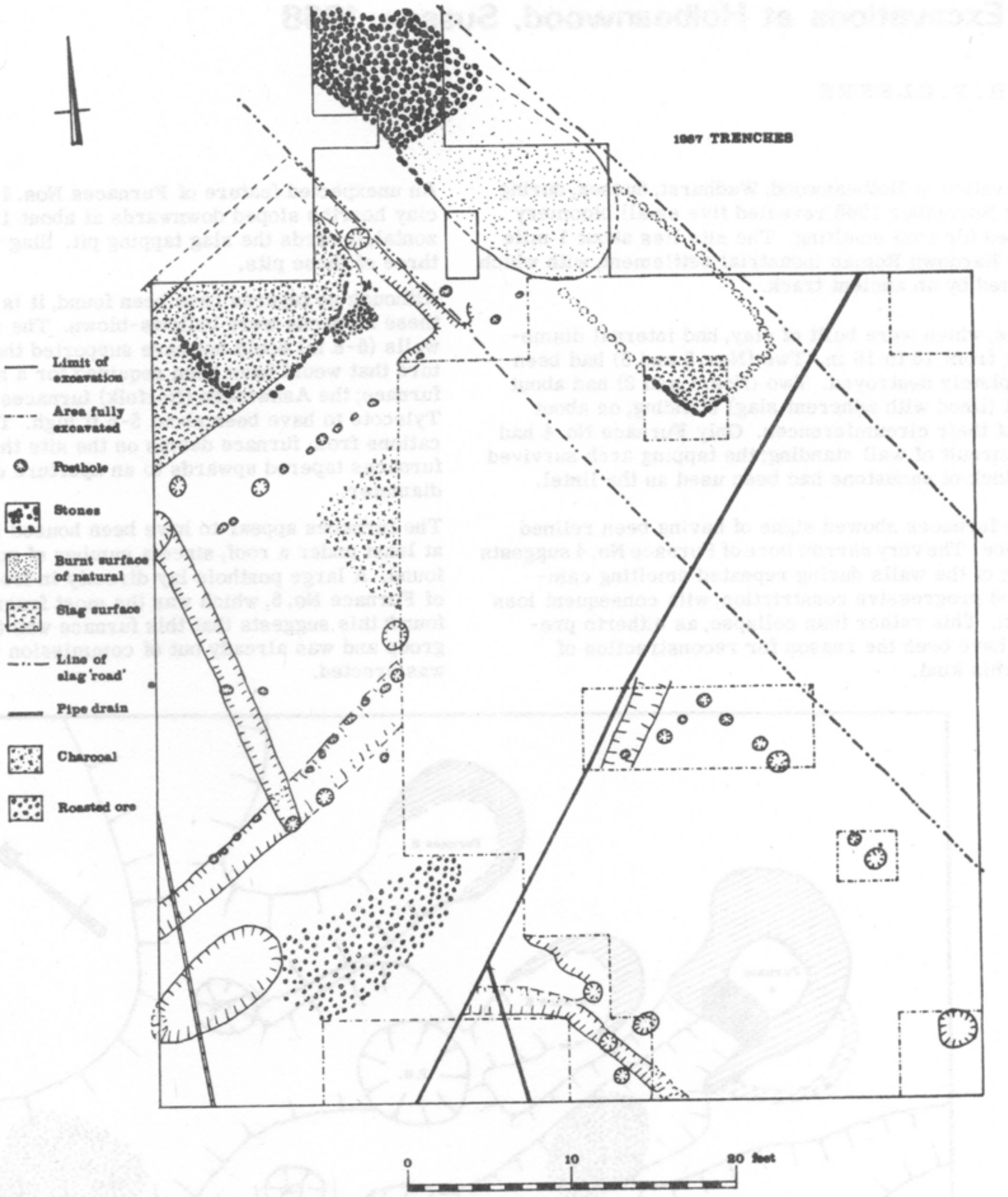
Digging was concentrated in part of the presumed "industrial" area of the site, immediately above the area investigated in 1967. An area 50ft square was cleared mechanically to a depth of 1ft, and this was followed by hand excavation. Unfortunately, loss of time due to bad weather and an unexpected depth of archaeological layers prevented the full excavation of the whole area down to the natural Ashdown sand; in total about 40% of the area was fully excavated.

The slag and stone metalled road found in 1967 running down towards the refuse bank was traced for a further 40 feet. In association and alignment with its earlier stone-built phase there were found postholes and sleeper-beam trenches, which formed part of a substantial timber-framed building of mid-2nd century date. This building appeared to have been used as a workshop. It had a floor of clay, overlaid in two areas by thick dumps of charcoal. An area edged with stones had been exposed to fairly high temperatures, and has been interpreted as a forging hearth; the adjacent area was roughly cobbled with stones and slag.

This building was also associated with the area of heavy burning about 10ft in diameter found in 1967. It seems reasonable, in view of 1968 finds, to interpret the latter as a permanent charcoal-burning hearth. Charcoal made in this area would have been stocked in the workshop building, for use on the forging hearth and also in the ore-roasting furnace (discovered in 1962) which lay outside the workshop. Considerable debris in the form of roasted ore particles was found in this area during 1968.

The next phase of development in this area involved the successive remetalling of the road surface with slag. At some point during these remetallings, the building was either demolished or fell down (there is no evidence of destruction by fire), since later slag spreads overlie the postholes nearest the road. During this period, the ore-roasting furnace continued in use.

