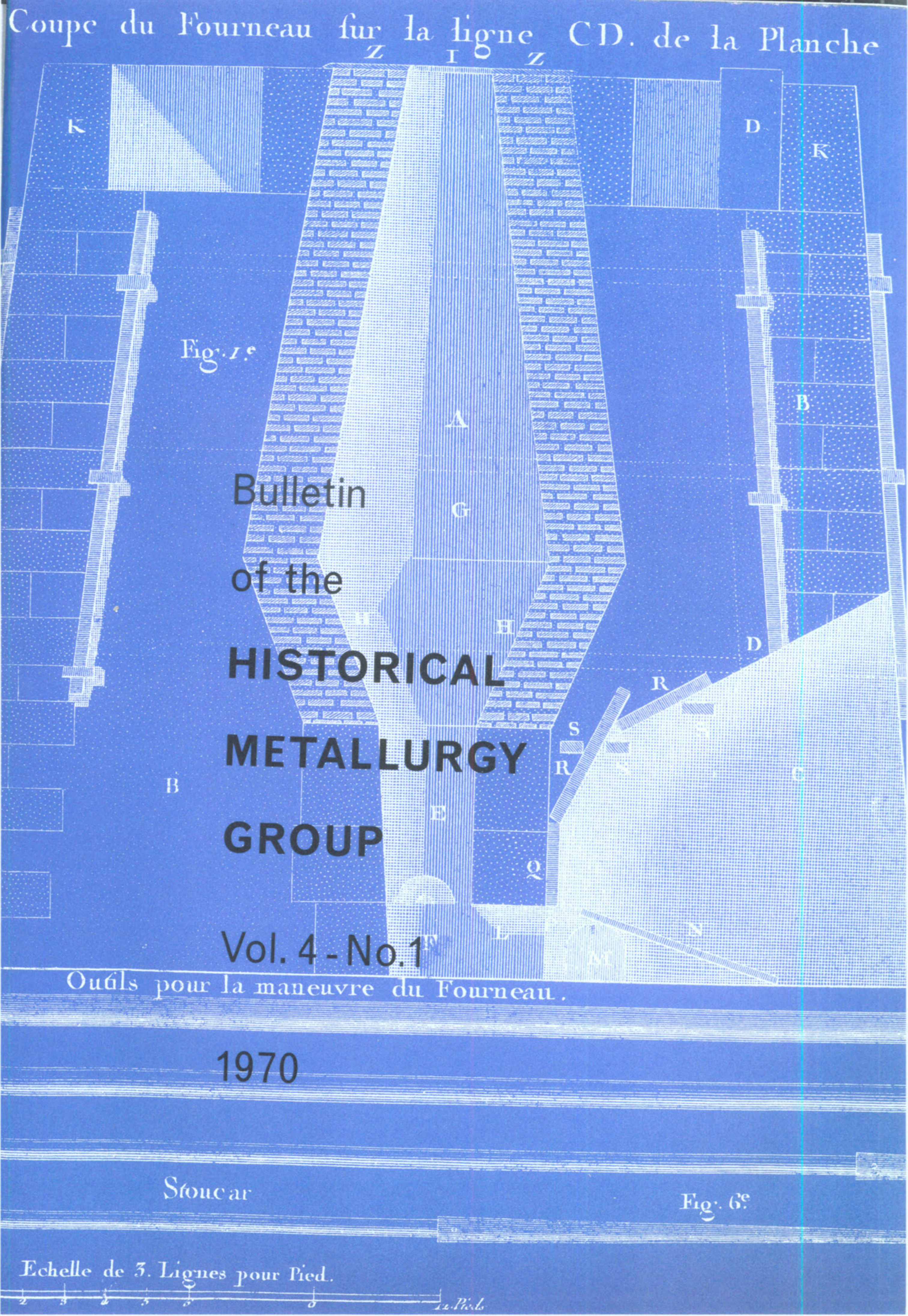

# Bulletin of the HISTORICAL METALLURGY GROUP

Vol. 4 - No.1

1970

# Bulletin of the Historical Metallurgy Group

*Washing tin-stone. Agricola Book VIII*

volume 4
number 1
1970

Contents

**Correspondence**

# Fifth Annual Conference: Cornwall 1969

The Group's 5th Annual Conference took place in Cornwall during the weekend 26-28 September. About 45 members attended and were accommodated in various hotels in Penzance.

The proceedings took place in the St. John's Hall in the Municipal Buildings and the Conference was opened on the Friday night by the Mayor of Penzance, Alderman J. C. Mann. After introductory remarks by the President, Mr M. M. Hallett, a stimulating talk was given by Mr J. K. Trounson on the past and future of Cornish mining. After this Mr F. B. Michell of the Camborne-Redruth School of Mines gave a most interesting lecture on the history of mineral dressing in Cornwall.

After discussion of the papers presented, the Conference formally elected with great acclamation Dr Harold Moore to honorary membership of the Group. Dr Moore, who is now in his nineties, has had long associations with research departments in the metal industry and the three metallurgical societies. It is right that he should be elected as our first honorary member.

The whole of the Saturday was taken up with a tour round the mining areas of Cornwall admirably guided by Jack Trounson. In the course of this, lunch was taken at the Basset Count House.

The conference ended at breakfast time on Sunday, as most of the members faced a long trip home. Members certainly felt that they had had a most enjoyable and instructive weekend and in addition went away convinced that Cornish mining and metallurgy had a glorious future as well as a past.

After this, the Committee met to consider the subject and place of the next conference. They are considering the possibility of holding it in South Wales towards the end of August, 1970.

The papers by Trounson and Michell and an account of the tour of mining sites appear on the following pages.

*CONFERENCE PAPER*

# Metal mining in the West of England

J. H. TROUNSON

The west of England mining region, which embraces the whole of Cornwall, part of Devon, and the western extremity of Somerset, is one of the oldest metalliferous mining areas in the world. It is estimated to have produced (at today's metal prices) more than £2,000 million worth of minerals. Contrary to the opinions held by some, the area's possibilities are far from being exhausted and, in view of the growing scarcity of base metals throughout the world, considerable interest is now being shown by mining companies in Cornish properties.

The beginnings of mining in Cornwall are lost in the mists of time, but it is apparent that most of the earlier operations were confined to the working of alluvial deposits, similar to those being worked in Malaya at the present time. Tin was much in demand among the ancient peoples for making bronze for weapons, tools, and ornaments, and the extensive early trade in tin has given rise to many tales, some of which are more fanciful than factual. However, the Phoenicians and the Romans certainly came to Cornwall for tin.

Cornish alluvial deposits were small and in due course the ore had to be sought underground, though alluvial tin was the basis of the industry when the earliest known charter was granted to the 'tinners' in 1201. This confirmed the already ancient rights of the tinners of digging of tin ore and turves for smelting it, and of diverting streams to suit their operations. There were other, less important, privileges, too, and under this charter, amended over the years but still placing the tinners in a special class of their own, Cornish mining continued until 1838, when the whole complicated legal structure was swept away.

Under the archaic Stannaries organization, confirmed by the Act of 1201, the business of mining in Cornwall was very complicated, and even after 1838 the industry carried traces of time-honoured procedures for many years. Indeed, it is only now that the Stannaries have really ceased to exist.

Alluvial tin could not provide the output which the world was beginning to demand by the middle of the 15th century. Instances of true underground mining (following the 'mother lode' from the alluvial deposit back into the ground) were known before this, but exploitation of the lodes on any extensive scale had to wait for at least another hundred years.

German miners taught the Cornishman the art of underground mining (as in fact they did in other parts of the country) and the use of gunpowder, introduced into Staffordshire in about 1670 and soon afterwards into Cornwall, made large-scale underground work possible.

Going underground brought its own troubles. Water followed the men, and mines became impossible to work until steam power, introduced by Savery in 1698 and Newcomen in 1712, provided a means of getting the water out. The industry was ripe for development when steam pumping became practicable. When James Watt introduced his vastly improved pumping engine in 1769 and entered into partnership with Matthew Boulton in 1775 to make the engine, Cornwall became, and remained for some time, his best market. With the Watt rotative engine of 1781 (improved further in 1784) the mines could not only be drained; the ores could be wound up from great depths, and improved ore-dressing machinery could be driven.

The rotative steam engine was important. Cornwall suffered ever since the early days of underground mining from too much water underground and not enough (for driving machinery and dressing the ore) on the surface. Watt's reciprocating engine pumped the water out of the mines, and his rotative engine drew the ore up the shaft and drove the machinery for dressing it.

With gunpowder, new techniques for working the ores, and steam power, the Cornish mining industry was well equipped to expand, and expand it certainly did. With its expansion the industry engaged in some useful 'self-help' as well as making use of the best machinery and practices it could discover outside the Duchy. The steam engine as left by Watt, for example, was modified and improved so that while retaining the Watt cycle as its operating basis its efficiency was raised out of all recognition. Competition among the Cornish engineers developed what came to be known well outside the Duchy as the Cornish engine to such a degree that for a quarter of a century it was the most efficient pumping device in the world.

The use of gunpowder, whilst aiding the driving of levels and working of stopes, gave rise to many accidents, often fatal, through imperfect or premature detonation of the charge, and it was a Cornishman, William Bickford, who invented the safety fuze in 1831. This gave a constant rate of burning, even under the wet conditions of many Cornish mines, and saved many a life. The safety fuze spread throughout the mining world and continued to be made in Cornwall until 1961, when electrical methods of firing and competition from abroad made it no longer economic to manufacture safety fuze in Cornwall and the business was thereafter concentrated at the large Ardeer explosives factory in Scotland.

Until about 1770 tin was the major (though not the only) product of the Cornish mines. Copper was also produced, along with smaller quantities of zinc, lead, silver, and other metals. Then copper became the principal product, and remained so until about 1865. From then on, because of the exhaustion of the best copper mines and the low price caused by other, more prolific producers elsewhere, copper mining in Cornwall declined. Today it is extinct.

However, it was found that, under certain geological conditions, lodes which had yielded principally copper changed in depth to tin, and there was an expansion of tin mining which rose to its zenith in 1871, when the mines produced 10,900 tons of tin metal. Production continued at a high level until the 1890s, when a disastrous slump reduced the output by half. Many Cornishmen had to leave their native county in search of work in the copper slump of the 1860s and 1870s; now thousands more followed. In most parts of the world where metal mining is carried on there will be found even today a substantial Cornish colony, evidence of successive mining slumps.

There was some measure of revival of tin mining which continued until 1913, and the purely artificial effects of the war of 1914-1918 helped to increase the demand. In the two world trade crises of the 1920s and 1930s Cornish mining, already in a weak state, nearly became extinct and although World War II kept some otherwise doubtful properties in operation, taxation and the competition of overseas producers (notably the Malayan alluvial deposits) combined to keep the industry effectively stagnant. By 1946 the output had fallen to less than 800 tons a year, but there was some recovery ahead and by 1968 the figure, helped by rising world prices, was 1,540 tons. Production is now growing at about 10% a

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The author is Chairman of the Cornish Mining Development Association.

year, and in view of current developments the figure should show a considerable rise in the next two or three years.

At present there are two mines actually at work out of a known total of about 2,000 which have been worked at one time or another. These will soon be joined by others and will themselves be developed by taking in adjoining properties and reopening them. Britain uses about 20,000 tons of tin metal a year, and it is unlikely that the country will ever again become self-sufficient. If present developments come to fruition, however, native production of tin can be substantial and the savings in foreign currency impressive.

[Mr Trounson illustrated his paper with photographs from his own unique collection]

# Notes and News

## Remains of ironworking from the Roman legionary base at Carpow, Perthshire

During excavation on this site in 1967, J. D. Leach and J. J. Wilkes found extensive remains of iron working in the upper levels of the filling of a ditch on the north side of the fort.* A layer of slag with small smithing or smelting furnace bottoms, more than 150 mm deep, extended across almost the entire width of the ditch. Amongst this was a tuyere which consisted of a 100 mm square lump of clay with a 24 mm dia. hole down the centre (Fig. 1). Half the tuyere is slagged (Fig. 2), and it would seem that this approximately square lump of clay was built into the furnace structure so that about 50 mm of it projected into the furnace. Some small pieces of slagged furnace lining consisting of red-burnt clay with grey vitrification were also found. The slaggy material could have been either smithing or smelting slag, but the tuyere looks like that from a smelting furnace rather than from a smithing hearth.

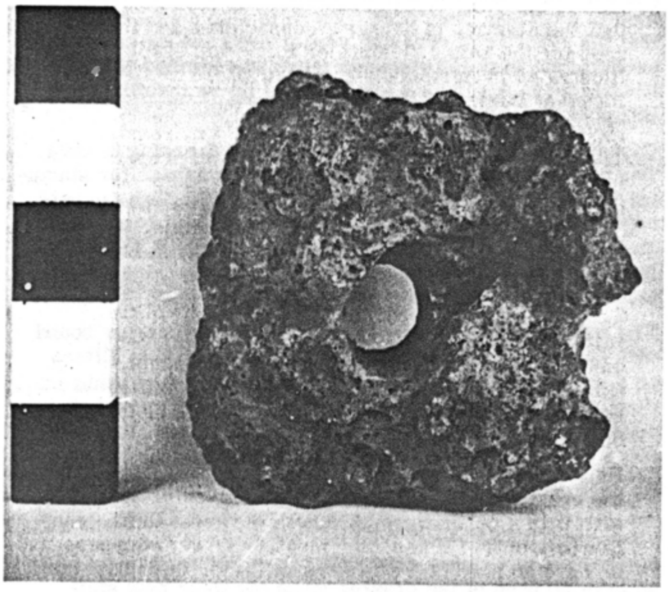

Fig. 1 — Tuyere from furnace side (scale in inches)

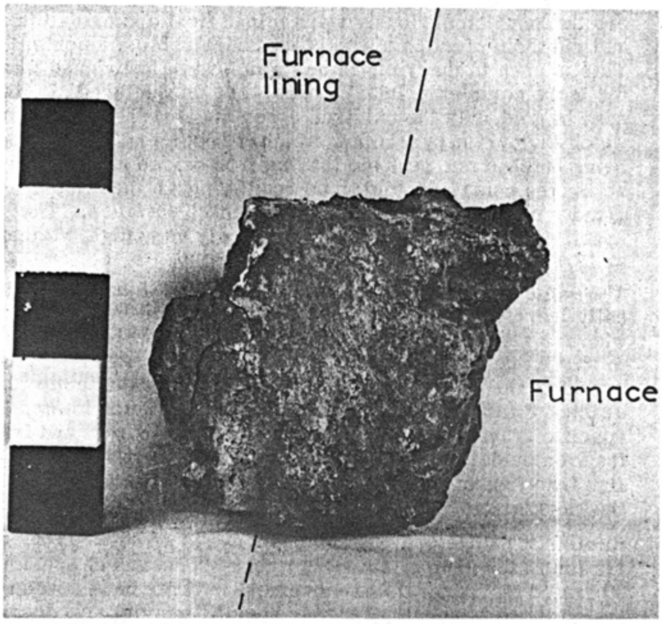

Fig. 2 — Tuyere block from side (scale in inches)

A similar tuyere can be seen in the museum at Zateč, Bohemia; it measures 130 × 90 mm and has a hole 14-19 mm dia. These tuyeres are typical of the Roman period but that from Carpow could be post-Roman in date.

R. F. T.

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* J. Roman Studies, 1968, 58, 177.

*CONFERENCE PAPER*

# The history of mineral processing in Cornwall

**F. B. MICHELL**

Mineral processing, or what was known formerly as 'ore dressing', is obviously almost as old as actual mining itself, since it was necessary to separate waste or gangue minerals from the valuable ore at an early date. It is true that, until comparatively recently, ore-dressing processes were somewhat crude and the development of many modern techniques only dates back a matter of 50 years at most.

Since almost all the metallic minerals worked had a considerably higher specific gravity than the associated waste, use was made of the differing specific gravities at a very early date and remained the most used method of mineral separation well past the turn of the 19th century.

It must be remembered that in the earliest times only simple ores were exploited, being mainly those from the oxidized zone or the top of the zone of secondary enrichment, since means were not available for separating and smelting the sulphide ores. In any case, the upper zones of any ore body are those which obviously were mined first and oxidation had rid them of sulphur and other undesirable elements. This is seen in many old mines which were abandoned when the more complex primary zones were encountered. In the case of gold, only the oxidized upper zones were worked, in which the pyrite, pyrrhotite, etc., had become oxidized, much being leached out, perhaps leaving iron oxides and thus enabling the contained gold to be readily caught by simple gravity means using hides and on blanket surfaces. (The specific gravity differential is obviously very high, with gold at 15. 6 to 19. 3 and quartz at 2. 65.)

The same applies to many tin lodes where the hard, chemically inert, cassiterite resists erosion and decomposition, whereas associated pyrite and arsenopyrite were oxidized to iron oxide, giving rise to Gossan outcrops. After suitable crushing, the greater specific gravity of the cassiterite (6. 9) enabled it to be readily recovered from the much lower specific gravity quartz and other silicate minerals and from the iron oxide which is soft and therefore appeared in the fine fractions of 'slime' which could be washed away from the cassiterite.

Similarly, nature provided both liberation and gravity concentration in the case of alluvials where processes of erosion liberated the mineral and movement in river beds concentrated those minerals of higher specific gravity. No doubt it was these alluvial deposits of gold and tin which were first worked. In the case of copper, native copper must have been first discovered and used, and later the carbonates, malachite, and azurite were mined. These do not possess sufficient specific gravity to be separated from the waste by gravity but the colour led to easy hand-picking, a method extensively employed for many years and one which is still in use where sufficiently cheap labour is available. In the last few years, however, mechanical optical sorters have been developed.

