ART. V.—*The 17th-century bloomery at Muncaster Head.* By R. F. TYLECOTE, M.Sc., Ph.D., and J. CHERRY, B.Sc.

Read at Tullie House, Carlisle, July 3rd, 1970.

THERE have been many reports about the existence of bloomery slag beside the Esk at Muncaster Head farm in Eskdale (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.[1]

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 mill-race that supplied water to the bloomery. Like the road, this contours the hillside 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-east 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.

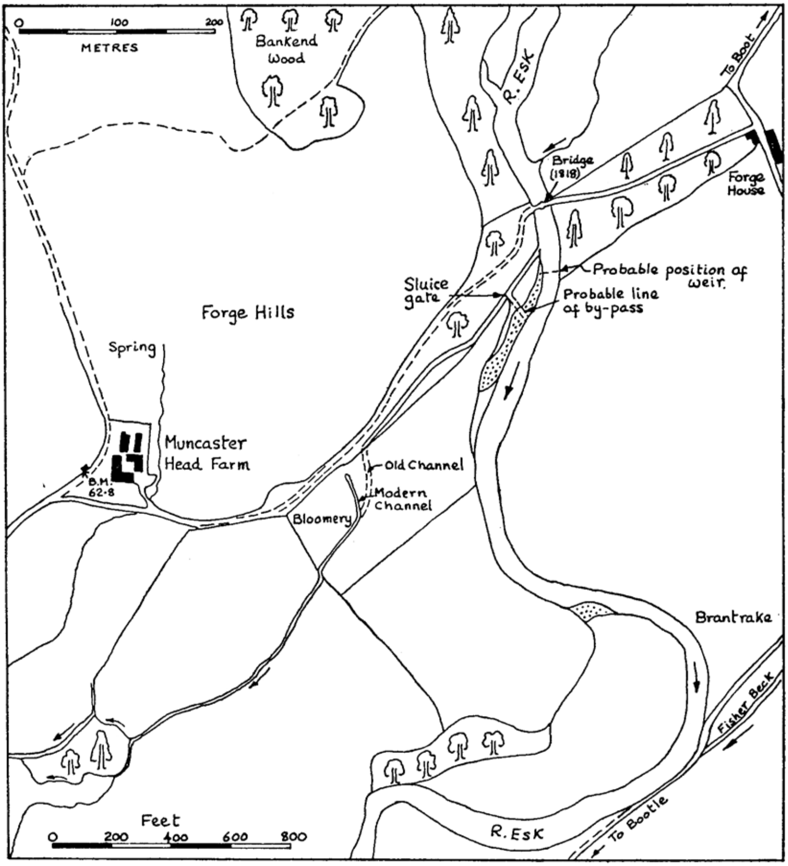

FIG. 1.—Sketch map of area.

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

A. HISTORICAL.

According to an agreement of 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 from the 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. 1,600 cords were to be bought by Gavin Braithwaite from the Stanleys and the other 1,600 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 5 years but must keep the equipment in good repair.

It was also agreed that Wright was to set up a coal-house 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 5 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.

B. RESULTS OF THE EXCAVATIONS.

1. 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 (Fig. 2) in which was fitted a permanent wooden sill about 1½ 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

PLATE I. Elevation of North-west slot.

between pp. 72 and 73.

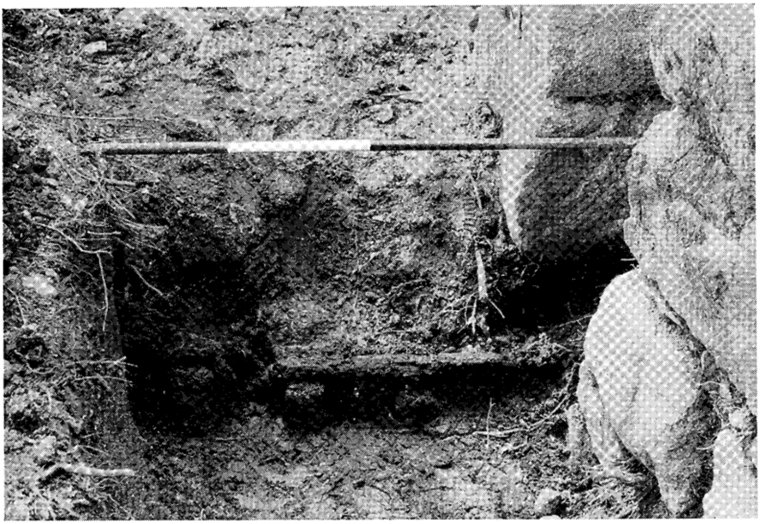

Plate II.—View of timber sill-board.

Plate III.—Stone revetment of wheel-pit.

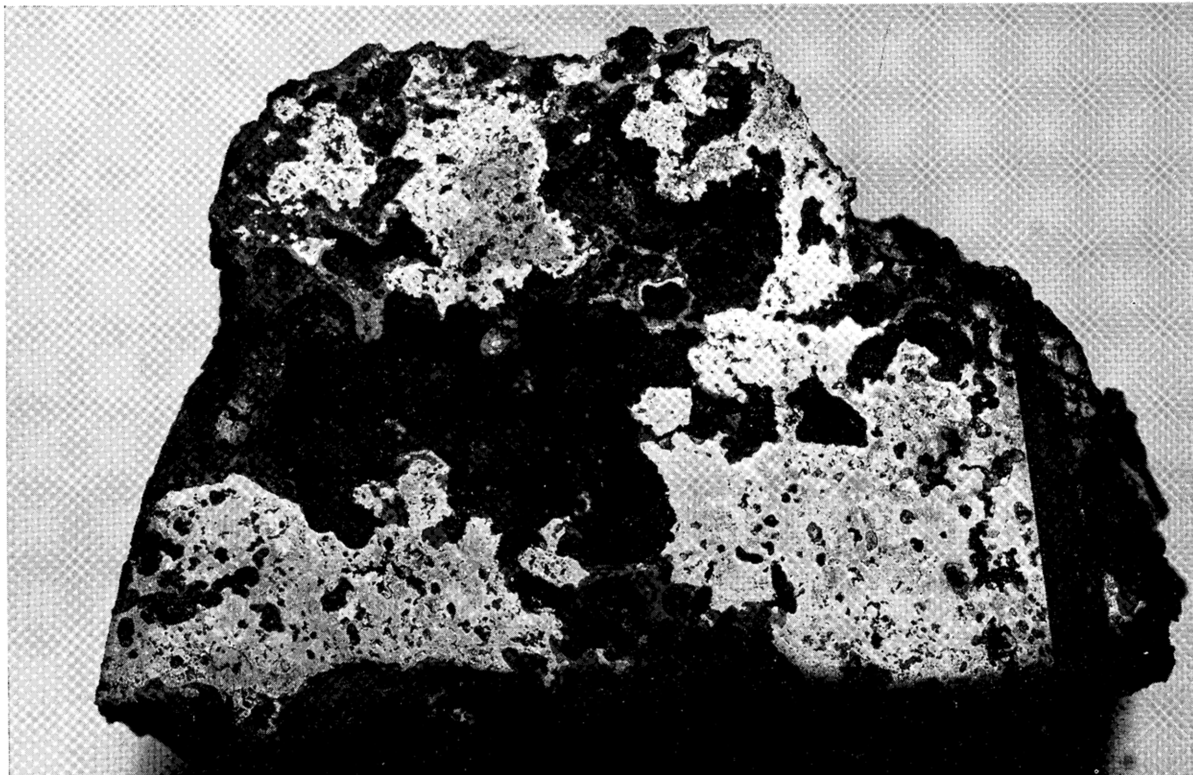

PLATE IV. Remains of bloom (Macrostructure) (x 1.7).

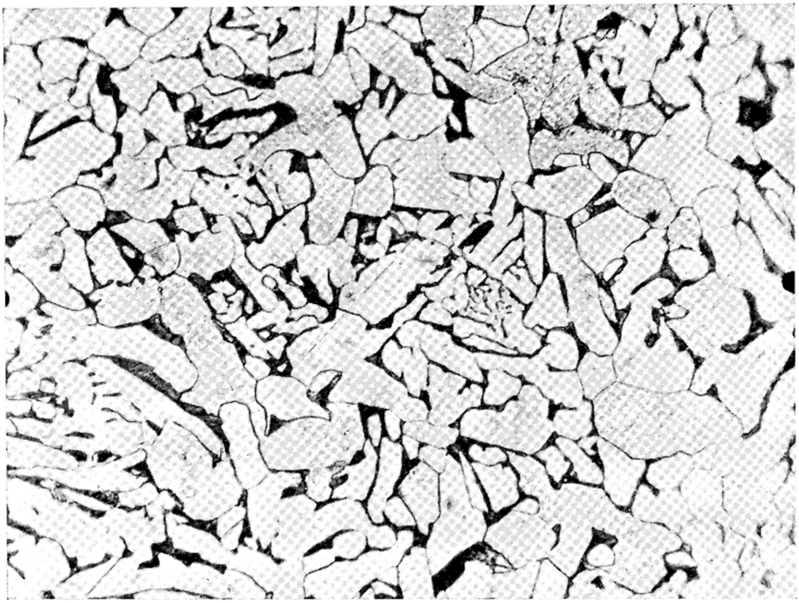

PLATE V.—Microstructure of bloom (x 280).