A second building lying further to the east (only partly excavated) had a history and structure similar to the first.



Since only a small area of the interior was excavated fully, it was impossible to define its purpose, although an associated latrine pit may indicate a domestic use.

By the first half of the third century, the whole area was being used as a rubbish dump: a layer of rubbish at least 1ft thick was found over the entire trench. From the finds in this layer, which were considerable, it would appear to have been in use well into the latter part of the third century: a single sherd of New Forest Ware implies a terminal date several decades later than had been assumed previously. The inference to be drawn is that industrial activities had either ceased or been transferred elsewhere by about A. D. 220, but the occupation continued. At some time at the end of the third century the refuse area appears to have been re-settled, since a small domestic hearth made of tile and stone was found, on the surface of this layer. This was associated with a stone alignment running across the site, which may have formed part of a building, of which one or two postholes were traced.

One of the most interesting features of the rubbish spread was the fact that no fewer than 22 tiles bearing the CL BR stamp of the Classis Britannica were found in this area. Hitherto, only three stamped tiles had been found—one in 1950 and two in 1965. The large number of stamped tiles found this year in the latest phase of the site may indicate a change of ownership or control in the early third century.

Other finds during the 1968 campaign included a bronze-melting crucible, two bronze fibulae (one inlaid with red enamel), several pieces of lead, including a pattern used for the manufacture of cast bronze keys, a number of coins (all except one of bronze and therefore illegible owing to the soil conditions on the site, which promote very severe corrosion of bronze coinage alloys), a considerable amount of glass, and an iron shovel, believed to be of Roman date.

An area outside the main building referred to above proved on the last day of the excavation to contain a number of very large sandstone blocks. It is proposed to excavate this area more throughly in 1969.

The plan shows features in the earliest phase.

Acknowledgments

Thanks are due to Commander I. A. Beattie, R. N. (Retd), owner of the site, and Mr W. de Salis, the tenant, for permission to excavate; to The Iron and Steel Institute for their grant towards the running expenses; to my wife for looking after the commissariat; to Mr R. Bray, MA, my deputy Director; and to the diggers, many of them veterans of several seasons at Bardown.

Excavations at Holbeanwood, Sussex, 1968

H. F. CLEERE

A trial excavation at Holbeanwood, Wadhurst, Sussex, during October and November 1968 revealed five small bloomery furnaces used for iron smelting. The site lies about 1 mile north of the Bardown Roman industrial settlement, with which it is connected by an ancient track.

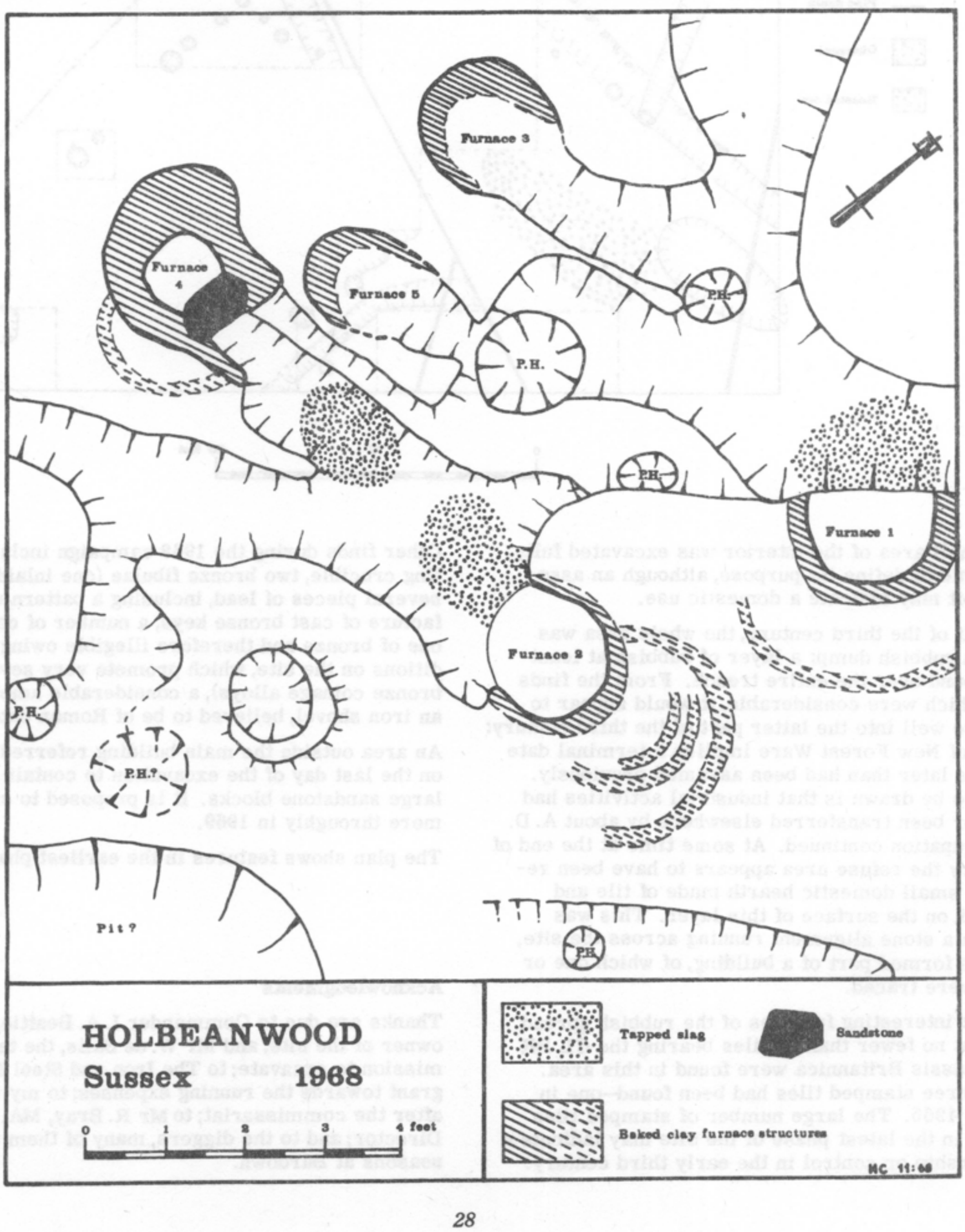
The furnaces, which were built of clay, had internal diameters ranging from 10 to 18 in. Two (Nos. 3 and 5) had been almost completely destroyed. Two (Nos. 1 and 2) had about 9 in. of wall (lined with adherent slag) standing, on about two-thirds of their circumferences. Only Furnace No. 4 had a complete circuit of wall standing; the tapping arch survived because a block of sandstone had been used as the lintel.

