HISTORICAL METALLURGY

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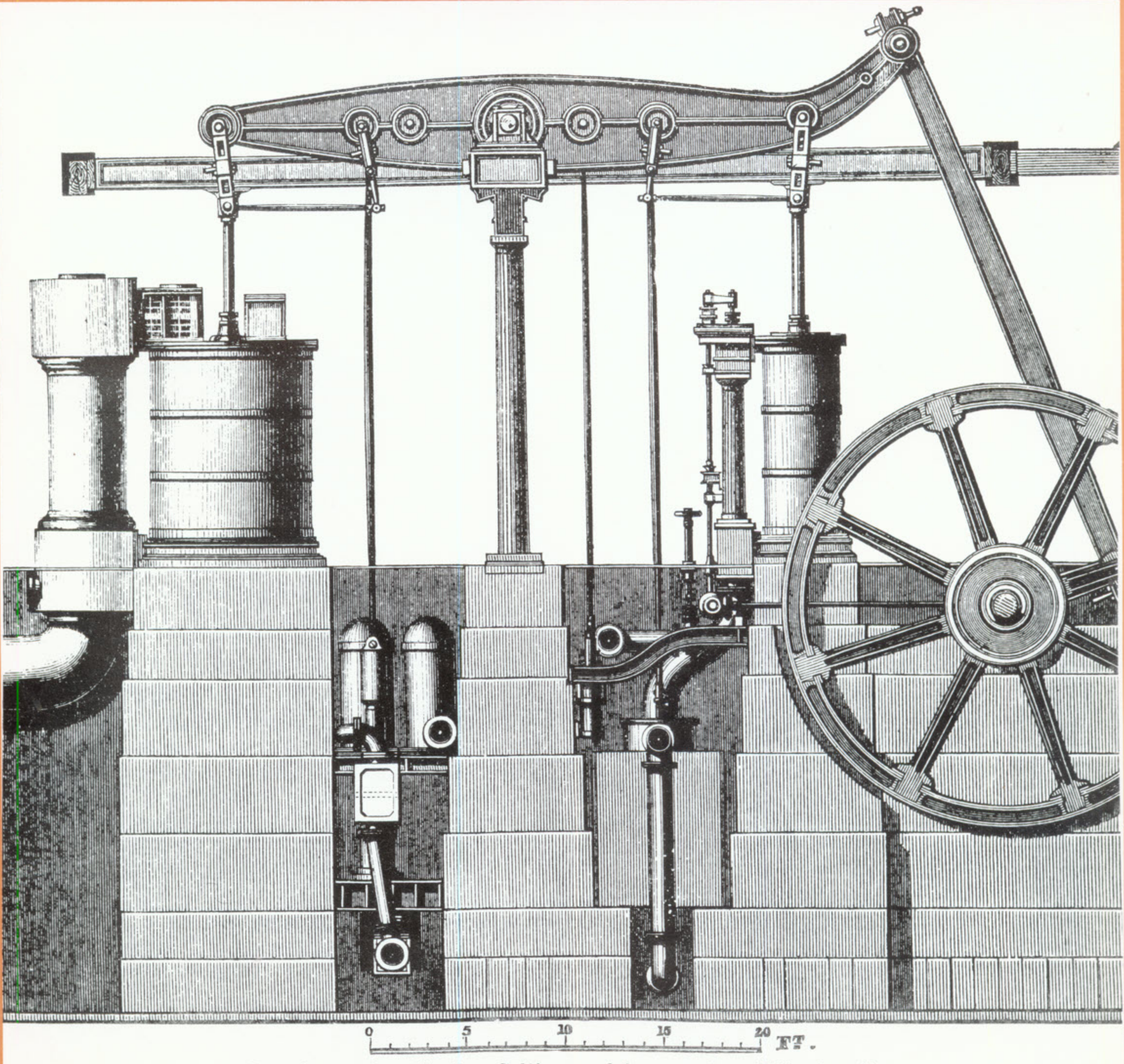

Blowing engine, Shelton Colliery and Iron-works. Side elevation.

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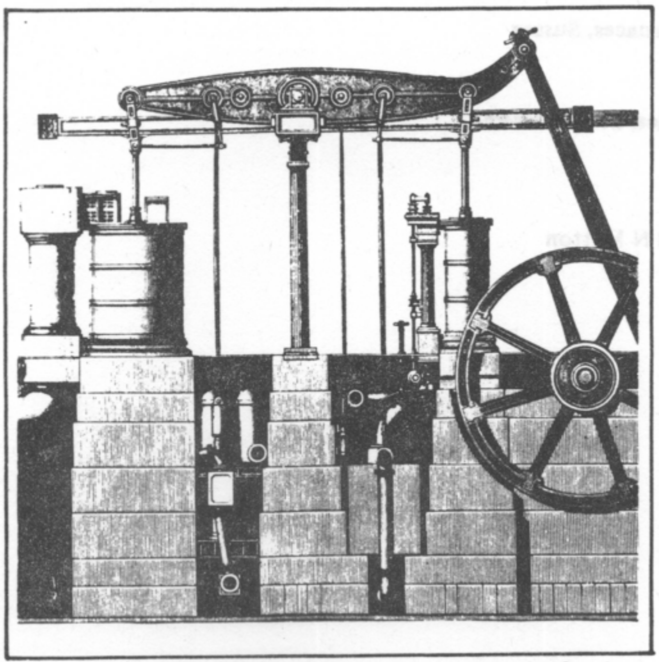
Shelton Ironworks blowing engine. Percy, Iron and Steel p 387

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Work in Progress

Iron age and Romano-British iron-working site in Minepit Wood, Rotherfield, Sussex

by J.H. Money, FSA

SYNOPSIS

From 1963 to 1965 detailed excavations were carried out on an early ironworking site in Minepit Wood, Rotherfield, Sussex. The workings began shortly before the Roman conquest of 43 A.D. and continued during the early years of the Roman occupation. Two periods were distinguished. Little remained of the earlier period except pits, pottery and some waste material of iron-working. At the beginning of the later period, which probably began soon after the Roman conquest, the site was tidied up and levelled, and a smelting furnace, which probably did not operate beyond the first century A.D., was established. Attached to the furnace was a timber shelter, which contained a hearth (possibly used for smithing) and occupation material in the shape of pottery, broken quernstones and sharpening stones. The adjacent heap of slag and other waste material from the furnace still survives.

INTRODUCTION

The workings *(TQ 523338)* lie beside the headwaters of a stream, at around 360 feet *(109 m)* above sea level, about two miles *(3.2 km)* N.N.E. of Crowborough *(Fig 1.)*. They are very remote; there is no public road within ¾ mile *(1.9 km)*; access is by tracks and across fields, which are often impassable in wet weather. This remoteness and the fact that the workings are in dense woodland are probably responsible for saving them from modern disturbance.

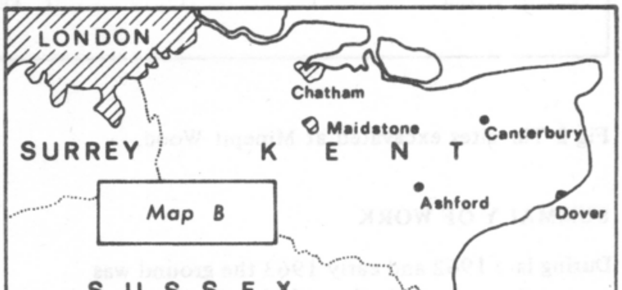
Almost the whole of Minepit Wood is on a down-faulted tract of Wadhurst Clay abutting against Tunbridge Wells Sand divisions and a thin belt of Grinstead Clay where it is faulted on the north.

The position was no doubt chosen because of the plentiful supplies of iron ore which the Wadhurst Clay, particularly the lower part, provided. Building stone was available from nearby outcrops of Ashdown Sand and Tunbridge Wells Sand; there was abundant oak and other types of wood for fuel and construction; and finally, the site was well drained and near fresh water.

The existence of early iron-workings in Minepit Wood was first detected by Straker, who was impressed by the large and undisturbed slag heap deep in the woods and took me to visit it in 1937. He gave me a copy of "Wealden Iron" and exhorted me to excavate the site, which I did in five seasons from 1963 to 1967.

The report which follows deals with three seasons' work *(1963-65)* on a two-period iron-working site *(Site A)* of late Iron Age and Romano-British date. During the remaining two seasons *(1966 and 1967)* we dug other remains which came to notice in 1965 and proved to be workings of medieval date *(14th/15th century AD)*. These *(Sites B, C and D)* are the subject of a separate report in **Medieval Archaeology, vol XV** *(1971)*, pp 86–111. The relative positions of the four sites is shown in Figure 2.

Fig 1 Map showing position of Minepit Wood, East Sussex. Based on the O.S. maps with the sanction of the Controller of HMSO. Crown copyright reserved.



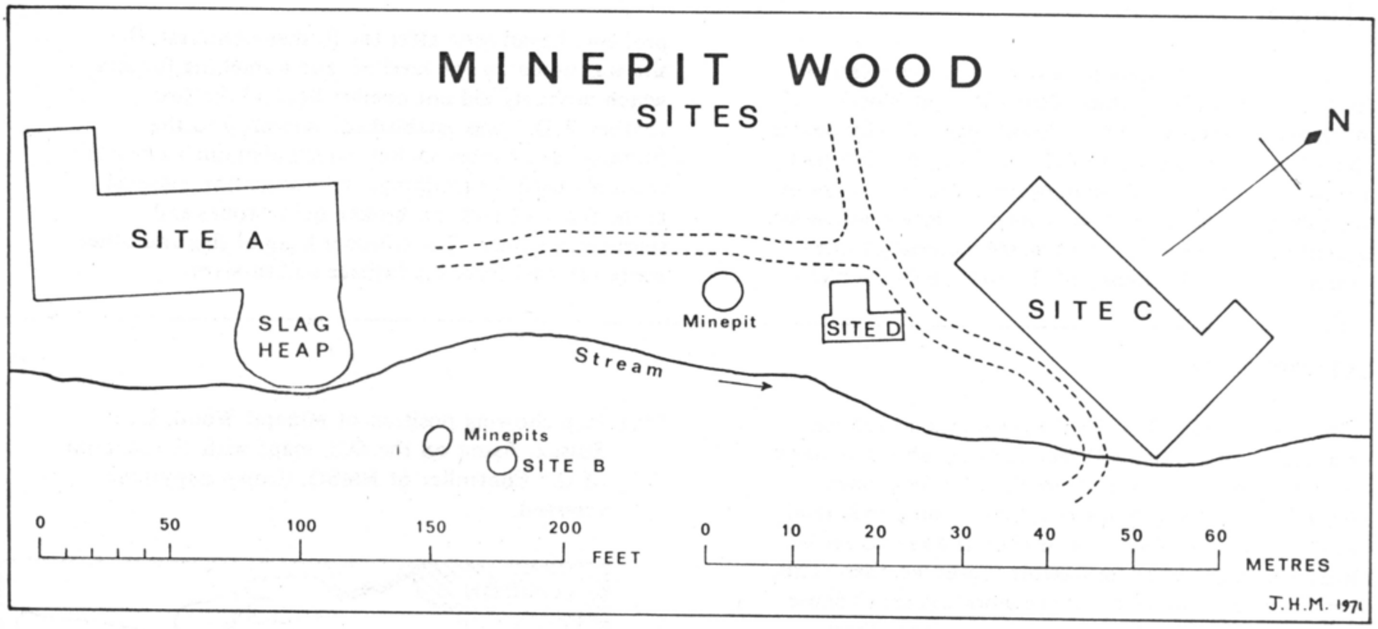


Fig 2 The sites excavated at Minepit Wood.

SUMMARY OF WORK

During late 1962 and early 1963 the ground was prepared for a section through the slag heap and an examination of the area immediately beside and behind it *(Figure 3)*. This operation brought to light a few pieces of stonework projecting above the ground, which looked like part of a structure.

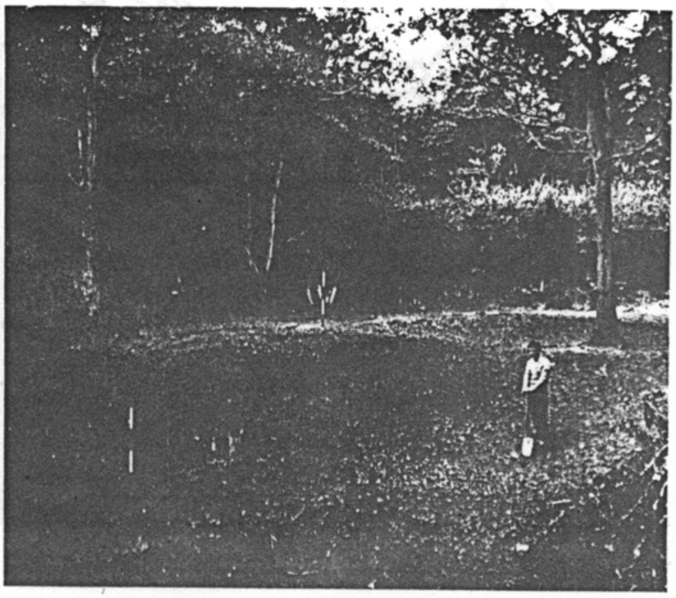


Fig 3 General view of slag heap and area behind it, looking west.

The main task of the first digging season (summer 1963) was a trench through the centre of the slag heap, which was found to have been dumped partly on a platform of compacted slag laid down as a filling of earlier pits and partly on natural clay bordering the stream-bed. Digging around the stonework revealed the top of what eventually proved to be a well preserved smelting furnace, from which the slag heap was in fact derived; charcoal from its last firing has a radio-carbon date *(BM–267)* of 1610 ± 150 years BP (between the late second century and late fifth century AD). This date is discussed on pp 10–11 below.

In 1964 and 1965 woodland south-west of the slag heap was removed and the cleared ground excavated in detail on a grid system. This produced more evidence of two periods. Belonging to the earlier were pits and gullies which had been deliberately filled in with clay and refuse of various kinds to provide a working area around the furnace; the filling included sherds of early first century AD pre-Roman pottery, and charcoal which has a radiocarbon date *(BM–363)* of 1949 ± 43 years BP (between the mid-first century BC and mid-first century AD).

Adjoining the smelting furnace and possibly contemporary with it was a timber shelter; and a small hearth (possibly for smithing) surrounded with fragments of tuyeres, pottery, and pieces of sandstone which had been used as querns, mortars and sharpeners. Trenches cut through the platform of compact slag showed how very solid it was and revealed some of the earlier pits and depressions beneath it *(Figure 4)*.

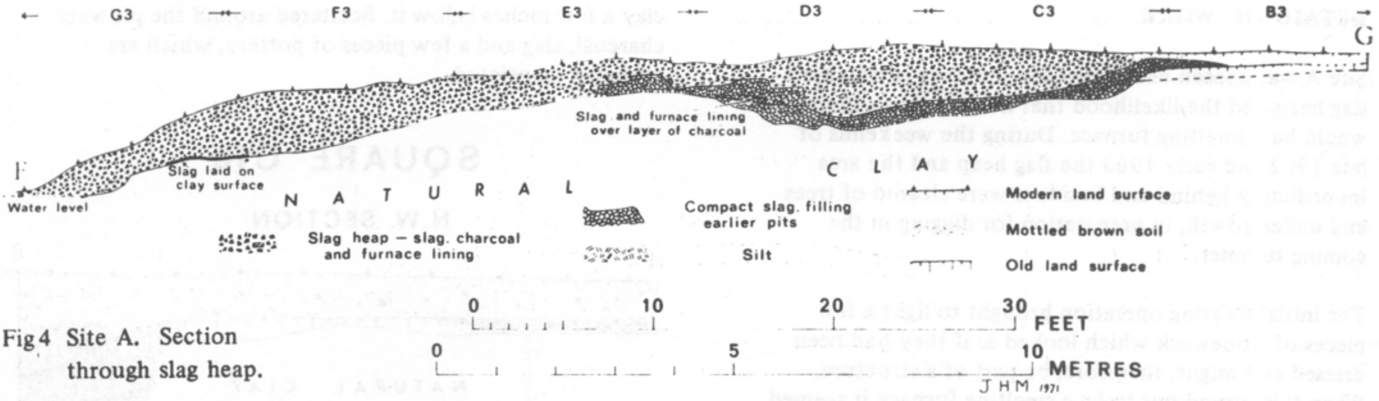


Fig 4 Site A. Section through slag heap.

Finally, at the end of 1965, work was completed on the smelting furnace, which was recorded in detail, and samples of its linings and refuse taken for testing.

The position of all these features is shown on the gridded plan at Figure 5 to which reference is made throughout the rest of the report.

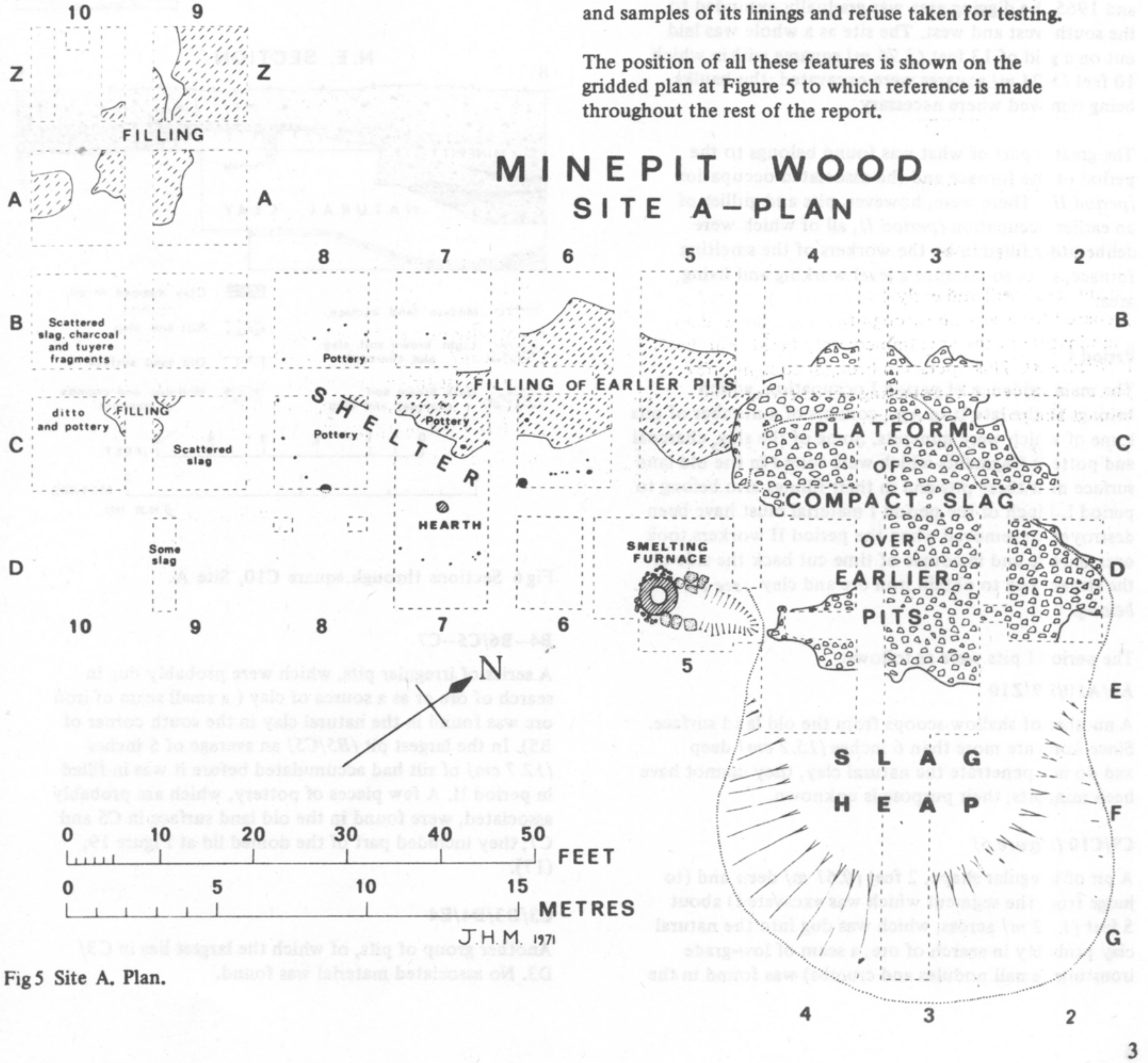


Fig 5 Site A. Plan.

DETAIL OF WORK

Site A was chosen because of the presence of Straker's slag heap and the likelihood that near the heap there would be a smelting furnace. During the weekends of late 1962 and early 1963 the slag heap and the area immediately behind and beside it were cleared of trees and undergrowth, in preparation for digging in the coming summer.

The initial clearing operation brought to light a few pieces of stonework which looked as if they had been dressed and might, therefore, be part of a structure. When this turned out to be a smelting furnace it seemed likely that the attendant occupation material would be found on this side of the slag heap, and during 1964 and 1965 the digging area was gradually extended to the south-west and west. The site as a whole was laid out on a grid of 13 feet *(3.96 m)* squares within which 10 feet *(3.04 m)* squares were excavated, the baulks being removed where necessary.

The greater part of what was found belongs to the period of the furnace and the associated occupation *(period II)*. There were, however, pits and gullies of an earlier occupation *(period I)*, all of which were deliberately filled in by the workers of the smelting furnace, so as to produce a level working and living area.

Period I

The main evidence of period I occupation, which belongs to the late Iron Age, consists of a number of pits some of which were minepits. Some of the slag, charcoal and pottery fragments which were found in the old land surface near these pits and in their fillings also belong to period I. Much of the period I material must have been destroyed or removed when the period II workers took over the site and in course of time cut back the side of the stream bed to obtain iron ore and clay *(see p 5 below)*.

The period I pits were as follows:

A9/A10/Z9/Z10

A number of shallow scoops from the old land surface. Since none are more than 6 inches *(15.2 cm)* deep and do not penetrate the natural clay, they cannot have been minepits; their purpose is unknown.

C9/C10 *(Figure 6)*

A pit of irregular shape, 2 feet *(0.61 m)* deep and (to judge from the segment which was excavated) about 5 feet *(1.52 m)* across, which was dug into the natural clay probably in search of ore; a seam of low-grade ironstone (small nodules and crumbs) was found in the clay a few inches below it. Scattered around the pit were charcoal, slag and a few pieces of pottery, which are probably associated.

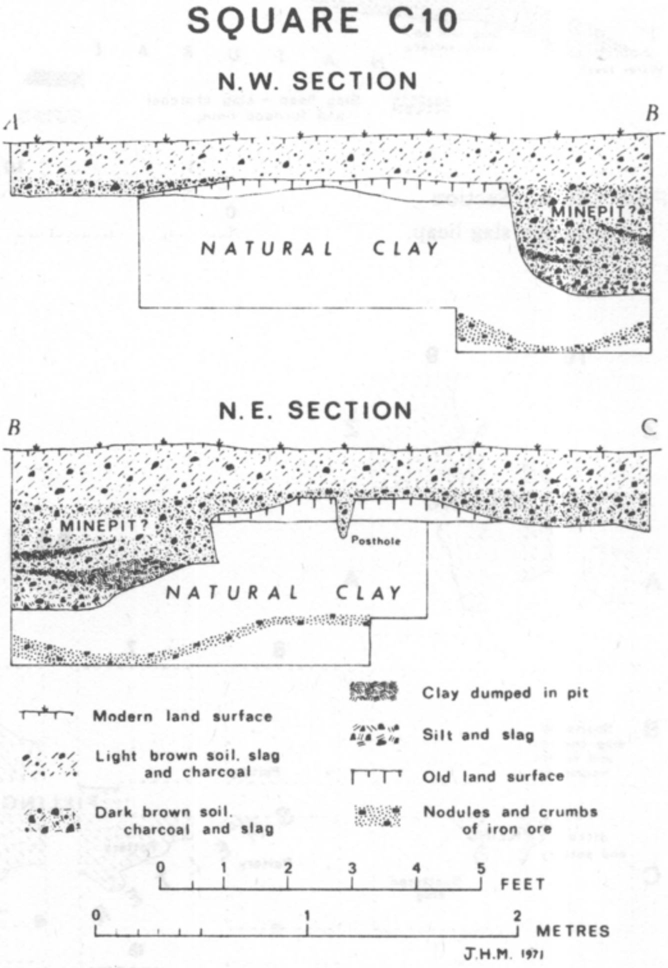


Fig 6 Sections through square C10, Site A.

B4–B6/C5–C7

A series of irregular pits, which were probably dug in search of ore or as a source of clay (a small seam of iron ore was found in the natural clay in the south corner of B5). In the largest pit *(B5/C5)* an average of 5 inches *(12.7 cm)* of silt had accumulated before it was in-filled in period II. A few pieces of pottery, which are probably associated, were found in the old land surface in C5 and C7; they included part of the domed lid at Figure 19, (17).

C3/D3/D4/E4

Another group of pits, of which the largest lies in C3/D3. No associated material was found.

Period II

Preparation of the working area

In period II the earlier pits were filled in and the area around the site of the new smelting furnace made more or less level. It is not possible to say how much of the in-filling was done immediately with period I rubbish left on the site and how much with material derived from their own activities. It is likely that as a start they dumped slag, cinder, ash, charcoal, tuyere fragments and broken pottery in the pits of B5/C5/B6/C6/C7, in order to dispose of earlier rubbish and provide a level space for the timber shelter south-west of the smelting furnace *(see pp.10-11 below)*. The pottery included a number of jars with everted rims *(Fig.19 (8-12))*.

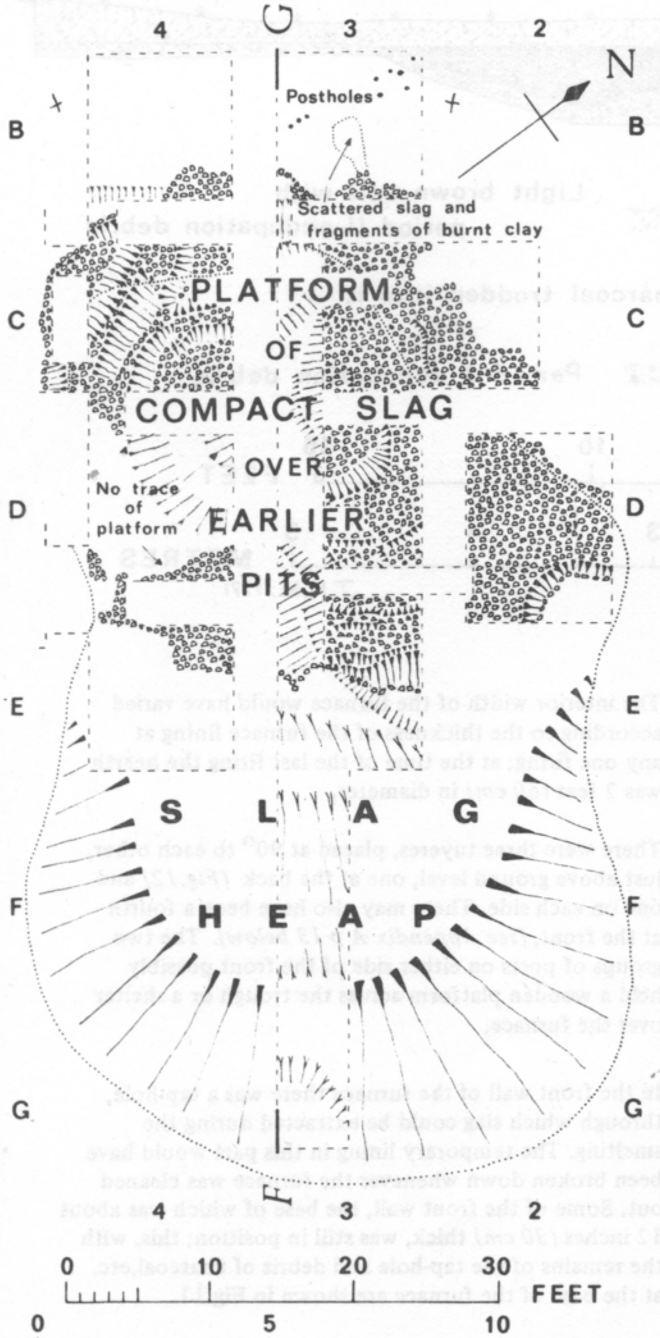


Fig 7 Plan of Site A, Slag heap, with earlier pits of Period I shown in red.

In the filling of the C5/C6 pit was oak charcoal with a radio carbon date *(BM-363)* of 1949 ± 43 years, B.P., which compares well with the associated Iron Age pottery, dated by Professor Cunliffe to the late first century B.C./early first century A.D. *(see Appendix B p 17 below)*.

A larger operation was undertaken by the period II workers in the area north and north-east of the smelting furnace, where various period I pits were filled with tightly packed slag, so as to create a relatively level working platform beside the furnace *(henceforth referred to as "platform")*. Details of the platform and underlying pits are shown in Fig.7. It is uncertain whether all this slag was already on or near the site when the period II workers arrived, or whether it was all derived from their own furnace, or a mixture of both. Levelling of this area as a whole was completed by dumping clay in the remaining hollows in the space *(B5/B6/C5/C6)* between the timber shelter and the platform; an example of this is shown in Fig.8.

Filling and levelling was also done in Z9/Z10/A10 and C9/C10. The former consisted of a single layer of slag bedded into a mixture of earth, ash and charcoal; there were sherds of pottery in A9. The period I minepit in C9/C10 was filled with slag, earth, unburnt clay and charcoal *(Fig.6)*; the filling included two sherds of pottery.

The supply of iron ore and clay

Of the small round pits which are scattered throughout Minepit only one was examined and was found to be mediaeval[2]. For the rest there is no dating evidence and nothing to link them with the site. There are, however, substantial excavations into the natural clay in woodland south and south-west of the site and these may have been quarries for iron ore and clay in period II. The stream bed also was extensively cut back in the area immediately south-east of the furnace. The section at Fig.4 shows the uneven surface under the slag heap from which the old land surface and top of the clay beside the stream were stripped. Immediately to the north-east of the slag heap, where the cutting-back ends, the bed of the stream narrows abruptly to its normal width.

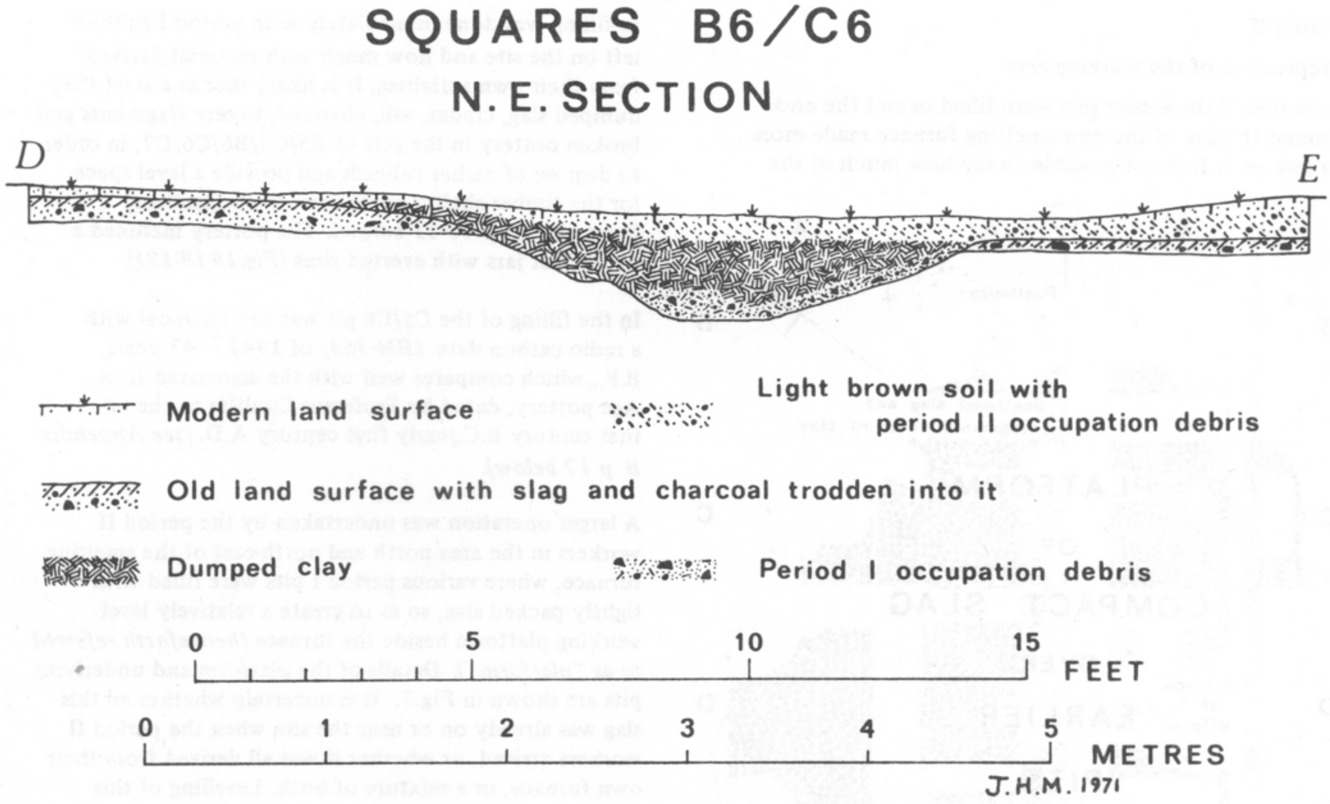


Fig 8 Section through squares B6/C6.

Tests on samples of unburnt natural ore recovered from occupation levels and natural seams show that all came from the iron-bearing strata of the Wadhurst Clay *(see Appendix A, p 15 below).*

The Smelting Furnace *Figs. 9, 10, 11, 12 and 13, and Appendix A pp 13–14 below).*

To accommodate the smelting furnace a shallow pit about 11 feet *(3.35 m)* long and 4 feet 6 inches *(1.37 m)* wide was dug in the natural clay. Small sandstone blocks were built up in a semi-circle against which the clay linings could be plastered. Some of these linings were built round a light timber framework of small stakes, which would have been interwoven with withies and twigs, so as to keep the clay in position until it had been hardened by firing; the charcoal-filled stake-holes of one of these frameworks can be seen in Figs. 9 and 13. Further forward slabs of dressed sandstone, three on each flank, were bedded into the clay on either side of the trough into which the slag was tapped.