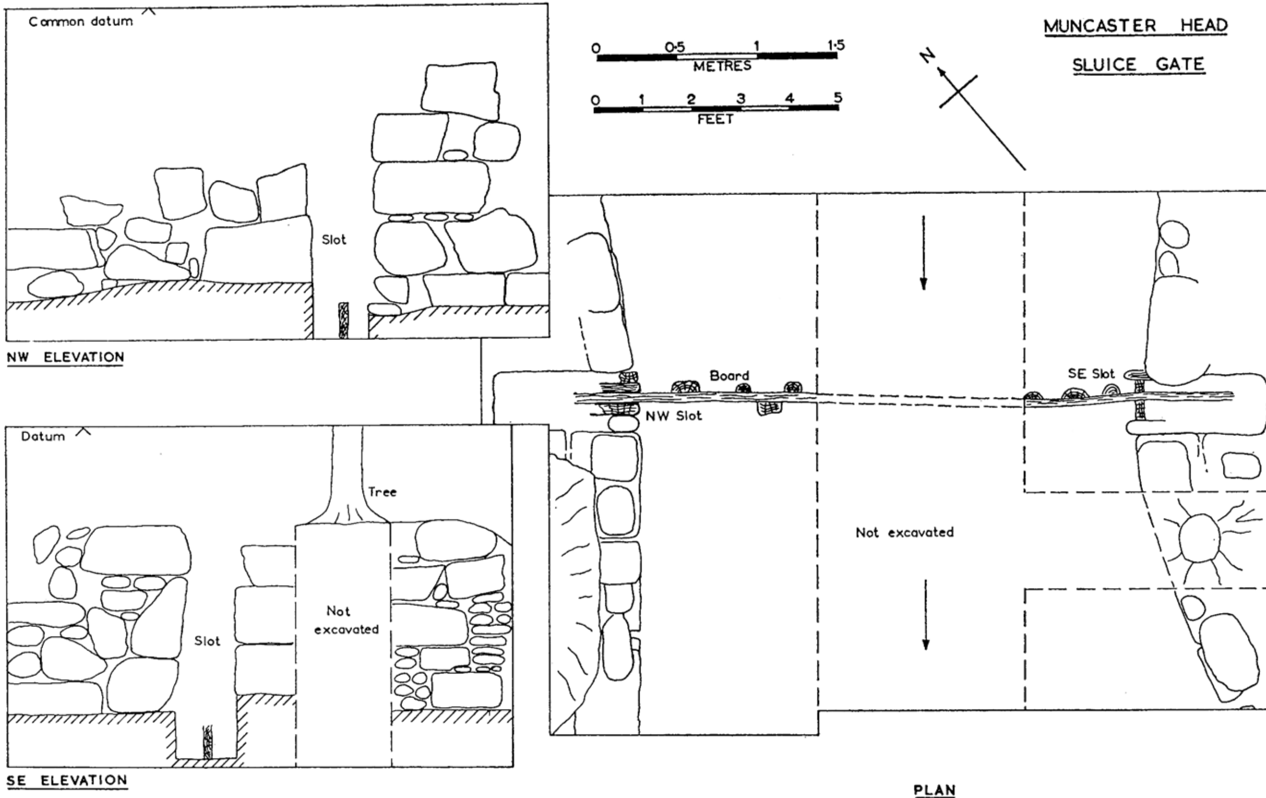

FIG. 2.—Sluice-gate, plan and elevations.

been regulated by means of a permanent weir across the river which 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 5 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. 3. 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 end of the high bank very closely, as will be seen from the contour map (Fig. 4). Excavations in the area of Q3 and 4 located the two sides of the race and showed that these had been revetted with stones (Plate III), but there were no signs of revetting in other areas excavated along the likely line of the race, i.e. L3, M3

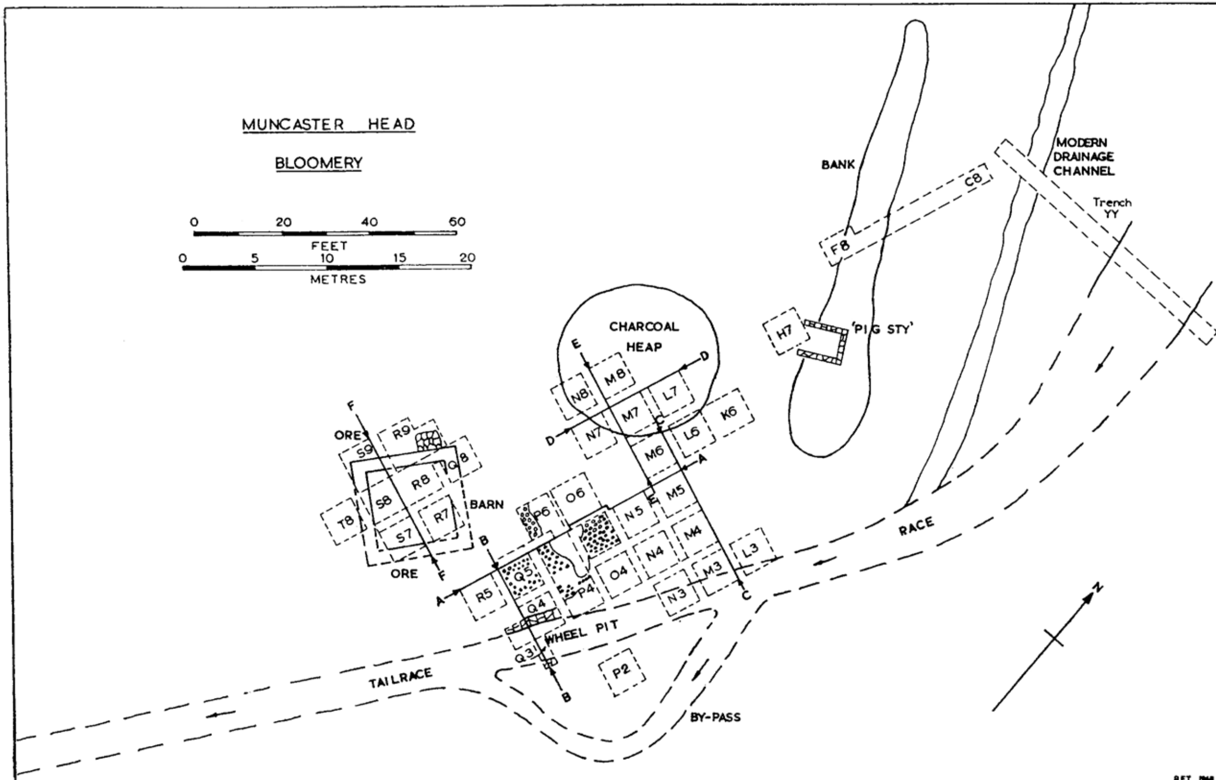

FIG. 3.—Site plan.