In Cornwall the major effort has been in the processing of tin and copper ores; in the early days only tin was probably mined, since we learn from Caesar that the copper or bronze used by the Britons was imported. It should not be forgotten that in the time of Moses at least six metals were known: he says of the spoils of the Midianites 'Only the gold, the silver, the brass, the iron, the tin and the lead shall be purified by fire'—Numbers XXXI, 22. (Incidentally, brass appears to have been accidentally discovered by melting copper in the presence of zinc carbonate, smithsonite, or calamine.)

It seems probably that concentration was effected by washing in a dish (much in the same way as the dulong is used in Malaya, the calabash in Nigeria, and indeed the prospector's pan). In working alluvial tin in the East and in Nigeria these operations are commonly seen, and there is no reason to think that the early miners in Cornwall did not use identical or almost identical methods. On many of the large hydraulicing operations in Malaya concentration is still effected in the sluice box or ditch line by simply stirring the settling gravel and then washing by hand. These hand methods are generally used to remove the easily collected concentrate and are now supplemented by screening and dewatering, desliming in cyclones, and concentration in jigs.

One can fairly safely assume that the early workers simply streamed the alluvials in ground sluices and finally washed up by hand. In the case of the coarser material, undoubtedly some would be hand-picked and possibly another fraction hand-jigged in a basket. When lode material was first treated, it was probably first hand-picked, to remove pure fragments of mineral and some mixed material for pounding to a finer size and hand-washing.

Little is known of dressing techniques until much later, but it is known that systems of dressing were in use in Germany in the 16th century, and these were doubtless introduced into Cornwall. In about 1562, acting on the advice of her Council, Queen Elizabeth I sent to Germany for some experienced miners; 'Dutch' miners were employed in developing lead and copper mines in Cornwall in 1583 and indeed also in smelting these ores. There is also ample evidence that the practice of dressing copper ores and the machinery used for the next 150 years or more was similar to those illustrated in Agricola's (or Bauer's) De re metallica published at Basle in 1546.

Carew gives a fairly clear account of tin dressing in 1602. The ore was first broken by hammers to prepare for stamping in the Cornish Stamp (really based on the German pattern) before concentration on green turves and being washed or 'shogged' in a bowl to remove light waste. It will be seen that this is not much different from the probable washing techniques used for centuries previously.

The stamping mill consisted of 3 or 6 logs of timber bound with iron bands and lifted up and allowed to fall by lifters on a wooden cylinder rotated by a water-wheel. At this time, apparently, the stamps were worked without water, because Carew says 'If the stones be over moist they are dried by the fire in an iron cradle or grate'.

He goes on to say 'From the stamping mill it passeth to the crazing mill, which between two grinding stones, turned also with a water wheel, bruiseth the same to fine sand. Howbeit, of late times, they mostly use wet stampers, and so have no need of the crazing mills for their best stuff but only for the crust of their tails'. In others words, although earlier the stamp mill had been used as a fine crusher to prepare the feed for fine grinding, by about 1600 only the wet or splash discharge stamp was being used for the initial comminution. On the other hand, middling produced from retreatment needed further grinding to achieve liberation of the cassiterite and this was done in the crazing mill.

Carew says 'the stream after it has forsaken the mill is made to fall by certain degrees one somewhat distant from another, upon each of which at every descent lieth a green turf 3 ft or 4 ft square and 1 ft thick.' The operator apparently put some of the same at the head of the turves and agitated it with his shovel, removing the cleaned black tin. After this it was washed in a wooden dish 'broad flat and round' (2 ft diameter) with two handles fastened to the sides.

In 1758 Dr Borlase in his 'Natural History of Cornwall' described the dressing of tin and copper. Quite a lot of hand selection was done underground so that comparatively rich ore was brought to surface. It was then sorted and the best broken down by hand using spalling and bucking (cruder than that described later, say around 1850-60); the fines were sifted into a large tub or kieve, using a crude jigging method on the undersize. The poorer ore was washed on strakes and all the richer bits were then picked out by boys and girls (who were paid 4d a day) and the residue stamped.

Later in the 19th century according to Henderson* the dressing copper ores was roughly as indicated in the flow-sheet (Appendices II and III).

Before 1806 the ore was all crushed by hand, but the introduction of rolls by John Taylor, who used two cast-iron pipes 16-18 in diameter to form counter-rotating rolls, at this time reduced the amount of manual work, at least on the softer copper ores.

In the bucking mills, the ore is 'bucked' and screened, and the bucked ore is swept back to the ground by the left hand. When bucking, the girls laid aside their bonnets and put kitty bags around their ankles. The ore was brought in hand barrows and all the girls kept time with their blows.

Cobbing was done by women seated on a low bench with an iron plate at their side and a curious shaped hammer. Their fingers were protected with mittens and the forefinger was covered with leather or a thin iron band. At the same time, picking was done by children who were seated before on low benches on which they rested their left arm, using the right hand to pick out the best ore from small piles placed before them.

In jigging, a sufficient quantity of ore was placed in the sieve on a layer of the heavier pyrite ($FeS_2$), making products as follows:

| Hutch | Concentrate | Middling | Tailing (Halvans) |
|---|---|---|---|
| Market | Market | Bucked or crushed in rolls and rejigged | Often stamped |

In the 'strips', wooden stops or riffles were put on to the lower end, as in a sluice box. This was dug out, making four products. Later, the square buddles were replaced by round buddles, and the strips were abandoned in favour of classification and direct feed to the buddles. Slime pits were dug out at intervals and rewashed to a trunking 'cover' where the mud overflowed and the excess water could be removed by means of holes in a board at the end. These were plugged as the contents rose.

By 1858, when Henderson read his paper, a number of mechanical appliances were in use, including steam stamps (still the Cornish pattern), rack frames with water tipping mechanisms, mechanical tossing devices, and roasters to oxidize the sulphide minerals and collect arsenic in the treatment of tin ores.

For treating copper ores, various types of power-operated jigs as well as crushing rolls and revolving screens were in common use. Later in the century the stone breaker was introduced, having been invented in the U.S.A. by Blake in 1858. As mentioned earlier, the prototype roll crusher appeared in 1806 at Wheal Friendship in Devonshire, having been designed by Taylor, and quickly replaced hand breaking of copper ores in east Cornwall. In 1831 his son, Richard Taylor, had an improved type working at the Consolidated Mines, Gwennap. The weighted levers to keep the rolls together, the trommel for dividing the ore into two sizes, and the return elevator wheel for the oversize were all the work of Cornish engineers. The Husband pneumatic stamp was introduced about 1870 and modified by Holman Bros, but wear was high and improved purely gravity stamps were often preferred.

Originally jigging was simply done with a round sieve, which was jerked up and down in a box full of water and operated by boys who stood bent over the boxes, which were sunk in the ground. A sieve was hung on a lever early in the 19th century, and between 1820 and 1830 a number of improved versions were introduced, called 'brake jiggers'. A mechanical version was introduced at Consolidated Mines in 1831 by Richard Taylor. About the same time Thomas Petherick, manager of Lanescot and Fowey Consols (St Blazey) introduced a hydraulic jigger using a movable plunger and a fixed sieve, whilst in Yorkshire at Grassington Mine, Capt Barrett hung the lever jig so that it could be worked mechanically.

The first continuous jigger appears to be that designed by Nicholas Troughton in 1843, and in 1864 the Hartz continuous jig was being described. Several machines were designed in the next few years, most of which were variations of the Hartz pattern.

As far as sizing before jigging is concerned, this was certainly being done at Devon Great Consols in 1856 by Isaac Richards, who also introduced a hydraulic classifier. This was not the first, and early attempts at hydraulic classification do not appear to have been very satisfactory, but about this time improved designs made them a practical proposition. A separating cone was introduced by Borlase of Redruth at Allenheads (Cumberland) in 1857. Convex buddles for sandy material seem to have appeared about 1848 and concave buddles 8 to 10 years later.

Mechanically tilting frames are shown by Henderson in 1858, but do not appear to have been used to any extent. The hand-operated dead frame was found in Cornwall earlier in the century, but it was not until about 1860 that Vincent designed an automatic dead frame and introduced it at Cook's Kitchen.

Although the Frue vanner, some of which have remained at Geevor until quite recently, was designed in 1874, they were not used extensively until considerably later, being introduced at Dolcoath in 1898. These machines used a travelling rubber belt as the concentrating surface but, unlike earlier belt concentrators such as the Brunton, they were equipped with a side shake to aid concentration. This prevents channeling, and probably the shear in the pulp on the surface aids the fall of the higher-density particles (although it is only recently that the importance of shear forces has been realised). Although these machines and a rather better mechanical design known as the Isbell vanner, which was also in use in Cornwall in the very early years of the present century, are now obsolete it is interesting to note that in the last few years a redesigned version of the Isbell machine is being made and used in Australia.

The mining industry in Cornwall was rather tardy to accept classification for feed preparation, apart from rough desliming, and it was claimed that the vanner accepted an unclassified feed. It is true that possibly it handles a wider range of particle sizes than a shaking table but its sphere of usefulness was in dealing with the finest sizes.

The shaking table appeared at the end of the 19th century, the Wilfley table being used at Dolcoath in 1896 and later (1902) at Tywarnhayle Mine. Provided that the feed is suitably sized or, often, better classified into equal falling particles, these tables do good work and are more easily controlled than the vanners. It is also possible to control the grade of the concentrate more easily and to make more than two products—a great advantage when a middle product needs grinding to liberate the valuable mineral further before retreatment. The necessary feed preparation was improved in the early years of this century, but first-class classification was not achieved until machines such as the Stokes hydrosizer became available.

Around 1929-30 the Fahrenwald classifier was tested at Wheal Kitty Mine; control was difficult, however, owing to the tendency for the valves to wedge open and it was not until Stokes made modifications and introduced his hydraulic discharge valve control that real success was achieved. Later, electrically operated valves were introduced and we

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* J. Henderson: 'Dressing tin and copper ores in Cornwall', Proc. I.C.E., 1857-58, Vol. XVII.

owe a great deal to these Stokes machines which have been responsible in no small degree for the excellent classification now found in most Cornish plants.

Early in the twenties, the world rights (excluding North America) for manufacturing the James table were obtained by Holman Bros. Ltd., and it is certainly one of the best tables available.

## The separation of other high specific gravity minerals from a gravity concentrate

As working became deeper, the presence of sulphide minerals along with the tin made it necessary to remove them. Since pyrite $FeS_2$ with a specific gravity of 5.0 to 5.2 and arsenopyrite $FeAsS$ with a specific gravity of 5.9 to 6.2 is too near that of cassiterite (6.8 to 7.0), simply gravity concentration alone did not yield a concentrate suitable for smelting. This meant that the concentrate had to be roasted in order to oxidize these minerals to iron oxide with the evolution of $SO_2$ and $As_2O_3$.

After such treatment the iron oxide can be readily separated from the cassiterite, not because the specific gravity of $Fe_2O_3$ is much lower in itself but because the resulting iron oxide is porous, giving it a lower effective gravity. In addition it is very friable so that with any mixed particles which are ground the soft iron oxide is slimed and easily washed from the cassiterite.

In the early days of working the troublesome pyritic ore, the roasting appears to have been carried in a simple reverbatory hearth but by 1829 the Brunton calciner was being used. This was of a revolving bed type, about 12 ft diameter, having two fire boxes set at an angle. It was used extensively in Cornwall for removal of sulphide and sulpharsenide minerals until the advent of flotation in the late 1920's. The Oxland and Hocking calciner was also used; this was of the revolving type.

Mention of Oxland calls to mind that the presence of wolfram in some ores caused difficulty in concentration. The tungsten mineral had no value and only served to contaminate the tin concentrate since it has almost the same specific gravity (7.1 to 7.5). In 1844 Robert Oxland introduced a process at Drakewalls involving roasting with sodium carbonate and then dissolving the sodium tungstate formed. This process proved quite effective and continued to be used for some years (it was used at East Pool Mine) until the introduction of magnetic separation. Even with modern high-intensity magnetic separators, such chemical treatment may be necessary for dealing with the very fine mixed concentrate when entanglement precludes the use of magnetic separation.

## Flotation

This is, of course, a relatively new process in the history of mining in Cornwall. The Elmore vacuum process was introduced for copper flotation at Tywarnhayle in 1902 and at Dolcoath a little later to remove chalcopyrite after stamping (about 1908). In 1923 the mineral separation process was introduced at Kingsdown and experimental work covering both sulphide flotation and attempts to float the cassiterite were undertaken.

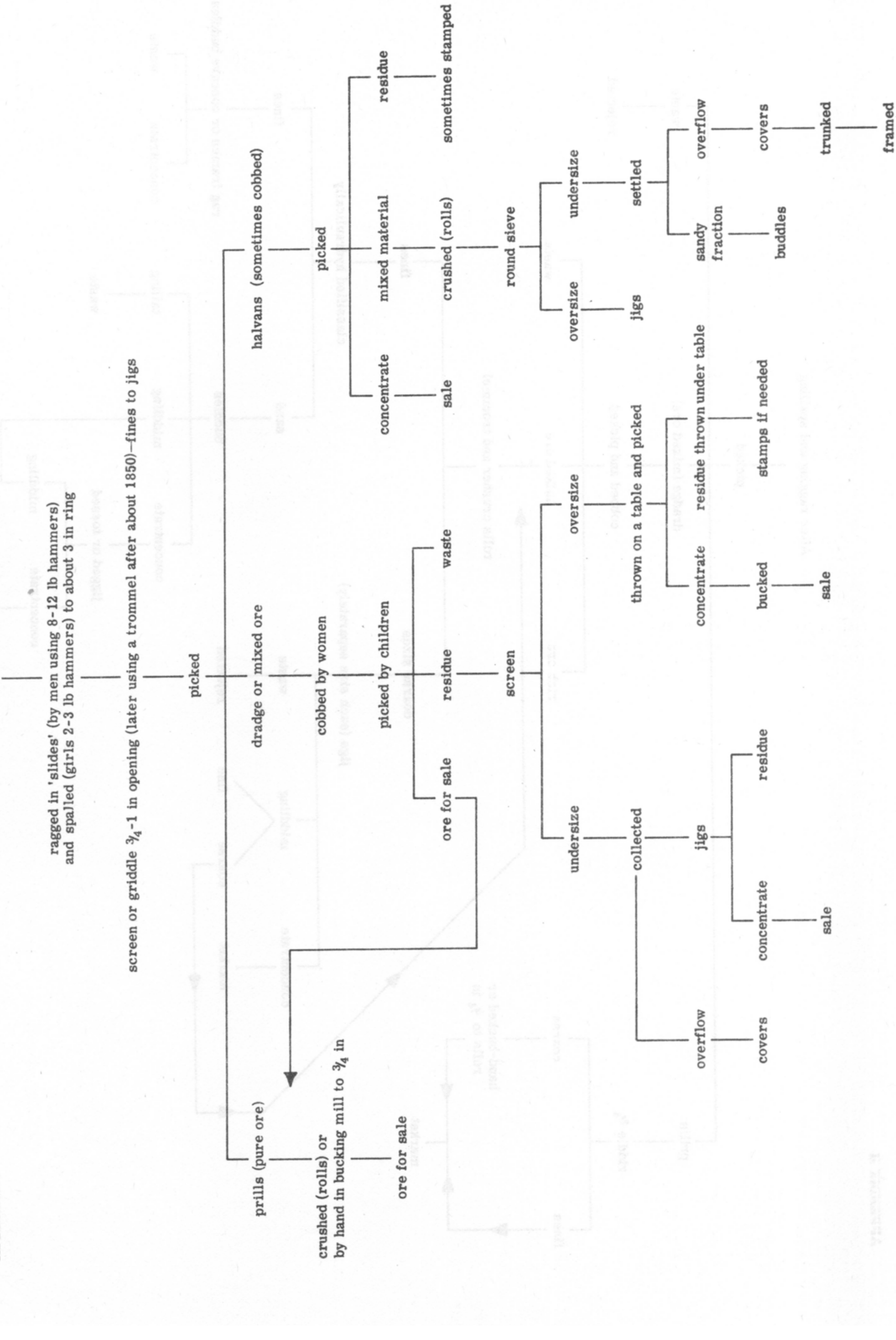
Flotation of the cassiterite is possible, but the difficulty lies in depressing many of the associated minerals. No commercial operations have appeared, although recently there are indications that a successful flotation reagent combination has now been developed.

The serious use of flotation for the removal of sulphide and sulpharsenide minerals appeared at Wheal Kitty (St Agnes) Parc-an-chy, Polhigey and Geevor in the years 1928-31. By this time it was successfully applied and very quickly the practice of roasting disappeared.