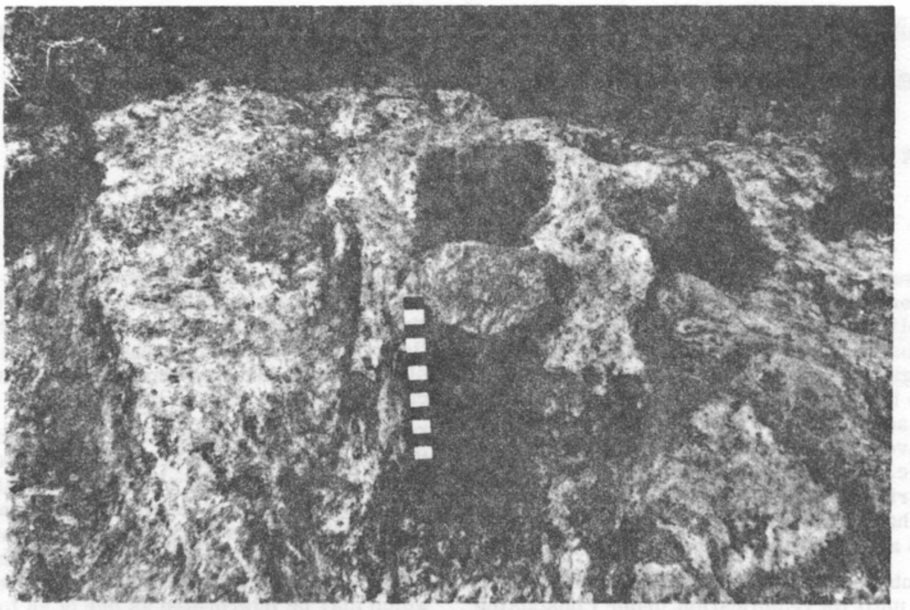
Three of the furnaces showed signs of having been relined more than once. The very narrow bore of Furnace No. 4 suggests that slagging of the walls during repeated smelting campaigns caused progressive constriction, with consequent loss of production. This rather than collapse, as hitherto presumed, may have been the reason for reconstruction of furnaces of this kind.

An unexpected feature of Furnaces Nos. 1 and 2 was that the clay hearths sloped downwards at about 10° below the horizontal, towards the slag tapping pit. Slag was found in situ in three of these pits.

Although no tuyeres have been found, it is presumed that these furnaces were bellows-blown. The relatively thin walls (6-8 in) could not have supported the large superstructure that would have been required for a natural draught furnace; the Ashwicken (Norfolk) furnaces were calculated by Tylecote to have been about 5-6 ft high. There are also indications from furnace debris on the site that the Holbeanwood furnaces tapered upwards to an aperture of about 6-9 in diameter.

The furnaces appear to have been housed inside a building, or at least under a roof, since a number of postholes were found. A large posthole lay directly in front of the open side of Furnace No. 5, which was the most fragmentary of those found; this suggests that this furnace was the earliest of the group and was already out of commission when the building was erected.





Holbeanwood Furnace No. 4

The only non-metallurgical finds on the site were a few sherds of coarse pottery, similar to the abundant Bardown material. It is suggested therefore that the Holbeanwood site was an outlier of the main Bardown settlement, where iron-making was first carried out in this area. Exhaustion of iron ore resources and deforestation in the immediate vicinity of the settlement would have resulted in the establishment of workplaces farther away, since it would have been uneconomic to bring large quantities of ore and timber or charcoal relatively long distances into the main settlement for working. It is anticipated that other sites of this kind may be found on the iron-bearing Wadhurst Clay around Bardown; one such site in Coalpit Wood, about 1 mile to the south-west, has already been identified.

It is proposed to explore the Holbeanwood site more fully in 1969, in the hope of finding a more complete plan of the building. The furnaces will also be sectioned, in order to study their construction and operations.

Acknowledgments

Thanks are due to Commander Hugh Mulleneux, RN(Retd), owner of Holbeanwood, and to Mr Peter Mulleneux for making the site known, for encouraging excavation, and for their tremendous help and enthusiasm, and to the loyal diggers who survived some very wet and cold weekends.