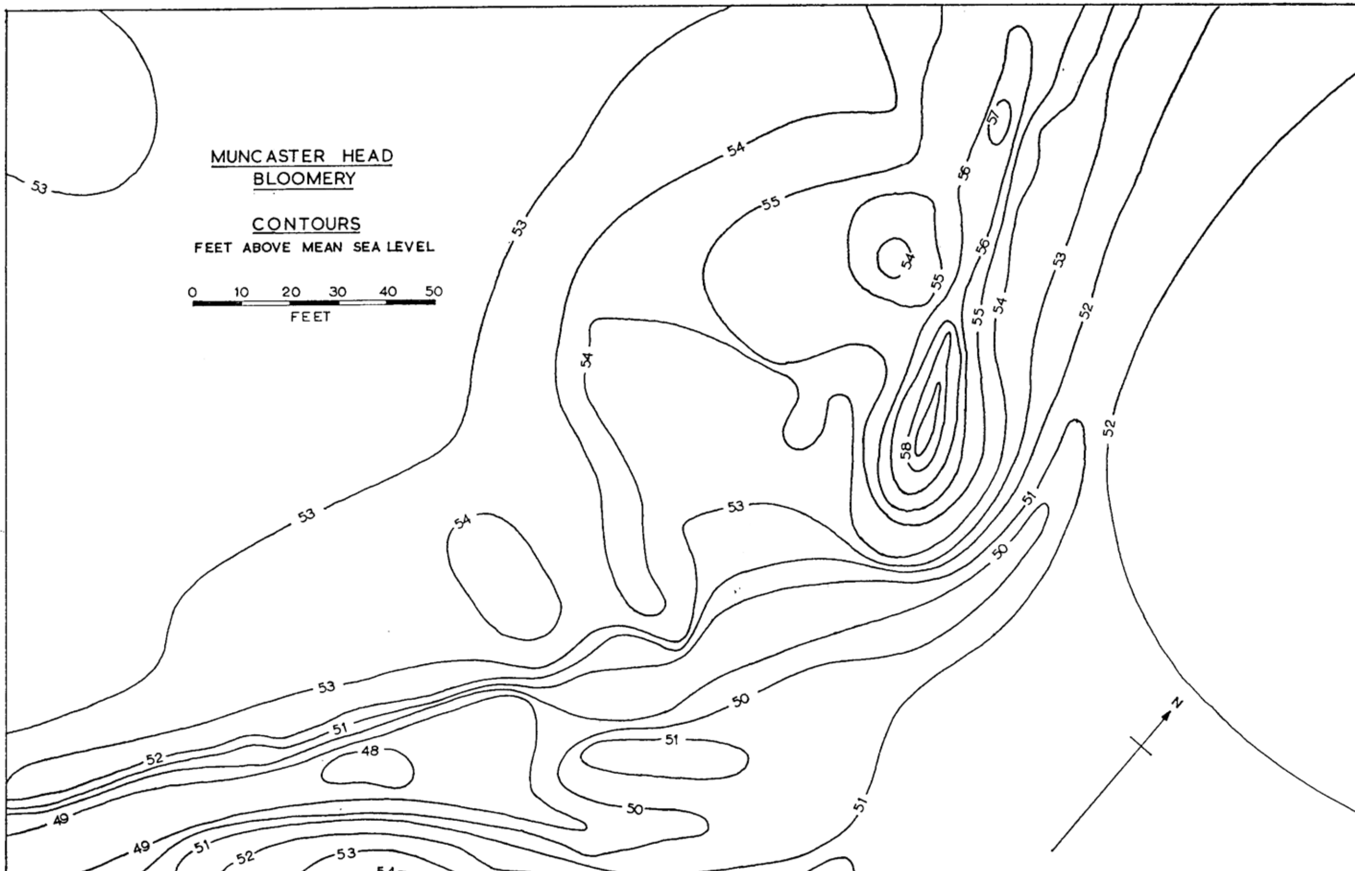

FIG. 4.—Contour plan.

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 (Fig. 5, section B) the remains of what appears to have been a wheel were found. These are shown in Fig. 6 and were made of oak. 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. Due 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. Appendix A gives calculations for both these possibilities with a 6-ft. wide wheel. Both these calculations give the same order of power available, i.e. between 15 and 17 h.p. This would be ample for 3 pairs of bellows and a tilt hammer or belly helve.

It is, of course, possible that the remains of the wheel are not in their original position and have been swept downstream. But 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

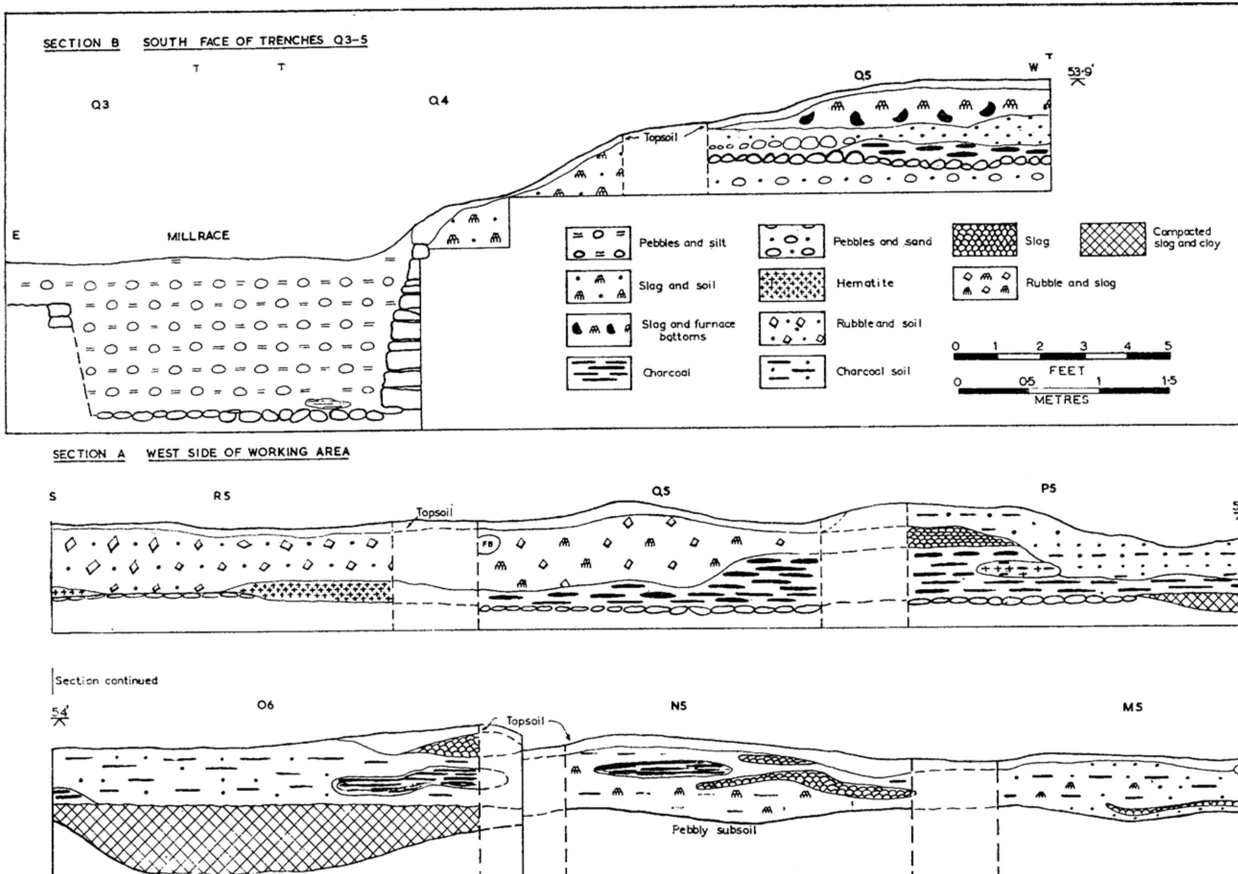

FIG. 5.—Section A through working area.
Section B through millrace.

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. 5, section B). 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. 5, section A) through trenches P5 or O5 and finally disappeared in N5. There must have been a gully in the area of O5 and O6 which 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 M and N4, and M and N5, the contours show that the levels are a good deal lower than on the working-floor itself (Figs. 3 and 4). 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 higher in the race. An examination of this area, which is best shown by section C in Fig. 7, 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. The remains found and the probable arrangement of the wheels and hearths are shown in the plan in Fig. 8.

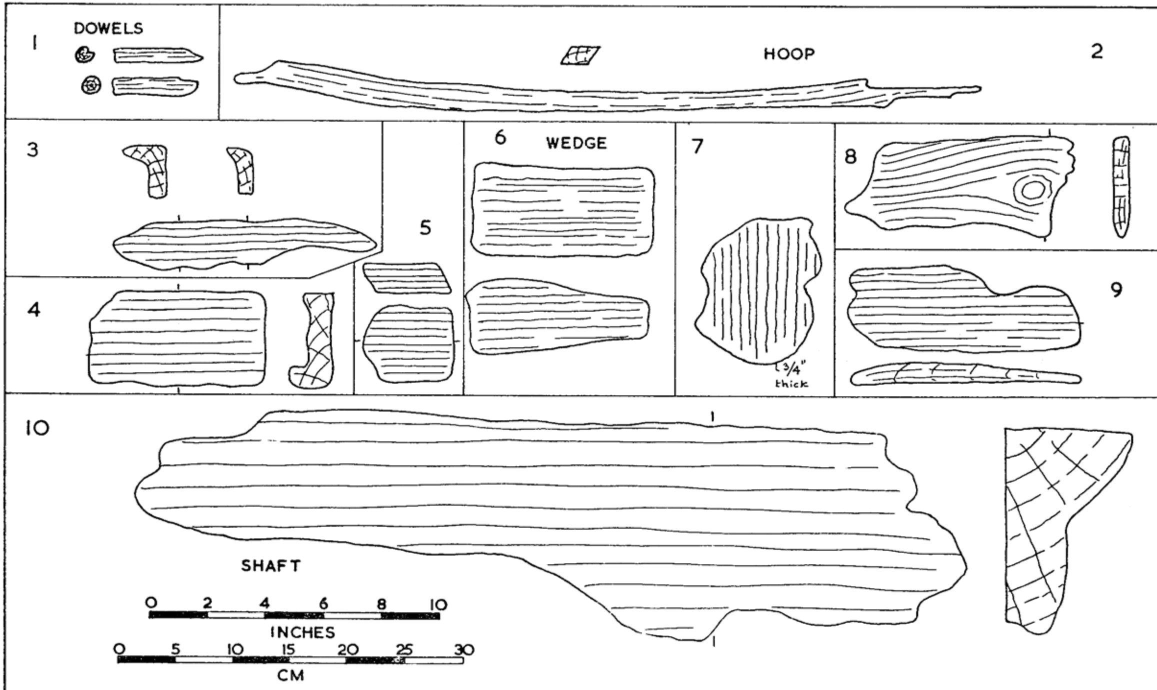

FIG. 6.—Remains of timber from race.