The superstructure was domed and originally about 3 feet 3 inches *(1.0 m)* high; in places it is still standing to over 2 feet *(0.6 m)* high. About one-third of the superstructure was above the original ground level.

The interior width of the furnace would have varied according to the thickness of the furnace lining at any one firing; at the time of the last firing the hearth was 2 feet *(60 cm)* in diameter.

There were three tuyeres, placed at 90° to each other, just above ground level, one at the back *(Fig.12)* and one on each side. There may also have been a fourth at the front, *(see Appendix A p 13 below).* The two groups of posts on either side of the front possibly held a wooden platform across the trough or a shelter over the furnace.

In the front wall of the furnace there was a tap-hole, through which slag could be extracted during the smelting. The temporary lining in this part would have been broken down whenever the furnace was cleaned out. Some of the front wall, the base of which was about 12 inches *(30 cm)* thick, was still in position; this, with the remains of the tap-hole and debris of charcoal,etc. at the base of the furnace are shown in Fig.11.

At the end of the trough, where it rose to ground level, there was a small depression 2 feet by 1 foot *(60 by 30 cm)*, the purpose of which is unknown. The completely excavated furnace is shown in Fig.13.

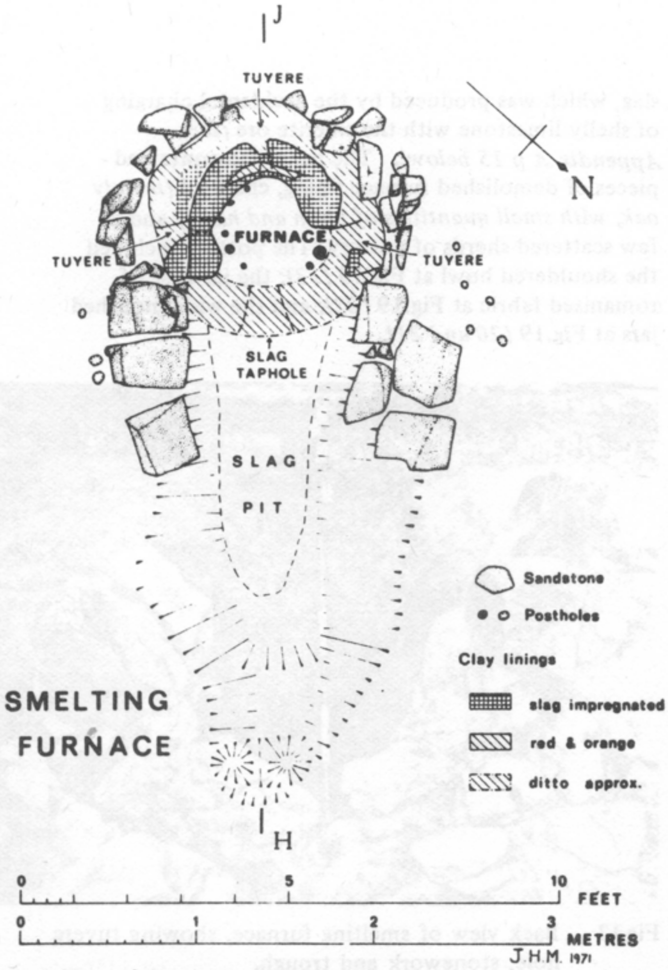


Fig 9 Plan of Smelting Furnace.

The Fuel

To judge from samples of charcoal taken from the base of the furnace itself and from the slag heap, the basic fuel was oak. The sample from the furnace was entirely oak. Samples from the slag heap were mainly of oak, but also contained small quantities of birch and hazel.

The method of working

No trace of a roasting furnace or dump of roasted ore prepared for smelting was found. There were, however, a few pieces of roasted ore amongst the occupation debris. The absence of roasted ore in the immediate vicinity of the smelting furnace is no proof that roasting was not part of the process, since any roasted ore which was prepared would probably have been consumed in the smelting furnace.

The smelting process is described in Appendix A, pp 19-21, which also discusses the furnace's place amongst other Roman furnaces in Britain and on the Continent.

The slag heap *(Figs. 3, 4, 7 and 14)*

The heap of slag and other waste material, which today measures about 64 feet *(19.5 m)* by 38 feet *(11.6 m)* and except at the edges is on average about 3 feet *(1.0 m)* deep, covers most of the artificial platform and the whole area between the platform and the stream; it appeared to be intact and undisturbed. As to the method of dumping, the waste material was probably first deposited on the platform *(particularly in the area of C3/C4/D3/D4, where the platform was*

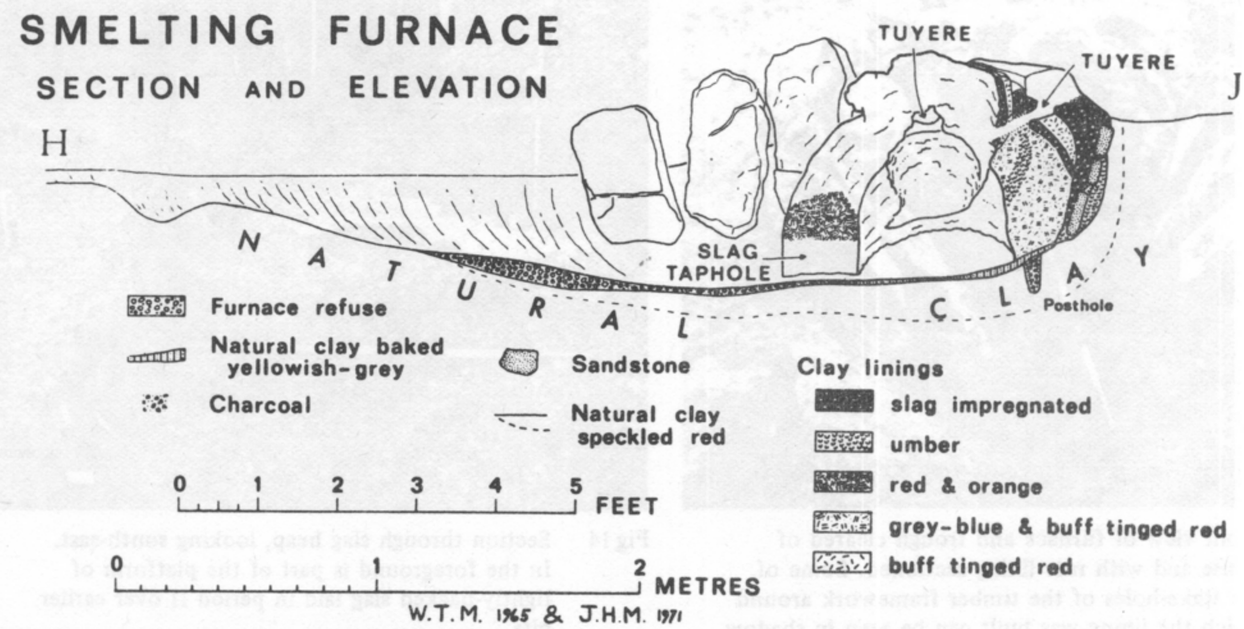


Fig10 Section and elevation of smelting furnace.

much worn away by the process of moving material on to and off it) and later tipped into the area between the platform and the stream. When the site was abandoned there was still a substantial deposit of waste material on the platform itself *(Fig.14)*.

Samples of waste material were taken at random from different parts of the heap. Almost all was tapped slag or cinder. There was a small amount of black glassy slag, which was produced by the accidental charging of shelly limestone with the siderite ore *(see Appendix A p 15 below)*. The heap also contained pieces of demolished furnace lining, charcoal *(mainly oak, with small quantities of birch and hazel)* and a few scattered sherds of pottery. The pottery included the shouldered bowl at Fig.19 *(13)*; the jar base of romanised fabric at Fig.19 *(22)*; and the wide-mouthed jars at Fig.19 *(20 and 21)*.

Fig 11 Smelting furnace partially excavated, showing stonework, remains of front wall, slag tap-hole and charcoal. The rear lining has been partly sectioned.

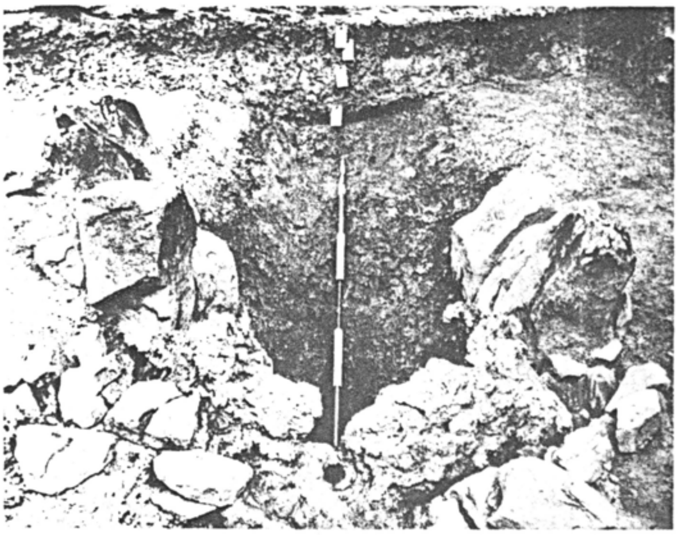


Fig 12 Back view of smelting furnace, showing tuyere hole, stonework and trough.

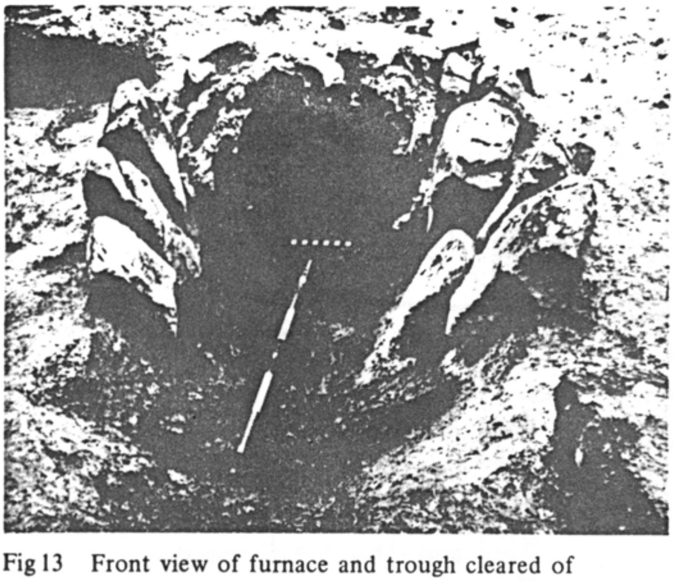


Fig 13 Front view of furnace and trough cleared of refuse and with rear lining sectioned. Some of the stake-holes of the timber framework around which the lining was built can be seen in shadow at the base of the furnace.

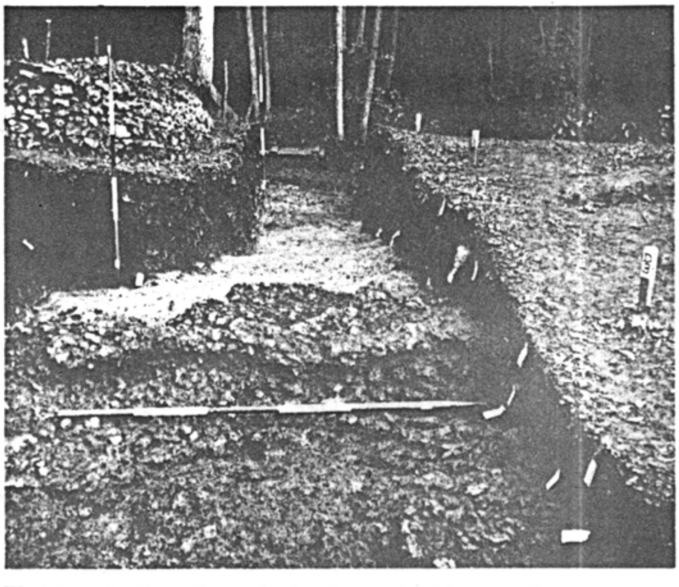


Fig 14 Section through slag heap, looking south-east. In the foreground is part of the platform of tightly-packed slag laid in period II over earlier pits.

The timber shelter and hearth *(Figs.15 and 16)*

There was a timber shelter a short distance south-west of the smelting furnace. Assuming that the workers would place the shelter to windward of the furnace, it seems likely that as a rule smelting took place when the prevailing wind was from the south-west, that is to say in summer, and that operations may have ceased in the winter season.

A small part of the shelter was built on the artificial filling in which had been deposited in the period I pits; the rest lay on the undisturbed land surface. The exact shape of the shelter and the extent to which it was roofed is uncertain. It appears to have been an irregular oblong of which the majority was covered: the N.W. end was perhaps open.

Under the covered part was a small hearth, whose base, consisting of completely non-magnetic, dense, heavy slag, and measuring 12 by 18 inches *(30 x 45 cm)*, lay on the natural clay. Part of the side of the hearth, consisting of similar pieces of slag, backed by clay, was still in situ. Scattered around the furnace, which itself was clean, were many small pieces of charcoal and 26 tuyere fragments *(which indicate that it was blown by bellows)*. Mr Cleere, who examined the base of the hearth and the tuyere fragments, considers that it was used for smithing. It is illustrated in Figs 16 and 17.

Other finds in this part of the shelter were: a few shreds of pottery including the wide-mouthed jar at Fig 19 *(19)*; two pieces of fine-grained sandstone, which, together with two more pieces of the same artefact

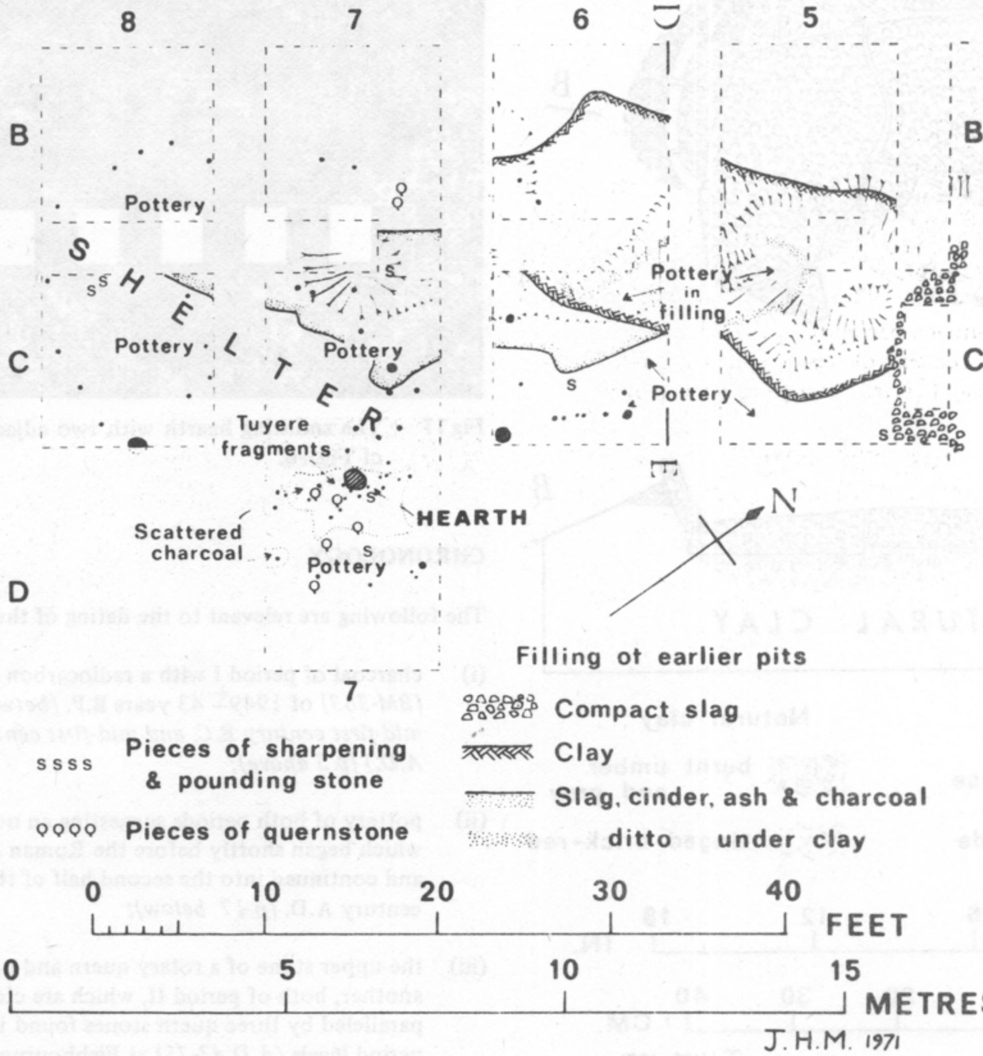


Fig 15[1] **Plan of central part of Site A with Period I pits shown in red.**

found at the bottom of the slag heap in D3, served variously as a mortar, whetstone and sharpener of metal points and blades; and the upper part of a rotary quern, of coarse-grained ferruginous sandstone, which had been broken into five pieces *(see Appendix C).*

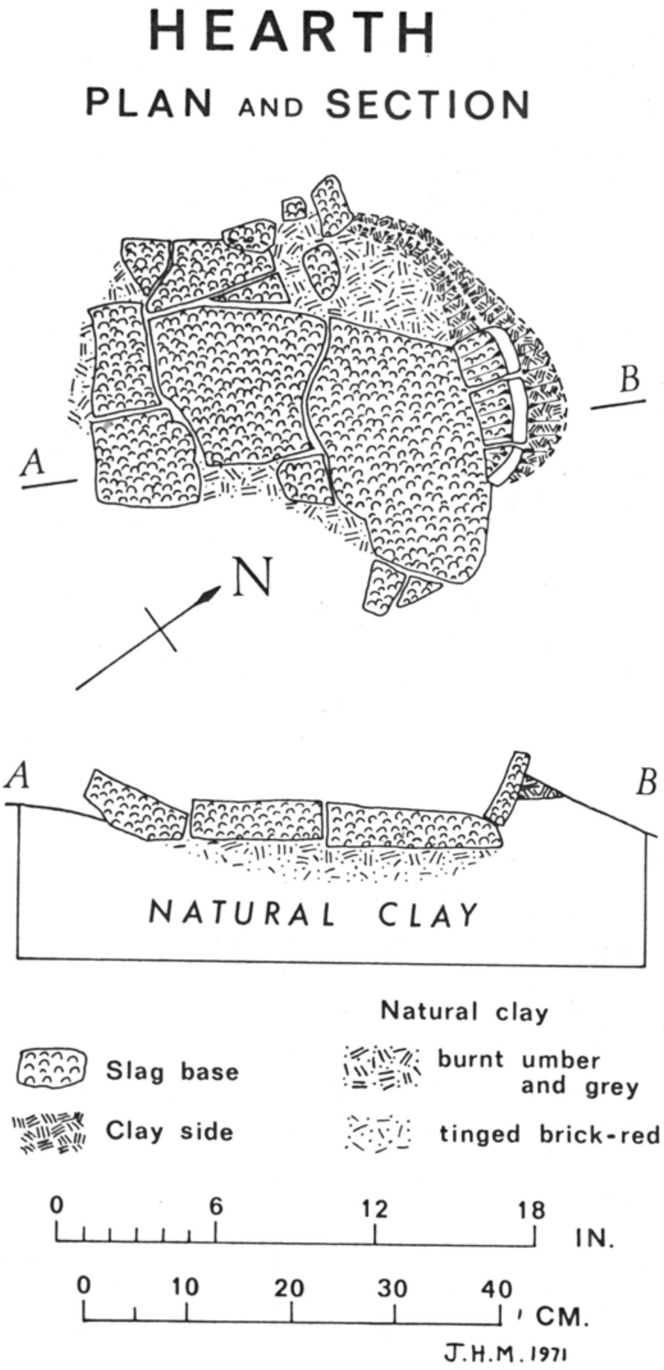


Fig 16 Plan and section of smithing hearth.

Pottery found in other parts of the shelter included the bowls in Fig.19 *(2 and 4)*; and the flagon neck in Fig.19 *(23)*.

In or near the shelter were: part of another quernstone broken into two pieces *(B7)*, a pestle or pounder *(C7)* and six broken pieces of sandstone with one or more of their sides smoothed and/or gashed and presumably used to sharpen metal blades and/or points *(C5, C6, C9 and C10)*; these are described in Appendix C.

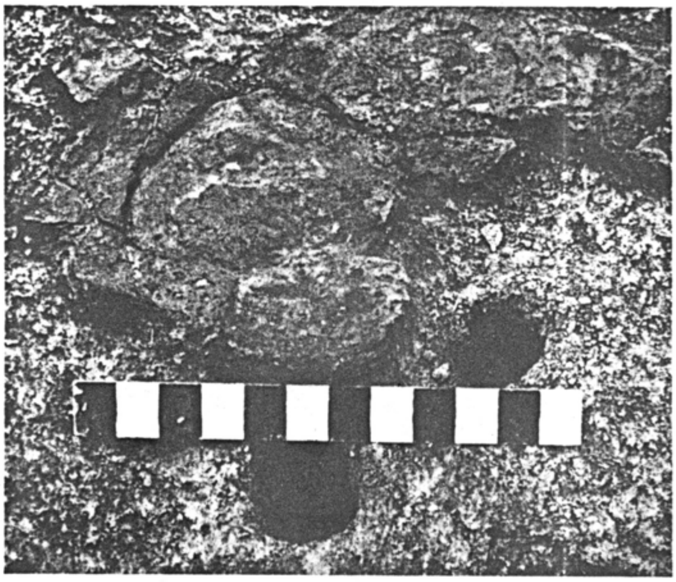


Fig 17 The smithing hearth with two adjacent postholes. cf Fig.16.

CHRONOLOGY

The following are relevant to the dating of the site:-

(i) charcoal of period I with a radiocarbon date *(BM-363)* of 1949± 43 years B.P. *(between the mid-first century B.C. and mid-first century A.D.) (p 5 above)*;

(ii) pottery of both periods suggesting an occupation which began shortly before the Roman conquest and continued into the second half of the first century A.D. *(p 17 below)*;

(iii) the upper stone of a rotary quern and part of another, both of period II, which are closely paralleled by three quern stones found in the first-period levels *(A.D.43-75)* at Fishbourne and a quern from the "mainly 2nd century A.D." site at Hassocks *(p 18 below)*;

(iv) the Pippingford Park smelting furnace, which is basically of the same type as that in Minepit Wood and is associated with pottery of the first century A.D. *(p 13 below);* and

(v) charcoal from the last firing of the smelting furnace *(and therefore at the end of period II)* with a radiocarbon date *(BM-267)* of 1610± 150 years B.P. *(between the late second century and late fifth century A.D.).*

(i) and (ii) both argue that operations in Minepit Wood began shortly before the Roman conquest of 43 A.D. The presence of mid-and late first century A.D. pottery in period II levels suggest that the smelting furnace was established shortly after the conquest. How long it continued to be worked is uncertain, but the presence of a flagon neck *(Fig.19 (23))*, which could be as late as the second century *(p 17 below)*, suggests the possibility of a second century date. The Fishbourne querns mentioned in (iii) strengthen the argument for the mid-first century. With regard to (v), the upper end of the bracket rests at the end of the second century A.D., while the median is as late as c.340 A.D.

The radiocarbon date appears in view of the other evidence to be somewhat late. On statistical grounds there is always a chance that the true date lies outside the limits of the associated probable error term. It is also possible that the charcoal was contaminated with more recent humic material and that not all of this was removed despite careful pretreatment of the sample before measurement. Either of these two factors or a combination of them could have been responsible for making the date younger than expected.

Taking the evidence as a whole, it seems likely that operations did not continue beyond the first century A.D.

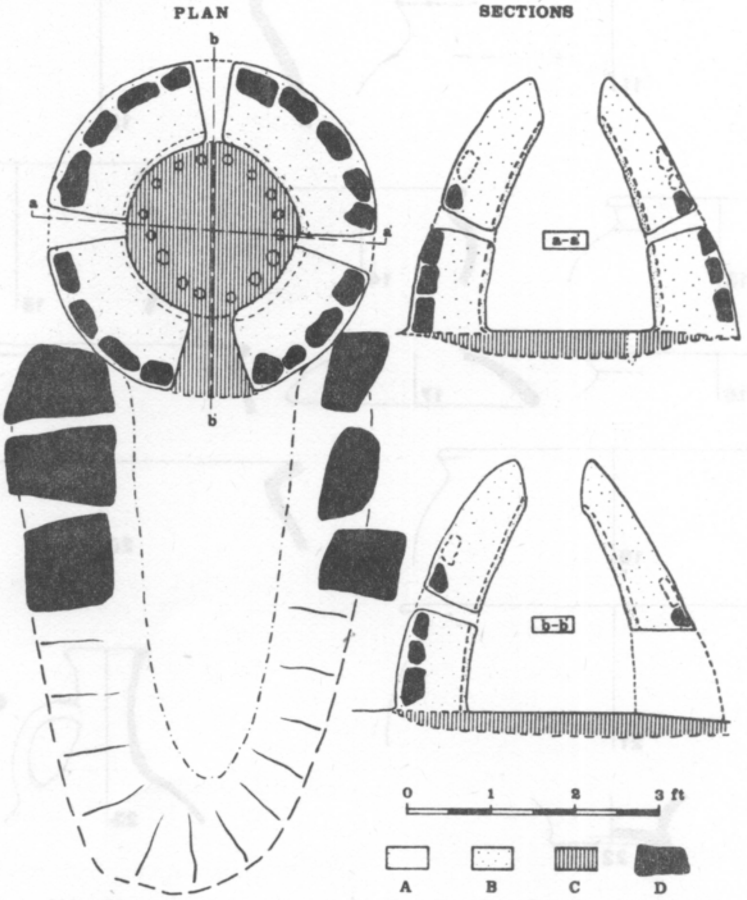


Fig18 Reconstruction of smelting furnace.

A	Furnace lining (prepared clay)	C	Clay hearth
B	Puddled clay superstructure	D	Sandstone blocks

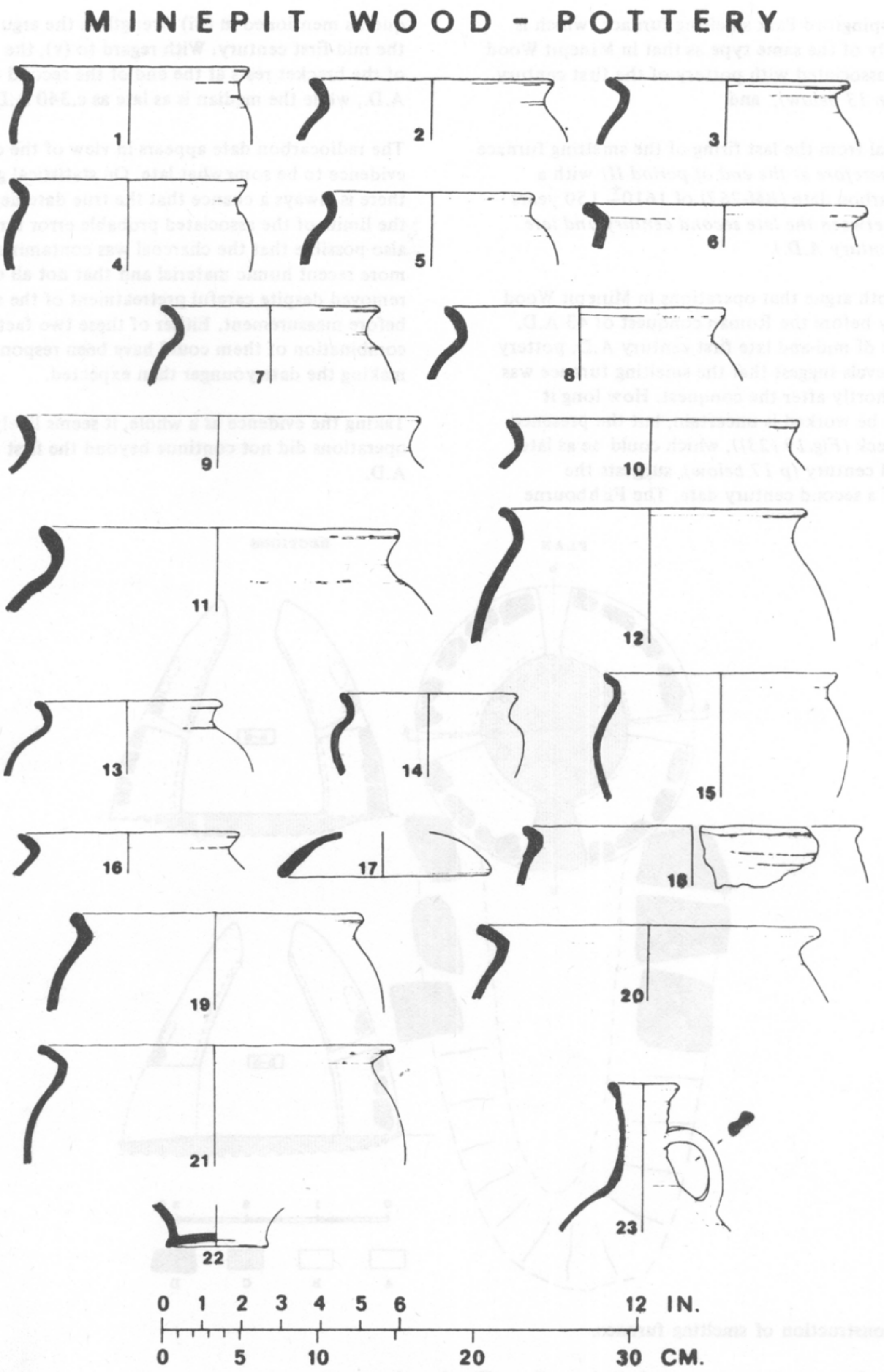


Fig 19 Minepit Wood pottery.

Appendix A

THE METALLURGICAL MATERIAL

by H F Cleere F S A

1. The Furnace

The furnace remains from the Minepit Wood site were very substantial *(Figs. 9, 10, 11, 12 and 13).* Essentially, they comprised the furnace hearth or base, measuring c. 2 feet *(0.6m)* in internal diameter and a considerable segment of the superstructure, standing to over 2 feet *(0.6m)* high in places. In front of the furnace lay a 6 feet *(1.8m)* long trough, lined at the furnace end with large blocks of sandstone.

The hearth of the furnace was filled with successive layers of furnace debris and charcoal, overlying the hard-burnt natural clay surface, suggesting that the furnace had been relined at least once, a new surface for smelting being built up on the debris of the earlier lining. This was confirmed by the section cut through the remaining furnace wall, which showed no fewer than three layers of slag-coated hard-burnt clay, indicating at least two rebuilds.

The other noteworthy feature of the remains was the existence of three tuyere holes, at roughly 90° from one another and approximately 1 foot *(0.3m)* above the hearth level. Unfortunately, all but the lower part of the front wall of the furnace *(ie that connecting with the trough)* had collapsed; the shape and size of the front arch could be made out, but there was nothing to indicate whether there had been a fourth tuyere or not.

A suggested reconstruction of the furnace in its first phase is shown in Fig.18. This is based on the remains found in situ and on large fragments of collapsed furnace lining found in and around the furnace. It is clear that the furnace was blown with bellows at a, a^1, and b; there may also have been in addition a bellows working through a tuyere inserted with the frontal tapping arch at b^1 *(which would have been blocked up with clay during the smelting operation).*

One point about the existing tuyeres that deserves comment is their height above the hearth. In single-bellows early furnaces, the tuyeres were generally lower, not more than 6 - 9 inches *(15 - 23 cm)* above the hearth. It is unlikely that sufficient heat could be generated on the hearth level itself with tuyeres working at this height, and so difficulties might have been encountered in starting the reduction process. However, it is possible that a tuyere placed at a lower level in the tapping arch would have been used in the first phase of operation, the others being brought into action as the heat built up in the lower area. A similar arrangement has been observed in early furnaces from the Holy Cross Mountains area of Southern Poland *(although in a slightly different type of furnace)*[3]

The reconstruction shows a domed superstructure. This is justified by the remains found in situ, and also by the curvatures measured on some of the larger fragments.

This was the first furnace of its type found in Britain. Another example[4] associated with first century A.D. pottery, but a somewhat later radiocarbon date *(B.M. -685, 1647 ± 60 years B.P. c. A.D. 303, which may have been affected by the same factors as B.M. -267, see p 11 above)* was found recently in Pippingford Park. It is a type of furnace that is known from Central Europe; examples are illustrated by Coghlan from Engsbachtal and Aalbach *(Germany)*, and similar furnaces are known from Bohemia[6]. However, these furnaces were either operated on a natural draught, operating through the large frontal arch, or were blown with a single bellows. The Minepit Wood furnace is exceptional in being operated with multiple tuyeres.

So far as its hearth diameter is concerned, this furnace is comparable with the Continental parallels, in which hearth diameters of over 1 metre have been recorded. However, it is much larger than Roman furnaces excavated in Britain *(eg Ashwicken, Norfolk[7], and Holbeanwood, Sussex[8]).* The latter represent a different tradition, being shaft furnaces *(ie with cylindrical superstructures)* which appear to derive from the Roman Empire, rather than domed furnaces, whose main concentration lies outside the limes, in the Celtic and German lands. This is well illustrated by Pleiner[9], in a distribution map showing furnace types.

One very interesting feature observed at Minepit Wood concerns the method of construction of these furnaces. The cylindrical furnace was relatively easy to construct, by using a tree trunk as a former, around which the clay shaft could be built up *(as ingeniously suggested by Tylecote[10]).* The meticulous excavation of the Minepit Wood furnace revealed a circle of shallow stake-holes, into which sticks could have been inserted, to act as the base of a former of withies and twigs. Clay was then plastered over this framework building up to a thickness of nearly 1 foot *(0.3m).* Blocks of sandstone were incorporated into the outer layers to lend strength to the structure; these were not found in the Ashwicken and Holbeanwood furnaces, which were built into a bank of clay rather than being free-standing, as the Minepit Wood furnace indubitably was.