Chemical analyses of some weight-reduced Roman folles minted between AD 307 and 318

LAWRENCE H. COPE AND HARRY N. BILLINGHAM

In three previous issues of the Bulletin (1),(2),(3) the authors have included the chemical analyses of a number of both the large and reduced folles, and have shown[3] that the large tetrarchic folles coinages minted between c. AD 294 and the middle of 307 had significantly different finenesses, after AD 299, according to their mints of origin in either the Eastern or Western administrative territories. Nevertheless they all appear to have been struck to a weight-standard of 32 pieces per libra (c. 10. 5g). The Eastern follis (of greater intrinsic worth by virtue of its much higher silver content) can be calculated to have had a metal value equivalent to 0.454g of silver, and a theoretical silver content of 0.353g.(4)

The coinage of the subsequent period reflects the sharpening divisions of Empire, until its reunification, under Constantine the Great, in AD 324; and the most recent coin assays reveal a few of the combinations of weight-standards and fineness levels pertaining to those weight-reduced folles, minted from AD 307 onwards, during a complex period of major political disputes, economic crises, and continued inflation. There are formidable problems in resolving the chronological sequence of coinage policies adopted by the principal rulers during the this period, but it is believed that the determination of the metallic composition of the main coinage issues, for each stage of weight-reduction under each separate administration, is of paramount importance to further progress. With this in mind, the authors make available, in Table I, the assay results which are beginning to reveal the similarities, and the major differences, in the minting practices and policies of the imperial rivals. We can now discern features of the coinage which may not have been generally known to the majority of the populace using it in the era in which it was produced.

One important fundamental principle appears to have been universally observed, even as the coinage was diminished in size and in intrinsic worth (and, no doubt, in purchasing power): no matter how debased they became, the reduced folles continued to be, in reality, a true "silver" denomination. Between AD 310 (5) and 323 (6) they appear to have constituted the only silver denomination. It is obvious that each Emperor recognized the necessity of incorporating some (though small) proportion of silver in the coinage alloys, perhaps to placate public opinion and to give the coinage an acceptable intrinsic worth beyond that of the base-metal content.

The weight-reductions

At the Constantinian mints of Londinium, Treveri, and Lugdunum, the first weight-reductions were effected in the spring and summer of AD 307. By the end of that year a new weight-standard (of c. 6. 5g) was in operation, and this continued for some two years until it was again revised (in late 309 or early 310) to one of c. 4. 5g. These step-changes (7) appear to represent changes in the minting practice corresponding to the production of 48 (and then 72) pieces per libra of alloy (8). The latter change coincided with the introduction of the gold solidus—also struck at 72 per libra—to which the current follis must have borne a direct token, as well as a weight, relationship, and to the demise of the "denarius argenteus".

Some time in late 312 a further weight-reduction was effected, to, perhaps, 96 pieces to the libra, before further reforms of the coinage took place (in 317 or 318) concerned with changes in weight and die-module, the issues of new types (9), and a probable universal revaluation of the coinage following the end of the first Civil War between Constantine and Licinius.

The mints in the Central Empire were severely disrupted in their operations between October 306 and 312 (10), in consequence of the revolt of Maxentius and his subsequent territorial acquisitions. Although the weight-reductions were roughly in phase with those initiated by Constantine, we are finding that both the finenesses and the base alloy compositions of the Maxentian coinage present a rather complicated picture which justifies separate consideration when more coin analyses have been completed.

Far from the scenes of major political turmoil, but nevertheless affected by the economic conditions in the Roman Empire as a whole, the mints of Antiochia and Alexandria do not appear to have been minting in the latter part of AD 307 (7). Early in 308, however, they began to mint folles at the new universal weight-standard of c. 6. 5g. These were rather more precisely controlled than in the West to a standard which may be interpreted as one of 48 to the libra (8). Later the Eastern folles were subject to a similar (but more precipitate and non-synchronous) pattern of weight decline to the Western folles.

Fineness standards and intrinsic worths.

At the Western mints the fineness standards of the argentiferous bronze folles coinage alloys appear to have been maintained for a while, at either 5 or 4 scrupula of silver per libra, during the initial coinage weight adjustments. For the period 307 to, perhaps, early 313, the Constantinian folles fell, therefore, in intrinsic worth, to two-thirds (and later to four-ninths) of the metal value of the large Western folles of c. 307. For the subsequent period (to 318) the assays in the Table reveal a certain lowering in alloy fineness to a consistent 4 scrupula of silver per libra (11). Further reductions in weight then brought the Western folles pieces down to less than one-third of the metal-worth of the tetrarchic folles of a decade earlier. It is in this light that we must now regard the papyrological evidence for inflation and the changes in the number of folles which equated with the gold pieces or equivalent bullion at different dates.

In the Eastern mints, where the strict and excellent metallurgical control of former days (3),(4) appears to have prevailed, the assays given in the Table, together with those published previously (2), taken in conjunction with the weight standards, enable quite a precise calculation to be made of the intrinsic worth of the first weight-reduced folles compared with that of the discontinued larger coinage. The four assays of Antiochene and Alexandrian weight-reduced folles point clearly to the adoption of a much lower fineness standard of three scrupula of silver per libra when coining was recommenced in 308: previously the large folles of Eastern mintage had contained 10 scrupula of silver per libra, in 32 pieces. The new pieces were, therefore, each worth only three-tenths of the previous folles, as metal, and the silver content of each individual piece had been reduced to one-fifth of what it had been before the reform. Thus, in 308, the Eastern follis lost the intrinsic superiority to the contemporaneous Western one at which it had been held, somewhat precariously, for seven years, and became, in fact, slightly inferior.