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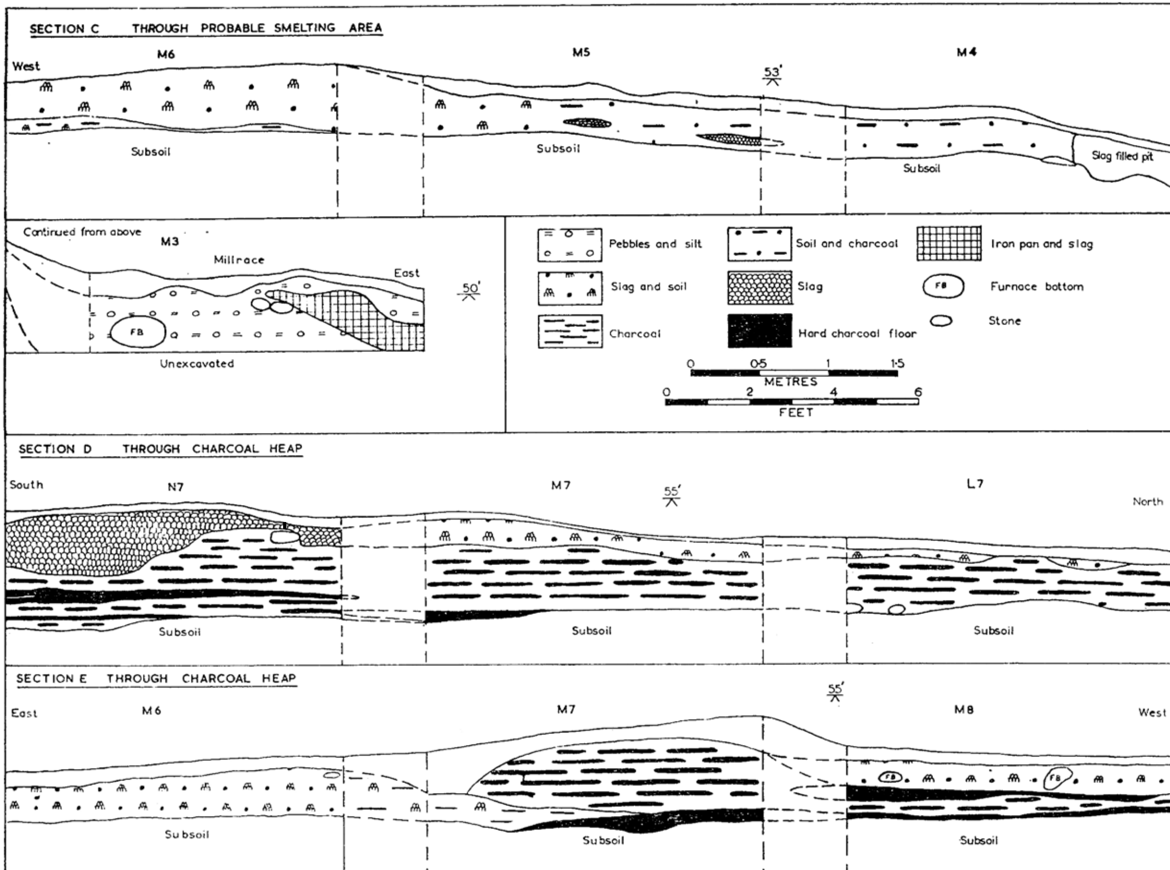

FIG. 7.—Section C through probable smelting area.
Sections D and E through charcoal heap.

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 that an enormous heap of charcoal had existed to the west of the supposed smelting area (Fig. 3). 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 (Fig. 7, sections D and E). 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 overlain 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 seemed that this was connected with the remains of a building at the southern end of the excavated area (Fig. 9). 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

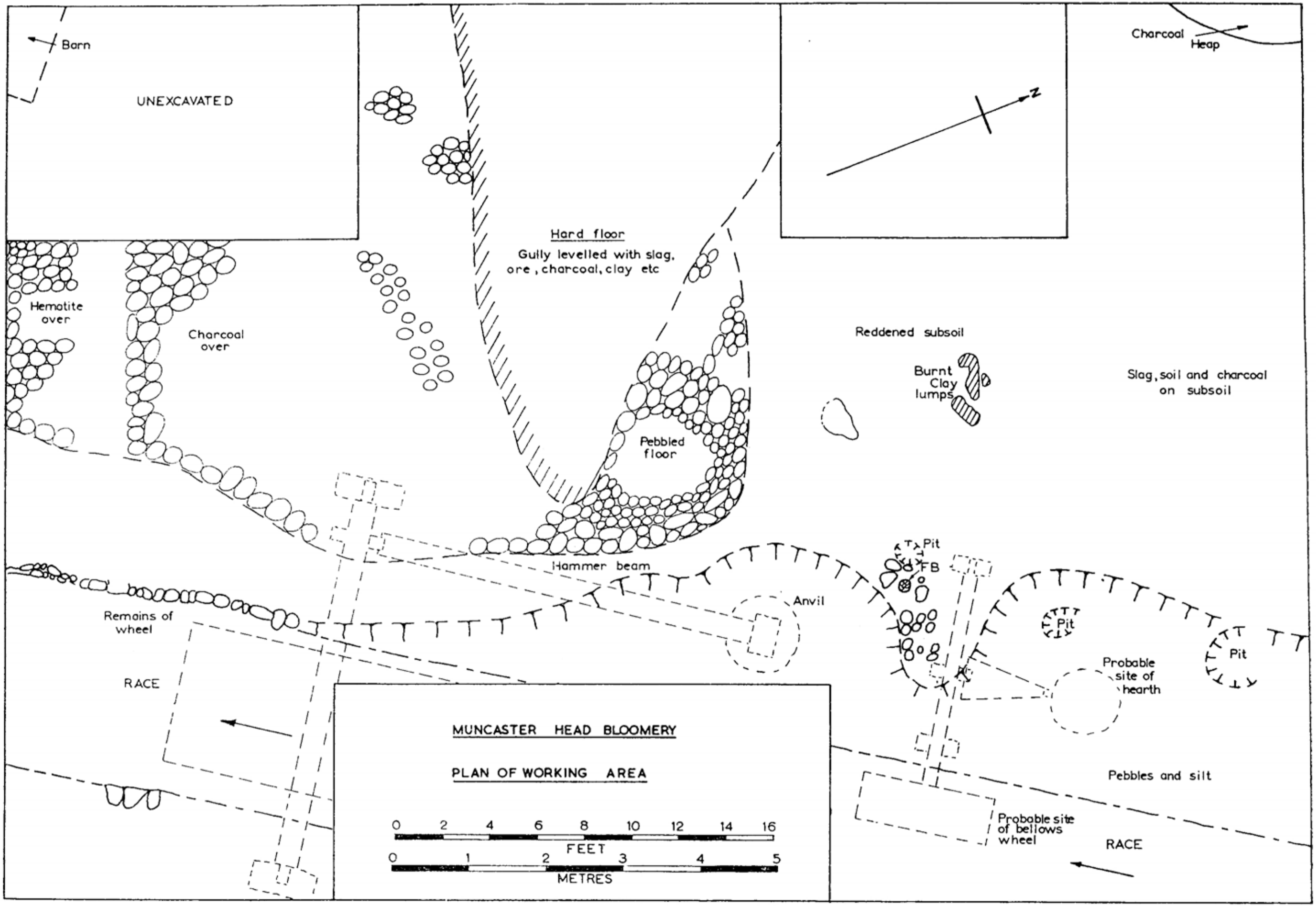

FIG. 8.—Plan of working area with outline showing probable arrangement of wheels, hammer and hearths.