The structure would have been allowed to dry in air, and then a fire would have been lit inside, the temperature gradually being increased. The wooden former would, naturally, be burnt away, leaving a clay dome. The latter would indubitably have been cracked and fissured by the heat, as modern experiments in early furnace construction have shown[11], and so the surface, both inside and out, would have been plastered with clay slurry, so as to render the superstructure air - and gas - tight. Particular attention would be paid to the inside of the furnace, so as to avoid any spalling off of large segments of lining during the smelting.

To summarize the above, it can be said that the Minepit Wood furnace is an example of a type of furnace not common in Roman Britain, the slag-tapping furnace, blown with a forced draught *(ie bellows)* and with a hemispherical or conical superstructure *(Group B.1.ii in the classification proposed by the author*[12]). It is a type that is well-known from non-Roman Germany and further east, but exceptional in that it was blown with not one but three or even four tuyeres.

It has also yielded valuable and unusual evidence of its method of construction.

2. The Process

It is not proposed to deal in detail with the method of iron smelting practised in this type of furnace; this has been described fully in the standard works on the subject[5,13]. However, a brief résumé is necessary to explain the significance of the products that were found in association with the furnace and are commented on in the next section.

Once the furnace was completed, it would have been pre-heated using wood, the inside temperature being gradually raised from ambient to about 500°C. At this point, it is likely that the frontal arch would have been stopped up with clay, and the fuel changed to charcoal. The bellows would then all have come into operation, and a temperature in excess of 1000°C would have been reached in the hearth zone; the stock level would have been kept constant by frequent replenishment through the top aperture.

When the furnaceman was satisfied, charging of iron ore would have begun. The roasted ore would have been added in small amounts, 1 - 2 kg at a time, with alternative equivalent weights of charcoal. The hot carbon monoxide formed by the combustion of the charcoal would travel up the furnace, reducing the ore according to the formula.

$$FeO + CO \longrightarrow Fe + CO_2$$

At the same time, part of the iron oxide *(FeO)* would combine with the gangue, or stony part of the ore, to form a slag *(fayalite; $2FeO.SiO_2$)* which would be molten at about 1200°C. The metal itself would not become molten, but would slowly fall under gravity down the furnace, to coalesce in the form of a spongy mass or bloom at tuyere level.

The molten slag would collect at the base of the furnace, and would be allowed to run out into the trough in front of the tapping arch. This may have been done periodically, the clay stopping being partly or wholly removed, or, as recent experiments[11] have suggested, continuously, through a "running taphole", in modern parlance, the solidified material being removed from time to time.

This process would be continued for many hours, until a bloom had formed that was just small enough to withdraw through the frontal arch. It is likely that a furnace of these dimensions would be run for ten hours and more, and would have produced a bloom weighting 23 kg or even larger. To remove the bloom the bellows would be removed, the whole of the clay stopping of the frontal arch would be pulled out, and the bloom would be extracted with tongs.

The raw bloom was, as already mentioned, a spongy mass, with many gas holes and containing much entrapped slag. It would therefore need to be heated and hammered repeatedly so as to expel the slag inclusions and to consolidate the metal into a solid ingot. This process would be carried out on a separate forging hearth, the site of which may have been identified in C7/D7 *(see p 3 above)*.

In addition to the iron, the furnace produced two other materials: tap slag *(the slag allowed to run out of the furnace)* and cinder *(slag which remained at the base of the furnace, adhering to the clay base, clinker-like in texture and containing much charcoal and unreduced ore)*. The latter quite often was removed in one piece, with some of the clay lining adhering to its under surface, and "furnace bottoms" of this type were found in the slag heap. Once the furnace had been cleared of this debris, any deficiencies in the hearth and walls would be repaired with clay slurry, and the process could recommence. It should be mentioned here, however, that no attempt was apparently made to remove the slag which adhered to the walls of the furnace. This was a wise precaution, since it lent strength to the structure and its removal could only be effected at the cost of detaching part of the clay lining: most of the fragments of furnace superstructure examined were more or less thickly coated with slag in this way.

The process is one involving heat and stress, and the superstructures would inevitably have given way after a number of smelts. Recent experiments[11] suggest that the frontal arch was the main source of weakness, and it is significant that most of this part of the Minepit Wood furnace superstructure is missing. It seems clear from the remains that only part of the furnace was rebuilt; however, instead of trying to incorporate the intact sections into a new structure, they were left in situ to form the basis or mould for that segment of the new furnace. This explains the superimposed layers at the back of the furnace.

3. Raw Materials and Waste Products

Ore

A number of ore samples were examined, from the slag heap, the slag platform, and elsewhere on the site. All came from the iron-bearing strata of the Wadhurst Clay.

They fall into two groups:

1. High grade nodular ore *("boxstone")*: fine grained siderite *(iron carbonate)* in an envelope of limonite *(iron oxide)*.

2. Lower-grade tabular ore: siderite, with higher content of quartz (silica) than the nodular ore.

Both ores are easy to smelt, but the nodular ore is higher in iron and so would produce a higher metal yield.

The siderite benefits from roasting outside the smelting furnace; the carbonate is converted to oxide, water is driven off, and the material becomes broken up into a size more convenient and effective for smelting. Both types of ore were found in both the roasted and unroasted states.

The presence of fine particles of ore is detrimental to the smelting operation; they clog up the furnace unless very strong bellows are used. The presence of layers of fine roasted ore particles indicate that here, as elsewhere, the fines were screened out and discarded.

A ferruginous, shelly, limestone, known as Cyrene limestone after its characteristic fossil, occurs in association with the iron ore in the Wadhurst Clay. At other Roman sites, this material appears to have been picked out; at Bardown, for example, it was used exclusively for building purposes *(an interesting precursor of its later use, whence the material derived the local name of "Bethersden marble")*. From the point of view of yield this was the sensible course, since the iron content is only about 8%. However, the material is high in lime *(46% CaO)*, which could "flux" the slag – ie combine with the silica *(SiO_2)*, thereby replacing the potential metal source of FeO in the normal fayalite slag. A number of finds of this shelly limestone were made at Minepit Wood and it appears *(see below)* that this material was being charged to the furnace.

Slag and Cinder

The bulk of the waste material examined was tapped slag or cinder. Most of the slag was the typical fayalite type associated with furnaces of this type: it is a blue-black material, very dense in character, the amount of porosity depending on the temperature at which it was tapped. One cake of tap slag, found in the slag heap, measured 13.4 x 12.6 x 2.4 inches *(34 cm x 32 cm x 6 cm)* thick, and was manifestly part of an even larger mass. This had obviously formed in the trough and then been levered out and broken up for disposal; burnt clay was still adhering to its underside.

The cinder was equally characteristic: a furnace bottom measuring 8.7 x 9.4 x 1.5 - 2 inches *(22 cm x 24 cm x 4-5cm)* thick consisted of a clinkery matrix of slag containing fragments of charcoal, ore, and burnt clay *(presumably from the furnace lining or the arch stopping)*.

A small amount of black glassy slag was also found in the Period II slag heap. On analysis, this proved to have a lower iron content *(9.5%)* than the usual fayalite slag and a lime *(CaO)* content of 19.8%. It is believed that this could have been produced only by the charging of a small amount of shelly limestone *(see above)* with the siderite ore. That this was accidental is manifest from the fact that so small an amount of this type of slag was found; unfortunately, the Minepit Wood ironmaster was not aware of the potentialities of the shelly limestone in increasing the yield of iron from his furnaces.

Tuyeres

A large number of tuyere fragments were found on various parts of the site. From what has been described of the process above, it will be clear that the interior of the furnace was very hot indeed, and indeed the outside would have been hot enough to char wood. Since the nozzles of early bellows are likely to have been made of wood, it would not have been practicable for these to have been inserted directly in the furnace wall.

For this reason, nozzles of clay were made, which would project through the furnace wall *(or the stopping of the furnace arch)*; the end of the tuyere which projected into the furnace was cylindrical and the "outside" end flared, to receive the bellows nozzle.

Two types of tuyeres are known – single and double.

Tylecote[13] illustrates single tuyeres, including Roman examples from Crowhurst Park, Sussex, and double tuyeres are described in a paper by the present author[14]. The latter appear to be exclusively Wealden in their

distribution: examples are known so far from Bardown, Beauport Park, Chitcombe, and Little Farningham Farm *(Sissinghurst)*.

Most of the tuyere fragments examined were too small for their type to be confirmed. However, one fragment from the filling of a Period I pit in B 10 was clearly double, of the author's type B^{12}. Interestingly enough, the fragments associated with the hearth in D7/C7 appeared to be from single tuyeres: if this was a small forging hearth, it might indicate a distinction in use between the two types of tuyere.

Appendix B

THE POTTERY

by Prof. B W Cunliffe, FSA.

The small group of pottery recovered from the excavations was divided, by the excavator, into three groups on stratigraphical grounds: pottery which can be attributed to period I, pottery from period I or II contexts and pottery definitely belonging to period II. A selection of the more typical forms is illustrated here *(Fig.19)*. In addition to the material chosen for description the collection included a quantity of body sherds in fabrics already represented by the illustrated vessels and a few rim fragments closely similar to jar types shown in Fig.19.

Description of the illustrated pottery

1-10 Small bowls and jars with simple everted rims. The fabric is smooth, grey/buff and tempered with soft grits. It is underfired and consequently the surface has flaked or been otherwise eroded. Nos. 3, 5, 7, 8, 9 and 10 are from periods I or II, Nos. 1, 2, 4 and 6 are from period II levels.

11-12 Large jars with everted rims in fabrics similar to the above. Both are from period I or II levels.

13 Shouldered bowl in soft crumbly dark grey ware fired to black on the surface which is carefully smoothed. Period I or II.

14 Shouldered bowl in smooth buff/grey ware with a well finished surface. Period II.

15 Bowl in a very much eroded soft buff grey ware with soft grits. Period II.

16 Bowl in a dark grey slightly sandy ware. Period II.

17 Two fragments of (?) the same vessel which appears to be a domed lid. One fragment comes from a period I level, the other from period II.

18 Vessel of beaker type decorated with exterior cordons. Smooth buff underfired ware with soft grits. Period I.

19 Wide mouthed jar in soft grey buff fabric. Period II.

20 Wide mouthed jar with everted rim in hard smooth grey ware. The exterior surface and the rim top are highly burnished and fired to an even black. Period II.

21 Wide mouthed jar in smooth buff ware. The rim has been painted with black slip inside and out to contrast with the ochre/grey surface. Period II.

22 Base: grey sandy ware. Period II.

23 Flagon with ringed neck: buff sandy ware. Period II.

Discussion

The pottery has few distinctive characteristics but romanised fabrics are present in period II levels. Of these two are illustrated, the base of a jar No.22 and the flagon, No.23. Neither can be closely dated but the flagon is of a type common in the second half of the first century A.D. continuing in fashion into the second century. The necked vessel, probably a beaker *(No.18)* is a local copy of an imported Gallo-belgic butt beaker, a type in use in the middle decades of the first century A.D. A similar vessel but without the pronounced cordons was found at the bloomery at Crowhurst Park, Sussex[15], a site with which the Orznash pottery has a general affinity. The wide mouthed jar with painted rim *(No.21)* is unusual but the use of paint as a means of enhancing decoration occurs on broadly contemporary pottery from Horsted Keynes, Sussex[16]. As to the rest of the vessels there is little to be said. The forms are simple and recur many times among the assemblages of Kent and East Sussex. Typologically they belong to a general class of wheel made bowls and jars which developed late in the first century B.C. and continued in use until sometime after the Roman Conquest, improving only in fabric. It would be pointless to attempt to classify such generalised forms in terms of locally defined styles but it may be pointed out that the characteristic types of the Aylesford-Swarling Culture of Kent and the group which has been called Southern Third B *(=South Eastern B)* in the Hawkes Scheme, distributed mainly along the Downs and Coastal Plain of Sussex, are absent. In a group of this size, however, little significance can be attached to the point.

Dating is difficult with any degree of precision, but occupation probably began in the decade or two before the Roman Conquest and continued into the second half of the first century.

Appendix C

THE STONE ARTEFACTS

by J H Money

The following stone artefacts were found in or near the timber shelter, south-west of the smelting furnace.

1. Multi-purpose stone *(Fig.20)*

It is a fine-grained sandstone, uncemented except for some secondary growth of quartz between the grains, and with some scattered glauconite grains; it probably came from the top of the Ashdown Beds *(or possibly the Tunbridge Wells Sand)*. It had a varied history and a number of different uses. At first, when it was unbroken and measured 10.8 x 11.5 x c.4 inches, *(27.3 x 29.2 x c.10cm)* it was used on one side as a mortar *(? for crushing ore)* - and this produced the concave surface *(ww and xx)*; on the other side *(yy and zz)* it served as a whetstone. After it had been broken down the middle, the two halves were used independently: (i) as whetstones *(zz being used rather more than yy)*, and (ii) for sharpening the blades and points of metal implements *(note gashes on sides)*. Both halves broke into quarters, but not necessarily at the same time. The quarters of the more worn half, which perhaps broke first, were thrown into the slag heap in D3; the other two were left near the hearth in D7.

A similar stone was found in the second century A.D. site at Bardown[8] in what was interpreted as a smith's workshop. This lends weight to the suggestion that the hearth at Minepit Wood was for smithing.

2. Upper stone of rotary quern *(Fig.21)*

The quernstone, which is a coarse-grained ferruginous sandstone from either the Ashdown Beds or Tunbridge Wells Sand, has a diameter of 16 inches *(40.6 cm)* and varies in thickness at its circumference from 2 to 2.75 inches *(5 to 7 cm)*. It was found in D7 broken into five scattered pieces near the hearth *(Fig.16)*. It was rejected when the concave surface had worn so thin that the middle disintegrated and the stone became unusable.

This quernstone is almost identical in size and shape to three stones *("made from a somewhat soft Glauconitic sandstone probably of Wealden origin")* found in first-period level *(A.D. 43 - 75)* at Fishbourne[17].

The Minepit Wood stone is also similar to the Hassocks stone in the Lewes Museum[18], which is of local Lower Greensand, has a diameter of 15.5 inches *(39.3 cm)*, is 2.5 inches *(6.3 cm)* thick at its circumference and has a rectangular hopper-hole measuring 2 x 3.25 inches *(5 x 8.2 cm)*. Curwen dates the Hassocks site, where the quernstone was found, as "mainly 2nd century A.D."

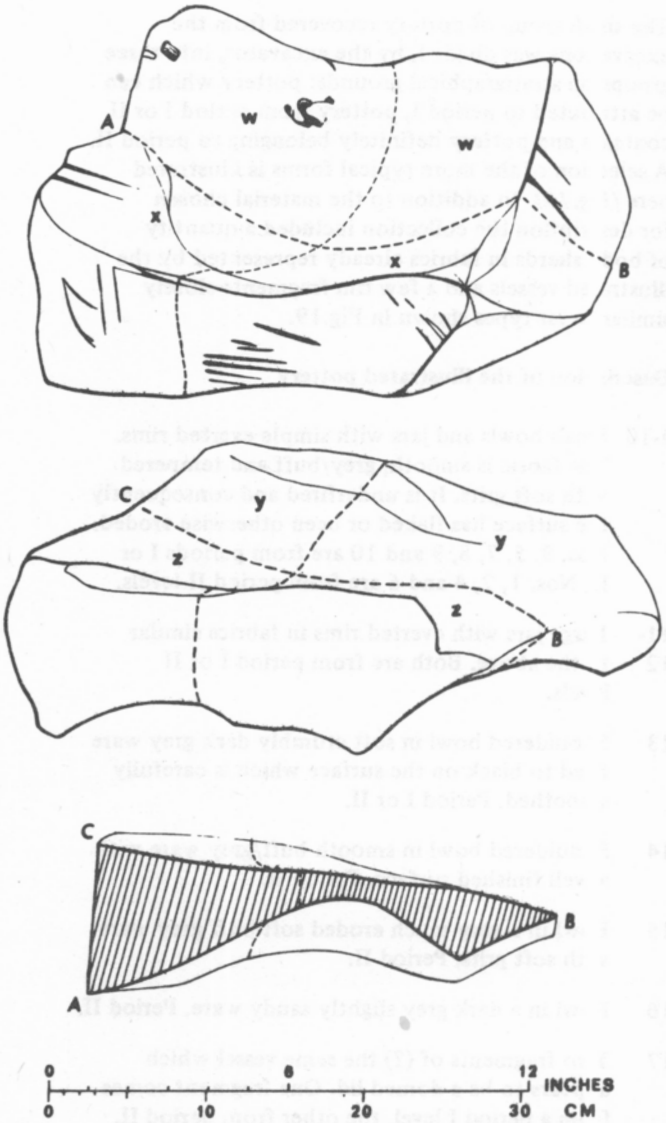


Fig 20 Multi-purpose stone.

3. Part of upper stone of rotary quern

About a quarter of a quernstone broken into two pieces. The stone, which is also a coarse-grained ferruginous sandstone, is 2.75 inches *(7.0 cm)* thick at its circumference and when complete would have had a diameter of about 15.5 inches *(39.3 cm)*. It thus closely resembles the preceding stone, but is rather less worn *(B7)*.

4. Pestle or pounder *(Fig.22)*

Of fine-grained current-bedded sandstone and measuring 8 x 3 x 1.75 - 4 inches *(20.3 x 7.6 x 4.4 - 10.0 cm)*, this artefact was used for pounding (? breaking up ore) at its smaller end. One of its longer edges is slightly rubbed and looks as if it was used for sharpening metal *(C7)*.

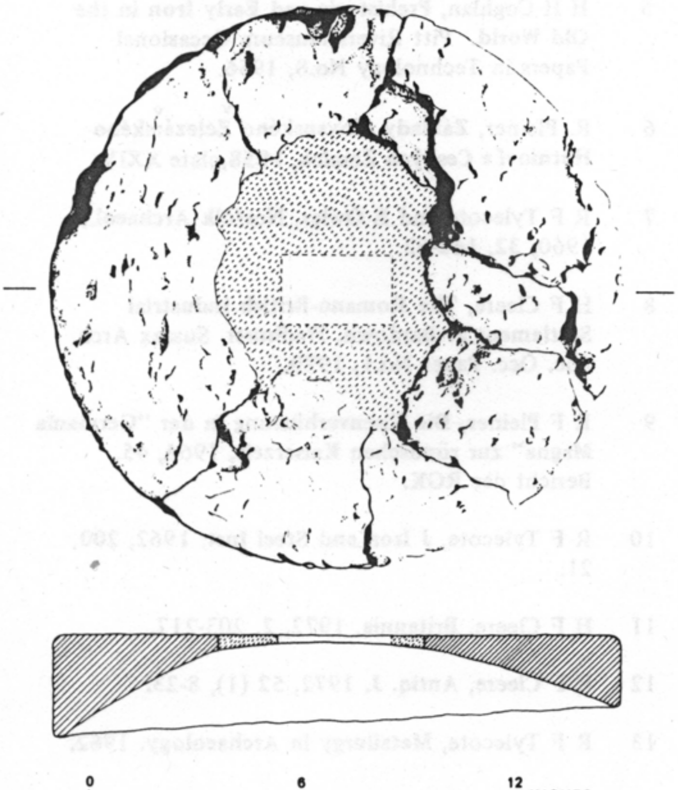


Fig 21 Upper stone of rotary quern.

5. Six fragments of sandstone used to sharpen metal

The following broken pieces had one or more of their sides smoothed and/or gashed and presumably were used to sharpen metal blades and/or points:

(i) coarse-grained ferruginous sandstone 4 x 3 x 2 inches *(10.0 x 7.6 x 5.0 cm)*, smoothed on one side *(C5)*,

(ii) fine-grained finely bedded sandstone 2 x 3 x 1.25 inches *(5.0 x 7.6 x 3.1 cm)*, smoothed and slightly concave on one side *(C6)*,

(iii) coarse-grained sandstone 2 x 3 x 1.25 inches *(5.0 x 7.6 x 3.1 cm)*, smoothed irregularly and slightly gashed on one side *(C8)*,

(iv) coarse-grained sandstone 3 x 4 x 1.25 inches *(7.6 x 10.0 x 3.1 cm)*, smoothed and slightly concave on one side *(C8)*,

(v) medium-grained sandstone 1.5 x 3 x 1.25 inches *(3.8 x 7.6 x 3.1 cm)* smoothed on three sides and two edges *(C9)*,

(vi) coarse-grained ferruginous sandstone 3.5 x 3 x 2.5 inches *(8.9 x 7.6 x 6.3 cm)* smoothed and gashed on two sides *(C10)*.

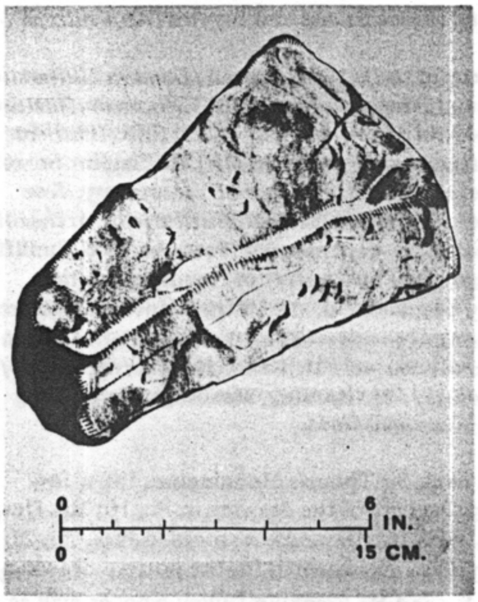


Fig 22 Pestle or pounder.

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Clearance operations, five seasons' digging, filling in on all four sites and the production of reports were costly, of this £436 was provided by subscribers to the Excavation Fund. Thanks are due to all the societies and individuals who contributed, in particular Mrs G von Harten, Mr I D Margary and Mr John Rogerson, who were especially generous.

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When I started work my knowledge of the techniques of early iron-working and the special problems which the excavation of such a site would present was extremely small. I was very fortunate, therefore, in having the help and advice of Dr R F Tylecote, *(Department of Metallurgy, University of Newcastle upon Tyne)*, and Mr Henry Cleere, who visited the site on many occasions and put their expert knowledge at my disposal. Mr Cleere also analysed and reported on the samples of ore, slag, furnace linings and tuyeres *(Appendix A)*.

I am grateful to Dr I W Cornwall *(London University Institute of Archaeology)*, Mr B C Worssam *(Institute of Geological Sciences)* and Mr S E Ellis *(ibid)* for help on geological problems; Mr J H Chaplin for soil analyses; Dr M Y Stant *(Jodrell Laboratory, Kew Gardens)* and Miss J Sheldon *(Institute of Archaeology)* for identifying the charcoals; Professor B W Cunliffe *(Southampton University)* for reporting on the pottery *(Appendix B)*; the British Museum Research Laboratory for undertaking two important Carbon 14 determinations; and Mr Henry Hodges *(Institute of Archaeology)* for cleaning, mending and restoring some of the small finds.

I must thank Sir Thomas Monnington, PRA, for contributing part of the drawing in Fig 10; Mrs Douglas Clarke-Smith for drawings of stones in Figs. 20, 21 and 22; Miss J Holdsworth for the pottery drawings in Fig.19; and Mr Franklyn Dulley who, as well as supervising, drew some of the preliminary plans and sections on which the published drawings are based. The photographs are my own.

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Iron smelting procedures in the upper region of Ghana

*by Leonard M.Pole**

INTRODUCTION

The fieldwork during which the following descriptions were recorded was done in April 1971 in two villages, as a part of the National Museum's investigations into indigenous iron-working methods. Four other villages have been visited in Upper Region where reconstructions of the smelting operations took place, and inquiries have been made in several other places.

Smelting sites have been noted in many places in Upper Region by Oliver Davies[1], and procedures similar to the ones described below witnessed or reported by several other workers[2]. A 30 minute television documentary has been made of the smelting of Jefisi by Ghana Broadcasting Corporation's Film Production Division, copies of which may be obtained from them[3]. A survey of the written material on this part of West Africa has so far not revealed any previous mention of the occurence of iron-smelting at either of the villages, Jefisi or Zanlerigu, specifically, but the sources agree that iron was formerly produced all over this part of the country, in and around Northern Ghana.

The smelting of iron from local ores has only recently been given up by blacksmiths in this area in favour of the less labour-consuming treatment of scrap iron. At least eleven instances have been reported from the Upper Region of iron-smelting in progress in 1924, and often in the 30's[4]. In two villages the work was being done in the 1950's. It is from one of these villages, Jefisi, that the first of the following accounts comes. The second account is from Zanlerigu, 170 km. to the East of Jefisi *(Fig. 1)* where iron-smelting has not been practised since the time of the First World War. The blacksmiths of Jefisi were successful in producing iron, those of Zanlerigu were not. Some reasons for the latters' lack of success can be gleaned from the following timed descriptions of each smelt, and are discussed below.

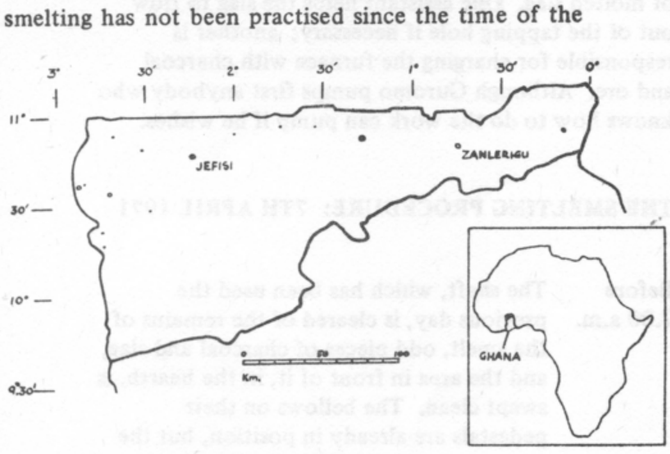

Fig 1 Map of Upper Region, Ghana.

Key: ● Smelting known to have taken place in 1920s and/or later, in the 1950s.

• Smelting demonstrated in 1971-1973.

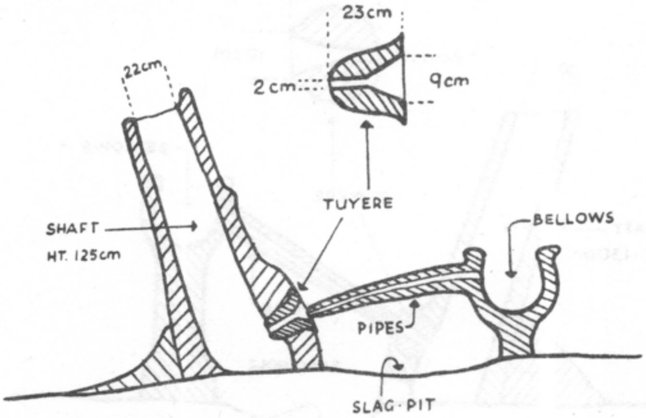

Fig 2 Cross-section of the furnace at Zanlerigu.

Throughout Upper Region, smelting is carried out in a clay shaft about 127 cm. high, inclined at an angle of between 20° - 30° to the vertical. The shaft is made from coarse-grained clay mixed with chopped grass; in both Zanlerigu and Jefisi the shaft is built up vertically of thick coils and after some five days of drying inclined in readiness for smelting. Elsewhere the shaft is moulded around a core of grass stalks[5]. Air is everywhere supplied by means of pot bellows made of the same kind of clay, over which animal skins are bound; either one or two pairs of bellows are used. The air is focussed into the shaft by the use of one or two tuyeres of the same kind of clay; each village so far visited has produced a different shape, but none is longer than 30 cm. The fuel is charcoal; the ore is mainly haematitic, taken from the lateritic crust a few inches below the surface.

There are several differences in structural detail between the furnaces at the two villages *(see Figures 2 and 3)*. The bellows at Jefisi are placed on pedestals so that they are 1 m high; those at Zanlerigu are only 50 cm off the ground. Consequently the Jefisi pumpers stand, but those at Zanlerigu operate the bellows in a seated position. The internal depth of the bellows bowls at Jefisi is 41 cm., at Zanlerigu it is only 23 ; the diameters of each are, however, about the same. At both places each bellows bowl is made in one piece *(Fig 4)*, but at Jefisi the pipe that connects each to the tuyere at the base of the shaft is made separately of a finer type of clay moulded around a wood core. Each pipe at Zanlerigu, is made in one piece with the bowl out of the same clay. The shape of the tuyere at Jefisi is in the form of a solid spherical pot with a rim and

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**Assistant Keeper, Ghana National Museum* a hole tapering from the rim to the opposite surface; that at Zanlerigu is paraboloid with a central hole. As will be seen, the smelting procedures also differ in detail.

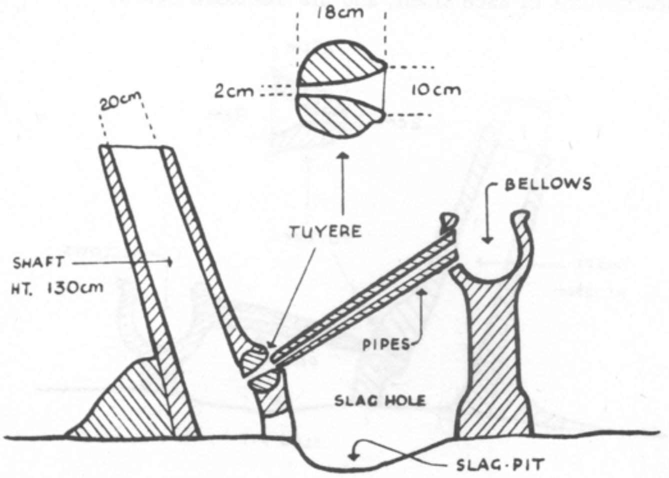

Fig 3 Cross-section of the furnace at Jefisi.

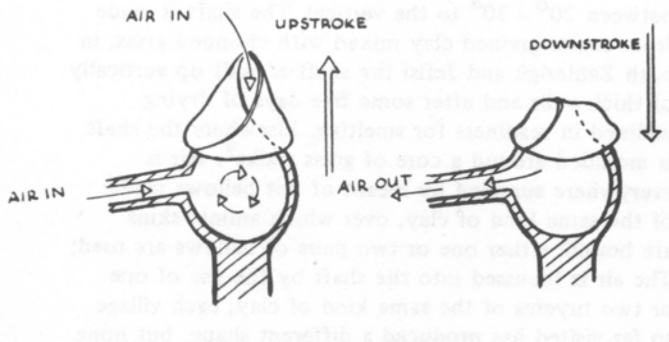

Fig 4 Diagram of the action of bellows-skins as valves.

THE OPERATION AT JEFISI

Jefisi is inhabited by people of the Sisala, a tribe speaking a language belonging to the Gur-grusi language group. The man in charge of the smelting is the third in the heirarchy of Jefisi blacksmiths. The chief blacksmith is tool old to work or even to direct operations; the second in line is still active and offers useful suggestions, but cannot direct the work which requires physical fitness; his name is Bawuisa. *(Both these old men have since died).* The youngest man who still has a detailed knowledge of the procedures is Guromo; he says he last smelted iron 15 years ago *(ie in 1956).* His age is difficult to determine, but he may be about 55. He belongs to the clan called 'Natawa', the taboo of which is the wearing of sandals made from animal skin.

The charcoal used in smelting is obtained by the blacksmiths of Jefisi from one particular type of tree which alone is capable of producing sufficient heat for smelting. It is also used in the forge[6]. The identity of the tree was kept secret. The ore is obtained from beneath a low ridge a few miles to the South; it is dug from only a few inches below the surface and consists of small nodules. Once it has been brought to the smelting site, it is broken up with a stone or an iron hammer on a stone anvil into pieces ranging from a half to one centimetre in diameter. Formerly the blacksmiths of Jefisi would have smelted iron in the dry season, from November to April, when work on the farms was at a minimum. The smelting work would have proceeded continuously for about 30 days, after which time the iron blooms would be consolidated in the forge and hoes and other tools made from them. Sometimes the making of tools would be held over until the onset of the rainy season, so that the dry season could be devoted exclusively to iron-smelting.

The tools used for the smelting are of the simplest. A knife is used in shaping the slag-tapping hole beneath the tuyere, and the hole in the bellows bowls in which the pipes are fitted. An iron spike is tanged into a short wood handle for probing the tuyere and keeping the tube free of slag. Axe heads shod on longer wood poles are used to prise the tuyere and its clay surround away from the shaft at the end of the smelt. The ore and charcoal are added using a small hemispherical calabash. An iron spear may be used for tapping the slag if necessary.

As is usual in this type of smelting, the blacksmith in charge is responsible for keeping the tuyere free of molten slag. One assistant helps the slag to flow out of the tapping hole if necessary; another is responsible for charging the furnace with charcoal and ore. Although Guromo pumps first anybody who knows how to do the work can pump if he wishes.

THE SMELTING PROCEDURE: 7TH APRIL 1971

Before 7.00 a.m. The shaft, which has been used the previous day, is cleared of the remains of the smelt, odd pieces of charcoal and slag, and the area in front of it, in the hearth, is swept clean. The bellows on their pedestals are already in position, but the pipes have yet to be fitted. The tuyere and clay surround used yesterday have been removed and thrown onto the slag heap.

7.05 Guinea-corn stalks are placed in the shaft and lit. Once they have burnt, the ashes are tamped down inside the base of the shaft.

7.10 Low wall of clay is built at the lower hole in the shaft in preparation for the clay luting for the tuyere.

7.11 Some charcoal is put in the shaft.

7.15 Tuyere is put in place in the hole and luted with fresh clay.

7.20 Luting is smoothed off with a covering of moist clay and chopped grass.

7.22 A small aperture is made in the clay below the tuyere, through which the slag will pass. The clay removed is returned to the tapping hole and acts as a door.

7.25-7.35 Bellows pipes are connected from the holes in the bellows bowls to the external lip of the rim of the tuyere. The ends at the bowl are luted in place with fresh clay, those at the tuyere-lip are raised above it slightly so that the blast from the bellows is directed straight into the furnace through the tuyere with the minimum of impediment.[7]

7.30 Shaft is filled to the top with charcoal plus one handful of ore.

7.37 Handfuls of sand and dust are put in each bellows bowl to seal any cracks that may have appeared.

7.38 - 7.45 One goatskin, softened with shea-butter (made from the fruit of the tree Butyrespermum Parkii), is fixed to each bellows bowl like a conical hat, and lashed tightly in place with locally made vegetable fibre.[8]

7.45 Pumping begins; Guromo[9]. His pumping rate varies between 120-130 strokes p.m.

7.50 Guromo hands over pumping to an assistant momentarily while he probes the tuyere hole with an iron spike[10].

7.53 A chicken that has been sacrificed earlier in the morning is placed beside the shaft, where it is gradually roasted throughout the day.