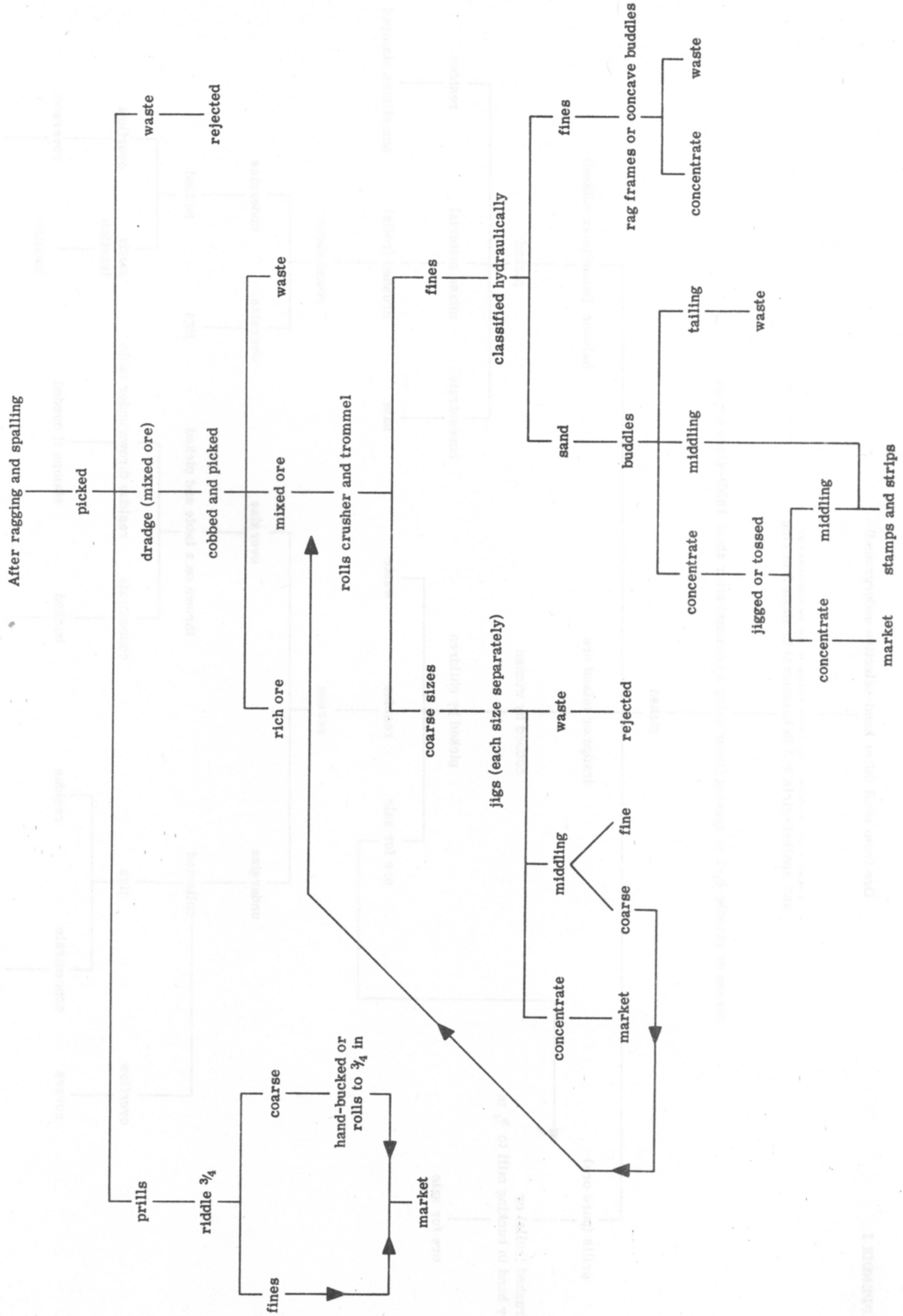
Some difficulty was experienced in separating large particles of pyrite for a number of years. In the years 1943-44 table flotation was perfected and has been used with great success for separating particles too large for froth flotation.

Other ancillary processes have been used from time to time but they are of only minor importance.

## APPENDIX I

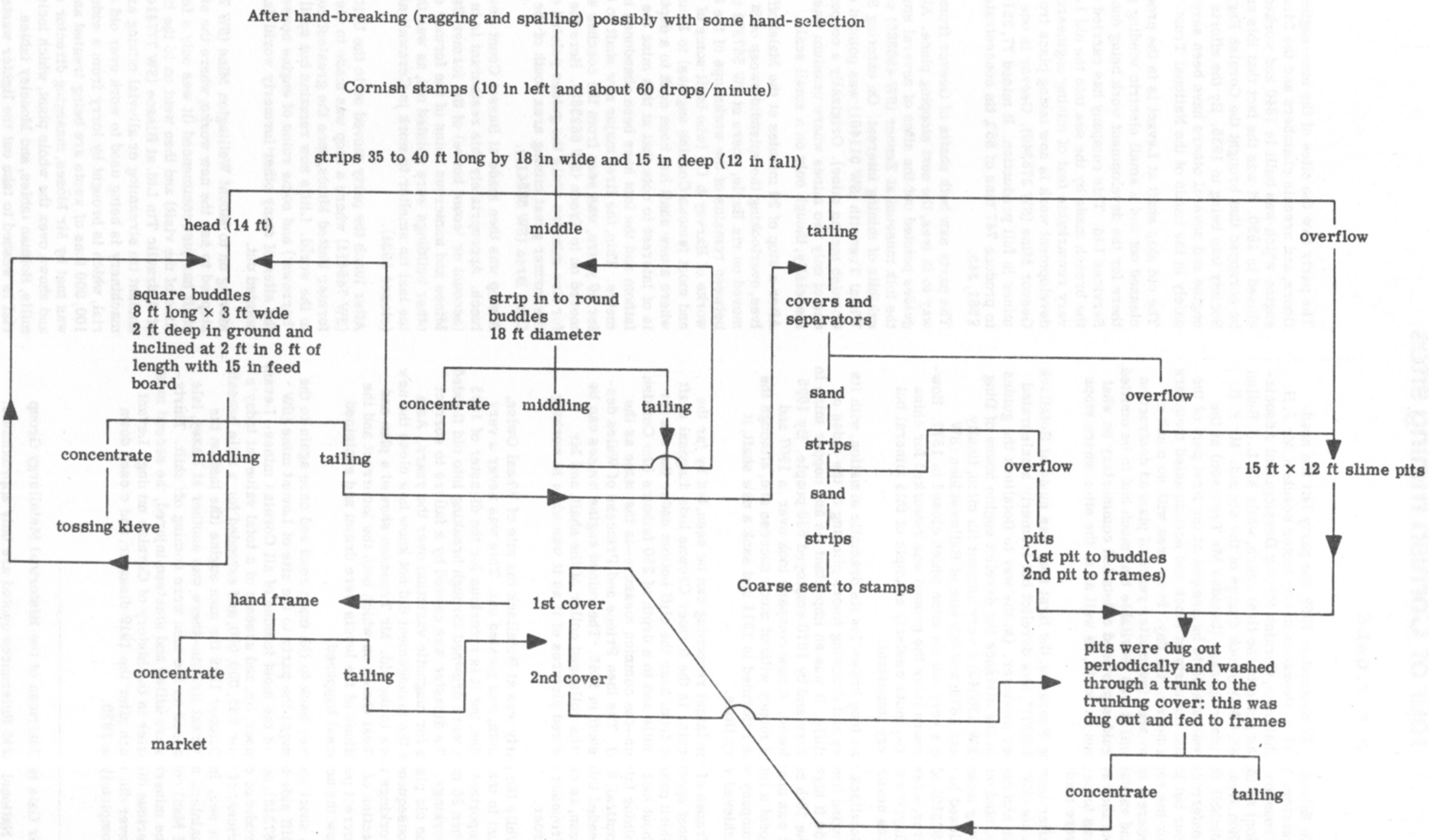

Ore from shaft (after hand-selection underground)
ragged in 'slides' (by men using 8-12 lb hammers)
and spalled (girls 2-3 lb hammers) to about 3 in ring
screen or griddle 3/4-1 in opening (later using a trommel after about 1850)–fines to jigs
picked
halvans (sometimes cobbed)
dradge or mixed ore
prills (pure ore)
picked
concentrate
mixed material
residue
sale
crushed (rolls)
sometimes stamped
round sieve
oversize
undersize
jigs
settled
sandy fraction
overflow
buddles
covers
trunked
framed
cobbed by women
picked by children
ore for sale
residue
waste
screen
undersize
oversize
collected
thrown on a table and picked
jigs
overflow
concentrate
residue thrown under table
concentrate
residue
bucked
stamps if needed
sale
sale
covers
crushed (rolls) or
by hand in bucking mill to 3/4 in
ore for sale

## APPENDIX II


After ragging and spalling
picked
waste
rejected
dradge (mixed ore)
cobbed and picked
waste
mixed ore
rich ore
rolls crusher and trommel
fines
classified hydraulically
fines
rag frames or concave buddles
waste
concentrate
sand
buddles
tailing
waste
middling
stamps and strips
concentrate
jigged or tossed
middling
concentrate
market
coarse sizes
jigs (each size separately)
waste
rejected
middling
fine
coarse
concentrate
market
prills
riddle 3/4
coarse
hand-bucked or rolls to 3/4 in
fines
market

## APPENDIX III

### Stamping and Treatment of Tin and some part of Copper Ores



# Tour of Cornish mining sites

W. K. V. GALE

On Saturday, 27 September 1969, the party left the headquarters hotel in Penzance in two motor coaches, Mr J. H. Trounson (Chairman, Cornish Mining Development Association) acting as guide in the first coach, while Mr L. J. Bullen (Hon. Gen. Sec, CMDA) took charge of the second. Mr F. B. Michell, the other speaker (besides Mr Trounson) at the conference, was unable to be present at the first part of the tour but joined the party at lunch and accompanied members for the remainder of the day. In an area with so much of interest to be seen (even after years of planned destruction and vandalism) it was inevitable that much had to be omitted, but the two guides provided a detailed commentary on what was to be seen en route, as well as at the sites where stops were made.

After leaving Penzance, the first stop was made at Botallack mine (SW 363337)*, now derelict but formerly a celebrated tin and copper producer. On the way to Botallack the guides pointed out in the distance the derelict engine house of Ding Dong mine (SW 430345) a very ancient tin mine, finally closed in about 1878, and the site of Balleswidden (SW 392310), also a very old tin mine which closed in 1873. However, a few years later the ground was reworked for china clay; it was the most westerly example of this mineral but was never very important.

Botallack was long known for its dramatic situation, with its engine houses and dressing floors clinging to the sides of 250 ft high cliffs. It was an important tin and copper mine in the 18th century and by 1870 employed 530 people. By 1895 it was abandoned. A new company took over in 1907 and spent a lot of money without much success and, although the company was reformed in 1911 and sank a new shaft, it achieved very little.

Traces of the latest reopening can be seen, but by far the most spectacular is the former Crowns lode diagonal shaft which passes from near the cliff bottom under the sea for about half a mile and to a depth of 250 fathoms (the Cornish mining fathom—the common measure—is the same as the nautical, 6 ft). The then Prince and Princess of Wales descended this shaft in 1865. The ruined engine houses can be seen, as can the collapsed collar of the shaft, and Mr Trounson showed pictures of it as it was when in working order.

While the party was at Botallack the site of Wheal Owles, just to the south, was pointed out. This was never a very important mine, but it is notorious for the disaster of 1893 when 20 men were drowned through breaking into old flooded workings. The disaster was caused by a failure to correct the old plans for magnetic variation over the years. As a consequence the management did not know how close the new workings were to the old. Mr Trounson showed a plan and section of Wheal Owles on which both the incorrect and the correct positions of the levels were drawn and explained how the accident happened.

A short journey back to the main road and once again to the cliff side brought the party to the site of Levant mine (SW 367346), one of the most famous of all Cornish mines. Levant produced copper, tin, and arsenic of a total value (at today's prices) of over £35, 000, 000, and extended for a mile beneath the sea. In October 1919 the man engine (the last on the mainland of Great Britain—there was another at Laxey, Isle of Man) collapsed as the men were coming off shift. Thirty-one miners were killed and nineteen injured, the second most serious disaster in the history of Cornish mining. Levant never did much after the 1919 disaster, and closed down completely in 1930.

The party saw the sites of the man-engine shaft, dressing floors, and arsenic chambers and the 24in beam winding engine which was built in 1840 and worked until the mine closed in 1930. It was the fact that this engine was about to be scrapped that brought the Cornish Engines Preservation Society into being in 1935. By the efforts of that society the engine and several others have been saved and are now safely in the hands of the National Trust.

The old skip shaft at Levant is in the process of being cleaned out and a small electric winding gear is now in place there for the development work being done by St Just Mining Services Ltd. This company has carried out the closing of the breach made by the sea into the old Levant workings—a very remarkable feat of mining engineering—and exploratory development work is now taking place from the nearby Geevor Mine (SW 375346). Geevor is one of the two Cornish mines in full production. It mined 77, 351 tons of ore in 1968 to produce 747 tons of 65% tin concentrates, which sold for £561, 343.

The party saw both shafts of Geevor from the coaches on the way to St Ives, the next stopping place. Also on the way the guides pointed out the sites of several smaller mines, and the folk museum at Zennor (SW 455385) which has numerous exhibits of mining interest. On entering St Ives the site of Wheal Trenwith (SW 511401) was pointed out ('wheal' in Cornish means mine). Originally a copper mine, this was one of only two mines where uranium was produced commercially, though only on a small scale.

After a stop of 20 minutes at the Malakoff bus station at St Ives, overlooking the splendid sweep of St Ives Bay, the party moved on via Hayle, where at SW 557372 the road passes between remains of the workshops of the former engineering works of Harvey & Co (who built some of the world's finest and most famous Cornish engines) to Pendarves (SW 644385) where a new shaft has been sunk to a depth of 260 metres. It is of interest to note that at this mine the traditional Cornish fathom and the foot have been abandoned in favour of the metre. This, the first major new shaft to be sunk in Cornwall for 40 years, was seen from the coaches and the party then moved on to Troon (SW 662380). Here the coaches stopped for five minutes while the guides pointed out the features of the former great mining area south of the granite mass of Carn Brea (SW 685417).

A stop was then made at Basset Count House (SW 692400) for lunch. Appropriately this restaurant is in the old office (account or 'count house) of the former Basset Group of Mines and numerous ruins of the former engine houses and other buildings were pointed out, as was the nearby site of the last tin smelter to work in Cornwall at Seleggan Hill (closed 1931).

After lunch the party moved on to the United Downs, Gwennap, (SW 745411) where a stop was made to view the sites of the former United Mines, once the greatest copper mining group in the world. Little now remains but spoil heaps (in Cornish, 'burrows') and some ruins of engine houses and stacks, but the sites of many other formerly world-famous mines were pointed out.

Moving on to Mount Wellington Mine (SW 762416) the party stopped to see the new works, where the sinking of a new shaft has just commenced (it was only a few feet deep at the time of the visit) and then went on to the tin-dressing works of Hydraulic Tin Ltd. at Bissoe (SW 777414). Here in a very ancient tin streaming or alluvial mining area, modern machinery is being used to work over old mine burrow material, which is brought by lorry from a wide radius. About 100, 000 tons of waste are being treated annually. The party was met by Mr Moses, managing director of Hydraulic Tin and shown over the whole plant, which includes ball and rod mills, Holman tables, and Moseley tables. The crushed material is washed to take out the lighter waste, leaving behind

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Mr Gale is Chairman of the Historical Metallurgy Group

* National Grid References quoted are only approximate.

tin oxide in powder form, which is sold to the smelters. Mr Moses demonstrated the use of the vanning shovel which is the basis of tin dressing.

A short journey from Bissoe brought the party to the Janes Mine or Wheal Jane (SW 774425) where the greatest single mining development in Cornwall is taking place. Here Consolidated Gold Fields Ltd is spending £6 million on a completely new mine which is expected to tap reserves of 5 million tons of ore and will employ 300 men in the initial stages and 500 later.

The party then headed west through the Scorrier mining area and by-passed Redruth to arrive at the former East Pool and Agar Mine, where the last visit of the day to Taylor's 90in Cornish pumping engine (SW 675419) was made. The engine was preserved by the Cornish Engines Preservation Society and, like that at Levant, belongs to the National Trust. It was made by Harvey and Co. in 1892 for Carn Brea Mines and moved to East Pool in 1924. Although no longer at work and minus its boilers, the engine is in full working order.

Mr Trounson gave a short talk on the history of the mine and the engine and then, in the top chamber of the engine house, described graphically how the heavy parts of the engine, especially the great 52 ton beam, were erected using nothing but hand winches, jacks, manual labour, and a great deal of specialized skill.

The two headgears of the working South Crofty Mine, only a few hundred yards to the south west, where another Cornish engine, Robinson's 80in, is preserved, were pointed out and the party turned for Penzance.

The journey covered 74 miles by coach and 6 miles on foot, as registered by the chairman's pedometer and it says much for the splendid organization (by Messrs Trounson and Bullen) that the party arrived at the headquarters hotel within three minutes of the scheduled time.

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# Notes and News

## Sussex Industrial History

The first issue of a new journal devoted to Sussex studies is planned for publication in the Spring of 1970. SUSSEX INDUSTRIAL HISTORY is sponsored by the Sussex Industrial Archaeology Study Group, and the journal will have the primary objective of publishing the results of recording, surveying and preservation of industrial relics done under the Group's aegis. But, as its title implies, its field will not be narrowly defined: SUSSEX INDUSTRIAL HISTORY aims to integrate the findings of industrial archaeology into general historical thinking and writing, by studying the impact of industrial change during the past two centuries on a rural county.