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 round, particularly on the west side, there was hardly any inside and the section (F in Fig. 9) shows that the construction trenches cut through layers of hematite or reddened soil. 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 plan and a west-east section are given in Fig. 9. 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 lbs. 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

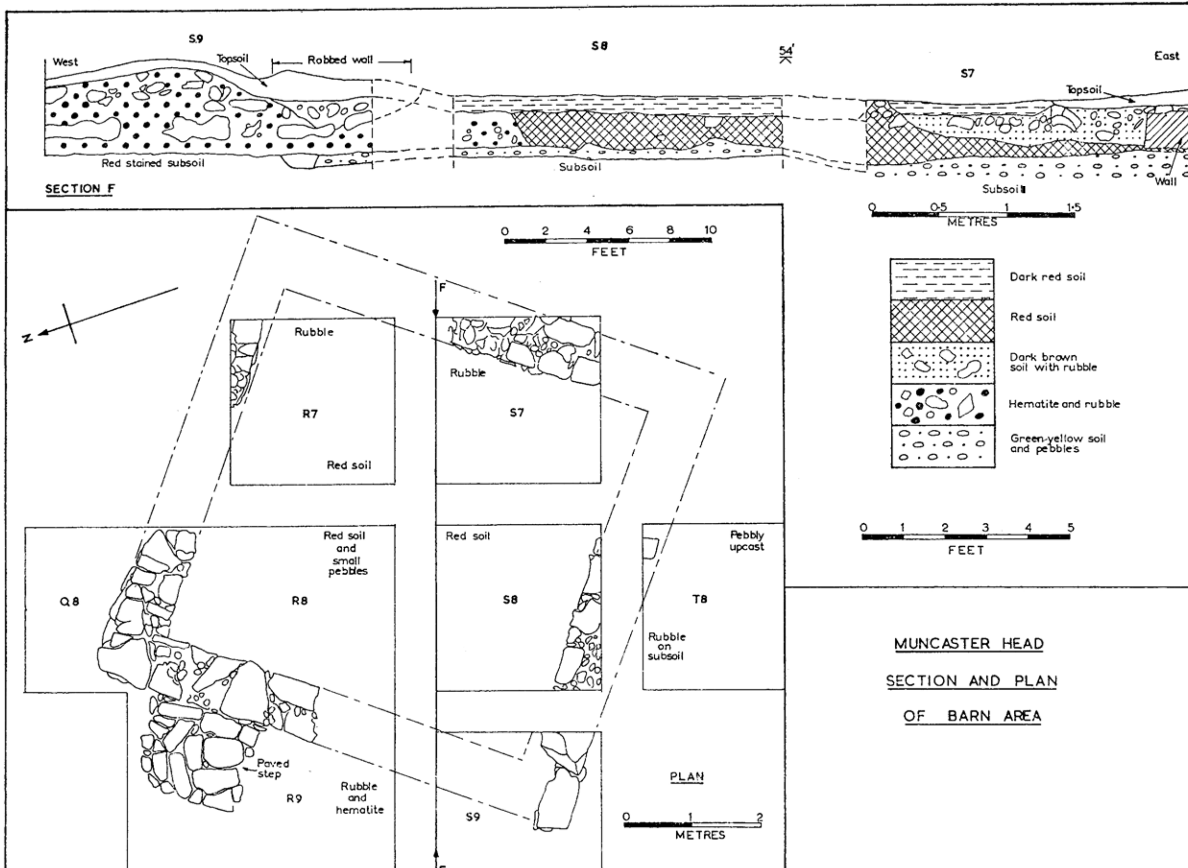

FIG. 9.—Plan and section of barn.

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-east end of the site, built into the high bank, is another building of agricultural purpose (Fig. 3). This is made of granite boulders and measures internally 8 x 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 post-dates the bloomery since its south-west end rests on an extension of the bloomery slag heap. Its N.E. end rests on the toe of the bank into which it has been built for support. It could not have been free-standing and therefore post-dates the bank.

C. EXAMINATION OF THE PRINCIPAL FINDS.

1. 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.

(a) Iron Ore.

The only iron ore found on the site was high-grade hematite. The analysis of this material is given in Table 1 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 1.

Analysis of ore from Muncaster Head and Eskdale (%).

	Muncaster Head			Nab Ghyll, Eskdale (Kendall[12])
	1	2	Fines	
Fe_2O_3	91.7	94.7	73.8	92.6
FeO	n.d.	0.6	1.2	n.d.
SiO_2	2.9	1.6	16.0	2.05
MnO	0.02	<1	<1	0.026
Al_2O_2	1.0	1.0	3.9	0.88
MgO	0.1	<1	<1	0.08
CaO	0.6	<1	<1	0.50
TiO_2	0.01	<0.5	<0.5	n.d.
S	n.d.	<0.01	<0.01	0.003
P_2O_5	n.d.	0.1	0.045	0.03
Na_2O	n.d.	0.01	0.03	n.d.
K_2O	n.d.	0.02	0.12	n.d.
H_2O	3.7	Dried		3.7

n.d. = not determined.

The massive ore was a typical fine-grained hematite with the silica content mainly present as pockets of secondary quartz, often containing crystals of specular hematite. It would seem that the fines consist of the same mineral contaminated with SiO_2 and alumina picked up from the soil.

(b) Slag.

The slag consisted of large furnace bottoms (Fig. 10) and smaller pieces of tap slag. Four of the furnace bottoms (A, B, C and D) were complete and when weighed gave figures of 48, 32, 36 and 39 lbs. 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 2, and it will be seen that it has an appreciable phosphorus content which is absent from the ore. The furnace bottoms also give high phosphorus values.

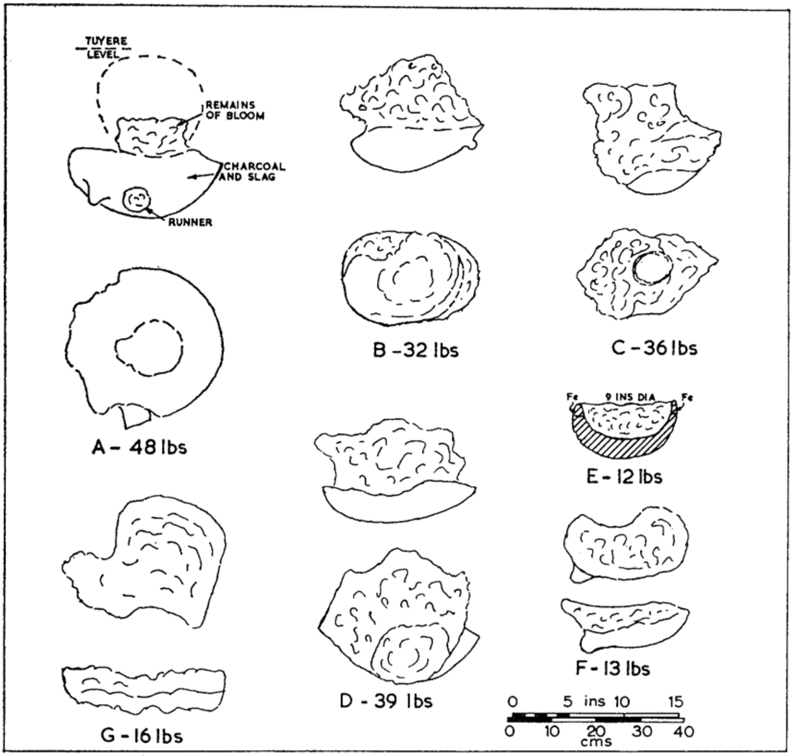

FIG. 10.—Furnace bottoms.

Table 2.

Analyses of slags from Muncaster Head (%).

	Tap slag		Furnace Bottoms	
	1	2	A	D
FeO	62.3	64.6	34.6	
Fe_2O_3	n.d.	8.0	32.7	
SiO_2	23.9	15.6	15.7	
MnO	0.1	<1	<1	
Al_2O_3	5.5	4.0	4.6	
CaO	4.5	2.8	4.7	
MgO	0.7	<1	1.0	
TiO_2	0.2	<0.5	<0.5	
S	0.01	0.05	0.08	
P_2O_5	0.65	0.22	0.29	0.43
Na_2O	n.d.	0.36	0.15	
K_2O	n.d.	2.38	0.74	

n.d. = not determined.