7.55 A mixture of ash and charcoal is made moist with water and is put in the tapping hole, forming a membrane which will be burst by the pressure of the molten slag, making the first tapping automatic.

8.02 One calabash of charcoal added.[11]

8.10 One calabash of charcoal added.

8.12 Half-calabash of ore added.[12]

8.18 One calabash of charcoal added. Pumpers rate is 128 strokes p.m.

8.26 One calabash of charcoal added.

8.35 Handful of ore added.

8.39 One calabash of charcoal added.[13]

8.50 Some green leaves put across the pipes in front of the bellows to protect the skins and stop them from drying out.

8.53 Half-calabash of ore added.

8.59 One calabash of charcoal added.

9.07 Guromo opens the tapping hole, allowing molten slag to flow onto a prepared bed of crushed charcoal.[14] The hole is stopped up with small pieces of charcoal, but some flames escape from it.

9.10 Change of pumpers.[15]

9.12 Half-calabash of ore added.

9.15 Calabash of charcoal added.

9.17 Repairs made with fresh clay to clay tuyere surround.

9.20 Change of pumper.

9.25 One calabash of charcoal added.

9.31 Slag tapped; it flows evenly out. The hose is afterwards blocked up.

9.40 Change of pumper, whose rate of pumping is slower, 110 strokes p.m.

9.45 One calabash of charcoal added.

Change of pumper.

9.52 Double handful of ore added.

9.54 Slag tapped.

9.59 One calabash of charcoal added.

Change of pumper.

10.07 One calabash of charcoal added.

10.13 Half-calabash of ore added.

10.14 Change of pumper.

10.15 Change of pumper.

10.16 Slag tapped; hole refilled with charcoal.

10.17 One calabash of charcoal added.

10.18 Change of pumper; his rate of pumping is 130 strokes p.m.

10.24 Change of pumper.

10.25 One calabash of charcoal added.

10.30 Half-calabash of ore added.

10.33 One calabash of charcoal added.

10.42 One calabash of charcoal added.

10.47 One calabash of charcoal added.

10.48 Slag tapped.

Change of pumper.

Double handful of ore added.

10.55 One calabash of charcoal added.

10.58 - 11.04 Guromo removes leaves from pipes, unties, adjusts and reties skins which have become loose and repairs one of the junctions between the pipe and the bellows bowl with fresh clay.

11.09 One calabash of charcoal added.

11.19 Half-calabash of ore added; c.5 handfuls.

11.21 Slag tapped.

11.24 One calabash of charcoal added.

11.32 One calabash of charcoal added.

11.39 One double handful of ore added.

11.42 Change of pumper; his rate of pumping varies between 100-110 strokes p.m.

11.48 One calabash of charcoal added.

Change of pumper.

11.53 Change of pumper.

11.58 One calabash of charcoal added.

Change of pumper.

12.05 Half-calabash of ore added.

12.07 Change of pumper.

12.12 One calabash of charcoal added.

12.14 Change of pumper.

12.21 Change of pumper.

12.22 One calabash of charcoal added.

12.27 Change of pumper.

12.28 Half calabash of ore added.

12.37 Slag tapped.

12.40 One calabash of charcoal added.

Change of pumper.

12.45 Change of pumper.

12.47 Half-calabash of ore added.

12.56 One calabash of charcoal added.

13.04 One calabash of charcoal added.

13.11 Half-calabash of ore added.

13.12 Change of pumper.

13.15 One calabash of charcoal added.

13.26 One calabash of charcoal added.

13.27 Pumpers changed three times.

13.35 Half-calabash of ore added.

13.40 One calabash of charcoal added.

13.54 One calabash of charcoal added.

13.55 Change of pumper.

13.59 Half-calabash of ore added.

14.09 One calabash of charcoal added.

14.15 Change of pumper.

14.17 One calabash of charcoal added.

14.30 Half-calabash of ore added.

14.40 One calabash of charcoal added.

14.49 Change of pumper.

One calabash of charcoal added.

14.50 Half-calabash of ore added.

15.00 One calabash of charcoal added.

15.08 One calabash of charcoal added.

15.13 Half-calabash of ore added.

15.20 One calabash of charcoal added.

15.31 One calabash of charcoal added.

15.34 Change of pumper.

15.40 Change of pumper.

15.43 - 16.14 Many changes of pumper.

16.04 Buckets of water are brought nearby.

16.07 Guromo probes slag tapping hole, to estimate when to stop the smelt.[16]

16.14 Pumping stops.

Skins on the bellows are unlaced.

Slag in front of the shaft is removed.

16.17 Slag tapped, and removed; the area is swept.

16.20 Two wood sticks, one shod with an axe head, the other fitted with an iron spike, are used to chip away at the clay surround to the tuyere. When it has been loosened, it is prized away from the shaft, revealing the white hot interior. The remaining slag and unburnt charcoal is raked off and the shaft doused with water. The iron bloom remains as a black lump with a spongy texture adhering to the back and the base of the shaft.

16.25 The bloom is lifted out using the same tools and set to one side to cool.[17]

THE OPERATION AT ZANLERIGU

The people of Zanlerigu are Nankanse, speaking a language of the Gur-Mossi group of languages; however, they usually call themselves 'Fra-Fra' a name given them and their neighbouring peoples by others and by the Colonial administrators. The name of the blacksmith in charge of the smelting operations is Satiah Nyaba, aged about 65; his assistant, named Duuri is older, about 80. Neither had themselves smelted, but both had helped their fathers in the work; in addition, Satiah Nyaba's sister offered useful advice since she had also helped her father.

The pisolithic ore has been obtained from a site about 19 km East of Zanlerigu, which contained many old slag-heaps and furnace remains, and lies close by the place where the people of Zanlerigu used to live. Having been brought to the smelting area, the ore is left in a heap without being further broken up. The average size of the nodules is about 2 x 1.5 cm. The charcoal is obtained from brewers of 'pito', local millet beer, since it is capable of producing sustained heat (the millet infusion is boiled continuously for two days).

One person is continually engaged in pumping the bellows, but it can be anybody. One person is responsible for adding charcoal and ore, and another for tapping the slag and keeping the tuyere inlet free of slag. The blacksmith in charge is not fulfilling any of these tasks, being more an overseer.

As at Jefisi, the blacksmiths only smelted during the dry season, leaving the rainy season for work on the farm. The tools used here are the same as those used at Jefisi, except that a greater number of axe-head-shod poles were needed for the removal of the large lump of slag (see below) and a wood stick is used to rake the contents of the shaft from above. One large basket is used for the charcoal, and a small one for the ore additions.

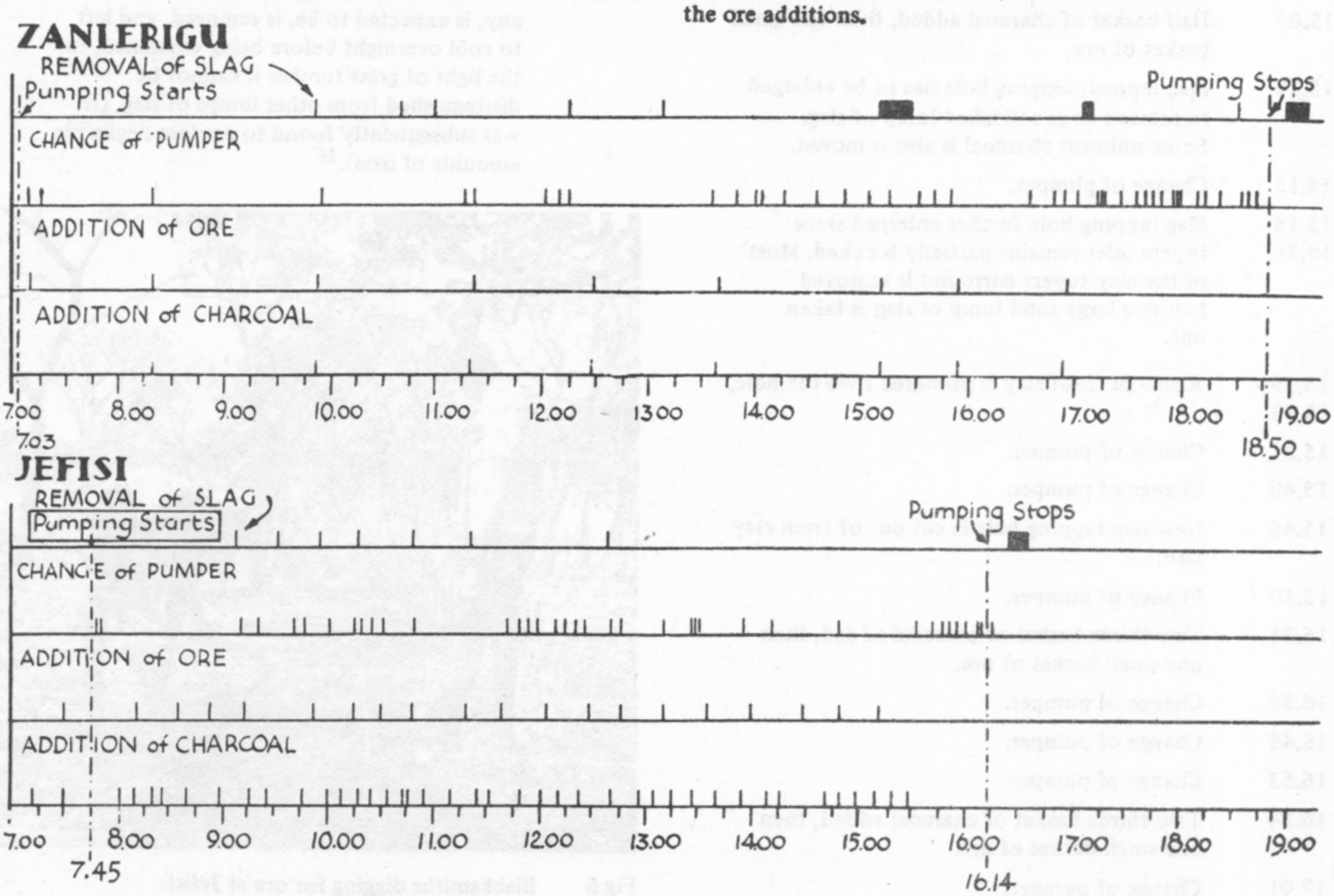

Fig 5 Summary of data from both smelting operations.

12.15	Change of pumper.
12.27	Two-thirds basketful of charcoal added, followed by one small basket of ore.[24]
12.45	Pumper's rate is 144 strokes p.m.
12.55	Pumper's rate is 160 strokes p.m.
13.07	Slag tapped; it is black and solid, removed with difficulty.
13.36	Change of pumper.
13.37	Two-thirds basket of charcoal added, then one small basket of ore.
13.46	Pumper's rate is 194 strokes p.m.
13.50	Change of pumper; his rate is 168 strokes p.m.
14.00	Change of Pumper.
14.04	Change of pumper.
14.17	Change of pumper.
14.35	Change of pumper.
14.51	Change of pumper.
15.03	Change of pumper.
15.09	Half basket of charcoal added, then one small basket of ore.
15.10	Slag tapped; tapping hole has to be enlarged to remove large solidified lump of slag. Some unburnt charcoal is also removed.
15.15	Change of pumper.
15.15 - 15.26	Slag tapping hole further enlarged since tuyere inlet remains partially blocked. Most of the clay tuyere surround is removed before a large solid lump of slag is taken out.
15.29 - 15.33	A slab of fresh clay is plastered over the hole.
15.31	Change of pumper.
15.40	Change of pumper.
15.46	New slag tapping hole is cut out of fresh clay slab.
15.50	Change of pumper.
15.55	Two-thirds basket of charcoal added, then one small basket of ore.
16.35	Change of pumper.
16.48	Change of pumper.
16.53	Change of pumper.
16.54	Two-thirds basket of charcoal added, then one small basket of ore.
17.01	Change of pumper.
17.04 - 17.11	Slag tapped; still solid.
17.11 - 18.23	Pumper changed 14 times. Rates ranged between 155 - 200 strokes p.m.
18.25	Slag tapped; cracks which appeared over the past 3 hours render the front of the furnace, including the tuyere, in danger of collapse. Slag still solid.
18.28	Change of pumper.
18.36	Change of pumper.
18.40	(Darkness has fallen) Change of pumper.
18.45	Water is brought.
18.50	Pumping stops. Skins are untied from the bellows, bellows removed.
18.52	Area in front of shaft is cleaned of all slag and charcoal.
18.55	Tuyere and surround come away easily, using axe-head shod on wood pole. Interior of shaft is doused with water and the excess slag and unburned charcoal removed.
19.00	The final lump of slag in which the iron, if any, is expected to be, is removed, and left to cool overnight before being examined. In the light of grass torches it cannot be distinguished from other lumps of slag. (It was subsequently found to contain negligible amounts of iron).[25]

Fig 6 Blacksmiths digging for ore at Jefisi.

THE SMELTING PROCEDURE: 6TH APRIL 1971

6.05 Blacksmiths arrive.

6.10 Stalks of elephant grass are brought, together with termite-hill clay and grass to mix with it.

6.15 The front hole of the shaft is partially filled with a clay slab, on top of which the tuyere will rest.

6.20 The shaft is filled with the elephant-grass stalks, which are lit.

6.30 Ashes of the burnt grass are flattened in the base of the shaft.

6.35 - 6.50 Tuyere is put in place in the hole, and luted in with clay: the surface is covered with chopped grass and the slimy fluid from a certain root. Slag tapping hole is made in the wall below tuyere.

6.43 One basketful of charcoal is shot into the shaft.

6.45 Second basketful of charcoal added, filling shaft as far as the horizontal ash line.

6.46 The addition of half a basket of charcoal fills the shaft.

6.48 A forked stick supports the lower outer edge of the tuyere while clay luting dries and is smoothed.

6.55 Each bellows pot with pipe attached is put in place, leaning each against the other, the further tips of the pipes just touching the lower outer edge of the tuyere.

7.00 Skins are tied onto the bellows bowls.

7.02 A slab of wet clay is put over the ends of the pipes near the tuyere, to test that air can also enter through the skins themselves; it is later removed so that air can be drawn through the pipe.

7.03 Duuri starts to pump.[18]

7.07 Small basketful of ore is added in the top 5 cm. of the shaft.

7.08 Change of pumper, to Satiah Nyaba.

7.10 Pumper's rate is 156 strokes p.m.

7.17 Change of pumper to Satiah Nyaba's son; his rate is 178 strokes p.m.

7.27 Pumper's rate has slowed to 144 strokes p.m.

7.30 Iron spike set into wood stick is used to clean tuyere inlet.[19]

7.40 Pumper's rate now 160 strokes p.m.

8.08 Shaft stoked with a stick at the top, in preparation for receiving more charcoal.[20]

Pumper's rate rises momentarily to 194 strokes p.m., then falls to 156 strokes p.m.

8.12 Clay slab replaced over outer end of tuyere, because too much heat is emanating from this area. Cracks are appearing in the tuyere surround.

8.18 One large basket of charcoal is added, followed by one small basket of ore.[21]

8.19 Change of pumper; his rate is 196 strokes, increasing to 200 strokes p.m., but shallower than the former pumper;

8.33 Pumper's rate has slowed to 172 strokes p.m.

8.55 Cap of clay over tuyere is replaced from time to time as it dries and shrinks.

9.30 Pumpers rate set at 200 strokes p.m.

Pumping stopped momentarily to tighten the strings round the skins.

9.46 Shallow pit dug at the base of the shaft in front of the slag-tapping hole.

9.48 Hole opened up; a lump of black solid slag is removed and the clay 'door' to the hole put back.

9.50 Two-thirds basket of charcoal added, then one small basket of ore.

9.51 Change of pumper.

9.50 - 10.00 The cracks appearing in the tuyere surround are repaired with fresh clay.

10.00 Pumper's rate is 168 strokes p.m.

10.20 Musicians play to help pumper keep to rhythm.[22]

10.40 Slag tapped; the lump is again solid not flowing.

10.58 Slag tapped; still solid.[23]

11.14 Change of pumper.

11.20 One large basketful of charcoal added, then one small basketful ore.

11.21 Change of pumper; his rate is 220 strokes p.m.

11.45 Tuyere surround repaired again with clay.

12.03 Duuri takes over pumping.

12.10 Change of pumper.

12.13 Slag tapped; now glowing red, flowing sluggishly. Some pieces unburnt charcoal also come out.

Fig 7 Making the furnace shaft at Jefisi; stage one.

Fig 8 Cutting out the hole for the tuyere.

Fig 9 Smelting in progress at Jefisi; note hemispherical calabash for charging ore and charcoal hanging from beam.

Fig 10 The bloom being removed at the end of the smelt.

DISCUSSION

A comparison of the two procedures reveals certain significant differences *(see figure 4)*. Preparation of the ore is careful at Jefisi, non-existant at Zanlerigu; in neither place is the ore subjected to such processes as are recounted from elsewhere.[26] At Zanlerigu nothing was done to the ore particles after being dug out of the ground, thus the iron compounds would not have been exposed to the reducing atmosphere unless and until they had been cracked open by the heat of the furnace. It is interesting to note that the first and major reason given by the blacksmith in charge of the Zanlerigu smelt for its failure was the 'strength' of the ore, *(ie its resistance to being broken down either physically or chemically)* which was first noted by him at 12.27. An analysis of the ore from Zanlerigu gives an iron content of 35.5% *(see Table)*. A comparable figure for the iron content of what little metallic iron was produced gives 33.2%, the rest being made up of inclusions of slag and charcoal. The former figure is at the lower end of the range within which ore particles can be smelted; it would appear therefore that adequate preparation of the ore would have been essential in this case. Ore containing 26.67% iron was successfully smelted elsewhere in Upper Region.

The preparation of the charcoal is also given consideration elsewhere; at several of the other sites visited where smelting was done, the charcoal pieces were kept below a certain size. No attempt to sift the charcoal was made at Zanlerigu. Furthermore, it is a belief of most blacksmiths in this part of the country that only certain species of tree yield charcoal of the requisite quality for smelting. The kind chosen by the blacksmiths of Zanlerigu may have been the wrong one *(It is intended to conduct some experiments to check these beliefs later this year - a testable hypothesis would be that the more close-grained the wood the more concentrated the charcoal, therefore the better for smelting purposes)*. At Jefisi, the identity of the tree from which the charcoal was made was the most closely guarded secret.

The third essential ingredient. air, was also not controlled, nor was there evinced by the blacksmiths any concern for control. The difference in pumping rates at Zanlerigu and Jefisi was very marked. At the latter place there was little variation outside the range 100-130 strokes per minute, whereas at Zanlerigu the range was between 140-220. Although the depth of the bowls at Zanlerigu was less than that of those at Jefisi, this does not enter into the comparison because the skins are depressed in either case to a level only just below the rim. Thus only the air contained within the skin cone is pushed into the furnace on each down-stroke. It was noted that the rims of the bowls at both places had approximately the same diameter, therefore, given that the skins were about the same size, the volumes inside each skin would be similar. The differences in pumping rates noted above would therefore mean that approximately 50% more air was pumped into the Zanlerigu furnace per minute than was pumped into that at Jefisi. It is reasonable to suggest that if the air-inflow rate at Jefisi was sufficient to produce about 4 kgs of workable iron bloom, that at Zanlerigu may have served to oxidise what little metal there had been produced. *(It is hoped to conduct experiments at the Museum in Accra to discover the range of rates which provide ideal smelting conditions)*. Despite our questions, the blacksmiths of Jefisi and Zanlerigu were not able to indicate if they had any idea of the importance of controlling the atmospheric conditions inside the furnace. In neither place was a blue flame observed at the top of the shaft, but in bright sunlight it would be almost invisible. In one other place in Upper Region the top of the shaft was deliberately ignited by a burning stick if a colourless flame did not spontaneously appear after each charge of ore.

There is little doubt that the practice of allowing the level in the shaft to fall about 18 inches before refilling with charcoal and ore at Zanlerigu did not assist in the production of iron. Research conducted elsewhere in Upper Region indicates that there is a temperature gradient of about 22°C per inch, and the temperature

TABLE

	Furnace		Ore					Charcoal				Length of smelt							
	ht. (cm)	est vol. (cc)	piece size (cc)	vol.of charge (cc)	no. of charges	ave. wt (kg)	total wt. (kg)	vol. of charge (cc)	no. of charges	ave. wt. (kg)	total wt.* (kg)	hrs	min	wt. of bloom (kg)	% Fe in ore	wt. of Fe in ore	% iron in bloom	wt. of iron in bloom	% Eff.
Jefisi	130	41000	1.50	700	20	0.68	13.5	2000	39	0.6	38	8	44	c.4	49.8	7.0	56.3	c2.2	31
Zanlerigu	125	47500	6.0	2000	9	1.8	16	16500	9	5.0	56	11	47	–	35.5	5.6	–	–	–

* This includes the amount needed to fill the shaft.

at the top of the shaft is in the range 300-370°C in these inclined shafts. Thus the charging of the shaft with cold charcoal to a depth where elsewhere temperatures in excess of 700°C have been recorded cannot but reduce the overall temperature. In addition to that, the large scale excavation of the base of the shaft half-way through the afternoon would also have had a deleterious effect, although by this time the failure of the smelting operation was undoubtedly assured.

It is difficult to evaluate the effect of loss of heat on the smelting, since there would be no difficulty in attaining the temperatures needed for chemical breakdown of the iron oxides inside such a furnace, provided that the active substances are present in the correct proportions. I would therefore conclude that the lack of preparation of the ore and possible excess of oxygen are the more crucial of the errors made by the Zanlerigu blacksmiths.

NOTES

1 See map on p.242 of 'West Africa Before the Europeans', some sites are also referenced in Field Notes, vol.2.

2 See Charles *(1911)*; Cline *(1937)* 38,45; Junner *(1936)*; Labouret *1931)* 65-72; Cooper *(1927)* in Davies *(1967)* 298-9.

3 For further information write to P.O.Box 1627, Accra.

4 At Balie, Billaw, Biri, Busie, Chiana, Cherepon, Chung, Jefisi, Pudo, Tumu area, Zambo in 1924. The majority are sited in extreme North West of Ghana. There are no published reports of smelting in the Zanlerigu area.

5 For more detailed information on the construction of the various parts, and smelting operations elsewhere, see Pole *(forthcoming)*.

6 Elsewhere the wood of the shea-butter tree *(Butyrospermum parkii)* is often preferred; it is a hard, dark wood, heavy and close-grained. However, at Zuarungu, 9 km from Zanlerigu, it was stated specifically that this tree was not suitable. At Tiza, West of Jefisi, a number of different trees can be used, of which the shea-butter tree is one of the less suitable, since it is said to burn too quickly.

7 The volume of air inflow is estimated to be between 4900-6600 c.c. per stroke, ie an average of c.11500 c.c. per second.

8 Air is drawn in through the pipe at the tuyere end on the up-stroke, but the skin itself also acts as a valve: The air is allowed in through the gap between the two over-lapping edges on the up-stroke, but on the downstroke the wrist is turned so that the edges are held against each other closing the gap *(see figure 3)*.

9 Although Guromo is in charge of the smelting, he operates the bellows for the first 90 minutes since it is considered a privilege; until the slag flows for the first time he must, however, stay at his post.

10 The pumper himself is in the best position to see when the tuyere hole is blocked; normally he would tell someone else to clear it. It is done continuously throughout the day.

11 The calabash is approximately hemispherical, 20 cm. in diameter. Three basketsful of charcoal have been dumped in the ground; when this amount of charcoal has been charged into the furnace, no more is added. The length of the smelt is therefore measured through additions of fuel, rather than ore.

12 This is equivalent to four handfuls, sufficient to cover the charcoal. The average weight of ore is 680g.

13 Additions of charcoal are made regularly to keep the shaft 'topped up'; this may or may not require a complete calabashful. Whatever is not added is returned to the heap.

14 It was necessary to open the hole manually as the level of molten slag inside the furnace affected the tuyere hole.

15 Now that the slag has been tapped, pumping ceases to be a privilege; any one can work the bellows for as long as he wishes.

16 Smelting stops when the charcoal level falls to a point a few inches above the tuyere.

17 The bloom was estimated to weigh about 4 kgs. Analysis or ore, slag and bloom is as follows:-

	Ore	Slag	Bloom
Iron	49.8%	28.3%	56.3%
Carbon	13.4	6.2	14.1
Cobalt	0.06	0.07	0.14
Manganese	0.01	0.014	0.003
Magnesium	0.16	0.41	0.10

Nickel	0.10	0.09	0.09
Copper	0.04	0.027	0.050
Chromium	0.06	0.06	0.04

18 He pumps in a seated position, as is normal with these bellows; however, some pumpers prefer to work standing up.

19 This operation is done continually.

20 The shaft is stocked regularly before each charge of charcoal.

21 The large basket has a volume of c.16,400 cc, the small c.2000 cc. The weight of each ore charge is estimated to be 1.8 kg.

22 Elsewhere where music accompanies the smelting, it rather serves to render the pumper's task less tedious than to keep up rhythm, since an expert pumper can sustain his own rhythm for more than two hours without wavering. No music was played at Jefisi.

23 Slag is only tapped when it is seen through the tuyere opening to be impeding air-flow.

24 Blacksmith indicates that more charcoal than first estimated will be needed since the ore is 'stronger' than expected.

25 Analysis of the ore slag and bloom is as follows *(The small quantity of bloom available for analysis renders the latter percentages suspect).*

	Ore	Slag	Bloom
Iron	35.3%	25.1%	33.2%
Carbon	11.64	–	–
Cobalt	0.08	0.04	0.14
Manganese	0.02	0.01	0.02
Magnesium	0.15	0.30	0.54
Nickel	0.06	0.04	0.28
Copper	0.02	0.001	0.06
Chromium	0.07	0.10	0.05

26 See account by Bellamy *(1904)*, Gardi *(1969)*. Others are reported in Cline *(1937)* and Tylecote *(1965)*.

ACKNOWLEDGEMENT

All the photographs are provided by courtesy of the Ghana Broadcasting Corporation.

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The examination of metallurgical material from Abu Matar, Israel

by R F Tylecote, Beno Rothenberg and A Lupu

This site was discovered in 1952, and excavated in this and subsequent years by Jean Perrot[1]. It lies 1.5m to the west of the old city of Beersheba and stands just above the Beersheba valley on its north side. The site is dated to the Chalcolithic *(Beersheba - Ghassul culture)* of the 4th millennium BC. The metallurgical material, which was the object of our examination, was as follows:

AM 60	Slag from fragments of crucibles from 1oc.B6.
AM 78	Fragments from a large hearth in B6.
AM 510	Fragments of furnace lining.
AM 769	Pieces of ore.
AM 785	Fragments of ore and slag with snail shells from 1oc.M.
AM 845	Slag from fragments of crucibles from 1oc. 202.
AM 920	Pieces of ore.
AM 922	Pieces of ore and charcoal from 1oc.233.
AM 117	Part of an axehead from Safadi; 1oc.307.

The ores and crucible slags were analysed by X-ray fluorescence spectroscopy and diffraction, by wet chemistry and differential thermal analysis *(DTA)*.

TABLE 1 Analyses of Ores. *(wt %)*

	A AM 769	B AM 922	C AM 920	D AM 785	E (Bentor)
Cu	62.7-72	57-58.7	38.6-64	23.9	56.1
SiO_2	1.43	7.88	25.17	33.8	19.2
FeO	1-3	8-32	8.7-15	13.1	13.84 (Fe_2O_3)
Al_2O_3	4.65	5.24	5.30	11.8	
CaO	4.20	3.50	1.82	6.5	
MgO	–	0.50	0.10	0.5	
S	0.54	1.09	2.84	1.4	
Zn	<0.1	<0.1	<0.1	–	
Pb	nil	nil	nil		
Sn	nil	nil	nil		
Minerals (DTA)	Malachite Cuprite	Cuprite Chalcopyrite	Malachite Chalcocite Chalcopyrite	Malachite Pyrite	

The results are given in Tables 1 and 2. Table 1 also gives Professor Bentor's analysis of ore from the same site, for comparison.

Ores. Examination of the lumps of ore which varied in size from about ½ to 3 cms showed that they were mainly malachite and cuprite with a small amount of chalcocite and chalcopyrite. This would explain the high copper content which Reymond[2] was unable to reconcile with pure malachite which has a theoretical copper content of 57.5%. When ground, the ore becomes reddish powder - typical of cuprite, or green - typical of malachite. The sulphur content is small *(0.54-2.84%)*. After roasting the ore becomes black and friable and grinds to a blackish powder which is the black oxide CuO-tenorite.

Slags. The slag analyses show the presence of large amounts of copper and in this respect are typical of some early crucible slags even to the extent of containing iron[3]. Such slags are normally formed during the re-melting of previously smelted copper in clay crucibles. Some of the crucible slags contain sulphur suggesting that ores containing some sulphur had been smelted. Both the slags AM 60 and AM 845 were removed from the inside of the crucible sherds shown in Fig 1. Some of the smaller pieces in the boxes which enclosed these specimens were highly magnetic and in this respect resembled the pieces AM 78 *(vide infra)*. Otherwise none of the material was magnetic.

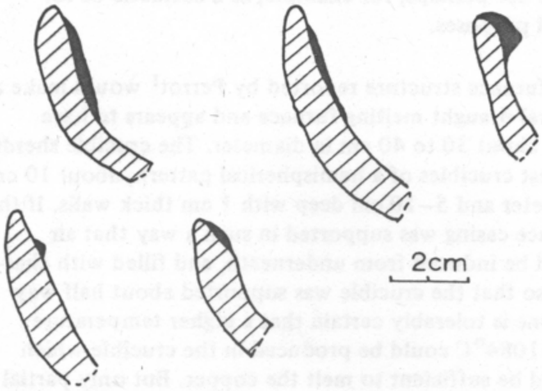

Fig.1 Chalcolithic crucible sherds from Abu Matar. Top right AM 845; the rest AM 60. Deposits shown in black.

The magnetic properties of most of the material labelled AM 78 was an unusual feature of the material from this site. Externally, this material was green, no doubt due to a patina that had formed during its period of weathering in the ground. When fractured, it resembled in appearance the ore, AM 920, and was mostly reddish. A petrological examination on a non-magnetic piece showed the presence of light, thin, needles or plates *(Figure 2)*. X-ray diffraction analysis revealed the presence of the following crystalline phases:

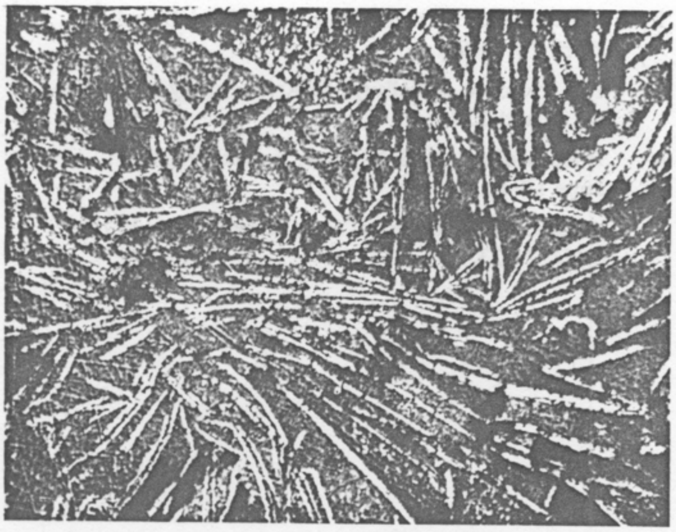

Fig.2 Structure of furnace lining AM 78. Silica or silicate needles in glass phase. X 160

Alpha quartz
Cristobalite } SiO_2
Alumino-silicates
Potash feldspar
Hydrated ferric oxide

The vitrified phase was reddish and it would therefore appear to have copper in solution. The structure varied across the specimen giving more vitrified material on the one side and more clay-type material in the other. It would appear that it is a piece of clay lining or crucible which has been slagged on one side with copper ore and fuel ash. Some of the magnetic material in this box was probably partially roasted ore or slag in which the iron had been oxidized to magnetite. The hydration of the iron oxide must have occurred in the ground after deposition.

The slags given in Table 2 have a variable copper content, a high content of silica (46–48% SiO_2) and a low content of iron oxide (6.45–7.47% Fe0). This composition is very near to the Timna casting slags with 40.60% SiO_2, 5–10% Fe0, 0.5–3% Ca0, and 5–15% Cu. The difference in the two sets of analyses reflects the inhomogeneity of the material; it reflects the fact that the crucible deposits consist of varying amounts of oxidised metallic copper in a silicate slag.

TABLE 2

Analyses of Crucible Slags. Wt %

	AM 60		AM 845		AM 510,328
Analyst	B	L	B	L	L
Cu	47	7.74	42	8.31	8.17
FeO	10	6.45	25	7.47	7.82
MnO	–	0.12	–	0.08	0.12
SiO_2	–	46.81	–	48.22	60.42
Al_2O_3	–	9.95	–	8.08	8.86
CaO	–	14.54	–	11.08	10.81
MgO	–	2.39	–	2.57	1.88
P_2O_5	–	0.40	–	0.52	0.68
Pb	abs.	–	abs.	–	–
Sn	abs.	–	abs.	–	–
Zn	<0.1	–	<0.1	–	–

The melting temperature range of the slags is from 900°C to 1300°C. The melting temperature was measured by an Heraeus tubular furnace designed so that the whole melting process could be followed optically. This large range of melting temperature reflected the non-homogenity and very viscous characteristics of the slags. The copper was present in the slags as metallic particles and as cuprous oxide.

During the casting process various impurities were picked up, probably from the crucibles, including sand *(silica)* and lime with a content of 15–20% MgO *(dolomitic lime)*. The manganese and P_2O_5 content is relatively small.

Metal. Only one piece of metal was examined and this was the end of an axehead from Safadi, 4 miles south of Abu Matar *(No.117)*, Figure 3. A microexamination showed that it had a cast and worked structure. The grains were equiaxed and showed slight residual coring. There had been some recrystallisation and there were some bent twins but no slip bands. The hardness was 92 HV. This object was made from an impure copper containing 0.2–0.3% As which has been either hot worked, or cold worked and annealed. Finally it has been given some cold work to harden it. According to Reymond[2], the ores found at Abu Matar contained very little arsenic.