That impact has often been indirect and negative, but nevertheless worthy of study: the last two hundred years have seen, on the one hand, the demise of the Wealden iron industry in the wake of improved smelting methods elsewhere in England, and on the other hand, the growth of the holiday industry, 'one of the social results of the Industrial Revolution'—two industries which alone give industrial history and archaeology in Sussex a distinctive mark. Agriculture will not be neglected in the journal, as in Sussex that has long been an industry (as against subsistence farming) while the study of those groups engaged in servicing agriculture and in processing farm products is needed to fill a notable gap in rural history.

SUSSEX INDUSTRIAL HISTORY hopes to attract contributions from student, amateur as much as professional, of a wide range of disciplines—engineering and metallurgy as well as history and geography—using many techniques. If you would like to contribute, please contact the Editor as soon as possible; he will be pleased to discuss any ideas for articles. The first issue of SUSSEX INDUSTRIAL HISTORY is projected as about 48 quarto pages, selling at approximately six shillings.

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Or, 27 Bloomsbury Place, Brighton, BN2 1DB.

# Some observations on the structure of ancient steel from South India and its mode of production

K. N. P. RAO, J. K. MUKHERJEE, and A. K. LAHIRI

## INTRODUCTION

The use of iron in India dates back to several centuries before the Christian era. From surviving iron objects from ancient times and the fact that steel was used for weapons, implements, etc., metallurgists have agreed that both wrought iron and steel are of great antiquity in India[1,2]. It is thought that the iron for making the famous Damascus blades was manufactured in India and sold in the markets of Egypt several centuries before Christ.

From available knowledge and from ancient slag heaps scattered in different parts of India, it is evident that iron-making was practised throughout the country where iron ore and charcoal were available. The methods used in different areas varied but there is no record of the process that was used in antiquity. However, an idea of the process used may be derived from observations made in the last century when the production of iron and steel in India by primitive methods was still extensively practised. It should be mentioned that iron is still made by tribal people in some areas by these methods, the properties of which have been studied in detail by Ghosh[3] and Lahiri et al[4]. It is presumed that no marked difference in the method of manufacture exists between the recorded method and the method practised in antiquity.

In most parts of the country the material produced was wrought iron, but in a few cases (especially in the South India) the art of making 'wootz' steel was perfected. The first step in the production of steel consisted in general of producing low-carbon wrought iron, and this was followed by carburization. While the general outline of manufacturing process has been given by Heath[5], Holland[6], and Voysey[7], no detailed examination of the manufacturing steps is available in the literature. It was therefore considered worth while examining steel ingots produced by the ancient method to throw more light on the metallurgy of the process. To enable these studies to be carried out, samples were kindly supplied by Dr B. P. Radhakrishnan, Director, Geology & Mines, Govt. of Mysore. The samples were originally collected for display but the actual dates of manufacture of these particular pieces are not known.

## EXPERIMENTAL RESULTS

### Appearance of samples investigated

Two crucibles and three ingots were received for examination. One of the crucibles was empty and unused and the other was a used one containing an iron ingot inside it with the mouth closed. The two crucibles are shown in Fig. 1. The unused crucible appeared to be made of clay, a light brick-red in colour. A fine dispersion of black particles in the clay was also noted. The used crucible was dark grey in colour and the surface had a glassy appearance, indicating that it had been fired to a temperature near its fusion point. The top was slightly deformed and was oval in shape. This crucible was sectioned to reveal the iron ingot, as shown in Fig. 2.

In addition to the crucible three ingots were supplied, the weights of which were as follows:

| | |
|---|---|
| No. 0/507 | 427 g |
| No. 0/505 | 350 g |
| No. 5052 | 335 g |

The shape and size of the ingots are shown in Fig. 3 The surface had a mottled appearance with large round pits. Ingot No. 0. 507 (A) was cut into two halves longitudinally. The interior showed the presence of blowholes along the rim and also near the top (Fig. 4). The ingot taken out of the crucible (B) was also sectioned; its interior was solid without any blowholes (Fig. 4).

### Macrostructure

The macrostructure of the polished face of one of the two sections of ingot A was developed by treating in 50% HCl solution at 75°C for 10 min. The structures are shown in Fig. 4. Sample B was deeply etched in nital to reveal the variation in structure as shown in Fig. 5. It will be evident that the rim of ingot A is etched darker than the interior portion. Coarse grains were observed in the interior portion,

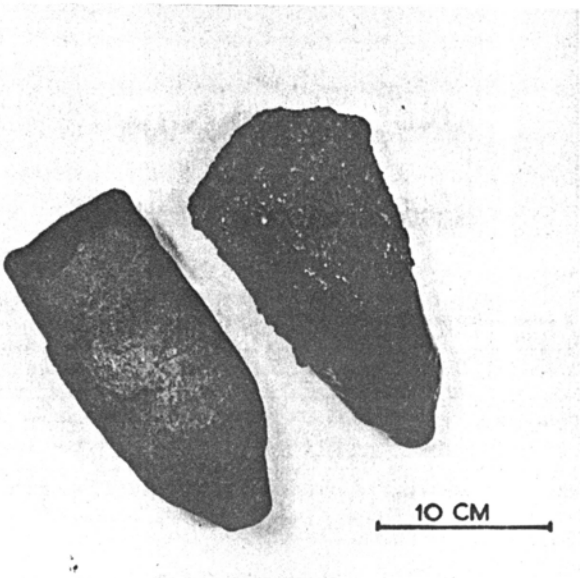

Fig. 1 — Photographs of carburizing crucibles. That on the left was empty and that on the right contained an ingot and had its mouth closed

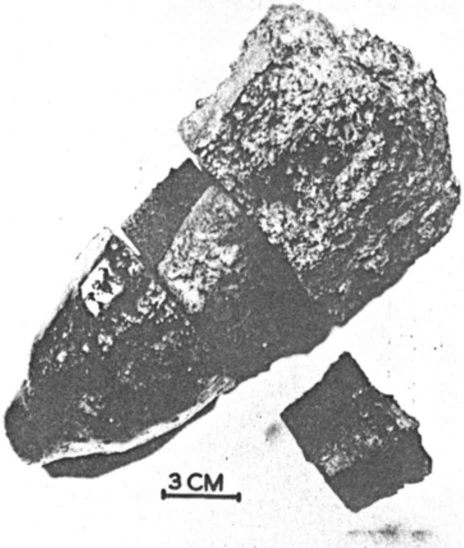

Fig. 2 — Interior of crucible containing ingot.

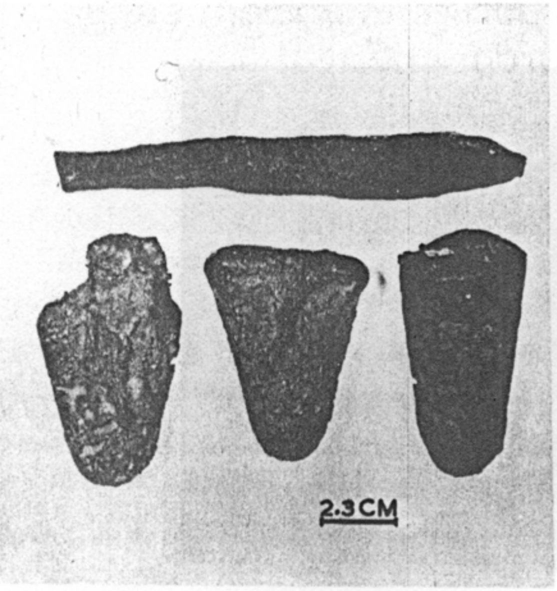

**Fig. 3** — **External appearance of ingots. That at the top is elongated and is presumed to have been hand-forged**

showing a cast structure. In case of B, the rim and bottom portion etched darker, while the centre and top etched lightly. The light-etching area had coarse grains.

### Sulphur print

The sulphur distribution of ingot A was determined by sulphur printing, but no marked variation was observed. The high-carbon areas (rim) were, however, found to have slightly greater sulphur content.

### Microstructural observations

The microstructure of ingot A was studied in detail. The structure was found to vary markedly and indicated variations in composition with the distance from the edge. There were high carbon contents at the rim, and the carbon concentration gradually decreased towards the centre (Fig. 6). The centre showed predominantly the presence of ferrite, whilst the rim was completely pearlitic (0.8% C approximate). There was a slow change in the carbon content from the rim to the centre. Just at the end of the high-carbon rim, the structure had a Widmannstätten pattern with ferrite distributed in parallel habit planes in a pearlitic matrix. This was followed by a decrease in the pearlite, and the high-carbon rim ended at the blowholes.

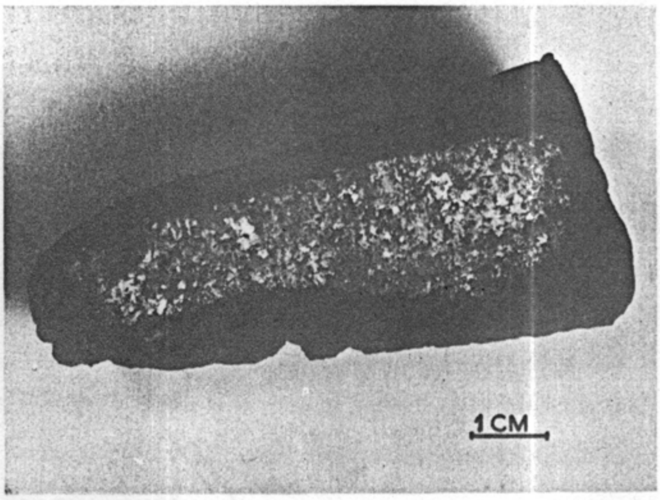

**Fig. 5** — **Macrostructure of polished section on ingot A**

The variation in carbon content was also ascertained by collecting drillings from the edge and from the centre (top, centre, and bottom) and is shown in Table I. The table also includes the overall average composition of certain other elements. The results of qualitative spectroscopic analysis are given in Table II. The change in carbon content was further confirmed from hardness data (Table III).

The microstructure of ingot B was also studied in detail. The structure was found to vary with the depth. The rim and the bottom half of the ingot (dark etching areas in Fig. 5) showed a high carbon content with precipitation of carbide at the grain boundaries and, as needles in parallel planes, inside the grains (Fig. 7). The top centre was pure ferrite with small amounts of pearlite (light etching areas). The interface between high- and low-carbon areas had varying carbon contents, as will be evident from Fig. 6.

### Visual and mineralogical examination of carburizing crucible

The crucible was sectioned and found to be porous and black with a glazed coating over some portions. The black colour appeared to be carbonaceous in nature, as on rubbing a black mark was left on the palm or white paper. It is probably the remnant of unburnt organic matter mixed along with the body of the crucible during manufacture.

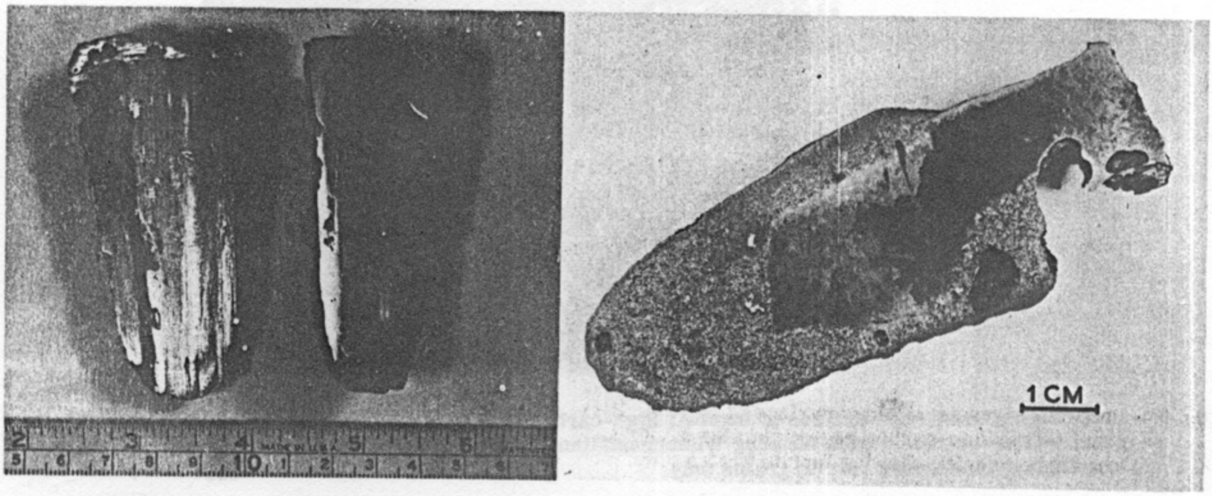

**Fig. 4** — **Cross-section of ingots. Ingot A (left) shows blowholes along the rim and at the top. Ingot B (right), which was removed from the crucible shown in Fig. 2, shows no blowholes.**

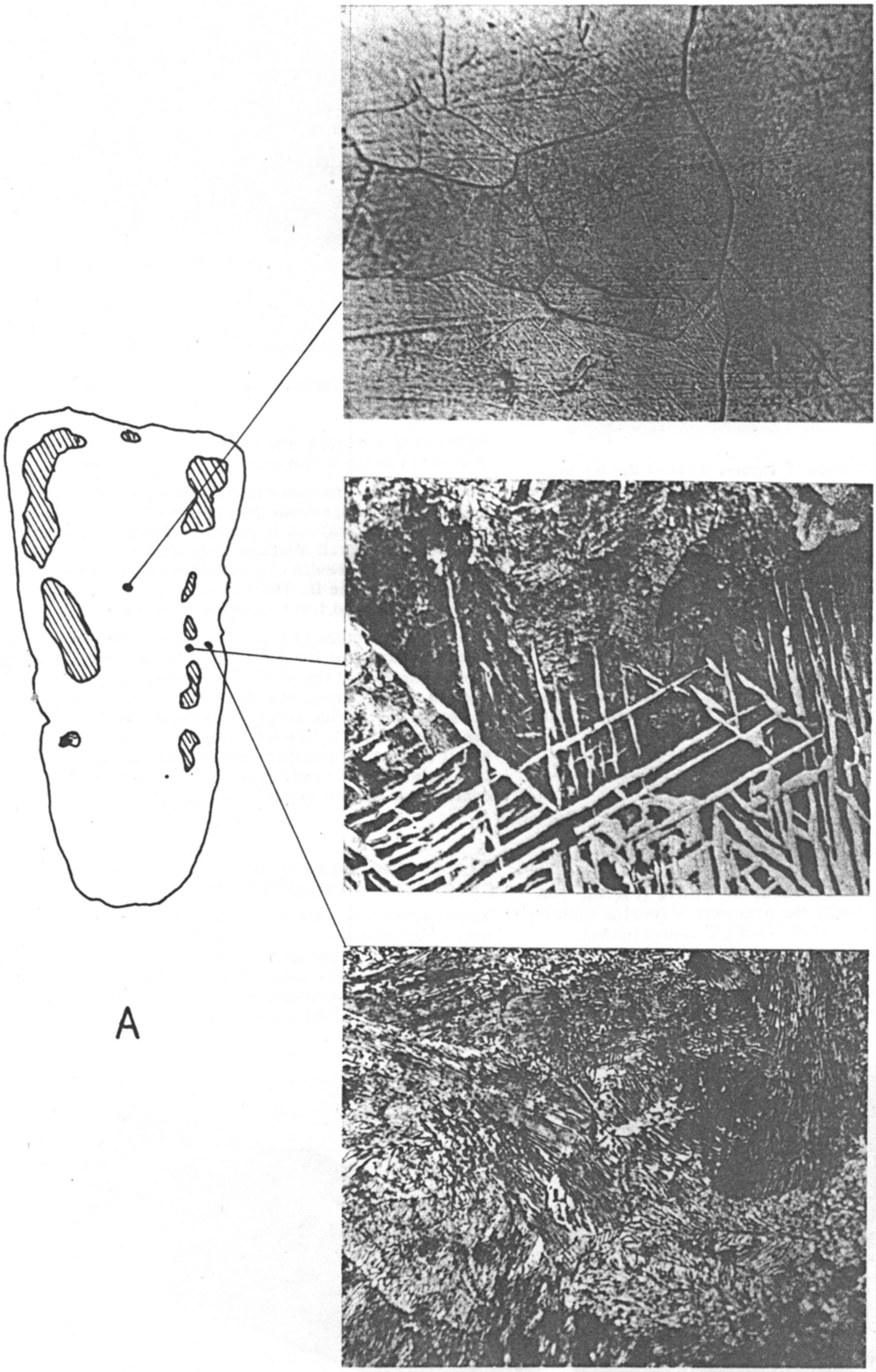

**Fig. 6** — **Photomicrographs of inner surface of ingot A: High-carbon region at the rim showing pearlite; medium-carbon region showing Widmannstätten patterns of ferrite and pearlite; low-carbon region showing ferrite grains only. ×210**