Petrological examination showed that the tap slag consisted mainly of the silicate, olivine, associated with wüstite and interstitial silicates. Small amounts of metallic iron were present which was partly rusted, and a few pores were rimmed by magnetite and hematite. Pieces from the furnace bottoms had a different structure, and one was found to contain partially reduced iron ore particles (i.e. Fe_3O_4). This shows that it was undoubtedly a smelting product and not a "mosser" or product of a forge. The other had a similar structure to the tap slag but the olivine occurred as two distinct phases of varying iron content. Iron sulphide and hercynite were present in minor amounts. The pores were often rimmed by extensive rust deposits, and very little metallic iron was preserved within the slag phase.

Furnace bottom, A, consisted mainly of charcoal and slag. The remains of a slag runner could be seen on the bottom (Fig. 10, A) and the probable position of the tuyere is shown 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 weigh 2.9 lbs. and to have a very high metal content. It was in fact the remains of the bottom of the bloom (Plate IV). The separation was relatively easy, due 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 combined carbon was present. The microstructure consisted of coarse ferrite with coarse angular pearlite grains, which were not easily resolvable at low power (Plate V). The ferrite-pearlite distribution was Widmanstätten in places, and this shows it to have been fairly rapidly cooled from a high temperature. But the fine spheroidized pearlite indicates that it had remained for some time in the range 600-700°C. The carbon content averaged about 0.2%. The full chemical analysis of drillings from the "bloom" is given in Table 3.

Table 3.

Analysis of "bloom" from Furnace bottom, A.

Mn	Si	S	P	Cr	Ni	%
nil	0.33	0.005	0.097 0.059	<0.01	<0.01	

As the drillings contained some slag, it is likely that the silicon is derived from the slag. These figures are typical of bloomery iron produced from a low phosphorus ore.

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.

Like the tap slag, the slag runners were non-magnetic. One of the furnace bottoms, E, was embryonic in that it consisted merely of a hemispherical shell (Fig. 10, E). If smelting had continued this would have have become the same as the others. 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 "bloom" from A, 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. F was the bottom half of a furnace bottom of the same sort as Fig. 10, A. It was almost entirely non-magnetic and no iron was found in it.

There was very little furnace lining 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.

(c) 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 lbs. which was found on the step of the barn. It is triangular in shape and about 2 in. thick with one corner pointed (see Fig. 11, A). From its position it would seem to be post-bloomery in date, 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 it 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. But whatever its use there is no doubt that the point was made during casting and not ground-on after. If these 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. But 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.

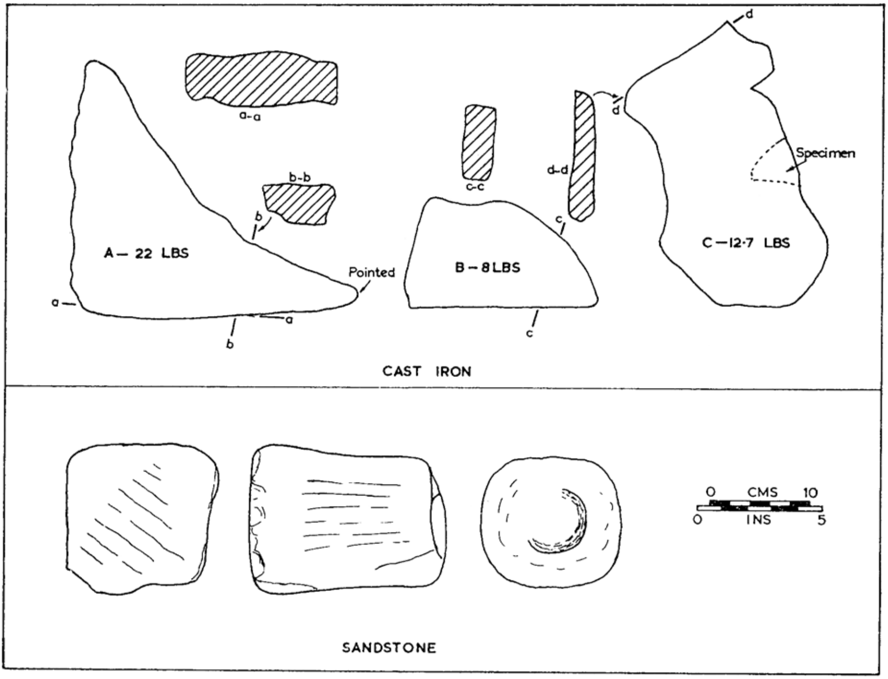

FIG. 11.—Cast iron and sandstone "anvil".

The other two pieces were found in the S.W. 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 and they are about 1 in. thick. The smaller of the two (Fig. 11, B) was again white iron and appeared to be broken, but it still has a straight side. The larger (C) 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[3] refers to the use of iron plates in a bloomery in North Lancashire near Milnthorpe in Westmorland in 1675. In Sussex in 1573 and in 1582, iron plates were used in the forges and fineries.[4] 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: (1) it is more resistant to cracking due to "growth", i.e. graphitization of pearlite and oxidation along the graphite flakes, and (2) a good deal of early charcoal iron was white, due to its low silicon content and the fact that a good deal 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.

The chemical composition is given in Table 4. There is no doubt that this is 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%

Table 4.

Properties of pieces of Cast Iron.

	2 in. thick A	1 in. thick B	C	
Hardness, HV30	493	481	177-212	
Graphite	none (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	

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).

(d) Sources and quality of Iron Ore.

The ores of Furness and south-west Cumberland have a high reputation for quality, especially in regard to the phosphorus content. Yet the slags and furnace bottoms on the Muncaster bloomery site contain appreciable phosphorus. A good deal of the ore came from pits near Egremont and it did seem possible that some of these sources might be higher in phosphorus, due to their proximity to the higher phosphorus ores of the coal measures.

The Leconfield papers (Box 240, bundle 46) contains references to Langhorn, Bigrigg and Wyndham mines. On 12 October 1639 we find the following from Robert Copley:

Move 46 tons of ore gotten out from the pits aforesaid pprs. Cofts and Shardgod of the said Wm. Pennington . . . to his ironworks at Muncaster . . . and

15 score tons of myno at 17 barrows to the ton . . . bring all disbursements by William Pennington and

Sold . . . the 27th October 1639 of the ore gotten at the pit aforesaid to Thos. Jackson . . . due to my lords and Mr Pennington.

There is little doubt that the Egremont area was the main source of supply for Muncaster bloomery. It is known that some of these pits gave rather higher phosphorus contents than the 0.03% P_2O_5 from Eskdale and Hodbarrow, for example. Florence is said to give 0.1 to 0.2% P_2O_5.

In order to check this, samples from the following mine heaps were tested (and compared with the results of other workers). The figures obtained were as follows:

Mine	% P
Pallaflat	0.003 – 0.0302
Ullcoats (Osgerby[6])	0.001 – 0.013
Florence	0.0045
Egremont "reddening stone"	0.0043 – 0.008
Parkside (Jeans[7])	0.0613

There is little doubt, therefore, that the ore cannot have been the source of the high phosphorus in the slags and that we must look elsewhere. Bachmann[8] found the same problem in relation to some Turkish slags which gave 1.95% P_2O_5 (0.85% P), while the ores only contained 0.05% P. He concluded that the phosphorus came from the charcoal which in this case had clearly not been peeled.

The removal of bark, which has a far higher phosphorus content than the wood, is only a commercial proposition when high prices are paid for bark, such as that from oak for tanning. Bark does not usually fall from the branches easily and can only be removed by hand in England during April or May. Of course, goats and sheep like bark and will strip it if it is left lying about long enough. It would seem, therefore, that in the cases of high phosphorus slags, where the phosphorus can only have come from the wood, the wood must have been charcoaled fairly soon after cutting, and that the finer fractions representing the bark must have been charged with the good charcoal. It is clear that this was the case at Muncaster. On the other hand it means that where the phosphorus content of the slag is low, care must have been taken either to strip the bark or remove the fines.[9]

2. The Charcoal

As we have seen, a good deal of charcoal was found on this site. The samples analysed, however, mostly came from stratified layers in the working area and not only from the 5 tons or so remaining in the charcoal heap itself. They therefore represent a typical cross-section of that made and used during the whole period of the site. There was no sign of charcoal-burning on the site and there is therefore no doubt that the charcoal was made in the woods and brought to the site by pack-animal.

We see from Table 5 that oak was responsible for more than 70% of the wood used.

3. The pottery and clay pipes.

Medieval smelting sites are generally not noted for the wealth of their pottery and this post-medieval site seems to be in the same tradition.

MH 77, 112 (Fig. 12, A).