It seems strange that these Roman coinages, of significantly different intrinsic worth, minted contemporaneously with similar module and weight, and (presumably) completely interchangeable throughout the Empire, should have circulated freely together. The solution probably lies in their token values having been placed just above the intrinsic worth of the superior pieces, so that it would have become an unattractive proposition for people to hoard or to melt down either of the current issues. Perhaps the Emperors relied also on attempting to keep the circulation of their own coinages largely within their own administrative areas; and on the superficial silver "wash" to belie what truly lay beneath.

TABLE I Analyses of Weight-Reduced Folles Minted Between A.D. 307 and 318 in the Extremities of the Roman Empire

No.	Code No.	Emperor	Date of issue (A.D.)	Weight (grams).	Reverse type	Mint	CHEMICAL ANALYSIS—weight per cent Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc	Total	Sample	Coin Reference
Western Mints:																	
1.	B.M. 82	Constantine I	c. 309-310	4.95	SOLI INVIC/TO COMITI	Lyons	87.11	4.33	1.28	6.98	Trace	0.04	0.02	0.02	99.78	1	RIC VI Lyons 307
2.	N.M.W. 26	Constantine I	c. mid-310	3.71	SOLI INVIC/TO COMITI	London	86.78	5.54	1.76	6.01	0.01	0.02	0.01	Nil	100.13	1	RIC VI London 121a
3.	B.M. 83	Constantine I	c. mid-310 -late 312	4.45	COMITI/AVGG NN	London	85.12	3.39	1.51	9.56	0.03	0.02	0.04	0.01	99.68	1	RIC VI London 153
4.	B.M. 85	Constantine I	310- May 313	4.42	SOLI INVIC/TO COMITI	Trier	87.46	5.27	1.74	4.88	0.03	0.04	0.05	0.02	99.49	1	RIC VI Trier 874
5.	B.M. 91	Licinius I	313-314	3.01	GENIO/POP ROM	London	90.12	3.35	1.42	5.00	0.03	0.03	0.02	0.01	99.98	1	RIC VII London 3
6.	Ca : 12	Constantine I	313-315	4.89	SOLI INVIC/TO COMITI	Trier	87.18	4.87	1.38	6.05	0.06	0.04	0.02	0.02	99.62	1	RIC VII Trier 42
7.	B.M. 94	Constantine I	314-315	2.91	SOLI INVIC/TO COMITI	Lyons	86.02	4.84	1.47	7.58	Nil	0.03	0.03	0.02	99.99	1	RIC VII Lyons 17
8.	B.M. 57	Licinius I	316	3.59	GENIO/POP ROM	Trier	89.70	2.99	1.34	5.35	0.06	0.08	0.07	0.03	99.62	1	RIC VII Trier 120
9.	Ca. 10	Constantine I	316-317	2.60	SOLI INVIC/TO COMITI	London	86.57	4.24	1.32	7.60	0.04	0.03	0.03	0.02	99.85	1	RIC VII London 92
10.	B.M. 98	Constantine I	318	2.91	SOLI INVIC/TO COMITI	London	89.50	4.27	1.27	4.47	0.02	0.03	0.04	0.01	99.61	1	RIC VII London 137
11.	B.M. 58	Constantine I	318	4.82	SOLI INVIC/TO COMITI	London	87.89	4.33	2.11	5.57	0.02	0.01	0.01	0.01	99.95	1	RIC VII London 140
Eastern Mint:																	
12.	B.M. 81	Maximinus Daza	Late 308 -310	6.59	GENIO IMP/ERATORIS	Alexandria	92.45	1.92	1.15	4.53	0.03	0.03	0.02	0.01	100.14	1	RIC VI Alexandria 107a
13.	M. 5	Maximinus Daza	c. May 311	7.09	BONO GENIO PII/IMPERATORIS	Alexandria	92.30	2.28	0.97	4.04	0.04	0.05	0.03	Nil	99.71	1	RIC VI Alexandria 144b
								2.12	1.48	(Filings which included the surface-silvered layer)						2	

The base-metal alloys

At both the Eastern and Western mints the changes in weight and fineness after 307 do not appear to have made any difference to the continuation of preferred metallurgical traditions of alloy manufacture. The practice of adding almost equal proportions of lead and tin, in the characteristic proportions already associated with individual mints (4), seems to have persisted. At the Central mints, under Maxentius, changes were made, however, in the direction of much more highly leaded alloys. It is planned to report these coin analyses in a future issue of the Bulletin.

Acknowledgments

Our grateful thanks are extended again to the Governors, the Principal (Mr H. A. MacColl) and the Head of the Department of Metallurgy (Dr G. J. T. Hume) of the Wednesbury College of Technology, for continued encouragement and for the provision of facilities for metallurgical analysis.

We are also deeply indebted to the following for their generous provision of disposable coins for analysis: Mr G. C. Boon, National Museum of Wales (Coin coded N.M.W.); Mr R. A. G. Carson, The British Museum (Coins coded B.M.); Mr Robert Hogg, The City Museum and Art Gallery, Carlisle (Coins coded Ca.); and Professor F. C. Thompson, The Manchester Museum (Coin coded M.).