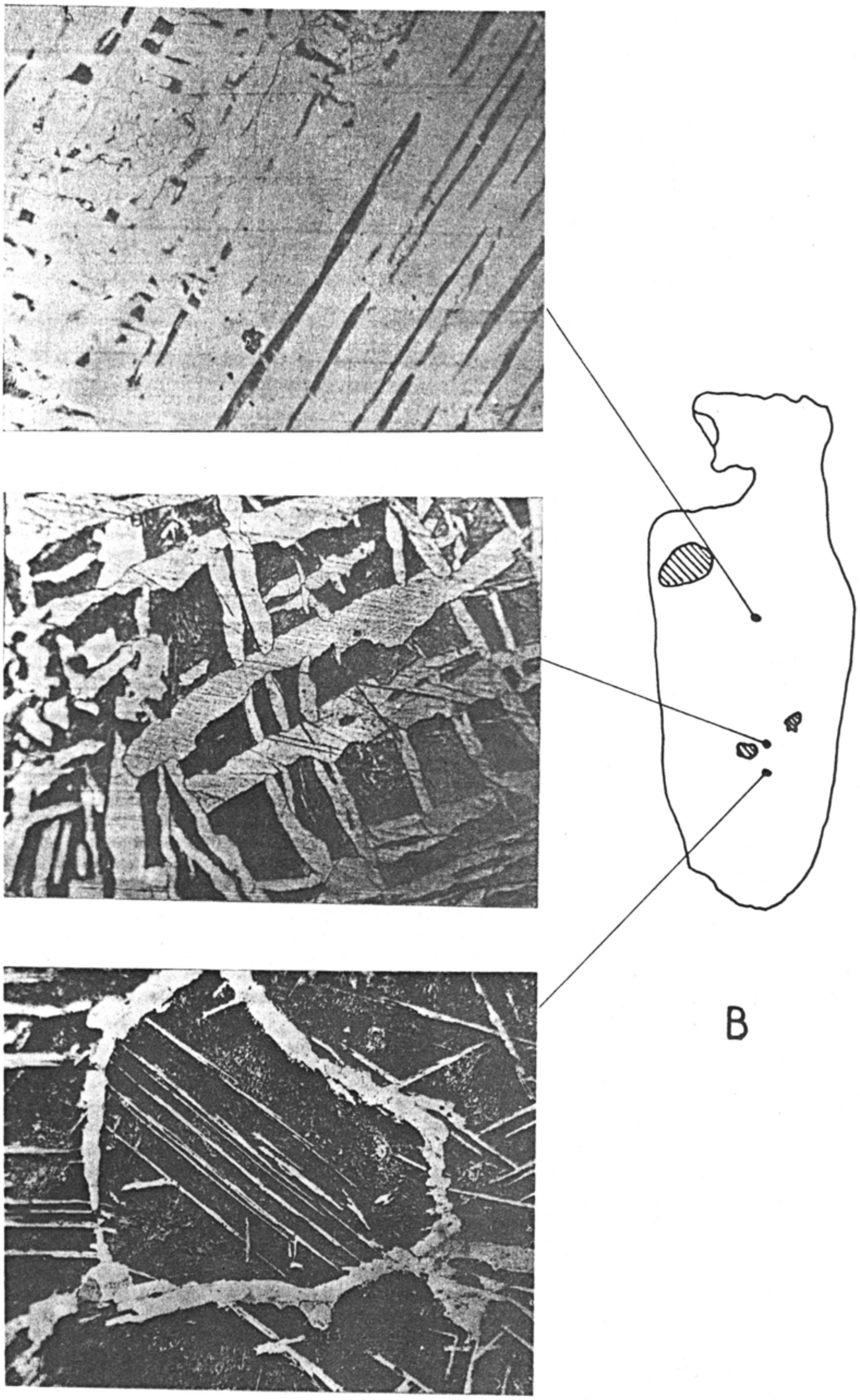

Fig. 7 — Photomicrographs of inner surface of ingot B: High-carbon region at the rim showing pearlite; medium-carbon region showing Widmannstätten patterns of ferrite and pearlite; low-carbon region showing ferrite grains only ×210

**TABLE I Chemical analysis of ingot A, %**

| | Average analysis | | Centre analysis | | | Average by collecting from all places |
|---|---|---|---|---|---|---|
| | Top | Centre | Bottom | Centre | Top | |
| C | 0.61 | 0.25 | 0.27 | 0.14 | 0.16 | 0.45 |
| Mn | – | – | Nil | Nil | Nil | Nil |
| P | – | – | – | – | – | 0.27 |
| S | – | – | – | – | – | 0.01 |
| Si | – | – | – | – | – | 0.14 |

**TABLE II Qualitative spectrographic analysis of ingot A**

| | |
|---|---|
| Major | Iron |
| Appreciable | Silicon, manganese |
| More than trace | Copper |
| Trace | Aluminium, lead |

The hardness at different distances from the rim was also measured and the result is given in Table III.

**Table III Hardness data on ingot A**

| Position from the rim to centre | | | | |
|---|---|---|---|---|
| rim | Middle portion | | | Centre |
| 1 | 2 | 3 | 4 | 5 |
| 213 | 177 | 144 | 92 | 89.9 |

A section of the crucible was impregnated in Araldite and polished. Under reflected light the following constituents could be distinguished:

(a) The main body consists of very fine-grained mullite mass formed as a result of firing the crucible at a temperature above 1250°C.

(b) Some coarse grains of quartz altered to cristobalite (or tridymite) are also present.

(c) Some glaze seeped into the pores of the crucible body and appears as a cellular network.

(d) Fine- to medium-sized rounded particles appear to be metallic iron.

(e) Large pores, impregnated with Araldite (grey), and small pores, which look black and possibly formed during grinding and polishing, were also present. The organic matter referred to may have been removed, forming pores.

### Chemical analysis of the crucible:

Chemical analyses of unused and used crucible are given in Table IV.

The analysis shows the crucible to consist mainly of clay, i.e. iron aluminium silicates and free quartz. The loss on ignition indicates the presence of carbonaceous material.

### X-ray analyses of crucibles

The nature of the constituents present in the crucible was determined by X-ray diffractometric and photographic examination of sample in a Philips Diffractometer Unit. CuK radiation at 30 kV and 20 mA was used.

**TABLE IV Chemical analyses of crucibles, %**

| | Fresh crucible | Used crucible | Oxide | Fresh crucible | Used crucible |
|---|---|---|---|---|---|
| Fe | 3.97 | 4.16 | $Fe_2O_3$ | 5.67 | 5.81 |
| Si | 24.34 | 29.66 | $SiO_2$ | 52.1 | 65.0 |
| Al | 11.71 | 7.64 | $Al_2O_3$ | 22.13 | 14.53 |
| Mg | 0.47 | 1.05 | MgO | 0.78 | 1.75 |
| Ca | 0.75 | 7.0 | CaO | 1.06 | 9.76 |
| Loss on ignition | 11.25 | 0.8 | | | |

## DISCUSSION

The observations made on the basis of the various tests carried out may be summarized as follows:

1. The ingots have a more or less stout conical form similar to the shape of the bottom end of the crucible.

2. The ingots weigh generally 320-450 g.

3. Two ingots were cut along the centre. One ingot taken out of the crucible (B) was solid without any blowholes. The other ingot (A), however, contained rows of blowholes, especially at about 3/16in from the edge of the ingot. This will be evident from Figs. 3 and 4.

4. The microstructures indicated the nature of the two ingots to be different. The centre of ingot A had a dark-etching rim continuously round the rim; the inside was light-etching showing large grains. Ingot B also showed two zones, the dark area being greater than in the previous one.

5. The microstructures clearly revealed the nature of the two zones. The dark-etching areas were areas of high carbon content. In ingot A, the carbon content in this area was 0.8% and in ingot B the same area was also about 0.8%. The carbon content decreased towards the centre, the interface of high-carbon and low-carbon areas showing variations in carbon content with depth, as will be evident from Figs. 5 & 7. The high hardness of the dark etching areas compared with the light areas confirmed the above observation.

6. The unused crucible was found to consist mainly of aluminium silicates and free quartz. The reddish colour indicated its ferruginous origin. Small black particles were found to be evenly distributed in the matrix. High loss on ignition and X-ray data indicated this to be carbonaceous in nature.

The fired crucible was found to be porous and consisted mainly of mineral mullite, indicating that it was heated to a temperature not less than 1300°C. Presence of cristobalite further shows that the crucible must have been heated over 1470°C at least for a short duration. Some unburnt carbon was also present. The glazed outer layer was of glassy material, which entered the external pores in the crucible.

### Process of manufacturing the carburized steel

It is difficult to ascertain the exact method used in antiquity for the production of steel suitable for making sword, spears, etc., with high surface hardness and toughness, However, the metallurgical characteristics as revealed in the studies carried out gives an indication of how the high-carbon steels were manufactured.

Krishnan[7] gives the observations recorded in 19th century literature on the method of manufacturing steel in South India, from where the present samples were collected. According to Holland[6], the first step in the production of steel was to make wrought iron direct from the magnetite ore. For making steel the cakes were broken into small pieces and charged into a pear-shaped crucible made of ferruginous clay and charred rice-husk. After charging with wrought iron, 4-5% of its weight of wood of the Avaram Tree (Cassia auriculata) and leaves (about 1% by weight) of Calotropica gigantea were added to the crucible. The mouth of the crucible was sealed with clay, which was tightly squeezed down upon the leaves.

A number of crucibles were placed together with their pointed ends downward in a saucer-shaped pit. The pits were then heated with charcoal with the help of blast from two goatskin bellows. After about 2 h, the centre crucibles, in which the iron had melted, were taken out.

The above method, described by Holland[6] and known as the Salem process, is a carburizing technique of steel making. There was another method in vogue in the Hyderabad region of Andhra Pradesh which has been described by Voysey[7]. According to him the crucibles were made of refractory clay derived from the weathering of granite to which were added fragments of old crucibles and rice husk. No charcoal was put in the crucible. The crucibles were heated in a circular furnace, the air for which was supplied by four bellows placed near the top and facing downwards. The crucibles were kept at a high heat for 24 h and then were taken out.

In the present case the shape of the ingots clearly indicate that the steel had melted during the process. The way in which the carburization was accomplished is also apparent from this study. The carburization gradient from the edge towards the centre indicates that carburization was effected in the solid state, as carburization in the liquid state would not permit such demarcation to be identified. The carbon present in the crucible probably acted as the source of carbon to diffuse inside the steel. From the description of the two processes given above it appears that in all probability the steel was made by the second or Hyderabad method, as described by Voysey.

The addition of leaves and branches inside the crucible was made not to carry out carburisation from the interior but probably rather to maintain a reducing atmosphere inside the crucible to avoid undue oxidation and facilitate the carburizing process.

The presence of blowholes along the side of ingot A is in all probability due to the fusion being imperfect throughout the mass. The other possibility is that they were formed by gases evolved during the solidification. The thin carburized rim in this case is due to the blowholes acting as barriers for the diffusion of carbon.

## ACKNOWLEDGEMENT

The authors wish to thank Dr B. P. Radhakrishnan, Director of Geology and Mines, Government of Mysore, for kindly providing the specimens on which the investigations were carried out.

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# Preliminary research findings relating to the bloomery period of the iron industry in the upper basin of the eastern Rother (East Sussex)

CHARLES S. CATTELL

The intention of this note is to make known recent discoveries made by the author, in so far as they relate to the bloomery period of the iron industry, and to suggest certain lines along which future investigation may be carried out. The area of study was that of the upper basins of the River Rother and its tributary the Dudwell, being situated in the parishes of Burwash, Heathfield, Mayfield, and Rotherfield. Field work was undertaken in the form of a systematic search along the whole length of the gills of the area in order to locate hitherto undisclosed traces of the iron industry. Although this field work was not carried out 'blind' but in the light of evidence shed from place-names and geology, these sources of information were not allowed to direct and restrict investigation to certain specific points within the area. The aim was to be systematic, to be uninfluenced but not incognizant of place-names that can be regarded as chance survivals of history. The object of the study was 1. to see how much systematic search would reveal; 2. to determine how far previous methods, based on forms of evidence external to that of the field were adequate; 3. to find out whether there were any significant trends in the distribution of bloomery finds that could point to another method of research. The information gained from field work was recorded on 6 in O.S. maps which geological and place-name data had been entered prior to their use in the field.

Before reviewing the results several points must be stressed. The findings are only preliminary and investigation of the propositions has not yet been carried out. Also, certain assumptions were made at the outset which guided the course of the search and which have still to be proved valid by further investigation on the part of the author. These assumptions were: 1. that bloomery sites were invariably located near streams, this being a response to the necessity of having a plentiful supply of water for washing the iron ore; 2. that the ore would not have been carried over large distances since smelting sites at this period did not call for heavy capital investment in buildings and machinery, and therefore, it would have been easier to shift the smelting operations to where the ore was being dug at the time; 3. that the early bloomsmiths would need a supply of water in which to quench their tools and the products they produced; 4. that prospecting for the outcrops of iron ore would have been most easily achieved by searching along the gills where the solid geology is often revealed in the banks and river cliffs. A further factor that guided the decision as to which areas were to be systematically searched was the belief that processes of mass movement, such as soil creep and slumping, have been operating in the Weald, and as a consequence, inspection of the material delivered to the streams down their valley sides enables one to know something of the make-up of the adjacent area without having to actually inspect it. This means that more ground is effectively 'covered' than would otherwise be possible. Where slag is found along a stream course it is followed up-stream to the point of origin where it is entering the stream from the banks. Clear distinction must be made between stream deposits of slag which have been redistributed from an original bloomery and now found in the banks of a stream and an in situ bloomery dump. Only the latter can be taken as indicating the site of former iron-working.

Within the area so far investigated, Straker[1] described three bloomery sites: Argos Hill, Meeres Farm, and Sandyden Gill. The additional thirty-one sites found by the author (see the appended list and map-Fig. 1) greatly alter the picture of the distribution and density of ironworking during the bloomery era. The distribution of the bloomeries, when seen in the context of the geology of the area under consideration, reveals a close relationship between the outcrops of the Wadhurst Clay and the actual sites. The base of this formation is the most significant part so far as iron-bearing strata are concerned. Number 1 borehole made in Wadhurst Park[2] just to the east of the region, disclosed six bands of clay-ironstone in the bottom 25 ft of the bed, near its junction with the underlying Ashdown Beds. Although slight variations in the height of individual horizons of clay-ironstone occur from district to district, the presence of this concentration of clay-ironstone in the basal part of the Wadhurst Clay is a constant feature and is particularly well marked in this part of East Sussex. Of the thirty-one sites listed, four (sites 7, 26, 28, and 29) are found more or less at the intersection of the streams with the junction of the Ashdown Beds and the Wadhurst Clay. A further eight sites (1, 2, 4, 5, 6, 8, 23, and 22) are found within 160 yards of this point, two others within 200 yards. Once prospecting along a stream had located a band of clay-ironstone, its outcrop could have been followed back downstream along the sides of the gill and worked either by digging out the ore from the sides or by shallow pitting from above. This could account for the larger number of sites that are found below the junction than above. Working the ore upstream of its outcrop in the stream bed would involve immediate pitting and greater problems of drainage. When the distribution in relation to the geological junction on the side of the valleys is considered, as opposed to the point in the stream where the ore would have been located first, seventeen sites are found to lie at a distance of less than 100 yards from such points. These cases apart, three sites (9, 24, and 25) occur well within the Wadhurst Clay outcrop and may have used ore from higher horizons that are known to exist in that formation.

In other cases the relationship is less close but it is notable that in areas dominated by an expanse of Ashdown Beds such as that immediately north and north-west of Heathfield, this formation proves to be a negative area for bloomeries except where the latter are found directly downslope of the outliers of the Wadhurst Clay that cap the divides here. This does not mean that bloomeries are never found on the Ashdown Beds in the absence of a nearby Wadhurst Clay outcrop. Sites 15 and 16 are found at a distance greater than 300 yards from the nearest area of Wadhurst Clay. Site 17 lies on the Ashdown Beds and site 18 on the Purbeck inlier of the Dudwell valley. With these bloomeries the source of the ore was probably ironstone from clay horizons that occur sporadically in the Ashdown Beds or perhaps, in the case of site 18, nodular ironstone from the Purbeck Beds.

From the list of newly discovered bloomeries, it can be seen that only two of the thirty-one sites have any definite place-name that could be linked with them. This circumstance presumably explains the very limited number of bloomery sites identified by Straker[3]. Thus it becomes apparent that place-name evidence when used in isolation is likely to reveal only a very small fraction of the large number of surviving bloomery sites. The number is probably even greater than the appended list suggests since at many points slag is found for which a source can not now be found, perhaps because it has been removed by stream erosion.