This group of sherds formed the base of a vessel about 4½ in. diameter. It consisted of a hard red fabric with dark brown shiny glaze inside and partial glaze on the top half outside. It came from the topsoil of EF8, i.e. in the trench intersecting the bank, but was typical of numerous body sherds from stratified deposits elsewhere. It is datable to the late 17th to early 18th century.

Table 5.

Analysis of Charcoal.

Trench	Level	Oak	Elm	Ash	Beech	Birch	Willow/ Poplar	Hazel
A. Stratified								
N4	Charcoal floor	1	2					
H7	Level 2	7						
P5	Charcoal	4	1					
S9	Hematite	1						
R9	Hematite					1		
Q5	Charcoal	9			2			
Section thro' bank		14				1	1	
O4	Char/soil	9		1	2		2	
N7	Charcoal	13	1		4		4	
N6	Charcoal	1		5			1	
L7	Level 2			1				
H7	Charcoal	17			1	1	1	
M7	Charcoal	2						
N8	Charcoal	1						
P5	Hard c/coal	5		1				
O5	Top c/coal	3						
P5/6	Working floor	3				1		
Total:		90	4	8	9	4	9	
%		73	3	6	7	3	7	
B. Unstratified								
N8	Topsoil	4			1			1
L6	Topsoil	6						
O6		5						
Wheel pit					1			
L3		1		1				
M7	Topsoil	19		1				2
O5	Topsoil	4					1	
R7	Topsoil	3						
EF8	Topsoil	20			1		4	1
M8	Topsoil	6						
P6	Topsoil	1						
H7	Fill	4		1				1
P5	Topsoil					1		
Q5	Topsoil	4						
Total:		67	0	3	3	1	5	5
%		79	0	4	4	1	6	6

MH 20 (Fig. 12, B).

Base of large dish from charcoal layer in M7. Pink-grey fabric; unglazed but well worn. Late 16th to early 17th century.

MH 58 (Fig. 12, C).

Handle, 1 in. wide, from clay deposit near the sill-board in the sluice-gate. Made from a pink-grey fabric with traces of a yellow or green glaze. Well weathered but datable to the late 16th or the early 17th century.

MH 115 (Fig. 12, D).

Base of probably an almost vertical-walled vessel of the stewpot type, external diam. *c.* 9½ in., from the slag in M6. Uneven base, roughly finished in coarse, badly wedged clay. Slight projecting basal angle, uneven (iron) glaze and reddish heat skin are all characteristic of this type of oxidized pottery and standard of potting. The pot and glaze fit in a period of mass production and lower standard of potting,

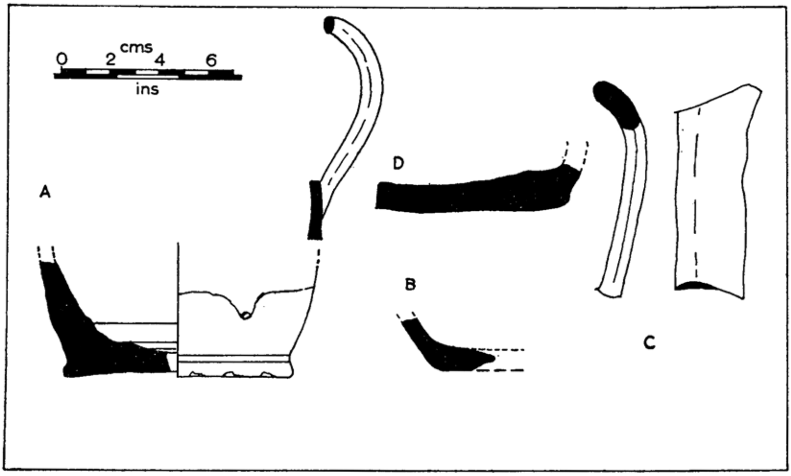

FIG. 12.—Pottery.

especially in the run-of-the-mill provincial forms. This begins in the 17th and continues through the 18th century. *c.* 1700-1750 would be a medial date but precise dating would be difficult.

MH 113.

Thick wall of vessel in fabric of a character similar to MH 115 from the topsoil in N3. The smoother exterior finish and smooth internal blackish glaze might indicate a slightly later date than MH 115, but this is not necessarily so. These particular black (iron) glazes are a well-established 18th-century characteristic. Roof tiles in similar glaze were on Monkwearmouth Hall which was burnt down *c.* 1790. Internal diam. *c.* 9 in.

MH 114.

Abraded wall sherd from the middle or lower part of a tallish vessel — jug?, with external diam. of *c.* 4½ in. from the charcoal in O4. Lead glazed on both sides, oxidized firing. Although retaining medieval characteristics, the fabric and glaze could be from a post-medieval pot, with a possible date range from late 16th to early 18th century.

MH 116.

Abraded wall sherd from pot similar to MH 114 and from the same layer; it could even be from upper part of same pot. External glaze as MH 114. Deterioration of fabric of both fragments suggests chemical action, probably due to acid soil condition.

Only two pieces of pipe bowl were found, the rest being 25 pieces of stem. Those stratified all fell into the period *c.* 1650 to 1710 or 1720.

Although somewhat meagre, this evidence effectively dates the site to the period *c.* 1600-1720. The earliest date is consistent with the agreement of 1636, and the evidence suggests that the bloomery had ceased operation by 1720. The only other pottery found on the site was dated to the 19th century, and none of it was stratified.

4. Stone "anvil".

A piece of worked red sandstone was found amongst a pile of granite pebbles in N4 (Fig. 3). This is shown in Fig. 11 and in shape resembles an early iron anvil, but is far too soft to have been used as an anvil. Its square top surface looks as though it could have been used for sharpening. But it has clearly formed part of a larger piece of stone which might have been some sort of pedestal.

D. RECONSTRUCTION.

Some idea of the positions of the principal items of equipment on the site have been shown dotted in Fig. 8. This has been taken a stage further in Fig. 13, where we give a probable reconstruction of the wheels and the hammer after Percy's description of a Catalan forge of the 19th century.[10] Since the velocity of the water in the channel is unlikely to have exceeded 7.5 ft./sec., the wheel would have rotated relatively slowly, i.e. at about 5 to 7 R.P.M. However, with 8 cams on the shaft this would give the hammer a working rate of 40 to 60 blows a minute, which, although rather slow by 19th-century standards, would probably be of the right order for a 17th-century bloomery.

The evidence for the hearth is based on the finds of furnace bottoms, particularly A with its bloom on top, and represents the earlier phase before the iron-plated bloomery hearth represented by the 1-in. thick iron plates. The details of the bellows are drawn from Evenstad's 18th-century Norwegian bloomery.[11] The

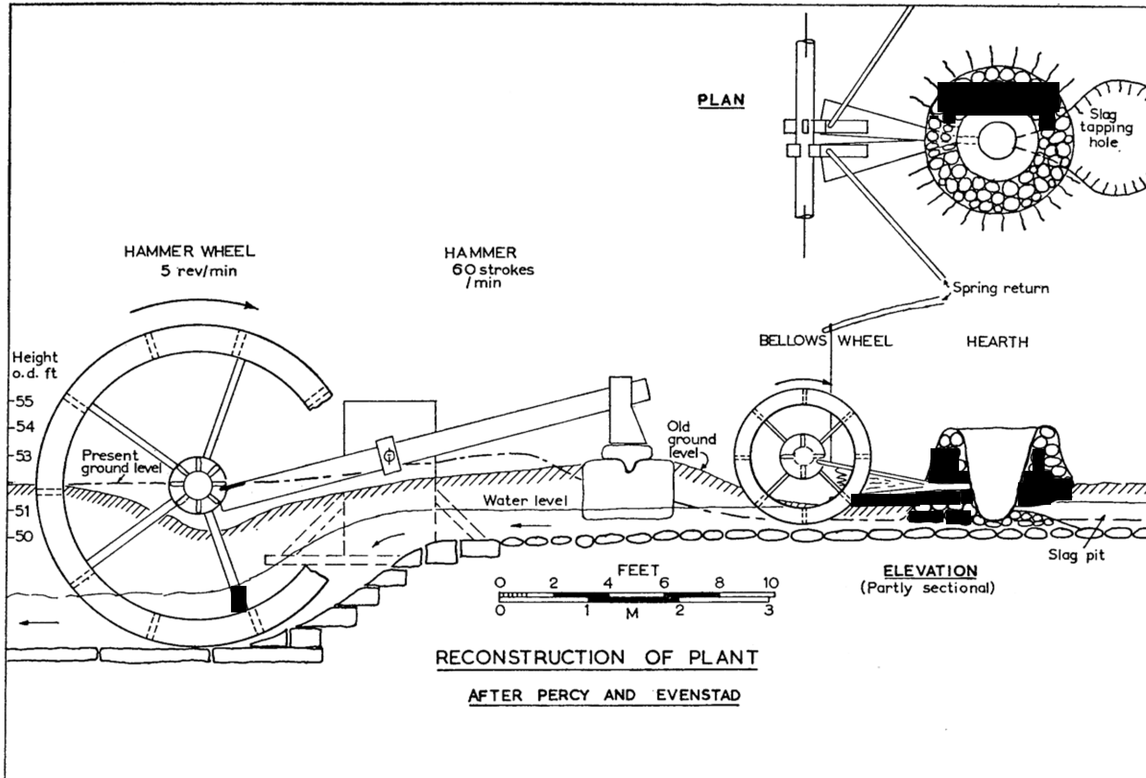

FIG. 13.—Probable reconstruction of wheels, hammer and furnaces on the site.

levels of the various items are based on the actual levels found on the site. The bellows wheel would rotate at about 10 R.P.M. and each hearth would receive air at the rate of 40 strokes per minute from the two pairs of bellows. Pleiner[12] found that small (4-ft.) blacksmith's leather bellows could accept a rate of 120 strokes/min.