Notes and references

1. L. H. Cope and H. N. Billingham: Bulletin of the Historical Metallurgy Group, 1967, 1, (9).
2. L. H. Cope and H. N. Billingham: Ibid., vol. 2, (1).
3. L. H. Cope and H. N. Billingham: Ibid., vol. 2, (2).
4. L. H. Cope: "The Argentiferous Bronze Alloys of the large Tetrarchic folles of AD 294-307" in The Numismatic Chronicle, 1968 (to be published).
5. When the "denarius argenteus", of finer silver, ceased to be minted.
6. When Constantine introduced a new silver piece (the siliqua), minted at one hundred and forty-four to the libra.
7. See, for the details, C. H. V. Sutherland: "The Roman Imperial Coinage", Vol. VI: Diocletian to Maximinus, AD 294-313 (1967).
8. A metallurgical explanation for the selection of these sub-divisions will be given in a final report to be offered to the Royal Numismatic Society.
9. The VICTORIAE LAETAE PRINC PERP issues of Constantine, in the West, and the IOVI CONSERVATORI AVGG issues with helmeted left-facing obverse busts, in the East. (Both coinages have finenesses superior to those of the preceding issues—work yet to be published).
10. Or, Oct: 311; according to the interpretation preferred for the date of the battle of Milvian Bridge and the death of Maxentius. C. H. V. Sutherland (op. cit.) argues for 312; P. Brown: "The Roman Imperial Coinage", Vol. VII: Constantine and Licinius (1966), argues for 311.
11. Item No. 11 in Table I could be indicative of a raising of the fineness standard with some of the last issues of the SOLI INVICTO COMITI coinage, before a distinct improvement with the next issues (Ref. 9 above).

Annual General Meeting, 25 April 1968

Minutes of the Annual General Meeting, held in the rooms of the Society of Antiquaries, Burlington House, London, at 2.30 p.m. on 25 April 1968.

Present: Henry Cleere, W. K. V. Gale, B. M. Hardman, B. Earl, J. R. Platt, W. I. Pumphrey, Hugh O'Neill, H. H. Coghlan, Leo Biek, L. B. Hunt, B. H. Tripp, E. E. White, Alan Davies, M. M. Hallett, and R. F. Tylecote with Geo. R. Morton in the Chair.

Apologies: for absence were received from the President (M. F. Dowding) A. J. Shore, D. M. Headworth, Charles Blick, Sir Alfred Owen, Norman Bridgewater, Sir Frederick Scopes, H. R. Mills, K. C. Barraclough, and D. W. Crossley.

1. Minutes of the last meeting on April 20th, 1967 were approved and signed by the chairman as a correct record.

2. Matters Arising No matters were brought up.

3. Chairman's Report

In his last report Mr Morton mentioned that the association with The Iron and Steel Institute and The Institute of Metals would result in an improvement of the facilities offered by the Group. This improvement could now be seen in the quality of the Bulletin and the distribution of reprints from the Institutes and the Institution of Metallurgists.

During the year the Group had been represented on the steering committee of the Confederation of British Industries for the preservation of industrial monuments, and as a result of recommendations from members attending the 1967 conference the Gloucester County Council had taken action to preserve the sites at Gunn's Mill and Whitecliff, both in the Forest of Dean. The work of the steering committee was now complete and a permanent committee was being set up.

Once again the annual conference had been an unqualified success, mainly due to the hard work of members in the Forest of Dean area. Members in the Lake District were in the final stages of preparation for the 1968 conference.

Work on slags had continued, but had been somewhat retarded by foot and mouth disease; nevertheless the prototype of a box of representative blast-furnace slags was ready and on view. It only remained to collect one more sample from a foot and mouth area and the set would be available on loan to members via the Joint Library.

Prior to the last A.G.M. it had been decided that the president and chairman should take office for a two-year period, and this year it was his turn to retire from the chair. This pattern was correct and, whilst he would sincerely thank all members of the Group for the considerable help they have given him, he was sure that continued enthusiastic support would be given to the new chairman who, he was sure, would serve the Group well.

4. Secretary's Report

The Secretary (Dr R. F. Tylecote) was again able to announce another considerable increase in membership. This now totalled 425, of which 272 were members of the ISI and probably other Institutes, 45 Members of the Institute of Metals, and 108 members of neither of the metallurgical Institutes. The Group was receiving the Bulletin of the Peak District Mines Historical Society and the Revue d'Histoire de Sidérurgie by exchange with the H.M.G. Bulletin, and both these journals could be obtained on loan from the Secretary.

As usual two Bulletins had been issued during the year. The first contained a wide range of subjects of ferrous and non-ferrous interest and the second contained the papers submitted to the Annual Conference in the Forest of Dean and some other papers of non-ferrous interest. An offprint of a paper on an Israeli copper smelting site was circulated with this issue. Once again thanks were due to the ISI for their help in producing the Bulletin which now had a very high technical standard.

The Annual Conference had been held in September in the Forest of Dean; it had been well attended and an undoubted success.

Members had advised or conducted a number of excavations during the year. These were at iron smelting sites in the Weald where Henry Cleere again dug his Roman site at Bardown and David Crossley his blast furnace site at Panningridge. J. H. Money had completed his excavations at Withyham. The Secretary had spent a fortnight on the excavation of a 17th century bloomery at Muncaster Head in the Lake District in July and completed this excavation during the Easter holidays of 1968. He had also advised on the excavation of a Nigerian site of the early iron age (5th-3rd cent. BC), where 13 iron smelting furnaces had been found.