Description of the sites in quantitative terms is difficult. Firstly, where the dump of slag has been made on a slope (the normal situation), it is difficult to assess how much migration of slag by the processes of mass movement has occurred. Secondly, in most cases the depth of the slag deposits has not been measured, as to do so would necessitate digging into, and disturbing a site, that at some future date

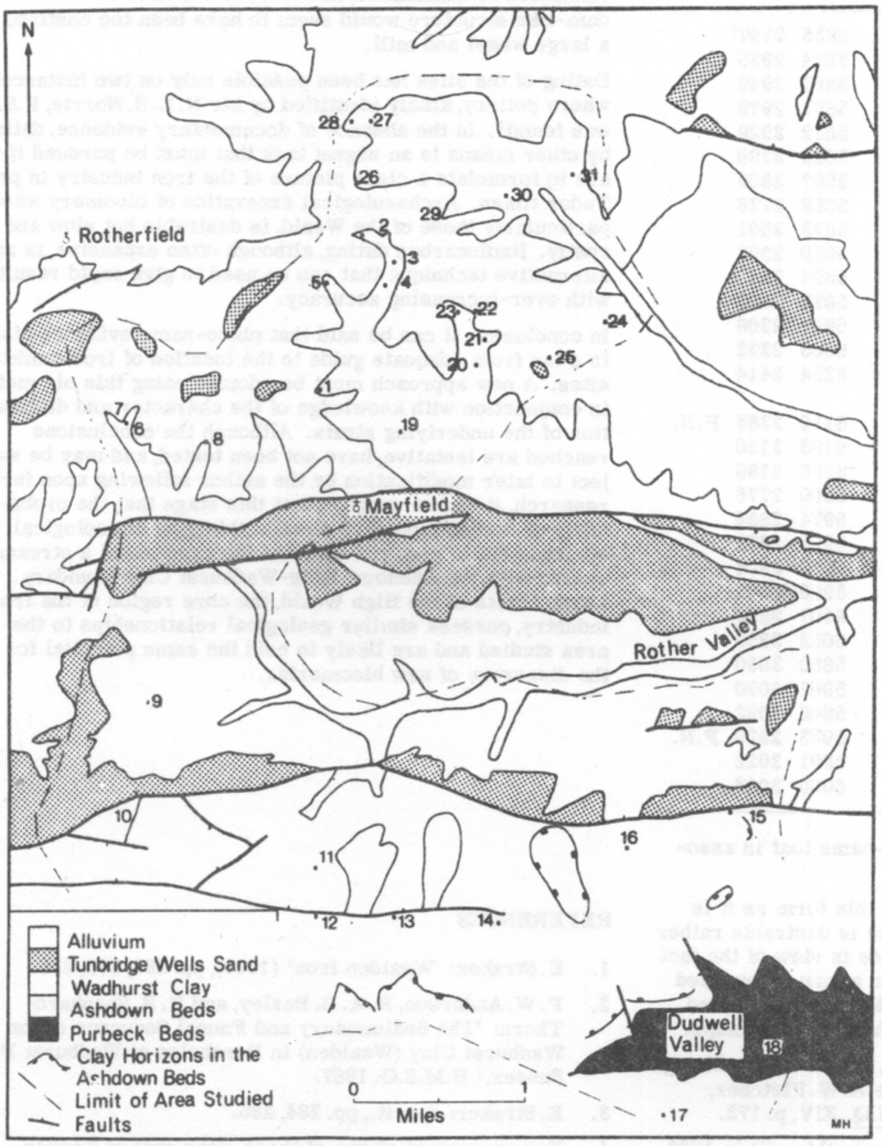

**Fig. 1 — The distribution of bloomery sites recently discovered in the upper basin of the eastern Rother. Geological boundaries based on Crown Copyright Geological Survey 1 in sheet 303 and on sheet 319 (revised area) by permission of the Director, Institute of Geological Sciences, and of the Controller of H.M. Stationery Office**

may be subject to excavation by archaeologists. A crude assessment of size has been made by measuring the length of the area covered by slag in a direction parallel to the valley side. Upon this basis an arbitary classification has been made below. These groupings indicate a large number of small sites and a moderate number of large sites, with few sites falling into the intermediate categories. Without the dimension of depth no estimate of the volume of slag found on these sites has been possible.

Several sites are of particular interest. Sites 3 and 27 reveal clear-cut sections of the thickness of the slag dumps and the type of material they contain: tap-slag, burnt clay, pieces of roasted iron ore, and charcoal. Sites 7 and 11 are exceptionally large, the latter perhaps being the fore-runner of Old Mill Furnace, Mayfield. Site 28 contains both the normal type of tap-slag and the glassy form. Site 26 is a

**Classification into size-groups of bloomeries as measured by the extent of slag in a direction parallel to the valley side**

| | less than 15 ft | 15-29 ft | 30-44 ft | 45-59 ft | 60 ft and over | Others not classified |
|---|---|---|---|---|---|---|
| Site | 14 | 17 | 12 | 8 | 11 | 9 |
| | 13 | 5 | 10 | 30 | 7 | 15 |
| | 16 | 18 | 2 | | 19 | 31 |
| | 6 | 3 | | | 26 | |
| | 4 | 1 | | | 27 | |
| | 20 | 21 | | | 28 | |
| | 22 | 23 | | | 29 | |
| | 25 | 24 | | | | |

complex area where ironworking seems to have been carried out on a large scale, with numerous bloomery dumps. The ground is much disturbed and the existence of a low bank suggests that this site may have been water-powered. This likelihood is diminished, however, as the area below the dam-like structure would seem to have been too confined for a large wheel and mill.

Dating of the sites has been possible only on two instances where pottery, kindly identified by Mr N. E. S. Norris, F.S.A., was found[4]. In the absence of documentary evidence, dating by other means is an urgent task that must be pursued if we are to formulate a clear picture of the iron industry in pre-Tudor times. Archaeological excavation of bloomery sites, particularly those of the Weald, is desirable but slow and costly. Radiocarbon dating, although often expensive, is an alternative technique that can be used to give rapid results with ever-increasing accuracy.

In conclusion, it can be said that place-name evidence alone is a far from adequate guide to the location of iron-working sites. A new approach must be adopted using this old method in conjunction with knowledge of the character and distribution of the underlying strata. Although the conclusions reached are tentative, have not been tested, and may be subject to later modification by the author following upon further research, it can be suggested at this stage that the probability of finding bloomery sites in this type of geological environment is greatest near the intersection of a stream course with the Ashdown Beds-Wadhurst Clay boundary. Large tracts of the High Weald, the core region of the iron industry, possess similar geological relationships to the area studied and are likely to hold the same potential for the discovery of new bloomeries.

## NEWLY DISCOVERED BLOOMERY SITES

| Site No. | Site Name | Dating | Grid. Ref. | P.N.* |
|---|---|---|---|---|
| 1. | Clay's Wood | | 5835 2797† | |
| 2. | Long Gill-Great Trodgers | | 5874 2925 | |
| 3. | Long Gill | | 5887 2949 | |
| 4. | Little Trodgers | | 5857 2978 | |
| 5. | Brick Kiln Wood | | 5822 2929 | |
| 6. | No Man's Hole | | 5623 2790 | |
| 7. | Castle Hill-Home Farm | | 5597 2803 | |
| 8. | Angle Wood | | 5698 2776 | |
| 9. | Almonds Wood | | 5673 2501 | |
| 10. | Little Inwoods | | 5620 2397 | |
| 11. | Quarry Wood | | 5824 2343 | |
| 12. | Orchard Farm | | 5822 2303 | |
| 13. | Coneyburrow Wood | | 5907 2306 | |
| 14. | Magreed Farm. | Romano-British | 6005 2292 | |
| 15. | Knowle Farm | Romano-British | 6234 2414 | |
| 16. | | 2nd & 3rd cent. | | |
| 16. | Baltham Wood | | 6130 2365 | P.N. |
| 17. | Bingletts Wood | | 6193 2120 | |
| 18. | Greenwood Farm | | 6296 2186 | |
| 19. | Brickhurst Wood‡ | | 5900 2776 | |
| 20. | Pitwood | | 5974 2854 | |
| 21. | Watlings Wood | | 5977 2872 | |
| 22. | Lakestreet Manor | | 5968 2904 | |
| 23. | Sprattsreed Farm | | 5960 2901 | |
| 24. | Cinderhill Wood No. I | | 6107 2883 | |
| 25. | Cinderhill Wood No. II | | 6052 2859 | |
| 26. | Stilehouse Wood (complex) | | 5850 3030 | |
| 27. | Sandyden I ‖ | | 5862 3090 | |
| 28. | Sandyden II | | 5846 3092 | |
| 29. | Harlings Farm (complex) | | 5933 2999 | P.N. |
| 30. | Devil's Gill | | 5991 3022 | |
| 31. | Bassetts Farm | | 6060 3042 | |

* P.N. indicates the presence of a place-name that is associated with the site.

† National Grid References are given in this form as it is considered that an eight-figure reference is desirable rather than the conventional six-figure reference in view of the fact that bloomery sites are often points upon a map as opposed to general areas. All lie within the 100 km square TQ and should be referred to in conjunction with O.S. 6 inch maps.

‡ This was probably the site found by A. W. Fletcher, although no precise location was given for it. See A. W. Fletcher, 'Primitive Bloomeries at Mayfield', S. N.Q., XIV, p. 173.

‖ Mr H. M. S. Malden had discovered slag in this gill in 1929 but had not been able to locate the bloomery. See E. Straker: 'Wealden Iron', (1931), p. 288.

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3. E. Straker: op. cit., pp. 284, 285.
4. For an account of one of these sites, that of Knowle Farm, see C. S. Cattell: 'A Romano-British Bloomery in Heathfield,' S.N.Q., XVII, 101-103.

# Metallurgical aspects of Chalcolithic copper working at Timna (Israel)

ALEXANDRU LUPU

Site 39, with its slags and Chalcolithic sherds,[1] was discovered about 500 m north-east of the modern plant of Timna Copper Mines by B. Rothenberg in 1960, and was excavated by the Arabah Expedition in 1965[2]. It is not far (about 4 km) from the Early Iron Age furnaces discovered and excavated in 1964-1966.[3,4]

During the excavation a stone-built smelting furnace was discovered on top of a stony hill, about 80 m high. Inside the furnace, pieces of slag, stones, and grey-yellow sandy material were found. Near the furnace also lay sherds, flint implements, slags and some pieces of ore. Chemical analysis and microscopical examination of the materials have made it possible to establish the metallurgical process used.

## ORES

The chemical analysis of four samples (Table I) shows a high content of copper for the first three (38.20-43.74% Cu) and only 3.39% Cu for the fourth. Using microscopical examination and differential thermal analysis (D.T.A.), the ores have been identified as malachite with cuprite, malachite and azurite, and malachite with (?) chrysocolla. The large amounts of silica and the shape of the nodules indicate the same origin as that of the E.I.A. ores, i.e. the White Nubian Sandstone. A Chalcolithic copper mine was found approximately 1.5 km south-west of site 39.

**TABLE I. Chemical composition of ores, %**

| ore | Cu | $SiO_2$ | $Al_2O_3$ | FeO | MnO | CaO | MgO |
|---|---|---|---|---|---|---|---|
| I | 41.60 | 4.92 | 0.33 | 0.33 | — | 1.61 | 0.12 |
| II | 43.74 | 10.70 | 7.84 | 1.04 | — | 5.60 | 1.17 |
| III | 38.20 | 7.89 | 4.70 | 17.72 | 0.33 | — | — |
| IV | 3.39 | 81.76 | — | 0.34 | — | 2.70 | 1.74 |

## FLUXES

Since the ores contain large amounts of other materials, such as silica and alumina, and not much iron, with the exception of ore III, and because these compounds have a high melting point, it was necessary to add fluxes for the metallurgical process. The nature of the fluxes used can be established from the composition of the slags.

From the chemical composition of most of the slags (Table II) it is possible to conclude that the fluxes used were iron ores. In other slags, a relatively large number (18 slags out of the 25 examined) there is also much calcium oxide (8-23% CaO) which indicates that limestone or some material rich in lime was added. Some other components of the slags such as alumina (1-17% $Al_2O_3$) may originally have been clays (flint clay) or limestone rich in alumina, which are also found in the region. From the ratio between the silica content and the other elements it is possible to estimate the addition of 10-20% of iron ores and 3-5% of other components such as limestone or clay.

## SMELTING PRODUCTS

### Slags

The smelting products found were merely slags with no metallic copper at all in distinct pieces. A few small drops of metallic copper were found in the slags. It was difficult to establish the characteristics of all the Chalcolithic slags since their composition is very variable. Their copper content is generally higher than that of the E.I.A. slags, i.e. 1.30-6.80% Cu (Table II), and in more than 50% of the slags the copper content is higher than 3%.

The silica and iron contents, and their ratio, are very variable. Manganese oxide is in general very seldom used as a flux; with the exception of slag 58 (25.94% MnO), the slags have only a very low content of manganese oxide.

A common characteristic of the slags is that the silica content is higher than that of iron oxide, which make them very different from the slags from the E.I.A. sites, where the iron content is higher than the silica.[3,4] Since the iron content of the slags is relatively high (30-40% FeO), it may be assumed that the same fossilized trees were used for iron fluxes as were later used by the E.I.A. smelters. This supposition is based on the fact that the fossilized trees are the only material in the region with a higher content of iron oxide than silica. In the ternary diagram of $SiO_2$—FeO—CaO (Fig. 1) the composition of the slags is not far from the region with the lowest melting point and viscosity. However, compared with the E.I.A. specimens, these Chalcolithic slags are spread over a larger area; a few samples show a high melting point and are very viscous.

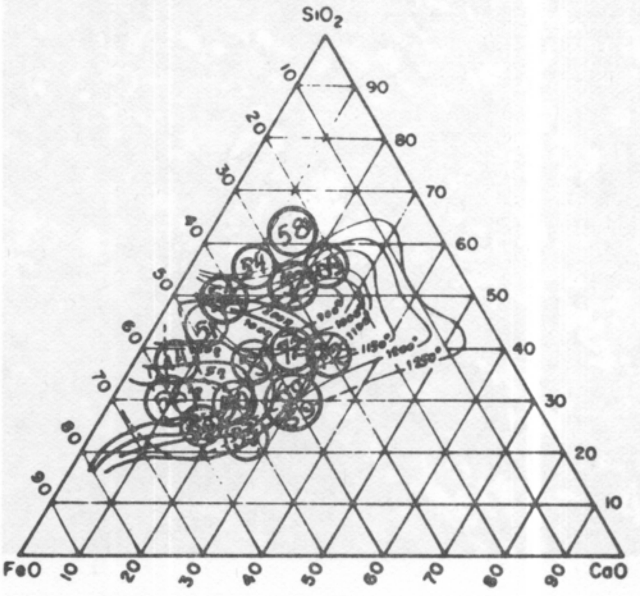

**Fig. 1 — The position of the Chalcolithic slags in the $SiO_2$—FeO—CaO diagram; isotherms (Weinhart) and isoviscosities (Loskutov) for 1300°C.**

The microscopical examination shows the presence of magnetite (Fig. 2). This amount of magnetite can explain the large content of copper in this type of slag by comparison with the E.I.A. slags. No sulphides were found in the slags or in the copper drops, which means that no sulphide ores were used in this period, and that only carbonates or oxides were obtained from the White Nubian Sandstone.

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The investigation is part of the Arabah Expedition's project on ancient metallurgy of the Near East. The Arabah Expedition is a project of the Museum Haaretz, Tel-Aviv, of the Technion-Israel Institute of Technology, Haifa, and of the Archaeological Institute of the Tel-Aviv University.

**TABLE II Chemical composition of slags, %**

| Slags | Cu | $SiO_2$ | $Al_2O_3$ | FeO | MnO | CaO | MgO | $K_2O$ | $Na_2O$ |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 1.31 | 30.71 | 6.83 | 49.51 | 2.00 | 4.06 | — | n.d | n.d |
| 51 | 2.48 | 39.22 | 11.11 | 37.31 | 0.32 | 6.39 | — | " | " |
| 51 B | 0.024 | 28.10 | 21.00 | 20.99 | 0.10 | 23.66 | 1.77 | " | " |
| 52 | 5.04 | 48.42 | 1.43 | 22.84 | 0.27 | 13.6 | 2.56 | " | " |
| 53 | 5.12 | 33.21 | 1.70 | 41.80 | 1.40 | 9.80 | 0.17 | " | " |
| 54 | 2.36 | 48.25 | 2.12 | 35.50 | 0.20 | 8.95 | 0.81 | " | " |
| 58 a | 15.12 | 34.25 | — | 21.69 | — | 22.13 | 1.62 | " | " |
| 58 b | 16.60 | 45.92 | 17.13 | 14.20 | — | 8.80 | 2.22 | " | " |
| 58 c | 0.73 | 30.11 | — | 30.35 | 29.33 | 12.17 | 0.98 | " | " |
| 59 | 1.89 | 21.50 | 9.06 | 43.00 | 1.06 | 12.04 | 1.37 | " | " |
| 60 | 1.72 | 30.10 | 9.00 | 32.71 | 0.82 | 20.13 | 0.88 | " | " |
| 64 | 8.36 | 16.26 | 0.37 | 43.12 | 0.16 | 20.80 | 0.23 | " | " |
| 69 | 6.81 | 40.96 | 2.96 | 33.06 | — | 11.24 | 1.07 | " | " |
| 09 | 11.10 | 44.78 | 3.93 | 22.38 | — | 11.42 | 2.65 | " | " |
| 09 b | 4.03 | 23.21 | 1.63 | 33.17 | — | 19.74 | 1.48 | " | " |
| 14 x | 4.21 | 28.90 | 4.77 | 48.75 | 0.4 | 6.32 | 0.29 | " | " |
| 14 b | 2.80 | 32.73 | 6.16 | 43.13 | 2.23 | 5.17 | 1.86 | " | " |
| 72 a | 2.64 | 36.77 | 0.98 | 34.91 | 0.80 | 12.10 | 1.42 | 4.04 | 1.36 |
| 72 b | 1.71 | 38.65 | 0.91 | 34.56 | 1.00 | 12.76 | 0.18 | 2.07 | 1.39 |
| 72 c | 1.32 | 40.50 | 0.41 | 31.48 | 1.13 | 16.85 | 4.48 | 2.65 | 0.74 |

n.d = not determined.