Since the hematite ore is very dense and not easily reduced we would expect it to be broken up before use into pieces less than ¼ in. But we have very little evidence for this since we have only found "fines" and large lumps. Perhaps all the ore prepared for smelting had actually been used by the time the bloomery stopped work. No large pieces have been found in the furnace bottoms themselves.

Considering that the furnace bottoms weighed about 40 lbs., and allowing for 10 lbs. of tap slag, we have a total slag yield of 50 lbs. From the slag composition (15% SiO_2 5% Al_2O_3) it would seem that 1 lb. of slag was derived from 5 lbs. ore. Therefore the furnace charge would be about 250 lbs. ore, resulting in a bloom weighing about 130 lbs. This would give an apparent yield of 84% which is very high for the period, and which could only be obtained from a very high-grade ore such as Cumberland hematite. If this is correct, there can be little criticism of the process from a metallurgical viewpoint. However, there does not seem to be enough space between the top of the slag block and the suggested tuyere height (Fig. 10, A) to take a single 130-lb. bloom. Furthermore, the withdrawal of such a bloom and the slag block through the top of the furnace would be very difficult. It is possible that several blooms weighing about 30 lbs. were withdrawn from the furnace at intervals as the smelt progressed, and that the slag block results from the smelting of 4 such blooms. The height of the tuyere would then be more in keeping with the calculation of yield.

The relative absence of tap slag suggests that a lot of it was taken away as ore or flux for the later blast furnaces. With an iron content of more than 50% this material was very popular. The furnace bottoms on the other hand would be too unwieldly for 18th-century blast furnaces.

No hammer scale, smithing furnace bottoms nor "mossers" were found on the site, and it would, therefore, seem that blooms were not worked up on the site but taken elsewhere to be worked up into saleable iron.

The civil engineering standard is impressive and clearly results from a long-standing tradition for such work in the area. If the metallurgical standard was as calculated, the economic status must have been very satisfactory and the site only rendered obsolete by the coming of the blast furnace after 1711.

E. CONCLUSIONS.

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 post-dates 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 earliest surviving lease for Muncaster Head farm dates from 1724 and is for a period of 21 years. It is, therefore, very probable that the farm was built about the beginning of the 18th century, soon after the bloomery had ceased working. Stone would be robbed from the bloomery site in order to help build the farm. 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 bloomery first started working with circular stone-clay bloom hearths which would have produced the furnace bottoms found on the site.

The existence of the flat plates of cast iron suggests a later more sophisticated type of bloomery furnace — perhaps built in the second half of 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.

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APPENDIX A.

Calculation of power required and power available.

(1) *Hammer.*

According to Percy,[10] the tail helve used in a Catalan hearth had a hammer head with a weight of 1400 lbs. which was raised about one foot at the rate of 100 times per min.

$$\text{H.P.} = \frac{1400 \times 100}{33{,}000} = 4.2 \qquad (1)$$

Assuming 50% Efficiency, we can allow 8 H.P. for this piece of equipment.

(2) *Bellows.*

One of us (RFT) has been making 7.5-lb. blooms with an air rate of 350 l/min. If we double this for the type of bloomery furnace at Muncaster, and assume that a pressure of 1 lb./sq. in. is necessary to get this through the tuyere and up the furnace,

$$H.P. = \frac{700 \times 144 \times 1 \times 1}{30 \times 33{,}000} = 0.085 \qquad (2)$$

Bellows are very inefficient and we can safely assume an efficiency of only 10%.

For three bloom hearths, we therefore need 2.5 H.P.

Max. total power required = 10.5 H.P.

Power available.

First we have to get some idea of the amount of water available. We know that the channel across the flood plain was about 15 ft. wide and could be 4 feet deep and that it was composed of sand and fine silty gravel. Longland[1] gives a maximum flow velocity of 1.5 ft./sec. for water in such a channel. If this is exceeded, considerable erosion will occur.

Therefore the maximum capacity of this channel will be

$$15 \times 4 \times 1.5 = 90 \text{ cu. ft./sec.}$$

If we assume that our wheel was of the low breast type with a fall of 3 ft., 6 ft. wide and 12 ft. diam., the effective horsepower according to Longland would be:

$$E.H.P. = \frac{0.50 \times 62.5 \times 3 \times 90}{550} = 15.2 \qquad (3)$$

As an undershot wheel, (4)

H.P. = 0.0028 VvA (V-v).
V = velocity of stream in ft./sec.
v = velocity of paddles = 0.4V.
A = immersed area of paddles, sq. ft.

Assume, Immersion of paddles, 12 in.
No. of paddles, 10.
Width of wheel = 6 ft.

Assume depth of water in the revetted race = 2 ft.
Cross-section of water in race = 2 x 6 ft.

$$\text{Velocity of water in race} = \frac{1.5 \times 60}{12} = 7.5 \text{ ft./sec.}$$

(Cross-section of water in open channel = 4 x 15 sq. ft.).

H.P. = 0.0028 (7.5 x 3.0 x 60) x (4.5).
= 17.0.

These two figures agree reasonably well. Even if we take the lesser, we seem to have adequate power available.

The velocity of the wheel (R.P.M.) for a flow rate of V ft./sec. is given by the equation:

$$R = \frac{60 \times 0.4V.}{\pi D} \qquad (5)$$

where D is the diameter of the wheel in feet.
R is R.P.M.

The large hammer-wheel has a diameter of 12 ft. and would therefore rotate at 5 R.P.M. In order to do 100 strokes per minute, which is what the Catalan hammer worked at, would need 20 cams — an impossible number. Eight would be the maximum, and if we assume some acceleration of the flow rate as the water falls three feet on to the wheel we could probably get 50 or 60 strokes per minute out of the hammer.

Bellows wheel.

Here we have a wheel of 6 ft. diam. and 2 ft. wide with water-flow rate of 7.5 ft./sec. It would have 8 paddles and be supported in the water by two bearings so as to overhang the race. Again, the paddles would be immersed to a depth of 1 ft.

Using equation (4) we find that the power available from such a wheel is 4.5 H.P. Its R.P.M. would be 10, which would give 40 strokes per minute with 4 cams. This is perhaps a little too fast for bellows and 2 cams would be sufficient. There would be plenty of power available for 3 bloom hearths.

APPENDIX B.

Calculation of Phosphorus Contribution of Charcoal.

1 lb. of iron requires 3 lbs. of charcoal.

Let ash content of charcoal be 3%. If the phosphorus content of this ash be 3%, i.e. assuming no peeling of bark, the manufacture of 1 lb. of iron will make available:

$$\frac{3}{100} \times 0.09 \text{ lbs.} = 0.0027 \text{ lbs. P.}$$

Therefore the manufacture of 100 lbs. of iron will release 0.27 lbs. P, of which about half will go into the slag and the other half into the iron.[3]

Assuming a bloomery yield of 75%, 100 lbs. of iron will produce 50 lbs. slag from about 200 lbs. of ore. (What is lost as oxygen from the ore will be gained as charcoal ash.) Therefore the P content of the slag will be:

$$\frac{0.13}{50} \times 100 = 0.26 = 0.59\%\ P_2O_5.$$

This compares favourably with the P_2O_5 contents of the tap slag and the furnace bottoms of 0.36 and 0.45% respectively.

One would expect the phosphorus content of the iron itself to lie between 0.1 and 0.2% on the basis of iron/ore partition of 0.25 to 0.5. The figures we have for iron produced at Muncaster Head gave 0.097 and 0.058%, which is about half that expected. However, if phosphorus is coming from the wood ash rather than the ore it is possible that it is selectively absorbed by the slag at the bottom of the furnace and that not so much of it enters the metal.

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