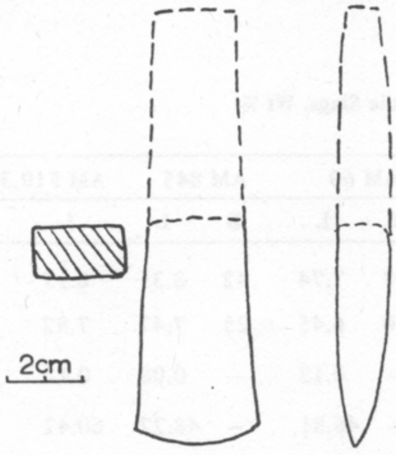

Fig.3 Chalcolithic Axe-head from Abu Matar.

Conclusions

Most of the material from this site is consistent with the metallurgical operation of melting and casting. It is interesting that the ores of the type found and analysed in Table 1 are those for which crucible smelting is a possibility. But we know from Rothenberg's excavation[4] on the Chalcolithic site at Timna *(No.39)*that normal furnace smelting with the production of an iron silicate slag was being practiced at this time[5]. The absence of such a slag suggests that the ore must have had some other use perhaps, for example, as a cosmetic or for ritual purposes.

The furnace structure reported by Perrot[1] would make a natural draught melting furnace and appears to have been about 30 to 40 cm in diameter. The crucible sherds suggest crucibles of a hemispherical pattern, about 10 cm diameter and 5–10 cm deep with 1 cm thick walls. If the furnace casing was supported in such a way that air could be induced from underneath, and filled with charcoal so that the crucible was supported about half way up, one is tolerably certain that a higher temperature than 1084°C could be produced in the crucible which would be sufficient to melt the copper. But only partial melting of the slags occurred giving viscous and inhomogeneous slags with a high copper content. The composition of the crucible slags shows that only impure copper has been melted, and that no alloying had been carried out. This is consistent with Chalcolithic practice.

Acknowledgements

We are indebted to M Jean Perrot for allowing us to examine this material, to Dr M H Battey for the fluorescence examination and to Professor K H Jack for the diffraction examination.

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Report on the manufacture of steel in Yorkshire and a comparison with the principal groups of steelworks in Europe

by Mons F le Play, Chief Mining Engineer
(Edited and translated by K C Barraclough)

State of the Steel Industry in Russia

For a long time, Russia has drawn the steel necessary for its own consumption from foreign countries, from Sweden, from the Central Alps, from the region of the Rhine and from Great Britain. But this state of affairs is gradually being altered. Over the last hundred years both the state owned forges and the private ones in the Ural Mountains have begun to produce in large quantity those irons which are eminently suited to the manufacture of steel and to export them to the west of Europe. It is natural, therefore, that these forges should also apply themselves to steel production and the government, some twenty years ago, in order to encourage this development, burdened the import of foreign steel with a customs duty which for unworked steel stands at approximately £10 per ton.

These efforts have had their effect; Russia to-day produces more than two thirds of the steel she uses, principally by the cementation method, and only receives from abroad those products which recommend themselves by their superior quality or the manufacture of which requires industrial traditions which are not yet sufficiently established within the Empire.

The principal group of steelworks is situated in very favourable conditions in the neighbourhood of Nijni Novgorod, at the junction of the Volga and the Oka, at the centre of the navigable waters of the Empire and at the very place where the greatest fair of Eastern Europe is held annually. In the regions adjoining (673) these works, and above all in the basin of the Oka, are large reserves of vegetable fuel and they are fed at low cost via the tributaries of the Kama and thence by the Volga, with the excellent steel-irons from the works of Nijni Taguilsk, Katav Ivanovsk, Iourzen Ivanovsk and Neviansk. Assuming wise administrative measures can assure the future replenishments of the forests connected by waterway to Nijni Novgorod, this district appears to me to be destined to fill, in the East of Europe and the North of Asia, the same role as Yorkshire in Western Europe. Already, in proximity to the steelworks proper, there are erected numerous workshops which work down their products into the shape of axes and other carpenters' tools, knives and penknives, scythes and sickles, balance beams and so on.

The other steelworks of the Empire are, for the most part, attached to the major forges of the Urals; the principal are those of Zlatoust and Goroblagodat, which produce steel by the direct refining of cast iron, and the cementation works of Nijni Saldinsk and so on.

Together these works produce approximately the following quantities of steel annually:

	Natural Steel tons	Cemented Steel tons	Total tons
Steelworks of Nijni Novgorod	Nil	1800	1800
State Works of the Urals	360	50	410
State Works of the Altai	10	10	20
Private Works, other than those of Nijni Novgorod	160	820	980
TOTAL	530	2680	3210

Russia imports annually around 1450 tons (674) of raw and worked steel. The raw steel is furnished principally by England: Sweden, which in the middle of the last century contributed a notable proportion of the import, now only sends her product to the old Swedish province of Finland.

Worked steel is principally imported in the form of scythes; around 90% of these implements, so necessary in a land which is largely agricultural in which enormous quantities of hay are made every year, are furnished by the steelworks of the Central Alps, entering Russia by the Galician frontier; the other tenth, imported via the Baltic, is provided by the works of the Rhine and by Great Britain. Finally, the cutlery and tools are provided for the greater part by the steelworks of Yorkshire.

One may evaluate the mean average imports of these products, in tons, as follows:

Raw Steel	100	TOTAL 1450 tons
Wrought steel: Scythes and Sickles	1000	
Wrought Steel: Cutlery and Tools	350	

The steelworks of Nijni Novgorod have already started to export their products into the Central Asian region, by several routes but above all along the shores of the Caspian Sea. The total of such exports has risen to 150 tons per annum. The steel trade of the Russian Empire can thus be summarised as follows:

Native production		3210 tons
Imports	1450 tons	
Exports	150 tons	
Excess of Imports	1300 tons	1300 tons
Internal Consumption		4510 tons

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The Steel Industry in Sweden and Norway (675)

Sweden has produced natural steel for many years in the same works in which the steel-irons worked in Yorkshire are produced. The destination of these steel-irons has naturally directed the attention of the Swedish owners towards the manufacture of cemented steel and this was introduced into Sweden and Norway during the first half of the last century*; but this industry is far from being developed to the extent appropriate to the abundance of the raw materials. It scarcely contributes a quarter of the total steel production of Sweden today, this latter being evaluated at approximately 2400 tons per annum**

Sweden does not import foreign steel in any form; far from this, for a long time now she has competed in all the markets of the world for the sale of her raw steel with the steelworks of the Central Alps and of the Rhine. The development of the steelworks of Yorkshire has in no wise interrupted these exports which now stand at an annual average of 1630 tons. The principal countries of destination, named in the order of importance of consumption, are Portugal and the Azores, the United States of America, the East Indies, Denmark, the Hanseatic Cities, and Finland. Sweden does not herself directly make all the exports; she sends, on average, some 510 tons of steel to the warehouses of Great Britain, which British trade then distributes to several markets, particularly to the East Indies, to Mexico and other American countries where mining flourishes, to Portugal and to Spain. Swedish steel is sought above (676) all because it forges easily and sells at a low price. I have established this last year that it did not cost on average more than £18.5.0 per ton in the warehouse in London. This warehouse also receives from Sweden, for the same destinations, considerable quantities of common iron which only sell on average for £12 per ton.

I have not yet established the quantity of steel produced in Norway; a Sheffield manufacturer, who knows the works of that country well and who draws his iron supplies thence, has affirmed that their production, of which the main part is obtained by the cementation process, barely rises to 500 tons.

The Steel Industry in the Austrian Monarchy

As I have already indicated, in the introduction to this report, near to the spathic iron ore deposits of Eisenertz and Huttenberg, in the central part of the Alps, the Austrian Monarchy possesses the principal group of steelworks on the Continent of Europe; provided with minerals of the same nature, several works also exist in the Tyrol and in the Lombardo-Venetian kingdom and tie up with the main group. At the commencement of the Christian era, these steelworks and the workshops attached to them already furnished steel, both raw and worked, to the western and southern parts of Europe. These products were exported in part via the Adriatic ports to the Mediterranean seaboard and to the Black Sea regions and for a long time the unworked bars have been known in commerce under the name of "Venetian Steel".

The natural steels of the Central Alps are particularly suited to the manufacture of scythes and it (677) is above all in this form that they have spread to all parts of the European Continent. The 1000 tons of steel which Russia draws each year from this group of steelworks are imported, as has been stated, via the Galician frontier; it is equally by land routes that the scythes from the Central Alps steelworks are sent throughout the Austrian Monarchy, to the North of Italy, to Bavaria, Wurttemberg, Switzerland, to the east of France, to the north of Germany, to Poland and so on.

It appears from the putting together of the information which I have managed to collect that the production of natural steel in the Austrian Monarchy stands at approximately 12800 tons per annum.

The Steel Industry within the German Customs Union

The steelworks group on the Rhine, situated in a region less rich in forests and water power compared with Styria and Carinthia, has never had the importance of the preceding group as far as the production of raw steel is concerned. But the proximity of the rich coal basin of the Ruhr has particularly favoured the manufacture in this area of forged steel and, above all, of cutlery, weapons, cutting tools and so on. The works which produce the raw material are spread along the watercourses and in the midst of the wooded hills in the neighbourhood of the Stahlberg, the principal deposit of the iron minerals, whilst the works which use the raw steel are grouped in proximity to the collieries of the Ruhr. The works which call for the use of water wheels are spread along the water courses which abound in the region of Reimscheid; those which require a (678) greater proportion of labour are grouped particularly at Sollingen.

Favoured by these happy circumstances and by the excellent quality of their products, the Rhine steelworks for many years have played the same role in North West Europe that the Central Alps works have occupied in the opposite region of Europe. I recall that, during the first half of the last century, before the development of the steelworks in Yorkshire, the English manufacturers supplemented their own provisions from the Rhine steelworks, drawing thence some 150 tons of forged steel annually.

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*The author is somewhat late in his dating; cementation steel was first carried out in Sweden at Davidshyttan in 1653 and there were five plants operating in Sweden at the end of the seventeenth century.

** The slow development was due primarily to the lack of coal in Sweden; direct firing of cementation furnaces with wood was not in general satisfactory.

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The average annual production of raw steel in the Stahlberg group and in the works close to the two banks of the Rhine rose in 1838-1840 to 6300 tons.

The group in Thuringia produces around 500 tons of natural steel per annum and many less important forges in Brandenburg, Silesia, Bavaria and so on produce around 300 tons.

With its abundant provision of natural steel, Germany has scarcely paid any attention to the manufacture of cemented steel; in Silesia and Westphalia there are some 100 tons made annually.

In summary, the states which constitute the German Customs Union produce around 7100 tons per annum.

The Steel Industry in Belgium

Belgium does not produce any natural steel, as I proved to my own satisfaction in 1835 when (679) my researches led me to visit all the forges of that country and there did not exist at that time a single works put to this manufacture. At that time also, Belgium imported considerable quantities of steel, provided by Yorkshire and the Rhineland provinces; the cementation furnaces set up when Belgium was part of France prior to 1814 do not appear to have prospered.

Crossed in its widest part by a rich coal basin, which is connected to the sea by many lines of canals and railways, Belgium now presents conditions eminently favourable to the manufacture of cemented steel. The insufficiency of the local market appears to be the only reason which prevents the provinces of Liege, Charleroi and Mons from entering advantageously into competition with Yorkshire.

The Steel Industry in Spain and Italy

It appears that the countries bordering on the Mediterranean produce very little steel, drawing from Styria and Great Britain the raw and wrought steel which they need. In the region around Guipuzcoa around 100 tons of cemented steel are made annually; Catalonia, Aragon, the Basque Provinces, the Asturias and Galicia produce from time to time in their iron forges around 200 tons of natural steel per annum. The Italian peninsula, excepting Lombardy, scarcely produces 200 tons of the two kinds of steel per annum.

The Steel Industry of France

France produces both natural steel and cemented steel, both under very complex conditions.

Production of the Steel Forges

The steel forges of the Isere, fed with the (680) spathic ores from Allevard and Saint Georges d'Heurtiéres, occupy, as has been said, the third place in Europe. Their production, limited by lack of vegetable fuel, varies but little from year to year and stood at 1570 tons in 1841.

In the north east of the kingdom, in Lorraine and Alsace, near the common boundary of the Moselle and the Lower Rhine, there exist many forges employing as raw material the steel making pig iron of the Rhine, adding only small quantities of pig iron and scrap iron of French origin. These forges, which are in reality the southern end of the Rhine steelworks group, produced 344 tons of natural steel in 1841.

Independently from these works which produce good quality steel, there are a large number which make, either regularly or accidentally, using French pig iron, types of steel which for the most part are only of common quality, used mainly for the manufacture of agricultural implements, which for this reason are often designated as "Aciers de terre". Six departments have been involved in the production of these kinds of steel in 1841 in the proportions shown below:

Nievre	758 tons
Vosges	204 tons
Saone (Haute)	118 tons
Cote d'Or	85 tons
Vienne (Haute)	41 tons
Charente	39 tons
TOTAL	1245 tons

Production of Cemented Steel

The principal group of cementation steelworks is situated in the south of the kingdom, in the region of the Pyrenees forges; it employs as raw material the iron (681) produced by these forges together with a small quantity of Swedish and Russian iron imported via Bordeaux. The coal for heating the furnaces is drawn in part from the coal basin of the Loire and in part from the basin of Carmeaux (Tarn).

The four departments in which the works are established contributed in 1841 in the following proportions:

Tarn	850 tons
Ariège	708 tons
Haute Garonne	396 tons
Aude	146 tons
TOTAL	2100 tons

The second group of cementation steelworks is established in the coal basin of the Loire, which provides them with fuel at a low price. Irons, imported in the main from Sweden and Russia via the port of Marseilles, reach the works by way of the Rhone and the railway from St. Etienne to Lyons. The steelworks also use a large quantity of iron from the Pyrenean forges. The Loire group in 1841 produced 903 tons of raw steel.

Many quite important steelworks, which one might call urban works, unlike the previous ones, are not placed near to the raw material or the fuel; they have been established above all with a view to profit from the immediate market offered them by many large towns; such are the works set in the neighbourhood of Paris, Tours, Orleans and Lyons. The works placed in such conditions produced 352 tons in 1841.

Finally, some less important works are attached to different forges which find therein a market (682) for their products; these works, situated in the Vosges and the Côte d'Or, produced in 1841 some 276 tons of raw steel.

To summarise, the production of the French steelworks in 1841 was as follows:

(1) Natural Steel:

Isère Group	**1570 tons**	**3159 tons**
Lorraine and Alsace	**344 tons**	
Other Steelworks	**1245 tons**	

(2) Cemented Steel:

Pyrenees Group	**2100 tons**	**3631 tons**
The Loire Group	**903 tons**	
Urban Steelworks	**352 tons**	
Other Steelworks	**276 tons**	
TOTAL		**6790 tons**

Production of Steel from 1831 to 1841

The steel industry is far from having followed the progress of the other branches of the iron industry; the production of the latter has doubled within ten years, whilst in the same interval the production of the steelworks has only increased in the proportions shown in the following table:

Production of Steel in France from 1831 to 1841
(quantities in tons)

Year	**Cemented Steel**	**Natural Steel**	**Total**
1831	**2374**	**2920**	**5294**
1832	**2281**	**2700**	**4981**
1833	**2917**	**3204**	**6121**
1834	**2968**	**3313**	**6281**
1835	**3254**	**2902**	**6156**
1836	**2127**	**2721**	**4848**
1837	**2813**	**3145**	**5958**
1838	**2974**	**3428**	**6402**
1839	**3050**	**3452**	**6502**
1840	**3797**	**3489**	**7286**
1841	**3631**	**3159**	**6790**

Leading from the considerations presented (683) in the second part of this report, concerning the benefits in fabrication presented by the use of cast steel as compared to cemented steel, it is worthy of note that the progress which has been observed in the production of the latter has been almost exclusively due to the development of the steel melting shops. These have produced the following quantities of cast steel since 1831:

1831	**156 tons**	**1835**	**318 tons**	**1839**	**597 tons**
1832	**166 tons**	**1836**	**387 tons**	**1840**	**845 tons**
1833	**320 tons**	**1837**	**463 tons**	**1841**	**948 tons**
1834	**262 tons**	**1838**	**633 tons**		

This production far from satisfies home consumption, above all where the best quality of steel is concerned, and France imports considerable quantities of bar steel and wrought steel each year.

Imports and Exports of Steel

Shear steel or cast steel, in bar form, makes up around half of the total weight of steel imported; the other half is made up of worked steel in the form of scythes and sickles, files and rasps, tools in fine steel, saws, wires and sheets. These imports increased in a rapid manner between 1831 and 1836; since then they diminished regularly but they still remain nevertheless at a higher level than they were ten years ago. The annual variations in imports from 1831 to 1841 are shown in the following table *(quantities in tons)*:

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Importation of Steel into France from 1831 to 1841 (684)

Year	Bar Steel		Worked Steel					TOTAL
	Wrought	Refined Cast Steel	Scythes and Sickles	Files and Rasps	Tools of Fine Steel	Saws	Wires and Sheet	
1831	520	30	244	157	20	18	10	999
1832	587	52	281	253	29	18	27	1247
1833	685	70	272	294	34	21	32	1408
1834	737	83	293	374	37	29	42	1595
1835	745	69	281	398	39	24	33	1589
1836	926	116	305	426	43	21	50	1887
1837	836	85	341	450	38	21	19	1790
1838	869	95	300	380	48	17	27	1736
1839	784	107	301	365	34	18	22	1630
1840	775	96	292	315	36	14	18	1546
1841	743	94	247	309	37	12	39	1481

Around four fifths of the forged steel bars are furnished by the Rhine forges; the other fifth comes from Yorkshire. The refined cast steel bars come exclusively from Yorkshire. The scythes and sickles come mainly from the Central Alps group; the Rhine works and those of Yorkshire export a small quantity to France. Three quarters of the files and rasps come from the German works and one quarter from the English works; the saws and tools in fine steel are always of the latter origin and the English works alone thus furnish almost one third of the total steel import.

Steel objects reputed to be of English or German manufacture are used in France in greater quantities than the figures in the above table would indicate. (685) This circumstance follows from the practice of some French manufacturers, when they have attained a standard of steel quality furnished previously by foreign manufacturers, hastening to sell their products under the guarantee of an English or German mark with the aim of having them promptly accepted by the customer. It is to be regretted that our laws and customs tolerate a practice so contrary to good faith and that in this respect, our works follow the example given them, in the last century, by the English steelworks at the time of their contest against the German steelworks.

Together with all people who appreciate the importance of the role which industry is called upon to play among civilised nations, I summon with all my prayers the time when international law will outlaw the use of such contrivances. The imitation of foreign trade marks is a deplorable counter-attack against the tendency which, more and more, the manufacturers show in founding a monopoly based on the secrets of fabrication processes. Industry will not reach the peak of its endeavours until, with government assistance, it has become organised on two principles of equal importance: the free propagation of working techniques and the respect of the marks which guarantee the origin and the quality of each product.

Exports of steel do not have much commercial importance; they did not rise more than from 74 tons to 95 tons between 1831 and 1841; they were made up principally of implements required for agriculture and building in the French colonies, for which the home country has the exclusive right of supply.

Consumption of Steel (686)

Neglecting all evaluations less than a ton and not counting exports *(which in some ways are nothing more than an extension of internal commerce),* we find that the consumption of steel in France has varied during the last eleven years as indicated in the following table *(quantities in tons):*

Year	Production	Imports	Consumption
1831	5294	999	6293
1832	4981	1247	6228
1833	6121	1408	7429
1834	6281	1595	7876
1835	6156	1589	7645
1836	4848	1887	6735
1837	5958	1790	7748
1838	6402	1736	8138
1839	6502	1630	8132
1840	7286	1546	8832
1841	6790	1481	8271

These compilations permit the affirmation that France is, among the continental powers in Europe, the one which uses the largest quantity of steel; one can also conclude that, having acquired experience in all branches of fabrication and having considerable markets, the French steelworks could aspire to increase their production in all possible security. I shall indicate later the measures which appear to me to be appropriate in bringing about this outcome.

The Steel Industry in Great Britain (687)

As I have already indicated in the introduction to this report, England is now the European country which produces the largest quantity of steel, both raw and wrought. The works in Yorkshire alone, in 1837, produced 18,000 tons of raw cemented steel. Already, however, this production has passed the limit of English trade and in the following years many works, imprudently built, have had to endure frequent periods of enforced idleness; production has not been maintained above 15,000 to 16,000 tons. It would have fallen to 13,600 tons in 1842 if during the last months of the year the state of trade had remained as it was during the month of August. To summarise, I think the average annual production in Yorkshire during the last seven years could be placed at 16,250 tons.

Many steelworks are established near to London and on the coal basins of South Staffordshire, of Somersetshire and of Lancashire. These deliver about 4000 tons of raw cemented steel each year. The average annual production in England can thus be evaluated very approximately at 20,200 tons.

During this same period, Sweden, Norway, Russia and the home forges have together provided the raw materials for this manufacture, approximately in the proportions indicated below:

Sweden	12600 tons
Norway	490 tons
Russia	4400 tons
England	2650 tons
TOTAL	20140 tons

The irons employed cost on average (688) £18.5.0 per ton; thus the total cost of this raw material can be evaluated at approximately £350,000.

The raw and wrought steels produced from these irons are exported to all the countries of the world with which England has commercial relations. The principal countries of destination, arranged in order of the value of exports for raw steel, are the United States, France, Hanover and the Hanseatic cities, Belgium, Holland, Canada, the East Indies, Russia, Australia and so on. For the steel worked into tools and cutlery, the United States again forms much the largest English market; then come Canada, the English Antilles, several German states, the East Indies, France, Australia, Brazil, the non-English Antilles, Italy, Holland, Russia, Belgium, the Cape of Good Hope, Gibraltar, Peru, Chile, Portugal and the Azores, the Rio de la Plata, the West Coast of Africa, Spain, the Canaries, Mexico, and so on.

The total value of exports passed £2,400,000 in 1836; within the last five years it has remained on average at about £1,800,000, that is to say as follows:

Tools and cutlery, containing over three-tenths of their weight (totalling 5000 tons) of steel and having an official value of	£1,690,000
Steel in bars, 3000 tons, of which the value can be estimated approximately at	£ 143,000
TOTAL	£1,833,000

This export of steel represents hardly half (689) the iron used by the steelworks, so that the work of these establishments and their attached workshops increases the value of the raw material almost ten-fold.

These assessments are sufficient indication that the irons from the North of Europe are to the metallurgical industry of England what the cotton of North America is to its textile industry; they make one appreciate the importance of the commercial edifice which England has built up over two centuries, by dint of its competency and its perseverance, upon a product foreign to its own soil.

Industrial Superiority of Yorkshire over the Countries Producing its Raw Material

It seems strange, at first sight, that Sweden, which produces the raw material, has not kept the monopoly of a technique which for England is the source of so great an advantage. This reflection, first recorded around the middle of the last century by a celebrated metallurgist *(Gabriel Jars, Voyages Mètallurgiques, Vol.I, p.156)* has often been repeated. But on getting to the root of things, one soon sees that the industry has sound reasons for its existence and that it does not in any wise rest with Sweden to displace it to her profit.

In the first place, the forges in which the best kinds of iron are made have, for the most part, pushed their annual production to the limits imposed by the product of their neighbouring forests; one cannot therefore find there the extra resources of fuel needed for the manufacture of raw and worked steel.

The researches which I have carried out in (690)

REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE

Yorkshire have shown me that the direct consumption of coal involved in the manufacture and all the working operations of steelmaking rises to eight parts for each part of iron and that this proportion rises to twenty parts if one takes into consideration the domestic consumption of the working population and that of all the allied industries which attend to the needs of the works and the local population. The manufacture and working of the 16,250 tons of raw steel produced per annum in Yorkshire would thus consume in Sweden around 77.5 million cubic feet of timber*. Since this provision of fuel cannot be obtained at low cost in a confined area *(Paris, one of those places in Europe where the provision of wood for fuel is very considerable and which is provided with an admirable transport system to this effect, does not receive more than 42.5 million cubic feet of timber annually)* it would here be necessary to spread the steelworks widely in regions where the timber had no other use, was abundant and was cheap; that is to say, it would be necessary to place them far from the population, the routes of communication and the markets, and thus to deprive them of all the advantages which are given to the steelworks of Yorkshire by the concentration of many thousands of shops whose operations are bound by a very intimate solidarity.

In the second place, even though one might succeed in solving all the technical and economic difficulties which operate against the transportation of the industry of Yorkshire near to the forges which produce the raw material, there still remains a very great obstacle to be overcome – that of the lack of markets. It is easy to predict that Great Britain, whose (691) institutions over the centuries have developed the production of manufactures which themselves consume at least three quarters of the steel made with iron from Northern Europe, would never hand over this vast market to the Swedish steelworks. These latter would also find themselves placed less advantageously than the steelworks of Yorkshire for the supply of the neutral markets, since even now the Swedish forges are obliged to resort to the warehouses of Great Britain for the disposal of a large part of their common sorts of iron and steel.

There exist, without doubt, several localities in Europe where the cementation steelworks are better placed than those in Sweden to compete against the English steelworks; but none of them possesses in the same degree as Yorkshire the elements of prosperity which have been pointed out in this report. To summarise, the pre-eminence of the group of cementation steelworks in Yorkshire, founded in part on an admirable harmony of natural conditions, will remain unassailable as long as Great Britain keeps its commercial supremacy and its vast markets.

For some long time to come, the production of Yorkshire, as well as that of the rest of the manufacturing districts of Great Britain, will not be limited by the state of its markets. The smallest temporary growth of sales immediately promotes the establishment of new works; and thereafter, as a consequence, also promotes commercial crises similar to that which has raged over the last few years. It can be understood very clearly, therefore, why Great Britain appears to be constantly preoccupied in extending the extent of its (692) market by trade treaties.

I confirmed in August 1842 that there were in Yorkshire some 60 distinct enterprises with the object of manufacturing raw steel, comprising 97 cementation furnaces and 774 melting furnaces. This plant would allow the production, at a pinch, of 32,500 tons of raw cemented steel and 15,250 tons of cast steel. The report of the production actually obtained from this productive capacity has been:

For raw cemented steel	50%
For cast steel	55%

Summary of the Production of Steel in Europe

I have collected together in the following table the principal facts relative to the production of steel in Europe, listing the different countries in order of the raw products which they contribute to commerce *(figures in tons)*:

Producing Country	Natural Steel	Cementation Steel	Total Product
Great Britain	Nil	20200	20200
Austrian Monarchy	12600	Nil	12600
German Association	7000	100	7100
France	3320	3710	7030
Russia	520	2640	3160
Sweden and Norway	1970	890	2860
Spain	200	100	300
Italian Peninsula	100	100	200
TOTAL	25710	27740	53450

The French steelworks owe the distinguished (693) rank which they occupy in Europe to the range of the market which they serve and to the protection afforded them by customs duty, rather than to the perfection of their products. Each year, as I have previously indicated, there is imported into the kingdom some 1500 tons of raw and worked steel which the consumers seek out in preference to the native production.

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*Quoted as 2,200,000 steres (1 stere = 35.317 cub.ft.)

Superiority of Foreign Steel over French Steel

The following figures, which indicate the Paris selling prices for steels of divers origins, give the measure of the preference accorded to foreign steel; they also show the superiority of the cemented steel made in France using the ordinary grades of Russian and Swedish iron over those similarly made from the iron from the Pyrenees. The prices refer to one ton of steel in bars of about ¾" section and less.

FOREIGN STEEL

Cemented Steel from Yorkshire

Cast and Refined, 1st. Quality *(called "Silver Steel")*	£137. 0.0.	Irons from Sweden and Russia
Cast and Refined, 1st. Quality *(called "Huntsman")*	£121. 0. 0.	
Cast and Refined, 2nd Quality	£109. 0. 0.	
Twice Forged *(called "Double Spur")*	£101. 0. 0.	
Once Forged *(called "Single Spur")*	£ 80.10.0	
Rolled, for Springs	£ 64.10.0	

Natural Steel from the Central Alps

Twice Forged *(called "3 Double Hammer")*	£88.10.0	Ores from Eisenertz and Huttenberg

Natural Steel from the Rhine (694)

Twice Forged *(called "Double Hammer")*	£88.10.0	Ores from Stahlberg and Bendorf
Once Forged *(called "Seven Stars")*	£78.10.0	
Drawn *(called "Oak Leaf")*	£68.10.0	

FRENCH STEEL

Cemented Steel from the Pyrenees

Cast and Refined	£80.10.0	Pyrenees Iron
Thrice Forged	£64.10.0	
Twice Forged	£58. 0.0	
Once Forged	£52. 0.0	

Cemented Steel from the Loire

Cast and Refined, 1st Quality	£105. 0.0	Irons from Sweden and Russia
Cast and Refined, 2nd Quality	£ 84.10.0	
Twice Forged	£ 84.10.0	
Once Forged	£ 68.10.0	
Rolled, for Springs	£ 52. 0.0	

Natural Steel from the Isère

Drawn, for Springs	£ 42. 5.0	Ores from Allevard and St. Georges d'Heurtières

This Superiority Not in the Nature of Things

It is, however, evident at the outset that the French steelworks, if they used the proper means, could supply all the needs of the home market. The example of Great Britain, indeed, proves that the products of a cementation steelworks supplemented by the melting shops can supply all the requirements of a most extensive and a most varied consumer market. Since the nature of the products depends above all on the raw (695) materials worked, it is clear that our own steelworks could place themselves in a similar position to those in Yorkshire if, like the latter, they applied themselves henceforth to the working of the best grades of iron from Sweden, Norway and Russia. Provided with a suitable supply of these Northern irons, the French industry would find itself better placed with regard to raw materials than Great Britain, since it would also have at its command the indigenous natural steel and the Pyrenees iron which are well suited to the manufacture of certain objects of common quality.

Unfortunately, at the present time, there are two obstacles imposed against our steelworks being provided with a suitable supply of Northern iron.

Monopoly Established by the English Merchants

In the first place, the English merchants, who have known for a long time that the superiority in production of cemented steel is of necessity the privelege of those who have the best raw materials at their command, have taken great care, and on long term contracts, to take up the exclusive receipt of the best Swedish grades. The French manufacturers, on the contrary, ill informed to this day in this essential matter, have done nothing to take a proportionate part of this high quality iron in relation to the importance of their manufacture; because of this omission, they are unable at the present time to obtain in Sweden other than those iron which are classified in Sheffield as brands of only third or fourth quality.

Viscious Tariff applied to the French Import of Steel Iron (696)

It is equally because of the lack of having regarded this matter in its proper light that the French government has, until now, maintained a customs tariff which raises considerably the price of these Northern irons to the manufacturers of cemented steel and which thus contributes, even more effectively than the established traditions and the commercial aptitude of the English, in confirming the monopoly of high class products to the Yorkshire steelworks. By maintaining a tariff so contrary to the native industry and to the very principles which led to the establishment of our customs houses, it has, without doubt, been considered that the French forges were able to furnish all the kinds of iron needed by the development of the steelworks and that the foreign irons did not have any advantage over them other than a lower cost price. It is important to prowe that this opinion is false, because I shall prove at the same time the expediency of freeing our steelworks from the greatest obstacle which weighs against them, and to reopen the question of the tariff on steel iron within the general principles of our commercial legislation.

Without entering here into those technical considerations which a full discussion would call forth, I must confine myself here to citing several facts which bring into the light the truth which I wish to establish.

Superiority of Foreign Irons over the Native Irons

The charcoal irons produced by the French forges are unsuited to most of the steelworks usage and, among those which can be used in this direction, the irons produced in the east of the Pyrenees Group, *(see Volumes V to X of the summaries of the statistical work of the Mines Administration for the definition of this group of forges)* without argument, occupy the first rank. If the French steelworks were to be restricted in (697) their supplies by the country's own resources, the quality of the Pyrenees iron would, without doubt, be a measure of the degree of perfection which the cementation steelworks might achieve. In order to judge the value of these resources, therefore, it suffices to determine the rank occupied by the iron from the Pyrenees compared with the steel irons from the North of Europe.

But, as I have shown in the first part of this report, the value of all the steel irons used in Yorkshire has been established, even to the slightest differences, by trials carried out unceasingly over two centuries, in a multitude of works situated in virtually identical conditions, concentrated in the same area and continually stimulated by the incentive of the most acute competition; the results obtained from such an experience are absolutely free from all theoretical concepts of steel working and can be cited as the most conclusive data which can be derived from this industry.

It also has been shown that the best charcoal irons from Sweden, those which by reason of their excellent quality may be exported to the outside world, show very different qualities as regards their use as raw materials for the steelworks; in this respect they are ordinarily classified into five grades with correspondingly very different prices.

The lowest grade is only accidentally used in steelmaking; it is little suited to this application, although it is eagerly sought after in all parts of the world for ordinary (698) uses.

The price of these numerous sorts of iron varies in the English warehouses from £11.5.0 to £13.10.0 per ton.

The numerous marks of the fourth quality iron cost from £14.0.0 to £16.0.0 per ton.

The marks of the third class cost £16.10.0 t0 £18.10.0 per ton.

The marks of the second class, already less numerous and produced by only 11 to 12 forges, cost £20.0.0 to £27.0.0 per ton.

Finally, the five forges which produce the irons reputed to be of the premier rank still present various differences in quality which are sufficiently marked for the prices to vary between £29.0.0 and £34.0.0 per ton.

On the other hand, several marks well known in the English market are used in large quantities by the French steelworks, along with the Pyrenees irons; this circumstance allows a measure of the relative value of these latter materials, by means of the scale so rigorously established in Yorkshire.