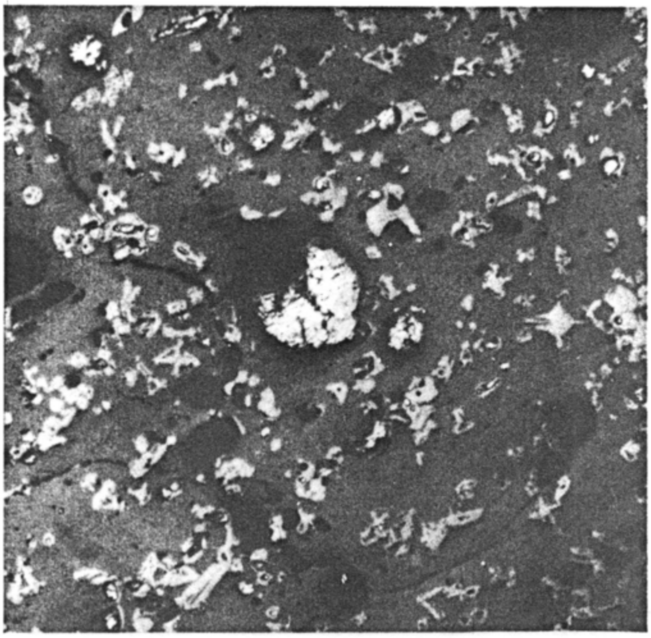

**Fig. 2 — Chalcolithic slag (53) with copper drops (white), and magnetite crystals (white-grey) × 250**

**Metallic copper**

No pieces of metallic copper were found, but in the slags there were metallic drops of 0.1-3 mm diameter with a relatively high content of copper (97.43-98.88% Cu), and only small quantities of iron (0.24-0.30% Fe), which may be the result of the large content of silica in the slags. In the drops there is some cuprous oxide and small quantities of lead.

## THE SMELTING FURNACE

One furnace was excavated on site 39 with a diameter of about 50 cm; the surviving furnace wall was 25-30 cm high. It is therefore most probable that the walls were higher. No tuyeres or parts of them were found. For building stones, compact sandstone was used (Fig. 3).

The bottom layer of the furnace consisted of a siliceous material with clay additions: 76% $SiO_2$, 11.84% $Al_2O_3$, 2.32% FeO, 1.73% CaO, 0.46% MgO.

A grey material found in the furnace had the following composition: 65.32% $SiO_2$, 7.57% FeO, 6.67% CaO, 0.20% MnO, 3.79% $Al_2O_3$, 1.43% MgO, 2.95% $K_2O$, 1.10% $Na_2O$, and 2.42% Cu.

The nature of this copper content was investigated using D.T.A. on a Stanton instrument (Standata type) with a rate of heating of 10° per minute, the very characteristic peak of malachite (380°C) was obtained. This malachite is either the original mineral or the product of secondary carbonation of the copper oxide or copper drops. The fact that the peak of malachite is the only one to appear is an argument for the hypothesis that it was the original mineral. The oxidation and carbonation products of materials recently obtained show a large number of peaks for oxides and carbonates and not merely one.

## FUEL

Pieces of charcoal with the same appearance as the charcoal found in the E.I.A. furnaces[3,4] were found in the furnace together with the slags. That means that the same acacia trees from the Arabah were used as raw material for the charcoal. This is the only material that can be used in the region to obtain the necessary temperature to smelt copper ores and at the same time obtain the reduction of copper oxides. The charcoal contains 0.7-1.0% $Na_2O$ and 1.5-2.5% $K_2O$, i.e. the same ratio as in the slags (Table II).

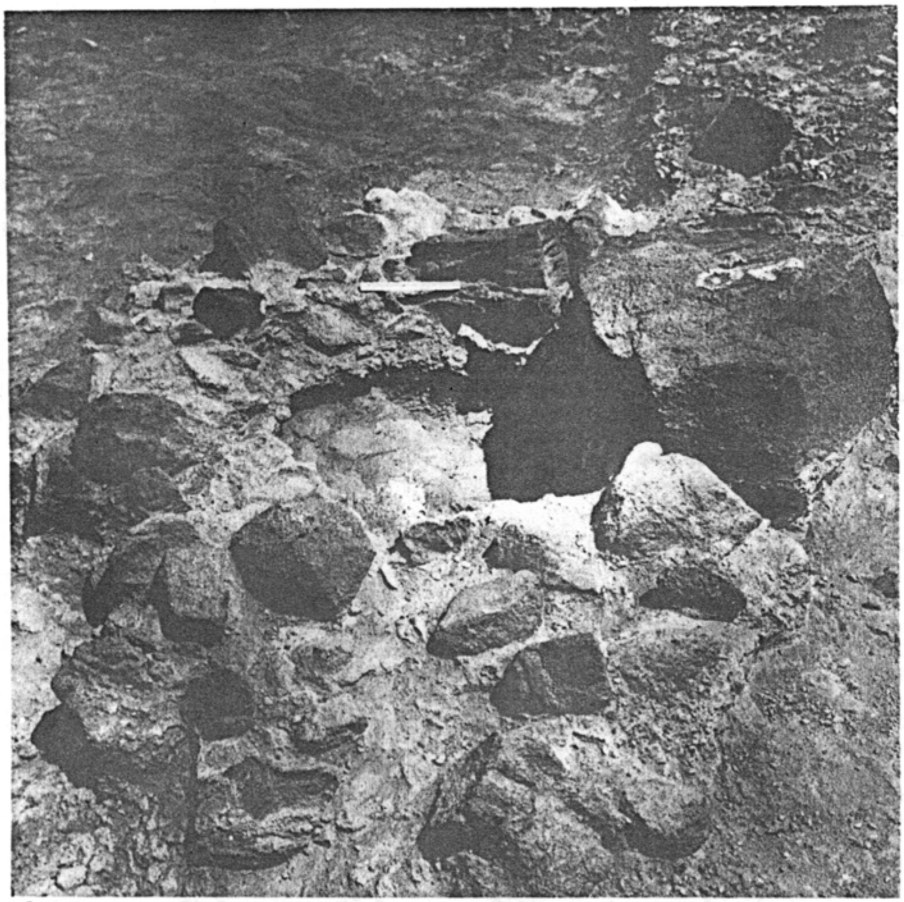

**Fig. 3 — The Chalcolithic smelting furnace (scale = 10 cm)**

## THE SMELTING PROCESS

The copper ores, carbonates, and oxides were crushed and mixed together with charcoal and fluxes, and smelted in the furnace which had silica sandstone walls. No roasting process was necessary since the carbonates have a low decomposition temperature (380-450°C). There is no doubt that air was blown by means of bellows since in such a type of furnace and in such a flat place any other method would have been impossible. The temperatures required for the reduction process were obtained by burning charcoal. During smelting the resulting copper sank to the bottom and, owing to its lower specific gravity, the slag formed a layer above it. After the furnace was filled with the smelting materials, the slags and the copper were allowed to cool in the furnace. The slags were broken and the solidified copper ingot was then taken out of the furnace. The temperatures obtained in the smelting process were 1180-1350°C (melting range of the slags).

The applied technology indicates an already advanced stage but not yet far from the first beginnings of copper smelting. Slags with 5-15% Cu indicate a very low extraction efficiency of less than 40-50%.

## SUMMARY AND CONCLUSIONS

The Chalcolithic smelting process was performed at temperatures of 1180-1350°C, using charcoal as fuel and air-blowing. The ores were carbonates and some oxides, and for fluxes iron ores (fossilized trees) and limestone were used. The slag compositions indicate a low efficiency of copper extraction, and not a developed technology. This stone-built furnace is the first furnace discovered for the extraction of copper from oxidized carbonate ores.

## AKNOWLEDGEMENTS

The author wishes to acknowledge the financial assistance provided by the Technion-Israel Institute of Technology. The author is pleased to thank Dr R. F. Tylecote (University of Newcastle upon Tyne, England) for very helpful comments and useful discussions about this investigation, and Mrs R. Malina for the chemical analysis.

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# Recent work on early ironworking sites in the Stamford area

R. F. TYLECOTE

One would not think as one goes through the charming town of Stamford, now by-passed by the Great North Road, that it was an important iron production centre in Roman and medieval times. Yet, a number of excavations in the last few years have shown that this is the case. The town lies astride the Northampton Sand ore deposits, and there must have been many outcrops of ore in the valley of the Welland and in the surrounding streams. Recent work by Simpson[1] in the town itself shows the site of eight Saxon/early medieval slag heaps and so far most of the excavated material belongs to this period.

In a sand quarry at Pickworth (N.G.R. TF 002148) about five miles north-west of Stamford, Smith[2] excavated the remains of two shaft furnaces which are clearly the same as those found at Ashwicken in Norfolk[4]. The Pickworth furnaces were dated by Aitken and Weaver[3] by archeomagnetic means to the period A.D. 100-150 and agree in this respect as well with those from Ashwicken. The archaeological evidence of colour-coated pottery also put the site into the 2nd century. At least three furnaces were built into the sides of a sand pit and were 3-4 ft high and 12 in diameter internally. The two excavated had a single opening at the front through which air was blown or induced, and slag tapped (Figs. 1-3). It would seem that there was only one slag-tapping pit in front of each of the furnaces. The shafts showed signs of alternate layers of red and blue burnt clay, but only one complete sequence that went from black on the inside of the shaft through blue-grey to red. Possibly the linings were built into old disused furnaces. As at Ashwicken[4], the clay showed signs of fingermarks due to fettling. There was plenty of tap slag but not much cinder or ore. The ore was nodular and one roasted nodule from the site was analysed (Table I, D), but this had a very low iron content and must have been discarded. A roasted ore nodule from the Co-operative site in Stamford gave a much higher iron content[5]. It is probable that the good and bad nodules could be distinguished after roasting. According to Taylor[7], nodules can be found at the base of the Upper Estuarine Series above the bedded ores of the Oolitic ironstone horizon which now produces most of the ore mined in the area.

The Roman villa at Clipsham lies seven miles north-west of Stamford (N.G.R. SK 995162) and has a late Roman or post-Roman bloomery built into it which at some stage would repay excavation. A good deal of tap slag and cinder is visible but no ore was found. There was a layer of charcoal below the slag heap which was retained by two walls of the villa. Slag runners could be seen which confirmed the tapping of the slag. As will be seen in Table II, the slag analysis is very similar to that from Pickworth.

The excavation of another Romano-British iron working site in this area at Great Casterton (N.G.R. TF 000 095) has already been reported[9]. It produced an iron-ore roasting furnace which was very similar to that found by Dakin at Bedford Purlieus (TF 048997)[10].

**TABLE I Analyses of ores, %**

| | Stamford[6] | | | Pickworth[6] |
|---|---|---|---|---|
| | A | B | C | D |
| | Crust from nodule (unroasted) | Roasted fines | Roasted nodule | Roasted nodule |
| FeO | n.d. | n.d. | n.d. | 0.4 |
| $Fe_2O_3$ | 41.2 | 55.2 | 80.2 | 17.1 |
| $SiO_2$ | 36.9 | 25.6 | 10.7 | 75.1 |
| $Al_2O_3$ | 3.7 | 6.9 | 5.4 | 2.2 |
| CaO | 2.4 | 1.7 | 0.6 | tr. |
| MgO | 0.1 | 0.1 | 0.1 | 0.6 |
| $TiO_2$ | 0.4 | 0.4 | 0.2 | n.d. |
| MnO | 0.1 | 0.1 | 0.1 | n.d. |
| $P_2O_5$ | 2.38 | 1.56 | 0.34 | 0.1 |
| $H_2O + CO_2$ | 13.02 | 6.92 | 1.25 | n.d. |
| S | 0.41 | 0.07 | 0.03 | n.d. |

**TABLE II Analyses of slags (%)**

| | Tap slag | | Cinder |
|---|---|---|---|
| | Pickworth[8] | Clipsham[8] | Stamford[6] |
| $Fe_2O_3$ | 1.71 | 3.00 | n.d. |
| FeO | 59.91 | 59.01 | 54.9 |
| $SiO_2$ | 28.76 | 25.28 | 16.6 |
| CaO | 2.5 | 1.3 | 3.0 |
| MgO | 0.18 | 0.86 | 0.1 |
| MnO | 0.98 | 0.05 | 0.1 |
| $Al_2O_3$ | 5.32 | 5.42 | 4.6 |
| $P_2O_5$ | 0.19 | 0.16 | 1.26 |
| $TiO_2$ | n.d. | n.d. | 0.3 |
| S | n.d. | n.d. | 0.09 |
| $H_2O + CO_2$ | n.d. | n.d. | 7.58 |

n.d. = not determined.

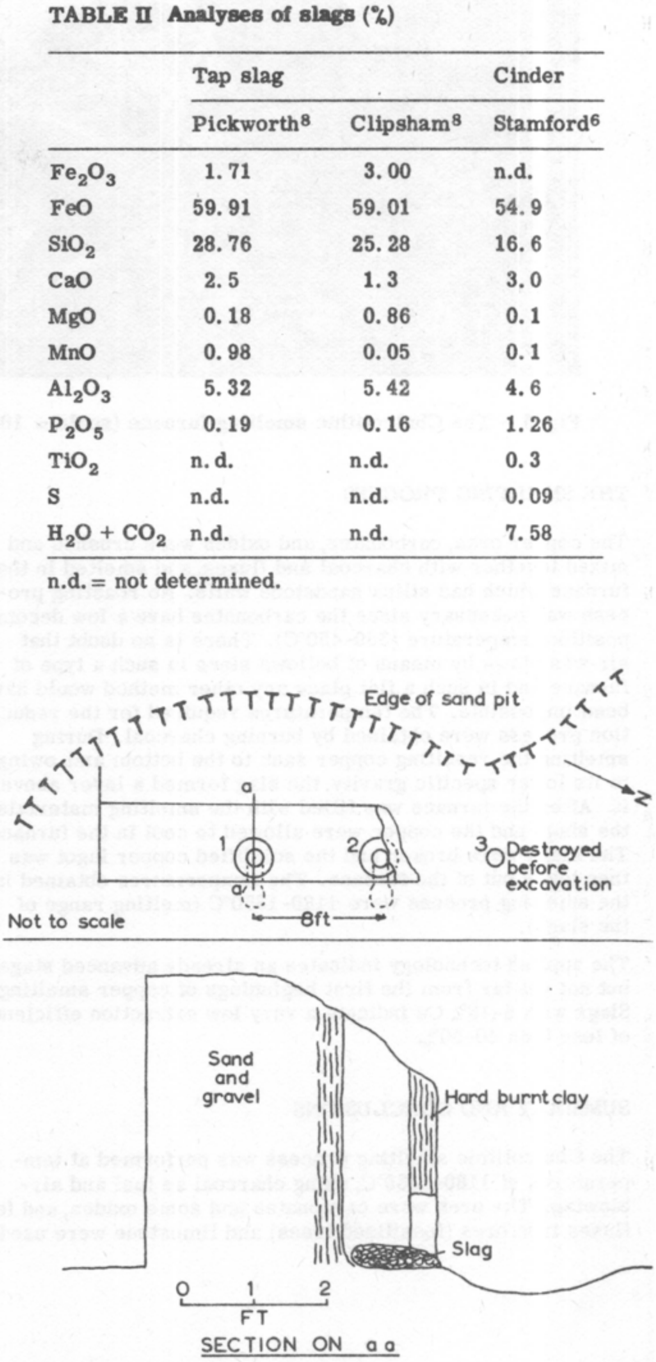

Fig. 1 — Sectional drawing of Pickworth furnace

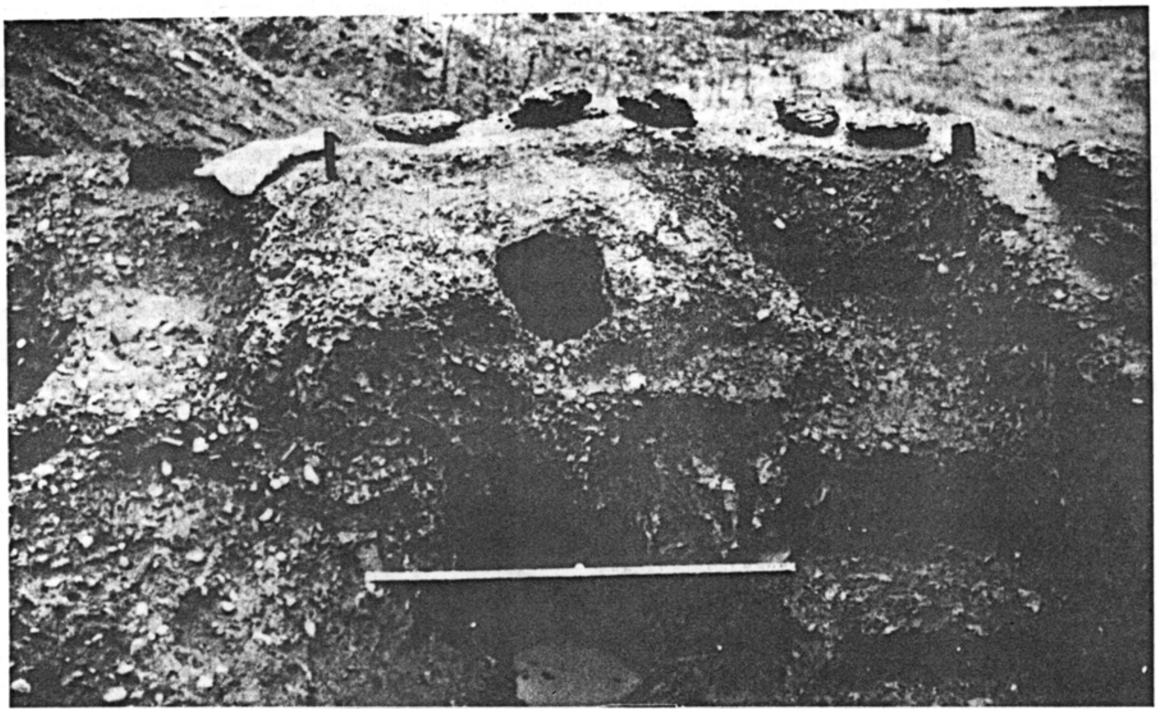

**Fig. 2 — Pickworth furnace 1 from east (rule is 3 ft long)**

**Fig. 3 — Pickworth furnace 2 from north**

There is little doubt that this area was extensively exploited in Roman times. Smelting of the nodular oxidized carbonate ores was preceded by roasting in large bowl furnaces. The smelting itself was carried out for the most part in shaft furnaces which are well adapted to working such easily reducible ores. There are now about eight examples of the 1 ft diameter, 6 ft high shaft furnace known, which makes it the most typical of Roman-period furnaces in this country.