With the advice of the Chairman, the Owen Organisation had been excavating John Wilkinson's furnace site at Bradley, Staffs.

The formation of the Wealden Iron Research Group had been a great success and, as Mr. Cleere was later to announce, the first meeting had been held with a very large attendance.

5. Treasurer's Report

The Treasurer (Mr M. M. Hallett) presented his audited balance sheet for the year 1967. This was put to the meeting and formally adopted. He noted that the conference continued to make a slight profit and that the Group had been able to make a donation during the year to Mr. Money's excavation. The small credit balance was therefore increasing towards a state where it would be possible to support more causes of this type.

6. Election of Officers for the year 1968-69

As there were no other nominations for the posts of officers or for the committee, the following were declared elected:-

Officers

Chairman:	W. K. V. Gale
Hon. Secretary:	R. F. Tylecote
Asst. Secretary:	D. W. Crossley.
Hon. Treasurer:	M. M. Hallett.

Committee

K. Barraclough
C. R. Blick
N. Bridgewater
M. W. Flinn
B. H. Hardman

After his election the new chairman took the chair and thanked the past chairman, G. R. Morton, on behalf of everyone for the great work he had done since the Group's inception. This was heartily endorsed by all.

It was recommended that The Iron and Steel Institute be requested if they would be willing to nominate G. R. Morton and H. F. Cleere as their representatives, and The Institute of Metals to ensure that Professor O'Neill should continue as their representative.

The Treasurer, in agreeing to stand for a further term, said that whilst he would be willing to do so, he felt that there should be regular changes in the list of officers and that it would be necessary to accept his retirement in due course. This principle of change was heartily endorsed by all those officers and members of the committee present. He moved the re-election of Dr Pumphrey as auditor and this was carried unanimously. He further recommended that the general subscription be maintained at 10/- and the overseas subscription at £1. These were also carried.

7. Fourth Annual Conference

This was to be held on the week-end of the 27th-29th September and would cover the area north of Lancashire and the southern end of the Lake District. It was hoped to visit the Hodbarrow mines on Saturday morning, and on Saturday visits would be paid to Penny Bridge, Spark Forge, Stoney Hazel, and Duddon Furnace. It was intended to centre the meeting on the town of Barrow. Saturday would be an informal evening as last year. It was hoped that Mr. Davies-Shiel would be able to lecture on the history of the non-ferrous industry in the Lake District and D. R. Wattleworth on ironmaking in recent times.

The Treasurer announced that, whilst he would collect the fee for the meeting, in view of the variety of accommodation available in Barrow and the surrounding area, this year each individual would be responsible for settling his hotel account.

8. Fifth Annual Conference

Various sites were suggested for this: South Wales, Cornwall, North Staffs, and Ireland, but the meeting felt that the choice lay between Cornwall and South Wales. Professor O'Neill reminded the meeting that the Siemens centenary would be due in Swansea by then.

9. Publications

Henry Cleere raised the question of abstracts. It was hoped that more members would contribute to this section. At the moment it was kept going largely on those published in the Iron and Steel Institute Journal, but would soon be supplemented by the British Archaeological Abstract service which had just started. Dr Pumphrey drew attention to those of the Mid-West Archaeological Society in Detroit, and it was noted that International Institute of Conservation also published abstracts, some of which might be of use.

10. Council for British Archaeology

As the Group was now affiliated to this body, the Group was entitled to two representatives at the half-yearly Council meeting. It was agreed that D. W. Crossley and H. F. Cleere should represent the Group.

11. Future Work

In order to make the A.G.M. more attractive, Henry Cleere suggested that there should be an annual lecture before or after it. It might be possible to invite an international authority to lecture on such an occasion. Dr Pumphrey drew attention to the mass of documentary evidence recently brought to light at Woolwich on cannon and ordnance and suggested that there might be a lecture and a visit. He felt that the Group tended to be too preoccupied with the smelting side and more attention should be paid to working and casting.

12. Next Meeting

It was agreed that there was a strong case for London. The venue could be Woolwich and the Rotunda Museum there. This was left to H. Cleere and W. Pumphrey to decide.

13. Other Business

Henry Cleere, in answer to a question, thought that any books which belonged to the Group could be housed in the Joint Library. Mr. Hardman referred to the function of the committee and the fact that it was very difficult for all its members to meet. It was agreed that an effort should be made to hold committee meetings before or after the A.G.M., on the occasion of the conference, and to have two other meetings during the year on fixed dates.

Notes and News

Consett blast furnace

The Consett Iron Company's magazine for October, 1968, Vol. 12, No. 10, has a photograph of the company's first iron-clad blast furnace erected in 1869.

Technical terms used in brass mills

It appears that the term "scruff" has another meaning. Mr I. C. H. Hughes of the British Cast Iron Research Association writes as follows:

"Following our discussion of the use of the word 'scruff' I am writing this note to place on record my understanding of its definition in the context of present day-usage.

"'Scruff' is a term used to describe slag-like floating debris which rises on the surface of molten cast iron, particularly that poured cold, in large castings. It is normally fairly rich in manganese and in sulphur, partially because manganese sulphide tends to separate from the molten metal at low temperatures when the manganese and sulphur contents exceed certain limits, and partly because manganese tends to be preferentially oxidised into the slag. It is sticky material and tends to adhere in patches on the sides of castings and to appear in layers on top surfaces. As far as I know the term is restricted to foundries in South Wales, so that there is an obvious geographical relationship with the Forest of Dean."