One of the principal cementation steelworks of the Pyrenees, which in 1840 drew most of its provisions of irons from the neighbouring forges, also alongside these employed a proportion of Russian and Swedish irons at the following prices: (699)

Iron of

Nijni Taguilsk	61.00 fr. per 100 kg. (£24.10.0 per ton)
Soderforss	57.50 fr. per 100 kg. (£23.5.0 per ton)
Hedwigsforss	56.00 fr. per 100 kg. (£22.10.0 per ton)
Dadran	53.60 fr. per 100 kg. (£21.10.0 per ton)
Awesta	50.00 fr. per 100 kg. (£20.0.0 per ton)
Pyrenees	46.00 fr. per 100 kg. (£18.10.0 per ton)

Since 1840, the price of Pyrenees iron having suffered a considerable increase, many steelworks which employed it along with the Northern irons have found it to their advantage to use a much greater proportion of these than in the past. At the prices indicated below, one of the Loire steelworks does not now use Pyrenees iron except for restricted uses:

Iron of

Nijni Taguilsk	66.50 fr. per 100 kg. (£26.15.0 per ton)
Soderforss	64.00 fr. per 100 kg. (£25.15.0 per ton)
Dadran	60.00 fr. per 100 kg. £24.0.0 per ton)
Thurbo and Wiksmanshyttan	58.70 fr. per 100 kg. (£23.10.0 per ton)
Swana	56.50 fr. per 100 kg. (£22.15.0 per ton)
Pyrenees	56.00 fr. per 100 kg. (£22.10.0 per ton)

On comparing these figures with those given in the first section in the general table of Steel Irons, it will be recognised that, for the French manufacture, the Pyrenees irons find themselves decidedly classified below the Swedish marks of the fourth class. In maintaining a legislation which drives away the use of the Northern irons, therefore, not only the steelworks which produce the raw steel but, what is more serious, the numerous workshops, which work down the material in all its forms and which in so doing increase its value tenfold, are condemned to an inferior position for all times.

Measures taken by England to Favour Importation of Steel Iron (700)

The English government, which has appreciated for a considerable period the interest which the home manufacturers have had in exploiting to their own profit the precious properties of the Northern irons, has not modified the tariffs other than to render importation more easy. Thus in July 1842, after the last revision of the tariff, in a period in which the government showed itself above all preoccupied in increasing its financial resources, the rate on irons from the North has again been reduced by 33%. The actual tariff, including the additional temporary rate of 5% established in June 1840 on all imports, is only 21/0d. per ton (or 2.60 fr. per 100 kg.). The principal rate has been successively reduced over 20 years in the following proportions:

To 14th June,1825	£6.10.0 per ton (16.13 fr. per 100 kg)
14th June 1825 to 4th July 1842	£1.10.0 per ton (3.72 fr. per 100 kg)
Since 4th July 1842	£1.0.0 per ton (2.48 fr. per 100 kg)

Opposite Measures taken by France

The tariff applicable to the same irons has followed an inverse trend in France; the import duty at the beginning of 1814 was 4.40 fr. per 100 kg. *(£1.15.6 per ton)*, but since 21st December 1814 it has been raised to 16.50 fr. per 100 kg. *(£6.12.6 per ton)* on irons carried in French ships or 18.15 fr. per 100 kg. on irons imported in foreign ships. Since, however, the freight charges in French ships is always higher than in foreign vessels, the French manufacturers always find it is an advantage to import their irons in these latter at the duty of 18.15 francs per 100 kg. *(£7.6.0 per ton)*.

The difference in the two tariff rates results in the burdening of the raw material for the French (701) manufacturers with a surcharge of £6.5.0 per ton. The average price of the marks of Swedish iron imported into France being around £16 per ton in Sheffield, this surcharge is equivalent to a rise in cost of 39% over that paid by the Yorkshire manufacturers. Such is the principal cause of the differences of 16 to 20 fr. per 100 kg. *(£6.10.0 to £8.0.0)* which the previous figures indicate between the prices of the same marks of Russian and Swedish irons in Yorkshire on the one hand and in the groups of steelworks in the Pyrenees and on the Loire on the other.

This inequality in the conditions of purchase of the raw material is increased still further by the losses which take place in the diverse working operations on the raw steel as the figures below show:

Difference in cost of iron	15.67 fr. per 100 kg. or £6.6.0 per ton
" raw cemented steel	15.53 fr. per 100 kg. or £6.5.0 per ton
" rolled to bar	15.98 fr. per 100 kg. or £6.8.3 per ton
" forge drawn	16.45 fr. per 100 kg. or £6.12.3 per ton
" once forged	17.46 fr. per 100 kg. or £7.0.3 per ton
" twice forged	18.44 fr. per 100 kg. or £7.8.3 per ton
" thrice forged	19.53 fr. per 100 kg. or £7.17.0 per ton

Novertheless, the cementation steel manufacturers are beginning to appreciate the qualities of the Northern irons and already they are approaching a third part of the total consumption of the French steelworks. The irons submitted to cementation during 1841 had in fact the origins shown below:

Pyrenees irons	2100 tons
Home produced irons of various other origin	450 tons
Swedish and Russian irons	1100 tons
TOTAL	3650 tons

Expediency of Removing the Import Duty on Iron for Steelmaking (702)

The considerations given above appear to me to be in the nature of demonstrating that the best means of improving the technical and economic situation of the French steelworks consists in favouring, by a special dispensation, the importation of the Northern irons specifically destined for the manufacture of steel. This modification of the actual tariff could be made without the general commerce in iron being affected in any way; it would suffice to apply to the cementation steelworks a similar arrangement to that in force for the soda factories. Under such a system, the supervision which would have to be made by the administration would be all the more easy since the process of cementation, instead of being continuous like that of the soda works, is essentially intermittent.

It is all the more appropriate to revise the article of French tariffs at this time, since a number of treaties contracted during the last century by the English merchants for their exclusive receipt of the best quality irons from Sweden are due to expire very shortly.

In order to make comprehensible how the measure which I am recommending would scarcely affect the general iron trade in France, it suffices to present the comparisons as follows.

In supposing that the irons from Sweden were substituded completely for the native irons in the manufacture of steel and that one imported from this time onward in the form of such iron all the raw steel and worked steel which France draws today from foreign countries, the total quantity of foreign iron which the French steelworks would then use would rise to 5100 tons; (703) the increase in importation would therefore be some 4000 tons.

But the production of iron in bars in the French forges has risen in 1841 to 260,000 tons and the average growth of this production over 11 years has been 12,000 tons per annum. In the extreme hypothesis given above, the increase in imports would, therefore, represent 1/65 of the native production at most; the market removed from the French forges would form only 1% of their production or one fifth of their mean annual growth over the last 11 years.

Future of Steel Manufacture in France

Should modification of the tariff and the dogged perseverance of the French merchants and the consular agents succeed in bringing to an end the monopoly which up to this time has existed in the export of the high grades of Swedish iron, France would be, without doubt, the country best placed on the Continent of Europe to travel the road which has made Yorkshire so prosperous. In such circumstances, whilst the established traditions, the experience gained by the English manufacturers and the long term treaties which still subsist for several marks of iron would not allow the French manufacturers to compete with those of Yorkshire in neutral markets, it is not in doubt that the French steelworks would soon find themselves in a position to supply all the needs of home consumption, to provide all the types of steel called for by the factories of the kingdom and to bring these latter out of the state of inferiority in which they have long languished.

The following reasons lead me to think that the principal group of cementation steelworks on the Continent is destined to develop in France rather than elsewhere.

France is the principal centre for the (704) consumption of steel and in this respect she greatly outweighs Belgium which, with similarly favourable technical and commercial considerations, would not have an extended market at its disposal.

Favourable Localities for the Development of Steelworks

The coal basin of Valenciennes offers conditions comparable to those of Yorkshire in many respects for the creation of cementation steelworks founded on the use of Swedish and Russian irons. Valenciennes, linked to the port of Dunkirk by good navigable waterways, is no further from the sea than Sheffield is from Hull. The mines of Valenciennes and those of Mons could furnish in abundance numerous varieties of coal at prices from 6/6d to 11/0d per ton. The port of Dunkirk is a little further from the Baltic than is the port of Hull but this circumstance in itself does not explain the advantage which the port of Hull possess today, in its relations with the Baltic, over the French ports of the North Sea and the Channel. This is mainly due to the fleets of England and Sweden, in taking advantage of a regularly established trade of long standing, being assured of finding in the English warehouses suitable return cargoes made up of colonial commodities and the products from across the Atlantic. But France is very well placed to take advantage of the warehouse trade which, prior to 1789, provided many ports with a large harvest and which has already, since the peace, shown some regrowth; it may be supposed that a large importation of Swedish iron into the Channel (705) ports would contribute at one and the same time to the extension of commerce and to the lowering of the cost of freight. Nevertheless, in the actual state of things, the difference in freight rates would only burden the French manufacture slightly; the mean rate of freight, which 8/0d per ton between the Baltic ports and Hull, would not exceed 14/6d per ton for the port of Dunkirk.

The works attached to this group and fed by the same fuels could also establish themselves with advantage in proximity to the places of consumption, on the navigable ways between Valenciennes and Paris. It is in similar conditions that there already exist important works in the departments of the Oise, the Seine and Seine et Oise.

The group of cementation steelworks on the Loire is obliged to draw the Northern irons, which they already consume in considerable quantities from the warehouses of Marseilles; but the excess freight which these irons have to pay to be transported to the Mediterranean rises at least to 12/0d. per ton, even though the movement of cumbersome merchandise takes place in the opposite direction. Moreover, the manufacturers have to pay the cost of land transport from Marseilles to their works, amounting to £2.4.0 per ton, so that the sum total of transport costs from Sweden to the Loire steelworks comes to around £3.10.6 per ton. But this grave burden is compensated in part by the very moderate cost of fuel, which does not exceed 5/9d per ton over the whole coalfield, and by the proximity of numerous manufacturers who work down the steel in Central France *(Loire, Puy-de-Dôme, etc).* It is evident, in fact, that under any (706) possibly imaginable conditions, the manufacturers must pay considerable transport costs for a product whose raw material has to be imported by a sea route. Just the same, these costs are almost as high today for the Pyrenean irons as for those from the Baltic.

But the steelworks of the Loire seem placed at a disadvantage for supplying the South of France and the Mediterranean coast in that the raw materials and the products must make, at a sheer loss, a very expensive double journey. Thus the coal basin of Alais appears to me to be called upon to play in the South of France the same role which the basin of Valenciennes will play in the North. The mean price of one ton of coal in the collieries in this basin is only 5/10½d. The railway from Alais to the Rhone, on which the movement of bulky merchandise has an embarkation point, would probably increase the cost of iron but little, so that the cost of transport from Arles to the steelworks would scarcely exceed 8/0d per ton.

It would be easy to send for the best marks of Russian iron at low cost by a route of which French commerce has not yet availed itself. These irons could be transported to Taganrog on the sea of Azov by means of the good navigable waterways which serve Southern Russia; from thence it could be obtained at the same price as at St. Petersburg. Ships of 250 tons, built with (707) shallow draught, similar to the Greek and Genoese ships which normally sail the sea of Azov, could easily make two voyages during the season when that sea was open, and carry the iron to Arles at a rate of 16/0d per ton, returning with coal from Alais, colonial commodities, wine and other French products, which would always give the ships an assured return load, which at present would only reach the sea of Azov after discharge at the port of Odessa.

Freight between the Baltic ports and Bordeaux is no higher than the freight between these same ports and Hull; on the other hand, the mean price of coal in the rich basin of Aubin *(Aveyron)* does not exceed 4/3d per ton at the present time. There would also exist, therefore, in this part of France, conditions very favourable to the establishment of steelworks, when there has been created a regular navigable waterway in the valley of Lot, between the basin of Aubin and the Gironde.

REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE

Summary of the Future of the European Steelworks

The facts and considerations concerning the probable future of the European steelworks can be summarised as follows:

The steelworks of Yorkshire, thanks to the development which has been made recently in the manufacture of cast steel, form today the most important group in Europe, having regard to quantity, variety and value of their products. Since this vast industrial movement is founded on the raw materials provided by the North of Europe there is no room for thinking that Great Britain will keep the supremacy which she has acquired by favour of technical and economic conditions so happily (708) coming together in Yorkshire and, above all, by reason of the extended market she has at her disposal.

Sweden, which produces almost all of the raw material employed by the cementation steelworks, cannot work them further in her own territory, other than by the aid of prohibitive measures, being lacking in sufficient fuel resources and a market.

Russia, provided with excellent raw materials, could, more easily than Sweden, concentrate in one region its great resources of vegetable fuel, using rafts on its excellent waterways; it has a wide market in its own territory in Central Asia; finally, in the basin of the Volga, it already has a group of cementation steelworks which already occupy the third place in Europe by virtue of the importance of its production. In truth, however, this group, being as much Asian as European, does not appear designated to compete with Yorkshire in the neutral markets; nevertheless, it should have a bright future if the forests with which it is fuelled are henceforth submitted to a regular system of conservation.

The German States, which for several centuries have produced natural steel in considerable quantities within-in their territories and have exported to all the countries of Europe, do not appear to be in a position to profit from the resources offered in certain parts of their territory for the development of the manufacture of cemented steel.

In many respects, Belgium offers conditions comparable to those which exist in Yorkshire for the manufacture of steel; nevertheless, this industry does not seem to have been developed at all since 1814. Belgium does not appear to have today a market sufficiently (709) extended to undertake this manufacture on a large scale.

Alone on the Continent does France present the necessary conditions for the establishment of important cementation steelworks. At the present time the steelworks based upon this method deliver more steel than the forges producing natural steel; they along in the future would be capable of following the progress of a consumption which already exceeds that of all the other continental countries.

Yet this industry, obstructed in its scope by a vicious legislation and by commercial management opposed to the natural course of things, is not yet established in this country in the most suitable conditions. The suppression of these impediments would permit new native steelworks to arise near to the North Sea, the Atlantic and the Mediterranean, in conditions comparable to those in Yorkshire, soon to provide all the needs of the French markets and perhaps to take part, in the not too distant future, in supplying foreign countries.

Summary of Improvements which could be introduced in the Economic Conditions of the French Steelworks

In support of these last conclusions, I have gathered together in the following table all the information which is necessary to permit a comparison of the economic situation of the two groups of cementation steelworks which exist today in France with that of the steelworks in Yorkshire. The same table gives also the measure of improvement which a better legislation would, without fail, introduce into the economic situation of the French steelworks.

NOTES ON TABLE: This has been redrafted for conciseness in reproduction. The following notes are therefore the translator's explanation of the layout:

(1) These three colums represent existing conditions

(2) These two columns represent hypothetical cases as outlined in pages 704-707 of the text

(a) These columns give cost per ton of material of per days work

(b) These columns cost per ton of forged bar produced

(c) This gives the cost of iron of Swedish or Russian origin equivalent in quality to the Pyrenees iron at foreign port *(Baltic Port or Sea of Azov)*, one ton of bar requiring 1.12 tons of iron.

(d) The sundry costs cover buyers commission, weighing charges, transhipment, warehousing and local dues

(e) Customs duty for Valenciennes and Alais is the reduced value postulated by the author as appropriate

(f) Coal consumption per ton of finished bar is as follows:

(1) for Cementation 1900 lb) Total
(2) for Melting 13400 lb) 17750 lb
(3) for Forging 2450 lb) *(7.92 tons)*

(g) Labour is itemised as follows per ton of finished bar:

(1)	for Cementation	2.33 days)	Total
(2)	for Melting	13.68 days)	36.31 days
(3)	for Forging	20.30 days)	*(days being "man-days")*

(h) Other Costs cover charcoal for cementation; carbonisation of the coal, crucibles and refractory materials, general costs and profits, itemised as follows:

(1)	for Cementation	18.1)	
(2)	for Melting	£5. 9.3)	Total
(3)	for Forging	£8. 2.0)	£14.9.4

The following are the author's own notes:

*The cost of transport per ton of iron from Hull to Sheffield is 12/6d. by canal and river and 13/6d. by rail.

** The cost of a days work in France is generally at a lower figure than in England but often it takes a greater number of days to produce the same result, which compensates for this. In admitting that such compensation exists within the steelworks I err a little from the truth but I am stressing the influence which the price of raw materials exerts on the cost of the steel.

TRANSLATOR'S POSTSCRIPT

The reader will have relatively little problem in having decided that, whilst Professor le Play's report is most valuable to us today as a first hand account of an industry which left little behind it in its country of origin in the way of records, it was written in an attempt to persuade those in authority in his own land, that whilst he was full of admiration for the way things were organised technologically in Yorkshire and fiscally in this country as a whole, he had no doubt that his own native France could do just as well if the chauvinistic attitude of the so-called experts with regard to the value of the French irons could be overcome.

What he did not say in detail was that the most successful steelworks in France at this time was being run by Englishmen, mainly with English workmen; James Jackson, who had spent some time in the Sheffield steelworks and later in their counterparts in Birmingham, emigrated to France in 1815 and set up a steelworks near St. Etienne; three years later he successfully applied for a licence to import Swedish iron. In 1843, James Jackson et Fils produced some 1060 tons of steel by the cementation process, two thirds of it subsequently being remelted in crucibles, this being about one quarter of this type of production in France at that time. Ten years later this firm produced 3500 tons from a total of 11,500 tons for the whole of France in the form of raw cementation steel at a time when the total steel production in the country had then risen to some 15,800 tons, an increase of about 12% per annum as compared with a corresponding increase of about 8% in Great Britain. The production of natural steel in France had, however, barely increased over the period: from 3320 tons in 1843 to 4214 tons in 1853, so that cementation steel production had increased at a rate equivalent to 21% per annum, so that Professor le Play's work may not have been completely in vain. The impact of the arrival of puddled steel on the scene within the next few years completely altered the picture; by 1859 total French steel production had risen to 19,000 tons, an increase of over 3000 tons over the 1853 figure, but the amount passing through the cementation furnaces had fallen by just about 50%; moreover, the English cementation furnaces appear to have increased their output from about 40,000 tons in 1853 to over 70,000 tons in 1859. The French industry, therefore, does not seem to have taken its full share of the increased demand brought about by the advent of the railways.

Whatever the long term effects of le Play's admonitions may have been, it is quite clear that they did not have the immediate impact which he desired for we find him returning to the same attack some three years later in his report on the Scandinavian and Russian iron manufacture; indeed, having given an account of his visit and findings in Part I, he devotes Part II to a survey of the rather miserable state of steelmaking in France over the past 150 years, Part III being a much enlarged version of his arguments in favour of a reduction in the tariff on steel-irons. He seems to place much of his complaint at the door of Réaumur and the aura of sanctity which has clouded the vision of officialdom in their dealings with those who wished to dispute Réaumur's dogma that good steel from French iron is only a matter of proper technique; he also queries the veracity of official reports made from time to time on steelmaking trials with native and foreign irons, implying that the very best French irons have been compared with grades of Swedish iron that the English would only use for direct forging to agricultural implements. A translation of his final summary to Part II of this report may well be of interest:*

"The history of the French steelworks can be summarised quite simply as follows. To this day, it has not been found possible to discover, within the bounds of this kingdom, the raw materials suitable for the manufacture of first quality steel. The disappointments which have

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*"Sur la Fabrication et le Commerce des Fers à Acier dans le Nord de l'Europe et sur les Questions soulevées depuis un siècle et demi par l'Emploi de ces Fers dans les Acieries Francaises", Annales des Mines, 4me. Serie, Tome IX, 1846, page 272.

been suffered throughout a century and a half by all the works established here arise essentially from the erroneous opinions propagated by Réaumur and supported by official reports with regard to the "body" of the indigenous French irons. The real successes which have only recently been obtained in France, that is to say, the only ones which could hold out for a single day under conditions of free competition, are due purely and simply to a method of operation on which, throughout two whole centuries, has been founded the prosperity of the English steelworks, namely the use of steel irons from the North and particularly of the best Swedish grades".

Postscript

It also seems a suitable conclusion to this postscript to give the translation of the footnote which appears on p.266 of the same report:

"One can read in another official report that the types of cast steel marked "Huntsman" and "Marschall" (Marshall was another famous name in Sheffield steelmaking at this time) are made with complex mixtures of cast iron and wrought iron; this is in error. These English manufacturers, who over a century have built up such a universal reputation, founded on the use of the best grades of Swedish iron, obviously refrain from compromising by such means the fortune associated with their names. These two houses, since the start of their operations, have never employed other than Dannemora irons. The purchaser who, in the absence of any means of examination, without hesitation pays more dearly for Huntsman steel than for any other kind is in no way submitting, as has been so unjustly stated, to a blind routine; he is paying the most logical hommage, so well deserved, to all the material and moral qualities which this trade mark has guaranteed for a whole century."

COSTS OF PRODUCING ONE TON OF REFINED STEEL UNDER DIFFERING CONDITIONS (710-711)

ELEMENTS IN THE COST OF MANUFACTURE	CONSUMPTION (Tons or Days Work)	In The Yorkshire(1) Group		In The Pyrenees (1) Group		In The Loire (1) Group		In The Coal Basin(2) of Valenciennes		In The Coal (2) Basin of Alais	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
IRON (c)	1.116 Tons	£12. 1. 0	£13.10. 0	£12. 1. 0	£13.10. 0	£12. 1. 0	£13.10. 0	£12. 1. 0	£13.10. 0	£12. 1. 0	£13.10. 0
Transport Costs:											
Port Duty	1.116 Tons	2. 6	2.10	2. 6	2.10	2. 6	2.10	2. 6	2.10	–	–
Sea Freight	1.116 "	8. 0	9. 0	8. 0	9. 0	£ 1. 6. 6	£ 1. 9.10	14. 6	16. 3	16. 0	18. 0
Port to Works	1.116 "	12. 6*	14. 0	16. 0	18. 0	£ 2. 4. 4	£ 2. 9. 7	9. 8	10.10	8. 0	9. 0
Sundry Costs (d)	1.116 "	14. 6	16. 3	8. 0	9. 0	8. 0	9. 0	8. 0	9. 0	8. 0	9. 0
Customs Duty (e)	1.116 "	£ 1. 1. 0	£ 1. 3. 5	£ 7. 6. 0	£ 8. 3.10	£ 7. 6. 0	£ 8. 3.10	5	6	5	6
COST OF IRON AT WORKS	1.116 Tons	£14.18. 6	£16.15. 6	£21. 1. 6	£23.12. 8	£23. 8. 4	£26. 5. 1	£13.16. 1	£15. 9. 5	£13.13. 5	£15. 6. 6
COAL (f)	7.924 Tons	7. 6	£ 2.19.10	£ 4. 1. 0	£16. 5. 0	5. 9	£ 2. 5.10	9.10	£ 3.17. 7	5.10	£ 2. 6. 5
LABOUR(g)	36.31 days**	2.11	£ 5. 8. 0	2.11	£ 5. 8. 0	2.11	£ 5. 8. 0	2.11	£ 5. 8. 0	2.11	£ 5. 8. 0
OTHER COSTS (h)			£14. 9. 4		£14. 9. 4		£14. 9. 4		£14. 9. 4		£14. 9. 4
TOTAL COST			£39.12. 8		£59.15. 0		£48. 8. 3		£39. 4. 4		£37.10. 3

Notes on lifting a furnace-base from the Romano-British Bloomery site at Broadfields, Crawley, Sussex — TQ 258353

by J Gibson-Hill

Rescue excavations in advance of a substantial building development at Broadfields will be completed by the middle of 1975. To date the excavations have revealed Late Iron Age and Romano-British domestic settlements surrounded by ore workings and industrial areas, which are thought to spread over approximately 12 hectares. Many of the stages of manufacturing iron via the bloomery process are represented by features including ore roasting areas, 3 slag dumps, 36 shaft type smelting furnaces, puddling pits, water reservoir and a blacksmith's shop which had been equipped with a stone built forge. A building represented by post-holes and a floor made up of burnt clay and successive layers of unburnt beaten clay, measuring approximately 11 metres by 5 metres and containing an oven, is thought to be part of the workmen's accommodation. More recently work has been concentrated on defining the limits of the 1st and 2nd century AD settlement, that is known to be surrounded on four sides by a shallow ditch enclosing an area approximately 76 metres by 63 metres.

The remains of two furnaces suggest a domed superstructure, with facilities for forced draught and slag-tapping; similar, in fact, to those found at Minepit Wood[1] and indicated at Great Cansiron[2]. Another six of the Broadfields furnaces conform to Cleere's[3] classification Group B.1i in that they are equipped for slag-tapping, were blown with forced draught and had a cylindrical superstructure. These have parallels with a 2nd century group discovered at Ashwicken, Norfolk[4]. A further twenty-two furnaces, while still conforming to the same classification, were free standing. In this and other details, they bear more than a superficial resemblance to the group of furnaces found at Holbeanwood by Cleere[5]. The latter appear to be the typical Wealden type worked during the early Roman period. The purpose of this paper is to describe the lifting of one of these furnace structures; a definitive report on the results of the excavation will be produced at a later date.

Fig I

NOTES ON LIFTING A FURNACE-BASE FROM THE ROMANO-BRITISH BLOOMERY SITE AT BROADFIELDS, CRAWLEY, SUSSEX – TQ 258353

Selection

Selection was partly dictated by the situation of the furnace and obtaining a suitable example of the Wealden type described above. Between Site II and Site I we located a slag dump and, during the sectioning of this, discovered a furnace set into and surrounded by broken slag fragments. Careful clearing of the surrounding material revealed two connecting pieces of clay which formed a figure of eight shape, 1.93 m x 0.86 m over all. This was balanced on a pillar of slag at the base of which was a thin layer of charcoal that was to prove crucial to the success of the operation. The structure itself consisted of an eastern part of unburnt clay *(Fig.4)* with two sandstone blocks, which probably represented the remains of the frontal arch. The furnace base was situated on the western side of these blocks and consisted of a surround on crumbled burnt clay lumps *(Fig 1)* that were derived from the outer wall. Inside this was the grey inner lining of the furnace shaft. On the north side this had partially collapsed to form the D-shape in plan. *(Fig 1)*. The shaft was partially occupied by a charcoal and soil fill.

Preparations

Before attempting to move the object, a means of consolidation had to be devised. Any first aid that would be carried out in the field, had to be of a type that would not prohibit subsequent conservation in a museum. The obvious choice for reinforcing the furnace would have been plaster of Paris, but this was quickly dismissed because of the enormous weight problems it would have involved. Finally, it was decided to fill the shaft with polyurethane foam and to coat the outside of the furnace with polyvinyl acetate emulsion. In this way to provide a suitable method of reinforcing the furnace during its excavation and subsequent transportation, but being light enough not to hinder the lifting operation. This process has been used in the lifting of various objects, notably the Romano-British pottery kiln from Highgate Wood[6].

Materials and Treatment

Polyurethane foam:- The foam is supplied in two component parts in separate glass containers, each weighing ½kg, which should make up about 3 cu ft *(0.27 m^3)* of foam. The components need to be mixed together by measuring equal parts into a mixing vessel. Mixing should commence as soon as the components are brought together and should continue for 30 seconds. This allows a further 15 seconds to pour the mixture into the cavity. It was found necessary to follow the suppliers' recommendations implicitly as to the equipment needed for the process, which should include an electric drill capable of 1400 revs per minute under free load and of adequate power for the size of agitator used. The size and type of the latter will depend on the individual circumstances. The agitator used is readily available from most ironmongers as a fitting for a household food mixer. *(Fig 2)*. The mixing vessel should be smooth sided *(eg. polythene bucket, paper cup etc.)* and of a size chosen to allow mixing without overaeration or splashing. A pair of rubber gloves and a stop-watch should complete the list of essential equipment.

Finally a word of warning. The foam gives off considerable heat and exudes toxic fumes. It should therefore be used in a well ventilated place. Toxicity is dependent on the type of hardener used such as Di-isocyanate. It may be preferable to use a relatively 'safe' version which contains MDI and is slightly less toxic.

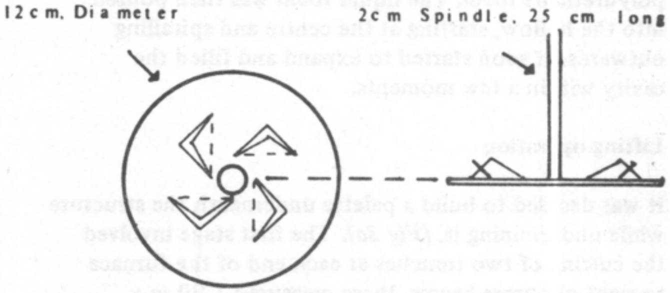

Fig 2 Mixer suitable for bucket mixing

Polyurethane foam is obtainable from:-

I.C.I.
Ship Canal House,
King Street,
Manchester 2.

The less toxic version described above is supplied by:

Frank W Joel
9 Church Manor,
Bishops Stortford,
Herts. BS 51496

Catalogue No. MC/M 1Kg = £1.00

Polyvinyl Acetate emulsion:- This thick white liquid is supplied in one litre polythene containers and can be diluted with water. For use as an emulsion, PVA can be obtained as Vinamul 6525 from:-

Vinyl Products Ltd.
Butter Hill,

Carshalton,
Surrey.

or from Frank Joel who will supply minimum quantities of 1 litre.

Catalogue No. CO/2 1 litre = .85np

Good results were obtained from soaking the furnace and surround in a weak solution of PVA emulsion, thereby allowing maximum penetration.
This was left to dry for one day, then the wall was covered with lengths of scrim making sure that they overlapped one another. To this we applied another coat of PVA emulsion and allowed it to dry. Finally, all the outer surfaces were coated with a stronger mixture to provide some mechanical strength. At this stage we laid sheets of aluminium foil inside the shaft. This was moulded to form a lining so as to protect the structure from coming into contact with the polyurethane foam. The liquid foam was then poured into the hollow, starting at the centre and spiralling outwards. It soon started to expand and filled the cavity within a few moments.

Lifting operation

It was decided to build a palette underneath the structure while undermining it. *(Fig 3a).* The first stage involved the cutting of two trenches at each end of the furnace to sight our cross-beams, these measured 1.90 m x 0.10 m x 0.065 m. *(Fig 3b).* The slag was then undermined taking care to leave supporting pillars during this operation. We inched scaffold planks *(2 m x 0.23 m x 0.03 m)* underneath the furnace. *(Fig 3c).* It was found impossible to complete the undercutting from one side due to the stress that was beginning to show on the furnace but this was achieved by inserting two planks from one side and two from the other. This left a narrow strip of slag and charcoal in the middle. Each of the planks were then chocked to take the weight of the furnace *(Fig 3d).* These were then nailed to the cross-beams and additional planks were fixed in an upright position around the side to make a complete palette. The area between furnace and planks was filled with packing *(paper, cardboard etc)* and the whole was covered by a polythene sheet. The lorry and lifting gear were brought to the side of the trench and chains were attached to the cross-beams of the palette. All now depended on the strip breaking off at its weak point ie the charcoal layer. The crane was started and in a continuous movement the furnace gradually began to lift out of the trench, breaking away exactly as we had predicted. The palette was then placed onto layers of fibre-glass that had been put on the lorry to act as a cushion and firmly strapped down. Later we were able to use a weigh-bridge to ascertain the weight of the structure which was found to be one and a half tons.

Summary

It was thought to be important to record this process in some detail, partly as a guide to the many other researchers working on the iron industry in the Weald, but mainly to illustrate that even on a rescue excavation it is possible to recover large objects, thereby saving

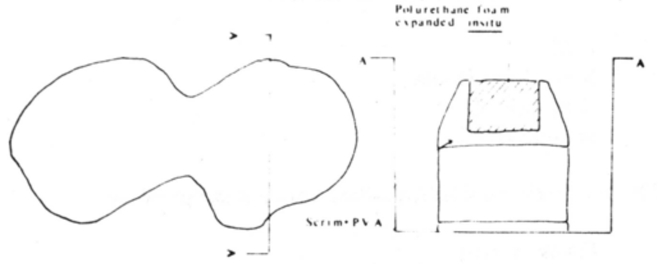

fig 3a

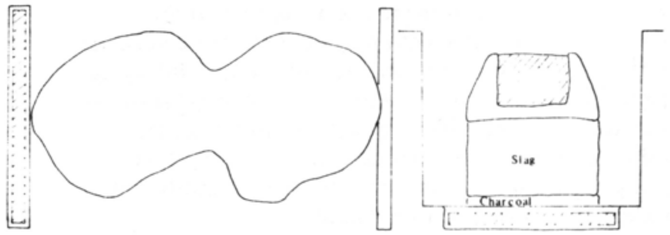

fig 3b

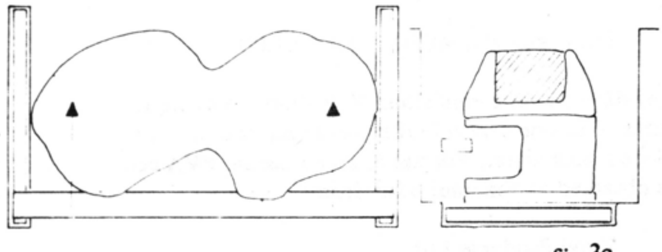

fig 3c

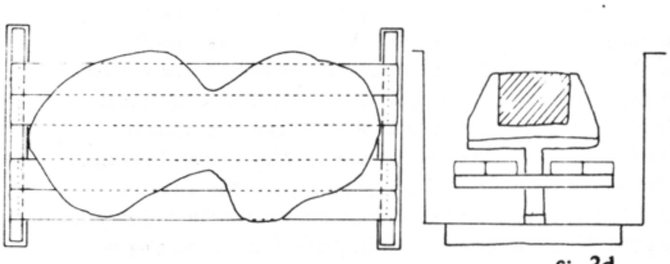

fig 3d

them from destruction and provide important material for serious academic study. The furnace was originally stored at the Sussex Archaeological Society's museum at Lewes and has recently been acquired by the Science Museum, along with other artefacts from the site to provide the centre piece of an exhibition on early iron working techniques, which will be displayed in their new historical metallurgy gallery.

The practical side of the operation took just over two weeks, being the first two weeks of August 1972.

Fig 4 General view of the furnace before lifting operations started.

Acknowledgements

The writer would like to place on record his gratitude to the following; the Crawley Urban District Council for permission to carry out the work on their land, the Department of the Environment for their financial support, Mr B C Worssam B.Sc. Institute of Geological Sciences,Mr H C Cleere FSA, Mr E W Holden FSA and Mr L R Day, Deputy Keeper of the Department of Chemistry, Science Museum, for their interest and support. Mr H Hodges FIIC, Institute of Archaeology, for his invaluable advice on consolidation and methods of lifting, Sir Norman Longley for his donation of both crane and lorry and interest in our work, Miss F Marsden, curator, and the Museum Committee of the Sussex Archaeological Society for providing us with storage facilities, Mr S Bracher, Miss E Horne, Mr J Kirby, Mr C C S Pratt and members of the Crawley and Mid-Sussex Archaeological Group without whose support the project could never have been successfully completed.