Erratum

The heading to page 68 of the last issue of the Bulletin, 1968, Vol. 2, No. 2. should read: "Metallographic examination of a spoon auger from Letchworth, Herts."

Abstracts

By arrangement with the Editor of the Journal of The Iron and Steel Institute, abstracts of papers of historical interest published in the abstracts section of that journal are published in the Bulletin, together with certain other abstracts prepared by members of the Group.

British Isles

Yarranton's blast furnace at Sharpley Pool, Worcestershire M. M. Hallett and G. R. Morton (JISI, 1968, **206**, July, 689-692) The remains of a blast furnace, erected by Yarranton in 1652 in North-West Worcestershire, were investigated. The plan was normal for 17th century furnaces, except that the interior was round. Details are provided of the raw materials and of the products. The pig iron produced was typical of charcoal blast-furnace operation, being low in silicon and manganese. The slag was sufficiently high in lime and magnesia to displace most of the iron oxide and appears to be the earliest dated example of such practice in England, published so far.

The Bowling Ironworks H. Long (Ind. Archaeology, 1968, 5, May, 171-177) The history of the Bowling Iron Co., 1788-1898, is reviewed.

19th century coke ovens to become museum pieces (Steel Times, 1968, **196**, April, 236-238) The history of the first by-product recovery coke ovens to be used in the UK, the old Simon-Carves ovens at Bankfoot, Crook (Co. Durham) —as originally described by Dixon in 1883 – is discussed. The dismantled ovens are to be re-erected at the Open Air Museum for the North of England.

Scunthorpe's first furnace T. Daff (JISI, 1968, **206**, July, 693-699) After a brief introduction describing the discovery of the Frodingham ore bed in 1858 and its early development, the paper goes on to describe the plant of George Dawes at the Trent Iron Works, Scunthorpe; these were the first of the area's iron works. From contemporary records, the paper describes the first campaign at Trent (January-December 1864). This was the first attempt to smelt the Frodingham ore other than as an admixture, and it was the first time that smelting operations had been undertaken in Lincolnshire in modern times. With the aid of various ratios and graphs the campaign is analysed as far as the input and ironmake figures allow. The furnace's second campaign (March, 1865—November, 1870) is similarly discussed and analysed, and comparisons are drawn between the two campaigns. The paper concludes with a few more general comments on furnace working during these early days.

Europe

The iron and steel industry in Czechoslovakia in the second half of the 16th century M. Kreps (Rev. Hist. Sidér, 1968, **9**, (1), 7—24) [In Fr.] The probable design of furnaces, types and quantities of iron produced are discussed.

Industrial archaeology of the iron and steel industry in Styria M. Wehdorn (Anschnitt, 1968, **20**, (2), 3—18) [In Ger.] An account is given of efforts to preserve the remains of ironworks and forges at Vordenberg, Steinhaus, Unterzeirung, and Zirbitzkogel in Austria.

The old hammer works in the Flöha valley G. Arnold (Metallverarbeitung, 1967, 21, Nov. 335—337) [In Ger.]

The beginnings of the Compagnie des Mines, Fonderie et Forges de l'Aveyron (Décazeville) (Rev. Hist. Sidér., 1968, **9**, (1), 63—91) [In Fr.] The minutes of three shareholders' meetings held in 1831 and 1832 are reported. At these meetings, progress of the company's activities was reported and plans for future development, raising of capital, and investment were agreed.

Metallurgical Investigations

Structure and manufacturing techniques of pattern-welded objects found in the Baltic States A. K. Anteins (JISI, 1968, **206**, June, 563—571) A number of pattern welded swords and spear heads from the Baltic area, of periods 5th to 10th century, have been examined. Some are wholly pattern-welded, others have pattern welded decorations applied to edge or point.

Some observations on ancient iron A. K. Lahiri, T. Banerjee, and B. R. Nijhawan (NML Techn. J., 1967, **9**, (2), May, 32-33) A brief discussion is presented on the long life of ancient iron, with special reference to the iron beams of the Sun temple of Konarak. Corrosion resistance is ascribed to slag coating.

Biography

Dud Dudley — a new appraisal G. R. Morton and M. D. G. Wanklyn (J. West Midland Reg. Studies, 1967, **1**, Dec., 48—65) The personal character, military career, technological achievements, and industrial competence of Dud Dudley (1599—1685) are reviewed. Dudley, often stated to be the first man to have used coal rather than charcoal to smelt iron ore, was the author of "Metallum Martis"; he was a confirmed loyalist during the Civil War and a relatively successful member of the XVII century middle class. It is suggested that his success as an ironmaster was limited to the production of pig iron and castings such as household ware and cannon, there being no evidence, it is stated, to suggest that Dudley successfully refined pig iron with mineral fuel.

Cornelius Whitehouse B. Hawkley (Iron Steel, 1968, **41**, May, 193—196) Cornelius Whitehouse's patent, of 1825, for the manufacture of welded tubing by drawing through a die, enabled James Russell to raise the Crown Tube Works, Wednesbury, to a very important place in local industry. When the patent was extended, many eminent engineers testified to the immense strength and reliability of tube made by this method. Whitehouse, however, had many vicissitudes and died in reduced circumstances.