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Can copper be smelted in a crucible?

R F Tylecote

It is often assumed that crucible smelting of copper is possible. This is certainly true of tin ore *(cassiterite)* and iron ores, and reactions between these ores and charcoal, coal or anthracite have often formed the basis of assay techniques. But, for copper minerals, this technique is rarely possible. It is, however, possible in the case of the pure oxides such as cuprite *(Cu_2O)*, tenorite *(CuO)* and the basic carbonates such as malachite. When a mixture of these and a reducing agent is heated in a crucible, grains of copper are formed and, if the temperature goes above the melting point of copper *(1084°C)*, spherical prills of pure metallic copper will be formed. With time, a certain amount of agglomeration will take place as the reducing agent is consumed, and much of the metal will form a "button" at the bottom of the crucible. 70% recovery can be easily obtained, and with a bit of patience nearly all the copper in the mineral can be recovered. *(Smelt 1)*.

But the situation is very different in the case of the complex oxide minerals intimately associated with gangue *(unwanted minerals)*. With copper sulphides it is even more difficult as the ore has to be completely roasted to oxide first. When CuO is mixed with some previously formed fayalite slag, ie from the iron bloomery or from copper smelting, and then heated with reducing agent to reduce the copper as before, the copper is reduced and forms a network within the viscous slag. As heating progresses, the slag gets reduced and becomes still more viscous which prevents the copper from separating. This is shown by the slag becoming magnetic, whereas it was non-magnetic before as the uncombined iron was in the form of wüstite. As heating continues further, the copper combines with the reduced iron forming a copper-iron alloy *(a mixture of the two solid solutions)* and the highly viscous slag effectively prevents separation, so retaining the copper in a finely divided, impure, and useless form *(Smelt 2)*.

Furnace smelting overcomes this problem by making it possible to maintain the necessary equilibrium between the reducing atmosphere and the slag that will retain the slag in the highly fluid form essential for good copper separation.

One is forced to the conclusion that, while pure oxidized copper minerals can be converted into metallic copper in a crucible, low-grade oxide or sulphide minerals cannot. This conclusion is supported by the use of furnaces in the Chalcolithic period as seen in Timna area of Israel on a site dated to about 3300 BC. This is the area of the Beersheba-Ghassul culture. So far, we cannot point to any certain cases of crucible smelting, perhaps because supplies of sufficiently pure oxide ores were so rare.

Crucible Smelting; experimental results

Smelt 1.

Charge,	CuO	30 g (= 24 g Cu)
	C	10 g

Product, Cu (1st separation) = 17.2 g
(2nd ") = 18.6 g (not complete)

% recovery > 80%

Smelt 2.

Charge,	CuO	10 g
	Slag	20 g
	C	10 g

% Composition of slag:-

SiO_2	27.1
FeO	56.8
Al_2O_3	10.2
MnO	3.0
CaO	1.4
MgO	0.8
P	0.73
S	0.022

The product was a mixture of viscous slag and a fine network of metal. Under the microscope it was clear that the metal phase had consisted of about 30-40% iron-rich dendrites in molten copper. The Cu-Fe phase diagram shows that at this composition the iron-rich solid solution would not have been molten at the temperature of the experiment, ie 1150°C. It is clear that metallic iron was reduced out of the slag and diffused simultaneously into the molten copper forming a copper-iron alloy between the solidus and the liquidus temperatures of 1100 and 1400°C respectively.

Metallurgy in Art

Through the good offices of Herr G Bauhoff of the Verein Deutscher Eisenhüttenleute the Historical Metallurgy Society has been presented with a collection of 30 reproductions of paintings depicting metallurgical subjects. These represent part of a series published by the Phoenix-Rheinrohr A G of Düsseldorf in 1961, and entitled "Das Eisen in der Kunst". One section of the series is entitled "Alte Eisenwerke und Erzgruben in Norwegen und Schweden". Many of the originals are in the possession of Phoenix-Rheinrohr and some belong to Jernkontoret in Stockholm. The latter are aquatints and aquarelles; the Norwegian examples are by Haas, and the Swedish by Martin and Linnerhjelm.

Many are well-known and some have been reproduced by Schubert in his "History of the British Iron and Steel Industry from c450 BC to Ad 1700". The Scandinavian pictures will be less well-known to British readers. Although naturally subject to artistic licence – some are even impressionist – such illustration of metallurgical techniques are a valuable aid to our understanding of early technology and are often a help in the interpretation of features found in the remains of metallurgical plant.

We could do with a lot more help of this sort and a comprehensive world catalogue would be most useful. Some recent examples of published collections of paintings are to be found in René Evrard's book, "Les Artistes et les Usines à Fer," Lüttich, 1955, and in F D Klingender's "Art and the Industrial Revolution," 2nd edition, London, 1968. An exhibition under this heading, dedicated to F D Klingender, was held in the Manchester City Art Gallery in the summer of 1968, and the catalogue is itself a very useful guide to what is available in Britain. In China, a number of traditional paintings on metallurgical themes dating back to the Medieval period have been regularly reproduced in calendars and similar works.

CATALOGUE

1. **Herri Met De Blès ca.1525**

Landscape with ironworks. *Oil, 50x82 cm Fürstl. Liechtenstein Coll. Schloss Vaduz.*

Well-known painting reproduced in Schubert's book; it shows a blast-furnace and finery; two hearths and a belly helve with wheel-shaft parallel to hammer-shaft. The bellows of the (?) chafery hearth are water-driven from a high-level wheel shaft.

2. **Herri Met De Blès ca.1540**

Landscape with ironworks and mining. *Oil on wood, 83x114 cm. Florence, Uffizi.*

Essentially as above but less clear.

3. **Herri Met De Blès ca.1540**

Landscape with foundry and mining. *Oil, 62x88 cm. Graz, Joanneum.*

Similar to No.1 but with better view of interior of finery hearth.

4. **Lucas Van Valkenborch ca.1580**

Rocky landscape with quarry, lime-kilns and foundry. *Oil on wood, 46-70 cm. Privately owned. Duisburg.*

Blast furnace showing very little detail; of particular interest are two circular lime-kilns, the lime-stone is being worked from the quarry face above and behind.

5. **Lucas Van Valkenborch ca.1590**

River valley with iron working. *Oil, 77x94 cm. Landesmuseum, Bonn.*

River divides leaving island between the two main streams on which are situated 3 water-driven furnaces, two of which are clearly blast furnaces. The third is covered and might well be a forge; there is a washing installation in the foreground *(for ore)*; to the left, on another island, a blast urnace, charged by means of steps. None of the furnaces appears to be more than 12 ft high; water wheels are of large dimensions and are undershot; they are greater than the height of the furnaces.

6. **Lucas Van Valkenborch ca.1590**

Landscape with iron working. *Oil 45x53 cm. Herzog Anton Ulrich Museum, Braunschweig.*

Blast furnace with relatively small water wheel and adjoining buildings. In the foreground two men are filling a conical basket with ore.

7. **Lucas Van Valkenborch ca1595**

Landscape with iron working. *Oil on wood 45x66 cm. Herzog Anton Ulrich Museum, Braunschweig.*

Typical blast furnace with overshot water wheel and adjoining buildings. Iron ore is being mined with the aid of a windlass and shaft.

8. **Louis Le Nain ca.1640**

Vulcan's smithy with Venus. *Oil; Musée des Beaux Arts, Rheims.*

Smith hammering a piece of iron on a square anvil.

9. **Louis Le Nain ca.1640**

Farrier in Smithy. *Oil 69x57.*

Louvre, Paris.

10. Johann Jakob Haas *(1756-1817)*

Blast Furnace of Norwegian type situated in valley; bellows *(not visible)* driven by water power. A shed built of wood and with a tiled roof surrounds the furnace. From the charging floor a slanting bridge leads to the depot where the ore and charcoal are stored. Men with baskets are carrying the charge to the charging floor.

11. Johann Jakob Haas *(1756-1817)*

View of charging floor; to the left hangs a scale on iron chains; two men are about to weigh the ore/charcoal contained in a basket. To the right a man pounds the ore with what appears to be a heavy stone.

12. Johann Jakob Haas *(1756-1817)*

Blast furnace with tapping in progress; most of the metal is being directed into pig moulds in the casting floor, some is being ladled into moulding boxes. The top of a crane is visible on right.

13. Johann Jakob Haas *(1756-1817)*

Forge with belly helve showing hearth to the left. Iron is being forged into bars about 6 ft long by 1 in. diameter.

14. Johann Friedrich Martin *(1755-1816)*

Mineshaft with wooden platforms and ladders. Hogborn, Grythytte (*Westmannland).*

15. Jonas Carl Linnerhjelm *(1759-?)*

Iron Mine of Dannemora.

16. Pehr Hillström ca.1781

Gentry visiting a German Steelworks. *Oil 82x129. Privately owned. Stockholm.*

Forge with belly-helve; no evidence of cast iron pigs; probably chafery hearth for the forging of natural steel.

17. Leonard Defrance ca.1790

Rolling and slitting mill. *Oil on wood 36x55 cm. Musée de l'Art Wallon, Lüttich.*

The metal is being removed from the furnace apparently as a bar and, after the first pass, is coming out as a narrow sheet; meanwhile the second sheet is going through the slitters.

18. Leonard Defrance ca.1790

Interior of foundry. *Oil on wood 50x70 cm. Musée des Beaux Arts, Brussels.*

Iron is being taken out of the hearth with ladles and cast into ornamental lattice work moulds.

19. Leonard Defrance ca.1790

Interior of foundry. *Oil on wood 36x48 cm. Privately owned.*

Forge with two hammers both are tail helves. Complicated operations are carried out on the anvil of the nearest hammer involving 3 men.

20. Pehr Hillström ca.1792

Interior of anchor smithy, Söderfors Bruk. *Oil 48x60 cm. Coll. Stora Kopparberg Bergslag A.B., Falun.*

The stock is being welded to the crossbar of the anchor in front of the hearth which has a well-defined Morris bar.

21. Pehr Hillström ca.1792

Charging floor of a Swedish blast furnace, half-roofed; lifting gear for ore on the left by windlass. *Oil 74x117. Berkinge nr. Forsmarks Bruk, Avesta, Sweden (Consul A A Johnson).*

22. J S Cotman c.1802

Bedlam Blast furnace. *Water Colour 26x47. Coll. Sir Edmund Bacon, Ravening Hall, Norwich, Norfolk.*

Impressionist.

23. Carl Vogt (Voigt) ca.1820

Exterior of blast furnace at Baerum with people in foreground. *Oil 173x174 cm. Norsk Folket Mus.Coll. Bogstad, nr.Oslo.*

24. John Neagle 1826/27

Pat Lyon at the Forge. *Oil 236x173 cm. Museum of Fine Arts, Boston, USA.*

25. Markus Pernhart ca.1850

Blast furnace at Hirt nr. Friesach, Carinthia. *Oil 54x80 cm. Schloss Freudenberg, Klagenfurt, Austria.*

Not in blast; smoke coming from ore roasting kilns; metal seems to have been cast into flat plates ca. 1 ft x 5 ft and ca. 1 - 2 in. thick. These are being loaded onto a cart.

26. John Ferguson Weir 1866

The Gun Foundry of Cold Spring *Oil 118x158 cm. Putnam Co. Hist. Soc. Garrson-on-Hudson, NY.*

Gun foundry with large brick-built cupola; a blast furnace not in blast. Crane carrying ladle full of hot

metal poured into vertical gun mould in a casting pit. Two guns seen in foreground.

27. J W Wallander 1869.

Gentry visiting steel bar forge at Forsmarks Bruk.
Oil 73x93. Stockholm, Oberst Odelberg.

Forge with belly helve and hearth obscured by smith forging by hand.

28. Adolph Menzel 1875

Rolling mill with carriage transporting white-hot bloom, and men feeding bloom into mill.
Königshütte, Upper Silesia. Oil 153x253. National Galerie, Berlin-Ost.

29. Alfred Sisley 1875

The Foundry at Marly-le-Roi. *Oil 54x73 cm. Jeu de Paume, Paris.*

30. Constantin Meunier 1880

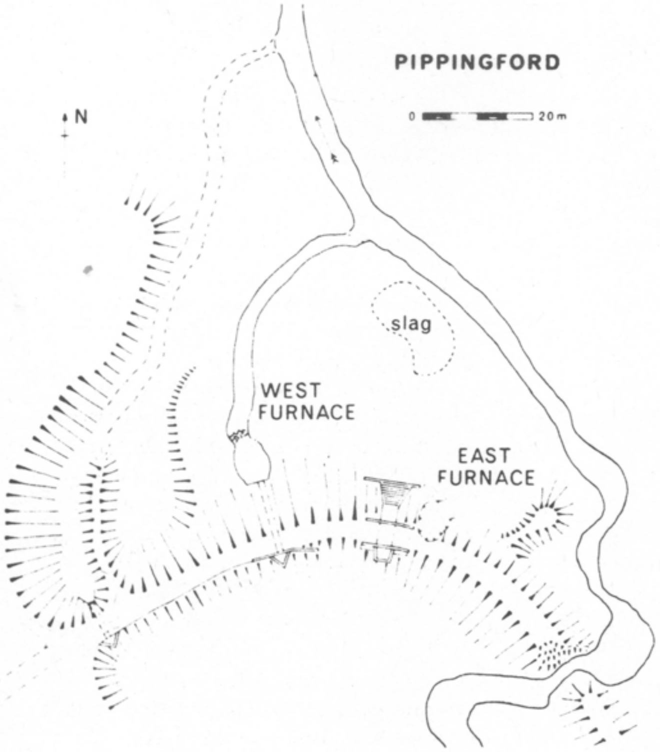
Bessemer casting pit of well-known type with tilting converter in centre and spare ladle. Teeming is in progress through a bottom tapping ladle.
221x303 cm. Lüttich, Musée de l'art Wallon.

Excavations at Pippingford furnaces, Sussex, July-August 1973

Interim Report

I

Two short excavations, in 1970 and 1972, had located fragments of a blast-furnace at TQ/450316, in Pippingford Park, Hartfield parish. It lay in the angle between a dam which had once impounded a pond to the south, and a spur running north from the dam in a manner suggesting a charging ramp from which materials could be taken across a bridge to the furnace top. Sparse documentation showed that a furnace worked here in 1717 and 1724.

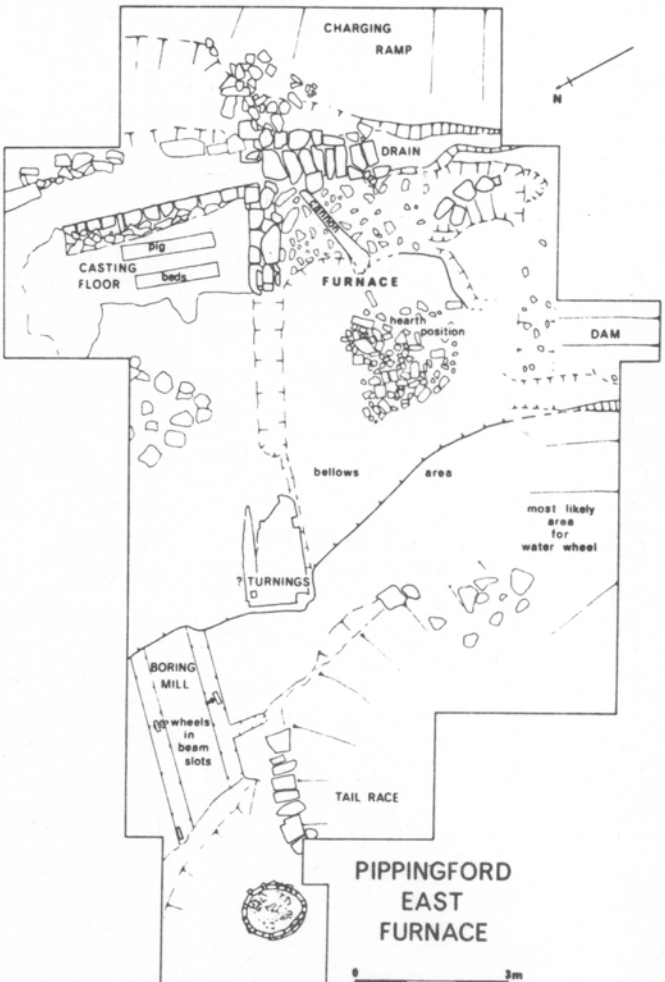


II

This season the area of the furnace and much of its surroundings were stripped of their deposits.

The furnace outline was finally established. The east wall, next to the ramp, was traced from robber trenches which had been cut through an overburden of clay, much of which appeared to derive from a raising of the dam after the furnace itself had been abandoned. Such was this overburden that the south-east corner had to be traced with the assistance of a mechanical excavator. The south wall appeared to have been robbed at an early stage: it had been built on the edge of the original dam, and only scraps of rubble lay between this and the material of the new high dam. The west wall could not be traced: it was indeed unlikely that there had ever been a footing on this side, the most likely location of the bellows arch. On the south side stood the fragment of masonry seen in 1970: its survival is a puzzle, perhaps only explicable if there had been a tree present when the large-scale robbing took place. Indeed this would correspond with the roots found close to the stones, and the suggestion made above that the major robbing took place some time after the structure went out of use. The western end of this north wall had been totally removed, and the trench filled in with slag identical to the material on and in which the footing had been set: thus only slight traces were discernible.

The interior corresponded with the outline plan. A circular hollow, outlined within deposits of hard clay, rubble and slag, showed where the hearth base had been. However, red burnt clay was absent, so the hearth itself must have been at a much higher level, allowing hot metal to be run over the topmost course of the north wall, the threshold of the fore-hearth.



The location of the latter was made clear by the presence of two pig-beds formed out of hard sand and in a fine state of preservation.

A great deal of attention had been given to drainage. A back-drain, covered by cap-stones where it had not been robbed, separated the charging ramp from the furnace foundation area, ensuring the removal of water seeping in from the east. Indeed this came as a small filled-in channel from the dam, beyond the reach of excavation. It fed a stone-lined drain along the east of the casting area. This latter length of channel had a well-dressed stone wall on the west side, but only a fragmentary and rough revetment on the east. The suggestion that this could have been designed as a wheel-pit in an early layout is hard to prove or deny, but it could not have operated thus when a casting floor was in use immediately to the west.

A striking feature was the build-up of slag on which the furnace lay. A deep scoop had been excavated in the natural clay, sloping away northwards. This was clear not only on the main site, but in a machine-cut trench to the north. The hollow had been filled with blast-furnace slag, and the front of the furnace and the casting area placed on a deposit up to 1.5m thick. This provided excellent drainage in general, and, in particular, would have allowed gun-casting pits to be constructed without their bases being cut into impervious clay.

When the pig-beds were removed, the underlying build-up of cinder and rubble was examined for signs of a gun-casting pit. No evidence was found, but this does not prove that a pit was never there; all evidence could have been removed in the substitution of the very solid foundations of the pig-beds.

III

There was indeed evidence that suggests gun-casting at this site. The least certain was perhaps the cannon which was found. This, a piece that may have been a two-pounder, found complete with its casting head, was less than conclusively stratified, despite being in the foundation of the furnace. It had either been deposited at an initial robbing very soon after abandonment, or - and the copious deposits of slag which had adhered to the metal make this the more likely - it had been placed in the foundation prior to a final rebuilding of the forehearth. It may seem illogical that several hundred pounds of cast iron should not have been taken away to be broken under a forge hammer and then added to a charge, or refined at a forge, but some combination of circumstances and cheap raw materials may provide an explanation. Clearly the cannon was made nearby, as its gun-head indicates, and it must be assumed to be faulty, but it was not necessarily made at this furnace. Far more satisfactory evidence came from the area west of the furnace. A flat area of slag had two oak beams set in it, on which were found three iron wheels, with a fourth displaced close by. There seems little doubt that here was the site of a boring mill, and the hard surface around the beams, and the adjacent heap of hard material solidified into the corner of a now-vanished timber structure, strengthens this conclusion. These appear at first sight to be deposits of turnings, but samples await examination. A further find in this area was a cast-iron object, possibly a socket or chuck for a boring bar, and a feature which may have been associated was a circular brick structure to the west, filled with some form of concrete and apparently designed to support machinery, possibly a winch to pull the cannon during boring. Thus Pippingford should be added to the list of known gun-casting furnaces.

IV

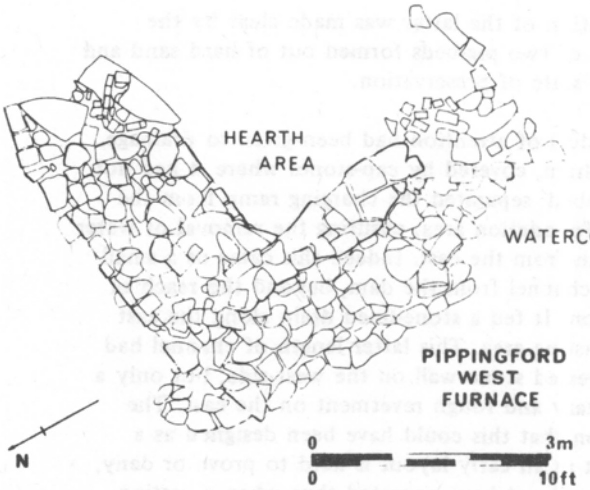
Perhaps the most unsatisfactory aspect of this site was the lack of firm evidence for water-operated machinery. Experience with the final phase at Chingley Forge had shown that in the Weald late in the seventeenth century timber wheel emplacements were being built which made no use of posts and post holes, and which could be dismantled without leaving traces, apart from tail-race deposits. Such must have been the case at Pippingford, for while the tail-race was obvious, at its head there was no more than a scatter of large tumbled stones which may have served some function connected with the foundation for the bellows wheel, whose probable position close to and parallel with the dam was not hard to judge. Whether the boring mill had been water-powered could not be established, for a later sluice through the raised dam, and its channel, had cut through the relevant area.

V

Late in the period of the excavation it became possible to examine an area 20m. to the west where burnt clay showed in the bank of a dry water-course. Stripping of topsoil disclosed the north and west walls of a blast furnace, with substantial masonry surviving. A further season's work will be required here, for it is to be hoped that evidence from this site will shed light on problems remaining over the east furnace. In particular it will be necessary to check whether the balance of datable objects from the newly-discovered west furnace is sufficiently earlier than those *(glass bottles and clay pipes)* from the east site to allow the suggestion that it provided the slag on which the eastern furnace was built. Any evidence of gun-casting at the western site would of course be crucial to a comment oh the piece found this year.

VI

I am very grateful to all who contributed to the success of this year's work. The Department of the Environment covered costs by a grant made through the Society for Post-Medieval Archaeology, Mr.Alan Morriss, owner of Pippingford Park, took a keen and helpful interest; Mr.Fred Tebbutt provided the essential base and link with local help; Dr.G.R. Rowlands kindly arranged accommodation; Mr. and Mrs.A.Meades provided a camp site; Mr.Jack Humphreys ensured direct access to the site. Equipment provided by a Nuffield Foundation grant was of great value. I must thank particularly the volunteers for putting up with conditions which, if not of the sheer wet discomfort of Panningridge or Chingley, were often made discouraging by the volume of overburden or underfoundation deposits, the remarkable lack of small finds, and the elusiveness of the robber trenches.



Perhaps the cannon, and for those who stayed into the last week, the western furnace, were some recompense.

David Crossley,
Department of Economic History,
The University,
Sheffield 10.

Report on Bloomeries at Eccleshall, Staffordshire

by Norman Mutton

Last Easter Mr Henry Butter, Senior, asked me to look at the sites of some 'Ironworks' on his farm, Fair Oak Grange, Eccleshall. He told me of two widely separated groups of slagheaps on opposite sides of his farm, and, incidentally, of the main watershed of England. Investigation showed one site on the west, which consisted of two small heaps of slag a few metres apart. The site was by a cart track in dense woodland, about 4 or 5 metres above a tiny stream, a headwater of the Coal Brook, which is a tributary of the Tern and so of the Severn. The heap contained some fragments of red and white sandstones, but was mainly bloomery slag. Its approximate location is SJ 745335.

Another small stream, which converges with the stream mentioned above, has three dams along its length, the lowest of which impounded until recent years The Monks' Pool. There is also a contour level leat, about one kilometre in length, leading to the next farm down the valley. The relationship, if any, of these works to the bloomeries is unknown.

Whilst we were investigating this first site, Mr Henry Butter, Junior, was ploughing more deeply than had been customary to the east of the farm. He ploughed up a patch, c.50 metres in diameter, of bloomery slag, charcoal, burnt clay, and sandstone which had not previously been noted. This site, at SJ 754339, lies about 300 metres to the east of the farmhouse and above the source of the river Sow, which is a tributary of the Trent. It lies some 200 metres north of the source of the Sow, in the dry upper valley. Slightly lower down the valley were two other quite separate slag heaps, again consisting mainly of bloomery slag. They are respectively near to the second and third old dams. The line of the river runs from SJ 760335 to SJ 755339.

Samples of the slags were taken from all the sites. Those from the newly unearthed site were dark bluish-black, little weathered, very dense and difficult to break. Slags from the other sites were similar except that the colour was a dead grey-black. The samples were microscopically examined by Mrs Joyce Wingrove, B.Sc., whose important work in this field is well known. She was specifically asked to pay attention to evidence for dating, as the bloomeries were totally without context, and documentary research had revealed nothing.

Her report *(abridged, below)* indicates a late date, ie not earlier than the sixteenth century, for the slags. This late date need not occasion surprise as there is documentary evidence for bloomeries in North Staffordshire, and elsewhere in the Midlands, to 1600 and later, notwithstanding the co-existence of a blast furnace plus Wallon forge industry from the 1560s.

The sixteenth century dating gave a focus for the documentary research which was also being undertaken. The sites are on land which, in the sixteenth century, belonged to the Bishops of Lichfield. Unfortunately no other evidence has yet been found, even though a late sixteenth century glassmaking industry there is well documented. Search continues.

The nearest known source of ironstone is in the next hamlet, Tunstall. Charcoal was plentiful, for the sites lie in the thousand-acre Bishop's Wood; the glassmakers were certainly attracted there by the timber. Water supplies, on present evidence, look feeble, but the spasmodic operation of the bloomery process did not need large quantities of water. The location of the sites, well away from any roads or even small centres of population probably did not matter in view of the small scale of operation of such a type of industry, and markets such as Newcastle under Lyme were not more than a day's walk distant.

Report on slag samples from Eccleshall (Abridged)

METHOD OF EXAMINATION

Each sample was examined visually *(after washing)* in the whole piece, the fractured surface examined, and fragments of various sizes tested with a magnet. The polished samples were examined microscopically after etching with 5% alcoholic ferric chloride solution to improve the definition of the phases, and again after drastic etching with concentrated HCl.

General remarks

All the slags were found to be non-magnetic, and there were no signs of charcoal or iron on or within any of them.

(Details of each slag, given in the full report, here omitted).

Conclusions

The constitution of the slags from these three sites is very similar, differences between samples from different sites being no greater than might be expected in slags from different runs in one furnace. Slight alterations in ore, gangue material, furnace temperature and methods of working can easily cause such variations.

The slags are definitely bloomery and not forge slags. The latter almost invariably contain large amounts of free wüstite and also some particles or droplets of metallic iron. Roman slags[1] and medieval slags[2] made by primitive methods contain large amounts of

free wüstite reflecting inefficient working and low yield of iron; the slag containing as much as 45% iron by weight, in the form of fayalite and wüstite. The slags from the Eccleshall sites are all low in free wüstite and probably contain about 40% iron *(estimated by comparing with similar slags which have been chemically analysed).* They represent efficient bloomery working. The complete lack of charcoal and ore fragments suggests that the furnace temperatures attained were sufficiently high for the whole charge to have reacted completely; it therefore seems likely that the furnaces were water-powered and certainly not earlier than the sixteenth century. In this area it seems probable that the ores used were derived from carboniferous deposits; this is borne out by the presence of hercynite which characterises slags from these ores, albeit in rather small amounts. The slags cannot be classed exactly with any of the medieval slags previously studied; they may best be described as being intermediate between Group B *(Fig. 2)* and the low wüstite, hercynite-fayalite-glass slag[2], Med.11 *(Fig. 7).*

Acknowledgements

More work on the sites themselves, on ore samples etc., and on documentary research is clearly needed. It is hoped that more work may be done in 1974, and a further report made.

In the meantime I wish to thank Mr Henry Butter, Senior, and his family; Mr F B Stitt, the Staffs. County Archivist and his staff; Dr Peter Spufford of Keele University; Mrs Joyce Wingrove; Mr Bernard Hardman; my wife, Mary; and the committee of the HMG who have all helped in varied ways.

References

The report on slag samples from three sites at Eccleshall, by Joyce Wingrove refers to the two standard papers on slags.

1 **Constitution of Bloomery Slags: Part I: Roman, G R Morton and J Wingrove, JISI., 1969, 207, 1556-1564.**

2 **Constitution of Bloomery Slags: Part II: Medieval, G R Morton and J Wingrove, JISI., 1972, 210, 478-488.**

Letters to the Editor

From Sir Frederick Scopes

Dear Sir,

I have been reading with considerable interest Mr Lyne's article in the 1972 Bulletin of HMG on the coke-ovens at Gregory Spring Colliery.

One point occurs to me which has no direct connection with Gregory Springs, but in a wider respect may be not only of interest but of some importance. This has reference to Mr Jos. Cliff of Wortley. I wonder if Mr Lyne is aware that it was this Mr Joseph Cliff who was responsible for the creation of the Frodingham Ironworks? The building of the first two of the Frodingham Ironworks blast furnaces was commenced in 1863 and they were blown in late in 1865 or 1866. In 1866 Mr Cliff's son, also Joseph, came to the works and continued in active management for many years. In the year 1888 the then partners in the Frodingham Iron Co. were Joseph, William, Walter and Stephen Cliff who decided to commence making steel at Frodingham. The Cliffs consulted Mr Gilchrist who recommended the basic open hearth process and suggested the appointment of Mr Maximilian Mannaberg as General Manager – he lived at Wortley House in Frodingham from 1894 to 1910.

This information comes from an excellent History of Appleby-Frodingham by G R Walshaw and C A J Bahrendt published privately in 1950 by the Appleby Frodingham Co. This contains interesting photographs of both Joseph Cliff I and II.

On page 37 of the book we read that as far as was known Mr Cliff 'a very successful brickmaker' had no previous knowledge of iron smelting before he went to Frodingham. It seems to me that his connection with Gregory Spring Ovens and their production of coke for metallurgical purposes may have some significance in this connection.

Yours faithfully
Frederick Scopes 15th February 1973

PS. *Incidentally there is a minor misprint in the last line of the last note to Lyne's article. The reference to Carr & Taplin should be pp 153-4 not 133-4. F.S.*

From Norman Mutton

Shifnal Blast Furnace – 17 December 1973

Dear Sir,

I should be grateful if you would find space for a brief amendment to my notes about Shifnal Furnace on p.26 of THE BULLETIN, vol 7 no 1.

In place of the paragraph beginning 'The water supply . . .' up to '. . . narrower immediately above it,' there should be the following: 'The water supply is from the partly-silted mill pool which covered more than three acres and was fed both by a spring arising about a mile away and by a leat from the brook. In spite of the substantial flow of water in the brook there is evidence for water shortage in the sixteenth century.'

I was able to make this amendment when addressing the Annual Conference at Keele, but I shall be grateful for its wider promulgation.

Yours faithfully,
Norman Mutton.

Book Reviews

Joan Day. Bristol Brass: the history of the industry. David and Charles, Newton Abbot, 1973. 8½ x 5½ in. 240 pages. £4.75.

This is a book that needed doing; indeed, it is surprising that it has not been done before. Our thanks go to Mrs Day for providing us with such an enlightening and unique work.

I suspect that for many the first acquaintanship with the people of Bristol and the processes that go to make the major part of this work will have been through one of the works of Swedenborg – De Cupro – one of the most readily available on this subject. Unfortunately Swedenborg had great difficulty in understanding the processes that he tried to describe in considerable detail. One was also conscious of the fact that Abraham Darby had something to do with Bristol. But at this point one's knowledge tended to die out, and Hamilton's book of 1926, "The English Brass and Copper Industries to 1800" tends to be too general to give much enlightenment on the subject of Bristol.

For the first time we are presented with an integrated work on Bristol's part in the copper-base metallurgical industry by a Bristol resident. We are introduced to the visible remains, such as the walls made of blocks of copper smelting slag and the annealing ovens, as well as the other remains such as the old mills and smelter chimneys. It is in this sphere that the new books score over the old. We get the total integration of industrial history and historical research by means of new photographs, scale drawings of the few remaining pieces of unique plant and the results of tape-recorded conversations with retired workers in the trade. In contrast, Hamilton's illustrations are not so technically informative; some are from Agricola, whose drawings relate to 16th century activity in an important but far-off country.

Mrs Day's treatment opens with the birth of the "new industry" in Bristol in the 16th century. The upsurge of the English copper industry at this time was in reply to the criticism of the state of the industry following the monopoly of the Elizabethan Mineral and Battery and Mine Royal Companies, so well discussed by M.B. Donald in his work on "Elizabethan Monopolies". Although Bristol was thought to be a good site for the copper industry in 1566, for technical reasons the new industry had to be sited elsewhere on the streams draining into the Wye valley near Tintern and Redbrook. But soon, with the increasing use of the coal-fired reverberatory furnace instead of the water powered blast furnace, the advantages of Bristol made themselves felt; there was the coal from the Gloucester and Somerset coalfields and the zinc ore from the Mendips, as well as one of the largest ports in the country.

During most of the 17th century, the Society of Mineral and Battery Works and the Company of Mines Royal still held their monopolies; but there were various small legal and illegal activities going on in the Bristol area. In 1689, a new act effectively abolished this monopoly in the brass industry and Bristol's industry advanced from then on. By 1696, the first copper smelter was established on the River Avon at Conham.

About 1702, Abraham Darby set up a brass works at Baptist Mills. But gradually his interest changed after he saw the potentialities of cast iron, and he gradually moved his operations to Coalbrookdale leaving the other partners to carry on the copper and brass business. By 1712, Baptist Mills was getting its copper from a second copper smelter established at Crew's Hole half a mile downstream from Conham.

The third chapter discusses the early techniques seen and reported by the Swedes, Kahlmeter and Angerstein. The process depended on a large number of small reverberatories lined with sand and Stourbridge clay. These were matting furnaces; the matte was broken up and roasted 10-20 times. After the last roast the cuprous oxide and sulphide went to the "refining" furnace where metallic "blister" copper was produced. This was refined before an air-blast in a hearth fired with charcoal.

In 1720, the Champions come into the picture, and in 1723 Nehemiah junior took out his patent for making brass by using granulated copper which allowed the zinc content of calamine brass to be increased to 40%. Of course, granulation was another Bristol invention – it was applied to lead shot from the 1690's. The second part of Champion's patent covered the annealing furnaces which seem to have been a special feature of Bristol. These were square, coal-fired muffles, with tall chimneys into which sealed containers 3-4 ft long by 2 ft wide could be wheeled. These lasted in a revised form until the end of brass-making in Bristol. Mrs Day has done us a great service by fully recording the existing remains at Saltford and Kelston by means of photographs and drawings. It is noteworthy that Baptist Mills had a fully equipped works laboratory in the 1720's.

The next step was taken at Warmley in 1738 when Nehemiah Champion's youngest son William developed his retort process for the production of metallic zinc. By this time metallic zinc was available from India and China and it was becoming clear to Europeans that calamine was an ore of zinc.

Like so many early industrialists in this country, the Champion's were Quakers; this connection assisted the supply of capital which the Warmley Co. badly needed.

Coal was also needed in quantity – 1 ton of copper needed twenty tons of coal – and the coal owners were invited to become partners. This firm became one of the largest pin manufacturers in the country with 2000 people said to be involved in some way or other. Steam-powered pumping engines pumped water back into the ponds to drive water wheels. However, economic and political problems caused the collapse of the company in 1769. From then on the Bristol Brass companies go into slow decline with the gradual taking over of the trade by Birmingham.

But invention was not stopped during this period. In 1758, the use of zinc sulphide in brass-making was patented by John Champion of Holywell in Flint *(who was related to the Warmley Champions).* In 1778, John Champion and William Rowe of the Macclesfield Co. were designing new calcining processes for the sulphide ores being worked in Anglesey. In 1781, James Emerson patented the production of brass by adding granulated zinc.

We also see the increased production of zinc itself and its use for castings and hot-worked material and galvanising. In 1815, the firm of Capper Pass arrived in Bristol, and then the National Smelting Co. at Avonmouth which was later to become the Rio Tinto Zinc Co. after its absorption of Capper Pass.

The copper industry continued its decline, but Harfords and Bristol Brass Co. continued at Saltford and Keynsham until 1927. Mrs Day has here done us a great service by interviewing the remaining few retired workers and getting down the details of their craft and recording the equipment. It is a pity that the small format of the book necessitated the reduction of these valuable drawings to such a small size that a magnifying glass is needed to appreciate their detail. We are even shown a slitting mill, drawn in 1941 from the memory of what it was in 1925. This was used for slitting brass for wire; coils 4½ in. wide x ¼ in. thick were slit to "slips" ¼ in. wide for wire drawing. This material was then rolled to rounds on vertical rolls before drawing. The Keynsham drawing bench used the cam-operated reciprocating drawing process, described by Diderot, for reducing sufficient material for setting up the continuous, capstan, drawing process. Mrs Day tells us that the pincers used in the reciprocating drawing process were known as "jacobites" and one wonders whether this had anything to do with the French connection in the 18th century Jacobite rebellions. The detailed drawings of this part of the book are probably unique, and these alone would make the book worth buying to some of us. Perhaps the last chapter could be reissued in a larger format.

The references are grouped at the end of the book chapter by chapter which means that a slip of paper has to be inserted while reading. The book has a glossary of technical terms and a useful gazetteer and map. Appendices show the type of slag blocks found in the Bristol area, purchases of copper ore, and a sales catalogue of the Harford and Bristol Brass Company describing their sites. The index is adequate.

R.F.Tylecote

Bernhard Osann. Rennverfahren und Anfänge der Roheisenerzeugung; zur Metallurgie und Wärmetechnik der alten Eisengewinnung *(Bloomery processes and the beginning of pig-iron production; the metallurgy of iron production and heat-treatment in antiquity).* **Düsseldorf. VDEh, Publication No.9001, Sept.1971. 2 volumes in A4 format 170 pages of text in Vol.1; 51 pages, 9 tables and 85 drawings in Volume 2. Price, 38DM + 5%.**

This monograph, written with great conscientiousness and knowledge, is divided into the following main chapters : I. Basic forms of bloomery hearths and furnaces. Raw materials used in the bloomery process; II. The role of air in the operation of bloomery hearths and furnaces; III. Combustion and combustion gases in bloomery hearths and furnaces; IV. Iron ore reduction in the bloomery furnace; V. Formation of slags during the bloomery process. Smelting experiment by Gilles; VI. The formation of wrought iron, steel or crude iron in the bloomery furnace. Steel from Nordic peasant forges; VII. Bloomery slags and slags obtained in crude iron production. The slags from Haus Rhade; VIII. The significance of manganese in early iron manufacture. Advanced bloomery furnace (*"Massenofen"*) at the site of Haus Rhade; IX. The significance of silica in the bloomery process. Smelting of low silica iron ores in the Wochein region *(Yugoslavia);* X. The bloomery slags from Gielde. Further remarks on the influence of silica. Refractory materials for bloomery hearths and furnaces; XI. Was crude iron an intermediate product of the bloomery process? XII. Furnaces with maximum air intake. The "primary flame zone" after Schuster. Direct reduction; XIII. Metallurgy of late bloomery furnaces *("Stücköfen")* XIV. Bloomery furnaces with slag pits; bloom or spongy iron?; XV. Corsican and Catalan forges; XVI. Recently excavated iron production sites.

Accepting the introductory remarks, that "even today not all the metallurgical and thermodynamic details of the bloomery process are completely known and that experts do not agree on all the details of the process", the book gives a well-balanced review of the history of early iron smelting as well as a summary of the research carried out so far. Together with analytical data and interpretations of excavation results, the importance of simulation experiments - employing modern methods of measurement - is justly emphasized. Cooperation between archaeologists, scientists and engineers is fulfilling a task, ruling out speculation and leading to scientifically sound results. It is to be regretted, that Osann could not include a discussion of the important experimental study by R F Tylecote, J N Austin and A E Wraith: "The mechanism of the bloomery process in shaft furnaces" *(Journ. Iron & Steel Inst., May, 1971, p.342-363)* in his book. This paper exactly meets the requirements set forth by Osann for a conclusive, modern experimental study: variation of operating procedures and process parameters to produce wrought or steel ad lib and to test the suitability of various types of ore for the smelting of iron. A physicochemical treatment of the bloomery process, a line already taken by Schuster, is equally stressed by Osann. Constants and calculations, theories and models are given to augment the sometimes rather lengthy descriptions, however, the whole material is presented with due emphasis to the importance of the subject; in short, the history of iron technology is given in a modern up-to-date manner.

The author's attitude towards his subject is adequately revealed by the following quotation from his book: "It is impossible to describe the bloomery process as such; one can only deal with one of the many variations of the process at a time and try to unveil it. These variations extend from the very primitive attempt, in which successful smelting of iron ores surprises the investigator, to the highly developed mechanisms revealing admirably sophisticated methods. Comparing the extreme ends of this scale of possible iron-making processes, it is difficult to comprehend that they should both come under the common heading : bloomery processes. The diversity of the bloomery processes makes it difficult to arrive at a general outline, important as it is."

The wealth of material - not merely quoted but also interpreted - gives this book almost the status of a standard reference source. Only the somewhat arbitrary selection of references - there are 74 altogether - imposes a limitation. Study of the contents of the book *(slightly hampered by the separation of text and figures into two volumes)* offers information and definitions not likely to be found elsewhere. This becomes evident from the following topics selected at random:

A clear distinction is made between bloomery hearths and furnaces; the relation between air supply, height of furnace charge, loss of pressure, height and width of furnace, velocity of ingoing air etc. is clearly outlined; the process of combustion is interpreted as one of direct and indirect reduction; slag formation and composition are dealt with adequately; the process steps resulting in the formation of wrought iron and/or steel are distinguished and interpreted; the hypothesis that the formation of wrought iron was only possible via the intermediate product of crude iron is thoroughly discussed; the concept of the "primary flame zone" introduced by Schuster, is outlined critically; this concept is confirmed by Osann for furnaces with maximum air rate, but it is dismissed for early bloomery furnaces with low air rate on the basis of experimental results; the formation of slag blocks in bloomery furnaces with slag pits - for a long time an unsolved problem - is explained on the basis of unpublished smelting experiments; the interesting process of iron production in the Catalan and Corsica forges is logically added to the other known methods of iron ore reduction.

Whoever is engaged in research on early iron production, including scientists, engineers and archaeologists, ought to be obliged to the author, he - one of the foremost German authorities in this field - has made his experiences and deductions available in this extensive monograph. The "Verein Deutscher Eisenhüttenleute" did well to start a series of forthcoming related papers with this important publication.

H G Bachmann

Abstracts

General

J A Charles. Heterogeneity in metals. Archaeometry, 1973, 15 *(1),105-114.*

The forms of inhomogeneity in metals and their origins are discussed in relation to the significance of analysis in an archaeological context. Particular consideration is given to the inhomogeneity that can arise from the redistribution of solutes during the solidification of an alloy casting.

C C Patterson. Native copper, silver and gold accessible to early metallurgists. *American Antiq. 1971,* 36 *(3), 286-321.*

The weathered zones of ore deposits that no longer exist are reconstructed by inference to provide estimates of the relative abundances of usable nuggets of native Cu, Ag, Au in ancient times. New analyses and selected data from the literature summarize metallic impurities in the native metals and in the oxidised copper minerals together with the impurities in lead carbonate and the silver halides. The influence that these occurrences and impurities had on the origin and the development of metallurgy in Mesoamerica and S America is discussed in relation to new analyses of artifcats and selected data from the literature. Topics emphasized are; the discovery of smelting and melting by the Moche *(Peru - 200 AD);* the inability of New World metallurgists to smelt copper from sulphide ores of Ag from lead ores; and the lack of influence of transoceanic contacts.

A Wyttenbach and P A Schubiger. Trace element content of Roman lead by neutron activation analysis. *Archaeometry, 1973,* 15 *(2), 199-207.*

The trace element content of 13 lead pigs and 20 water pipes, all of Roman origin, were determined by instrumental neutron activation analysis. The contents of Cu, As, Ag, Sn, Sb, and Au were determined with an experimental reproducibility of ± *7%;* the analytical values are given for all samples. The results are discussed with respect to the homogeneity of samples, the difference between pipes and pigs, the difference between bulk and joint material in pipes, and the possible correlation of the trace element contents with the place of origin.

C C Patterson. Silver stocks and losses in ancient and medieval times. *Econ. Hist. Rev. 1972, 25 (2), 205-235*

Throws light on a very vexing problem. Probably less than 300 tonnes has been found in native form over the world. The bulk came from lead ores after the discovery of cupellation about 2500 BC. Assesses the losses by means of an irrecoverable loss constant, L, which characterises loss due to many causes such as coinage, grave-burials etc. In later times the pattern changed due to losses in brazing alloys, photographic chemicals etc.

The loss rate constant is determined in many ways, eg from the number of coins in circulation compared with those issued. In this way L is obtained for modern times. This constant needs correction for pre-modern times to take account of the interchange between coin and non-coin uses. It is reckoned that the modern loss rate constant is 0.025 yr^{-1}, the medieval about 0.01 and the Roman about 0.02 yr^{-1}. The rate was much smaller in the Bronze Age and may have been as low as 0.003 yr^{-1} which is the wear loss of silver coin.

It is estimated that 5000 tonnes of Ag may have been produced between 2000 and 700 BC and should have reached an equilibrium level of 1000 tonnes at 1100 BC with a world production of 4 tonnes per year before cupellation. After 700 BC, production and stock again increased. The Laurion production was dependent upon an effective way of separating the zinc sulphide from the galena. The Aegean production was at about 10 tonnes/yr at about this time *(650-350 BC)* and much was exported. Stocks grew and seizures in battle were large so that the claimed 240 tonnes in the Persian treasury in 517 and the 2200 tonnes at 330 BC are considered feasible.

After the decline of the Aegean contribution attention is switched to the Roman where we see at first a doubling of production, mainly now from Spain, and then a decline. The medieval nadir was in the 13th century as a result of the opening of the German mines in the 10th. British stocks were about 25-30 tonnes in AD 1000, and 300 tonnes in AD 1300. Between 1550 and 1750 European stocks increased due to 40,000 tonnes from the New World.

Finally there is a discussion on the man-power – slave or otherwise – required to produce this wealth. This article contains some very useful tables and appendices.

BRITISH ISLES

Michael Robbins. The First Sussex Railway. *Railway Magazine, 1971,* 117, *(843) July, 355-357.*

Letters from William Jessop of the Butterley Iron Company to George Shiffner, now at the East Sussex Record Office, show that despite competition from Bailey, Ward and Co., who were situated "at the south fort of Blackfriars Bridge", Jessop's plans for the railway from the Offham chalk pit down an inclined plane to the Papermill Cut of the Ouse navigation were accepted. Rails three feet long, waggon wheels, a large wheel weighting 1¾tons *(for incline machinery?)* and all other equipment were sent from Butterley via Gainsborough and London in 1808. The line opened in March 1809 and was used until about 1870 when navigation on the river above Lewes ceased.

W Simpson *(Ed)*. Rules and Orders of an Early Foundry Union. *Foundry Trade J., 1971,* 130, *(2839), 437-448.*

A reprint of the rules and orders to be observed by the Friendly Society of Operative Iron Moulders of Great Britain and Ireland, published 1837.

Anon. Dolphins Anonymous. *Foundry Trade J., 1971,* 130, *(2837), 364.*

Dolphin lamp standards on the Victoria and Albert Embankments in London were cast by Masefield & Co. and Holbrook & Co., Chelsea, and bear the date 1870. Others were added round and near the County Hall in 1910, 1933 and 1964. Rather unexpectedly, one standard of this design can be seen at Cliffe Castle, Keighley and two at the main doorway of the City of London School. Further standards are now to be made in cast iron for the extension of the South Bank walk. *(1971,* **131.** *(2860), 431).*

Trevor Daff. Introduction of Furnace Blowing Cylinders. *Steel Times, 1973,* 201 *(5), May, 401.*

The author alleges that the successful introduction of cylinders to blow blast furnaces is often attributed to John Smeaton, in 1776. Earlier examples are given, including Crowley's Swalwell forge cylinders in 1748, the well-known 'iron bellows' of Isaac Wilkinson of 1757, and James Knight's apparatus of 1762. This reviewer is inclined to doubt that Knight's apparatus was, in fact, successful.

Anon. Forge Unearthed. *Foundry Trade J. 1973,* 134, *771.*

The foundations of 13th century forge unearthed at Waltham Abbey, Essex, are being reconstructed by the local historical society.

Anon. Axeheads Discovered. *Foundry Trade J. 1973.* 134, *771.*

Bronze axeheads, swords and daggers, along with tools, metal ingots and slag were discovered recently at Hoo, near Rochester, Kent while a water main was being laid. Half of the 44 axeheads were undamaged. The curator of the Rochester Museum dates them as between 1,000 and 500 BC.

C McCombe. Steel-bearing Furnace Charges in Victorian Times. *Foundry Trade J. 1973,* 135, *69-71.*

The sole surviving ledger of John Abbot and Company, Gateshead-on-Tyne, reveals that some furnace charges for cast iron used for chemical engineering components contained modest proportions *(up to 25%)* of steel scrap during the period 1877 to 1883. This is perhaps the earliest recorded instance of the manufacture of engineering irons by this technique. Decomposing pans for salt-making were among the components cast in this metal, but the records indicate that the life of these pans was disappointing compared with those cast from straight pig iron/cast iron mixtures. A wide range of pig irons, including Acklam, Ridsdale, Glengarnock, Redcar, Jarrow, Port Clarence, Royal Greek, Newport, Cargo Fleet, Walker Hematite and Carron, was in use in the works at that time.

P J Riden. The Butterley Company and Railway Construction. *1790-1830. Transport History. 1973,* 6, *30-52.*

The author attempts to describe and evaluate Butterley's activities as suppliers of rails and other castings to private customers and to canal and railway companies between 1790 and 1830, based on the company's own records now in the Derbyshire Record Office. A very brief account of the origin and development of the ironworks at Butterley and Codnor Park is also given.

C Humphries. The making of a Roman nail. *Metals and materials, 1972,* 6, *Sept., 392-394.*

A single nail from the Inchtuthil hoard was examined by scanning electron microscopy which showed that Si, K and Ca were higher in the slag stringers than in the iron itself. Also, two types of iron oxide were found, one from rust and the other from scale formed during the consolidation of the bloom. The nail contained many large unwelded fissures. The deformation of the head showed that after the nail had been hot-pointed, the head was cold or warm-formed as a second operation.

H O'Neill. Monastic archaeology and metallurgy. *Met. and Materials, 1972,* 6, *July, 295-298.*

A short summary of the part played by British early monastic establishments in the development of mining and the use of metals. It deals with tin in Devon and Cornwall, iron in most of Britain and copper-base pins and needles from the Midlands where pin-heads were made by soldering-on spirals or bending into a figure-of-eight. Reference is also made to the recent finding of 15th century alchemical apparatus at Stamford, Lincs. The patronage of the crafts by the monasteries declined during the Black Death after which the monasteries bought the blooms from the lay tenants and worked them up in their smithies. After the Suppression in 1537, some ex-monks continued to work in the industry.

I H Goodall. Industrial evidence from the villa at Langton, E. Yorks. *Yorks Arch. J. 1972,* **44,** *32-37.*

The finds include iron slag, with traces of metallic iron in it, and a stone disc which had been a mould for casting pewter plates. The period of occupation was the 3rd to 4th century AD. Crucible fragments represented crucibles of conical type without a lip, 6-8 cm dia. and 8-10 cm high. These were vitrified externally to a red or green colour.

T A Morrison. The Initiation of Mining Settlement on the Cardiganshire Orefield. *Industrial Archaeology. 1973,* **10***(2), 161-200.*

Includes a list of grid references for Cardiganshire Silver-Lead-Zinc mines. Those with a total output from 1845 to 1920 in excess of 1,000 tons of all ores are indicated.

D G Hey. The Use of Probate Inventories for Industrial Archaeology. *Industrial Archaeology. 1973,* **10** *(2), 201-213.*

Illustrations include some drawn from nailmaking, cutlery and scythe making and other craft industries in South Yorkshire in the period 1666-1757.

P D C Brown and F Schweizer. X-ray fluorescence analysis of Anglo Saxon jewellery. *Archaeometry, 1973,* **15** *(2), 175-192.*

X-ray fluorescence analysis of 30 pieces of Anglo Saxon jewellery, from the Ashmolean Museum, Oxford, is followed by a comparison with similar results obtained from contemporary coinage. The standards of fineness for the coinage are applied to the jewellery and used to date its manufacture. An appendix describes repeat-analyses of some coins which, at first, had widely differing results from XRF and specific gravity methods.

Colin Martin. El Gran Grifon; An Armada wreck on Fair Isle. *International Journal of Nautical Archaeology, 1972,* **1,** *59-71.*

Guns of various types were found; cast bronze and cast iron together with earlier breech-loading guns made from hammer welded strips and hoops. Lead ingots of 3 types; small boat shaped weighing about 100 lbs with Roman numerals on the upper surface; flat oval ingots with no markings; large rectangular ingots with a central hole and no visible marks.

Cast iron shot, and lead bullets *(some flattened by impact)* were also found.

Peter Marsden. The wreck of the Dutch East Indiaman 'Amsterdam' near Hastings,1749. *Int. J Naut Arch. 1972,* **1,** *73-96.*

Metal artifacts found include cannon-ball gauges, a bronze reamer and a small bronze cannon.

Honor Frost. The discovery of a Punic ship. *Int. J Naut. Arch. 1072,* **1,** *113-117.*

Metal artifacts found include a lead-wood anchor, a concretion containing the ghost of a socketed iron spear-head, "bronze" nails, and lead sheeting.

Margaret H Rule. The Mary Rose; an interim report, 1971. *Int. J. Naut. Arch, 1972,* **1,** *132-135.*

This ship was built in 1509. It contained an iron gun unlike any so far known which was built up from a single piece of wrought iron sheet bent into a cylinder and hammer welded along the seam. A series of iron collars and hoops had been shrunk on to strengthen the barrel. The gun was breech-loaded but the breech block is missing.

P McBride, R Larn and R Davis. A mid-17th century merchant ship found near Mullion Cove, Cornwall; an interim report. *Int. J. Naut. Arch. 1972,* **1,** *135-142.*

This produced a number of iron cannon in poor condition, 2 boat-shaped lead ingots, some brass spiral-wound globular head pins, brass candlesticks, pewter plate, bar and other types of iron shot, and cannonballs. The ingots weighed 134 kg each and all marks had been obliterated by corrosion.

R Middlewood. Mewstone Ledge site. ***A summary of work and results.*** ***1969-70. Int. J. Naut. Arch. 1972,*** **1,** ***142-147.***

This produced a number of cast iron cannon apparently with wrought iron "fins" near the chamber end. These may have been joined to the cast iron by accretion. Iron anchors were also found. The dating appears to be 18th century.

EUROPE

Early Medieval Studies, 5. Stockholm, 1973.

Torsten Hansson and Sten Modin. A metallographic

examination of some iron findings with a high nickel and cobalt content. *pp.5-23.*

Includes currency bars from Helgö and Hög, and a socketed axe from Eskilstuna. The high nickel and Co contents occur in "streaks" and it is claimed that two types of iron were used to make these objects. In the high-Ni streaks there is a considerable amount of retained austenite, but otherwise the structures are very typical of the piled material that was the mainstay of the Early and post-Roman iron ages. It is suggested that the ores used for the higher-Ni irons may have been rich in minerals of the Mi-Co-As type but so far no such ores have been found in Sweden.

Lena Thålin. Notes on the ancient iron currency bars of Northern Sweden and the nickel alloys of some archaeological objects. *pp. 24-41.*

Concerns narrow socketed spade-shaped currency bars - again with high-Ni streaks. The average Ni content here was 0.3-0.4% and some of the streaks had as much as 25% Ni. It is not considered that the origin of these streaks was meteoritic but that they were the result of some characteristic of the ore or the smelting process. Again it is noted that the high-Ni tends to go with high arsenic. But no suitable ore-bodies have been identified at present.

Jan-Erik Tomtland. Metallographic investigation of 13 knives from Helgö. *pp.42-63.*

The knives of typical migration period type are badly rusted but one can see signs of a number of the standard methods of using iron and steel in this period. One has a welded-on pearlitic steel edge to a ferrite back; another is homogeneous with globular cementite; a third consists of three pieces of steel, piled together and heat-treated to give martensite with a hardness of 559-861 HV; while a fourth has the common sandwich construction of a steel core backed by two plates of iron on either side. This last has been hardened to 700 HV. There was no evidence of cutting edges having been produced by carburizing.

Inga Serning. The prehistoric iron trade in Dalarna *(In Swedish). Jernkontorets Forskning. Serie H, Nr.9, 1973, pp.139.*

This monograph, in the historical series of the Swedish Iron Institute, describes the results of the excavation of eleven bloomery sites in Dalarna in central Sweden. The period covered is from about 500 to 1400 AD. Each excavation is the subject of a separate chapter or section and is complete in the sense that it gives full information on the ores, slag, furnaces and small artifacts found. The products are fairly typical of bloomery excavation. We meet the occasional pieces of cast iron and forged bloom. The slags are often assessed by the method of Morton and Wingrove and their free-running temperatures estimated by reference to the wüstite-silica-anorthite phase diagram. C-14 dates have been obtained from the charcoal.

The work ends with a summary of the ratio of phosphorus in the slag to that in the iron inclusions within the slag. This shows that the ratio varies from 2 to 11 as the carbon content increases from 0.02 to 1.44%. It also contains two appendices by Hans Hagfeldt. One of these analyses the yield *(in the range 36-52%)*, and the other a piece of heterogeneous 0.5% carbon steel found in S. Osterdalälven. It is possible that this is a piece of steel in the process of being worked into a sword.

This is a superb production; the micrographs are all first class, and all the required data is fully presented allowing us to extract the maximum amount of information from every site.

L H Cope. The metallurgical examination of a debased silver coin of Maximunus Daza issued by Constantine I. *Archaeometry, 1973,* **15** *(2), 221-228.*

Non-destructive methods of chemical analysis always involve uncertainties, and in some circumstances they can be quite unsuitable for a true analysis. The greater value of a completely destructive chemical analysis and a comprehensive metallographic study for revealing the intentions of the moneyers and the entire metallurgical history of an ancient coin is demonstrated for the case of a rare silver-coated debased silver issue of the early fourth century A.D.

ASIA

J D Muhly. Tin trade routes of the Bronze Age. *American Scientist., 1973,* **61***,404-413.*

A well-documented discussion on the trading contacts, involving metals, of the civilisations of the Near East. Mainly aimed at resolving the difficult problem of where the tin came from. Concludes that in the 3rd millennium the Assyrians had a monopoly of a source not available to the Anatolians. Presumably this was from the east, perhaps to the north-east of Assur in the vicinity of Tabriz, and tin from this source may have got as far west as Crete. By the Late Bronze Age, after 1600 BC, tin was becoming more plentiful, especially in the Aegean, and the author is now prepared to accept that it came by an overland route from Cornwall.

J D Muhly and T A Wertime. Evidence for the sources

and use of tin during the Bronze Age of the Near East; a reply to J E Dayton. *World Arch. 1973, 5(1), 111-122.*

They refute the suggestion of Dayton *(World Arch. 1971, 3(1), 49-70)* that the Akkadian word ANNAKU refers to a high-tin bronze and that this was the source of tin in the Near East. They point out that Anatolia was rich in minerals such as those of Cu, Pb, Zn and Fe but not tin. It is thought possible that there were small deposits of tin ores which were very quickly exhausted but they admit that the problem of tin is still unsolved.

K T M Hegde. A model for understanding ancient Indian iron metallurgy. *Man, 1973, 8 (3), 416-421.*

Details of an excavation of an Early Historic iron-smelting site near Dhatwa, Gujerat State. The dating was of the mid 1st millennium BC. The finds included several 100,000 kg of tap-slag, ore, a hoe, tools and nails. The ore was roasted limonite from the laterites. No charcoal was found. The metal contained 99.76-99.84% Fe, and the hoe had a hardness of 117-123 on the surface and 99-107 HV inside. No remains of the furnaces were found but recently *(1942)* the Ghadi Loharias and Agarias used 75 cm deep bowl furnaces with two inclined tuyeres.

Judith K Bjorkman. Meteors and Meteorites in the ancient Near East. *Pub. No.12 of the Center for Meteorite Studies, Arizona State Univ., June 30, 1973, pp.91-132.*

Mostly contains contemporary descriptions of occurrences of falls etc. but also contains a useful discussion on the epigraphy and etymology of meteoritic iron in the Near East. It concludes with a list of the 12 finds of iron meteorites from a context before 1000 BC giving pertinent details. Deplores the lack of analyses of early iron in this part of the world.

AFRICA

James Kirkman. A Portuguese wreck off Mombasa, Kenya. *Int. J. Naut. Arch 1972, 1, 153-157.*

This site yielded a copper-base alloy riveted bucket, a copper-base alloy breech-loading cannon dated to 1673, and a cast iron fire-pot or grenade.

AUSTRALASIA

C.Pearson. Restoration of Cannon and Other Relics from HMS Endeavour. *Defence Standards Laboratory Report No.508, Australian Department of Supply, Melbourne, June 1972. (Unclassified).*

Six cast iron cannon and a quantity of cast iron ballast were recorded in his log by Captain Cook as having been jettisoned from HMS Endeavour in 1770 in order to refloat the ship off a submerged coral reef on the north east coast of Australia. In 1969 an American expedition succeeded in locating and salvaging this material. Immersion on the sea bottom has caused extensive corrosion of some items over the 200 year period but the six cannon were in an excellent state of preservation, due mainly to encapsulation by coral.

This paper describes the conservation techniques used for preserving these relics. The various methods used overseas for the removal of corrosive residues from cast and wrought iron objects immersed in sea water are outlined and compared. The technique finally selected for the cannon was applied-current electro-osmosis, as this ensured the completely non-destructive preservation of the surface markings to a remarkable degree. This method was simple and ensured that all the soluble chloride was removed from the porous corroded graphitic layer, thus preventing any after-rusting. The cast iron ballast was cleaned by a combined heat treatment/mechanical cleaning process. The cannon, ballast and other relics were finally treated in a molten wax bath.

The form and mechanisms of the corrosion processes which have occurred and metallurgical aspects of the cast and wrought iron objects are given in detail. Extensive radiography has enabled identification of the coral encapsulated remnants of the wrought iron gun carriage fittings. Identification and authentication of the major recovered objects are also discussed.

The cannon are 72 in. overall, with external diameters varying from $10^3/8$ in. at the muzzle, down to 8¼ in. some 10 in. from the muzzle and then up to 12 in. at the breech end, the bore being parallel at 3¼ in. diameter. Weights chiselled on at the breech ends vary from 11.2.2 to 11.3.0 *(1290 to 1316 lb)*; the weights of the restored cannon are from 1165 to 1244 lb, individual corrosion losses being from 62 to 130 lb. The royal monogram *(G II R)* is embossed in relief between the trunnions; this type of marking was not usual before 1750 so that the guns can be roughly dated between 1750 and 1760. Three of the guns carry the embossed initial "IC" or "JC" on the end of the left trunnion; the other three have the letter "G" similarly marked on the end of the right trunnion. It is possible they were produced by Joseph Christopher and by Graham and Sons, both of who were making gun castings during this period.

The cannon themselves are in a grey cast iron; analysis shows them to be lower in silicon *(0.5%)* and higher in manganese *(1.1%)* and phosphorus *(0.6%)* than would be normal today. On the other hand the composition balance is such that the material would be fairly readily machinable *(although it is remarked that the bore of one of the cannon is markedly off centre)*. The sulphur content of the material is, however, much lower than would be expected today, indicating that the metal probably came from a charcoal blast furnace rather than one fired with coke.

The cast iron ballast, on the other hand, whilst still apparently a charcoal blast furnace product as indicated by the low sulphur content, is a brittle white cast iron with 1.17% phosphorus and, rather surprisingly only 0.01% silicon; the carbon content is also low, at only just 3%.

The small amount of wrought iron available for examination is typical in structure, with elongated inclusion streaks consisting of iron silicate with oxide; the analysis shows low carbon, silicon and manganese contents *(all under 0.05%)*, a sulphur content of 0.017% and a phosphorus content of 0.16%. Bearing in mind the age of this sample, it is presumably a finery/chafery product from a charcoal blast furnace iron.

SCIENTIFIC EXAMINATION

R Minto and W G Davenport. Entrapment and flotation of matte in molten slag.*T.I.M.M. (C). 1973,* 82,*59-62.*

Modern reverberatory slags contain between 0.3 and 0.8% Cu present as dissolved copper, or as matte or sulphide copper drops. It has been shown that SO_2 bubbles are capable of transporting drops of matte into the slag phase above, which disperse into very fine droplets which are held in the slag. This effect was investigated and it was found that the effect was reduced by increasing the matte grade (Cu content), acid oxide concentration, and the temperature.

G Varoufakis and E C Stathis. A contribution to the study of the corrosion of ancient bronzes. *Metallurgia, 1971,* 83, *May, 141-144.*

Gives the composition and structure of a 6th cent. BC statue of Apollo found at the Piraeus in 1959 *(10% Sn - no Pb)*. The corrosion was deep and intercrystalline and was accentuated by deformation and interdendritic porosity, and room temperature diffusion of tin from both the solid solution and eutectoid areas into the boundaries between them. These boundaries acted as anodes and were in turn dissolved away.

A second statue, of Artemis *(Diana)*, dating to the 4th cent. was found to be in a much more corroded condition and no analysis could be obtained. Advice is given on the method of preventing further corrosion.

R F Tylecote and R Thomsen. The segregation and surface-enrichment of arsenic and phosphorus in early iron artifacts. *Archaeometry, 1973,* 15 *(2), 193-198.*

Previous work on iron-arsenic alloys has shown that considerable superficial arsenic enrichment occurs during oxidation at high temperatures. This process is very likely to be the explanation for the layers of high arsenic concentration that have been observed in the microstructure of early iron artifacts by many workers.

Experiments have been made to determine how far the alternative theory of the use of Fe-As alloys as joining media could be responsible. It has been shown that Fe-As alloys can in some cases facilitate joining but that when they do the resulting joint is embrittled. When the arsenic concentration is reduced sufficiently to avoid this there is then no advantage over the normal hammer welding without an arsenic interlayer. Similar experiments have been carried out with phosphorus and similar conclusions have been drawn.

R F Tylecote. A contribution to the metallurgy of 18th and 19th century brass pins. *Post-med. Arch 1972,* 6, *183-190.*

Concerns the history and metallurgy of the spiral-wound globular headed brass pin which was known in the 16th century, if not earlier, and was finally replaced in the late 19th century by the upset-headed brass pin.

T R Shelley and R Shelley. Mechanism of stannic oxide solubility in molten oxide slags. *T.I.MM*(C), *1973,* 82, *54-56.*

The slags consisted of glass with opaque particles of dendritic form. The 500 μm particles were found to be rich in iron and tin; the former seemed to be present as Fe_3O_4. There was a strong positive correlation between iron and tin. The glass phase was saturated with tin; this value varied between 0.2 and 5.3% SnO_2 depending upon the analysis of the slag, which contained various proportions of Al_2O_3, CaO and SiO_2 besides tin. There seemed to be a direct correlation between the tin content and the %CaO in the glassy matrix. As the CaO content increased from 0 to 40% the SnO_2 content increased from 0 to 5%.

Naturally the main object of the work was to reduce the tin loss in the slags. It appears that these increase as the lime and silica contents respectively increase due to the formation of stable compounds of the type $CaSnO_3$ and $SnSiO_3$. There appears to be an optimum CaO/SiO_2 ratio for minimum tin losses in the slag.

This work shows some light on the occurrence of tin in early slags. It would appear that the solubility of tin is very limited and as soon as this is exceeded the excess appears either as metallic tin prills or as stannic oxide.

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