Let us now look at the town of Stamford in Saxon-Medieval times. In the winter of 1963-64 A. M. Burchard[5] excavated the Co-operative site in the centre of Stamford and at considerable depth came across an iron working site of the first half of the 11th century. The archaeomagnetic dating gives about A.D. 1050[11] and the presence of developed Stamford ware means that it could not be later than the end of the 12th century. The site produced the base of a smelting furnace of the shaft or bowl type with a slag-tapping pit in front of it. It also produced a large circular red-burnt area about 6ft in diameter and some 10 ft from the furnace; this was undoubtedly a roasting hearth. Most of the excavated area was covered with a layer of red ore fines 2-9 in thick. Besides the slag, cinder, and ore there were pieces of furnace bottom with slag attached, which suggested a furnace diameter of about 9 in. The largest piece of tap-slag was about 8 in × 5 in with a V bottom. As will be seen from the analyses (Table I, B and C), the ore was of good quality. The fines had a charcoal content of 5.02% which probably represented residual fuel from roasting. A layer of red fines lay above the hearth level, and above this was a layer of slag capped with clay on top of which was modern fill. There is no doubt that iron smelting went on for a considerable time after the period of the furnace.

Although only the bottom few inches of the furnace were found (Fig. 4), it does not seem to be as substantial as the base of the Ashwicken-Pickworth type furnaces, and for this reason I am inclined to classify it as a low shaft furnace as reconstructed in Fig. 5. No tuyeres were found and the clay of the base was very soft so the reconstruction

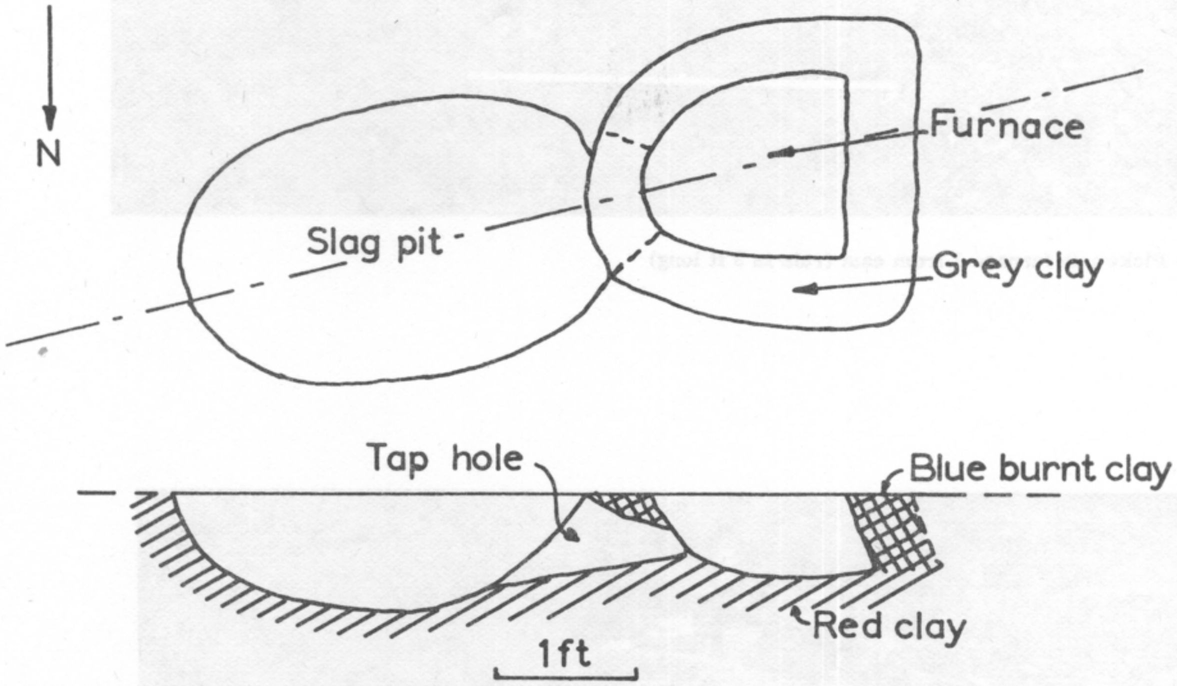

Fig. 4 — Stamford furnace

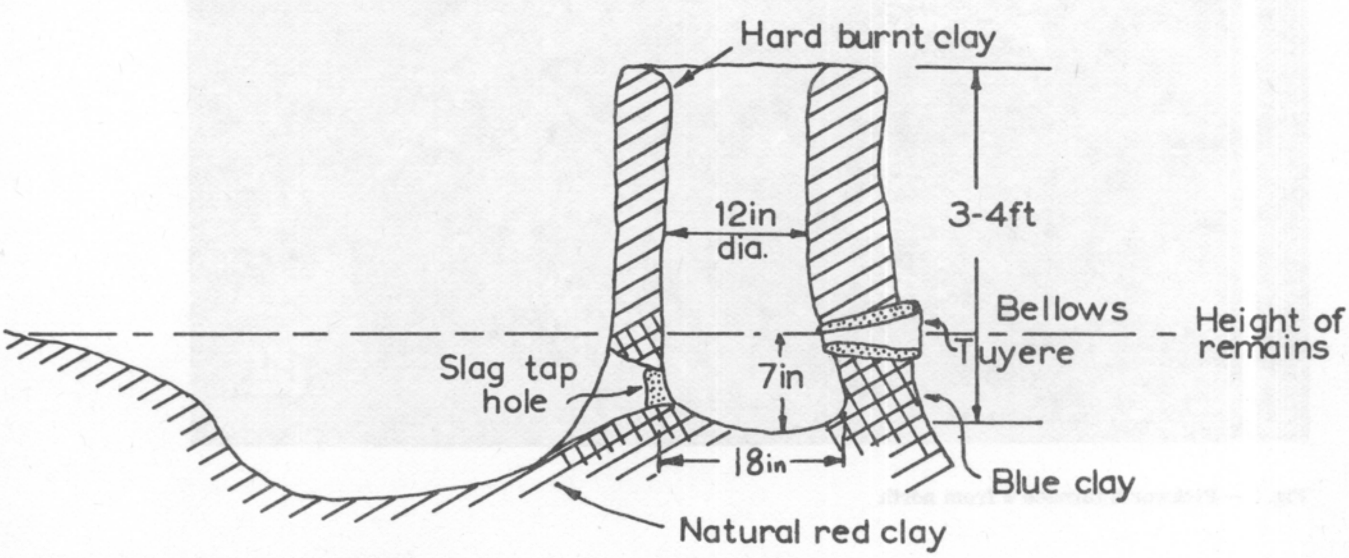

Fig. 5 — Reconstruction of Stamford furnace

must be regarded as being very tentative. In some ways it resembles the 13th century furnace from High Bishopley in Co. Durham.[13]

The excavations begun by Burchard were continued by Gavin Simpson[12], who excavated further Saxon-Medieval sites in the centre of the town. He has found more tap-slag, cinder and charcoal. A pit on one of his sites produced a large piece of unroasted marlstone containing a boxstone which would make very high-grade ore. The nearest known outcrop of the Marlstone series is about ten miles away to the west, but probably there are some nearer, but unknown, outcrops. This work is now being carried on by Miss Christine Mahany.

## ACKNOWLEDGMENTS

I am deeply indebted to the excavators, A. M. Burchard, W. G. Simpson, and I. M. Smith who so kindly allowed me access to their unpublished material. The archaeological aspects of this report may possibly be changed when the final excavation reports are published. The metallurgical conclusions are my own.

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# Excavation at Stony Hazel, High Furnace, Lake District, 1968-1969: an interim report

M. DAVIES-SHIEL

The site is listed in A. Fell's 'Iron Industry of Furness 1700-1800', as 'a bloomery forge, a dwelling house, Colehouses, iron house and other buildings and conveniences', built in 1718 and assigned two years later to the Cunsey Company (who erected the first Lakeland blast furnace in 1710).

Stony Hazel lies on the east side of Force Beck, 1/4 mile WNW of Rusland Church, and on an early packhorse trail leading from the head of Rusland Pool, once tidal. (N.G.R. SD, 336897)

The site (Fig. 1), consists of a ruined weir, 250 ft long headrace, 270 ft long millpond, 110 ft waterwheel race, and two main buildings, all under a steep river bank about 25 ft high. On the bank are clear remains of a loading ramp, beginning where the pack trail ends, and some rectangular pits and humps well strewn (at depth) with salt-glaze pottery. They may have been living quarters. On the trail is a heap of stone suggesting the site of the dwelling house.

Building A has now been almost completely cleared of +3 ft of debris. Building B has not been touched to date. Figure 2 shows the layout of building A. The ore bin (1) in the NE corner is bottomed with stone and only holds 3 in of hematite ore. The central stone of the retaining wall is worn with constant ore-breaking on it. Alignment of the buttresses (2) and (3) with the hearth ends suggests two main roof supports. At (4) were the clear remains of a wooden box 15 in square, that had contained several inches of finely powdered hematite ore. At (5) a natural rocky ledge has been turned into a staircase leading up the bank. At (6) in the central floor is a broken hammer-head, used as an intermediate anvil. It weighs close on 2 cwt but its complete weight must have been nearly 4 cwt. The floor around it is full of scale. At (7) is an anvil base made of a single large log over 2 ft in diameter, sunk into the ground vertically. About 14 in of length is showing and a worn shaped hollow into which the iron anvil fitted. There was an iron sheath around it, with iron sprigs holding it in place. One of these was found in situ.

Between the anvil and the gable/dam wall are two wooden baulks (8) and (9), sunk horizontally into the composite slag-ore floor. Baulk (8) is 11 ft long by 10 in square. Six inches of its cross-section lies below the level of the floor at the anvil. Baulk (9) is 3 ft 6 in long by 13 in square and 11 in of its thickness is sunk in the floor. Between the two is an exceptionally hard charcoal/slag area. Distance from wall to centre of anvil is 6 ft 6 in, suggesting a helve or belly-helve hammer.

In areas (11) and (12) the dam had previously burst and undermined the hard slagged floor crust, leaving a ragged edge. The wheelrace (11) to (17) varies from 3 ft at the dam to 5 ft width at point (13) where it appears the bellows waterwheel was situated. The hammer wheel could have been mid-breast but the bellows wheel would be undershot.

At (15) is a deep hole that appears to have been the end of the water-wheel shaft. A drain crosses the floor from (16) to (17), sunk 1 ft below groundlevel. At (18) is a pile of pure charcoal apparently dumped ready to put into the hearth. Pottery, some of it beautiful yellow slipware dishes, is at present at the Lancs R.O. being dated.

## THE HEARTH (Figs 3 and 4).

Two of the four detailed drawings recorded at various stages of excavation are shown. If Schubert's drawings* of a finery hearth are correct, this must be such as he shows for the 17th century, but much larger and with an unexplained clay-lined 'hearth' at the eastern end. Hammer weight and hearth size do not fit an Osmund hearth, though. No iron plates for the hearth are in position but some pieces about 1½ in thick were found near the furnace square. The stone above the tuyere arch had collapsed in and destroyed any clue as to the exact location of the tuyere in the 4-course brick wall beneath (now mostly crumbled away). Several large-headed nails came from the ground on the outer edge of this archway. No slag, charcoal, or ore lay on this ground,

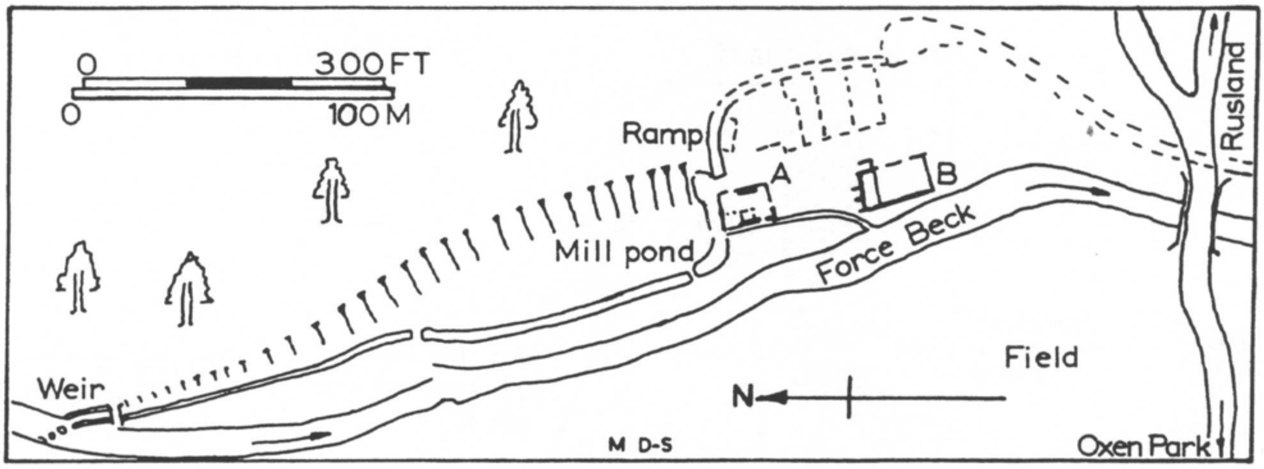

Fig. 1 — Stony Hazel Forge

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* H. R. Schubert: 'History of the British Iron & Steel Industry', Appendix 15, p. 421.

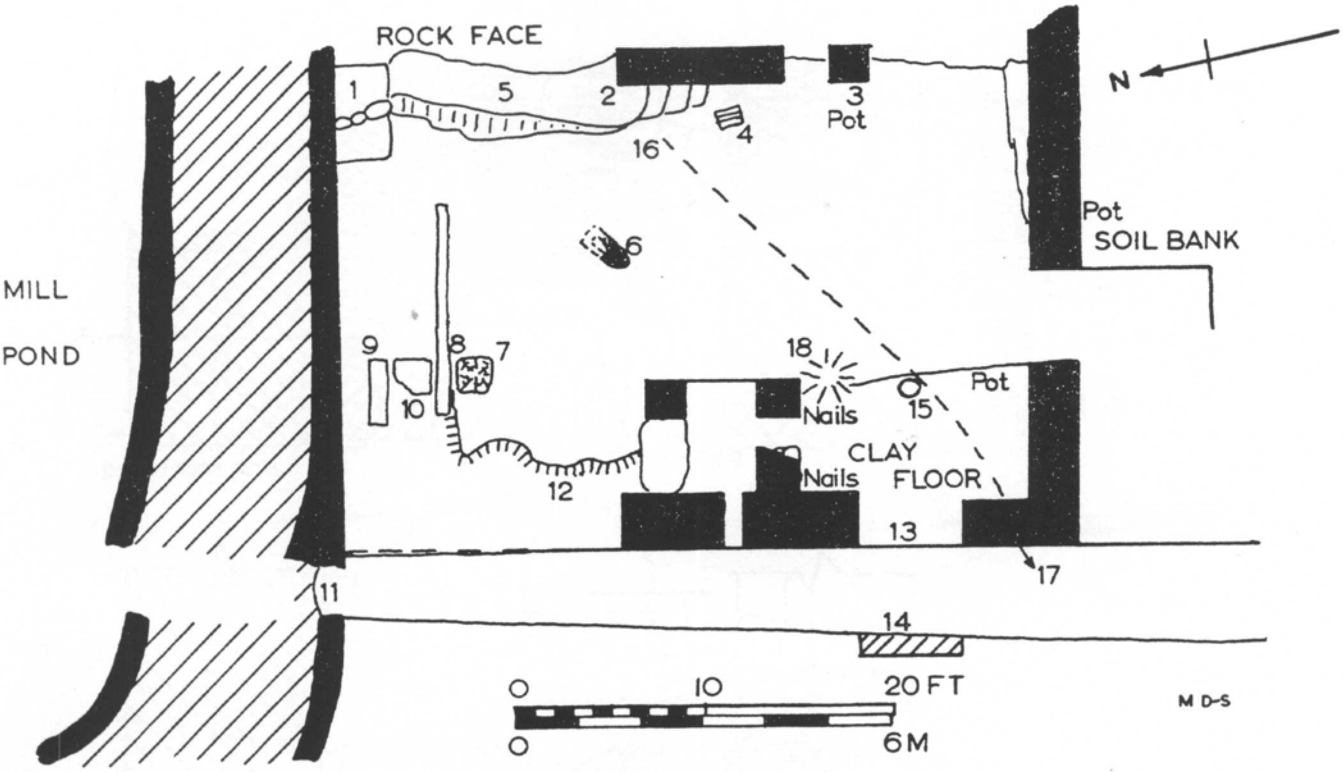


**Fig. 2 — Plan of building A**

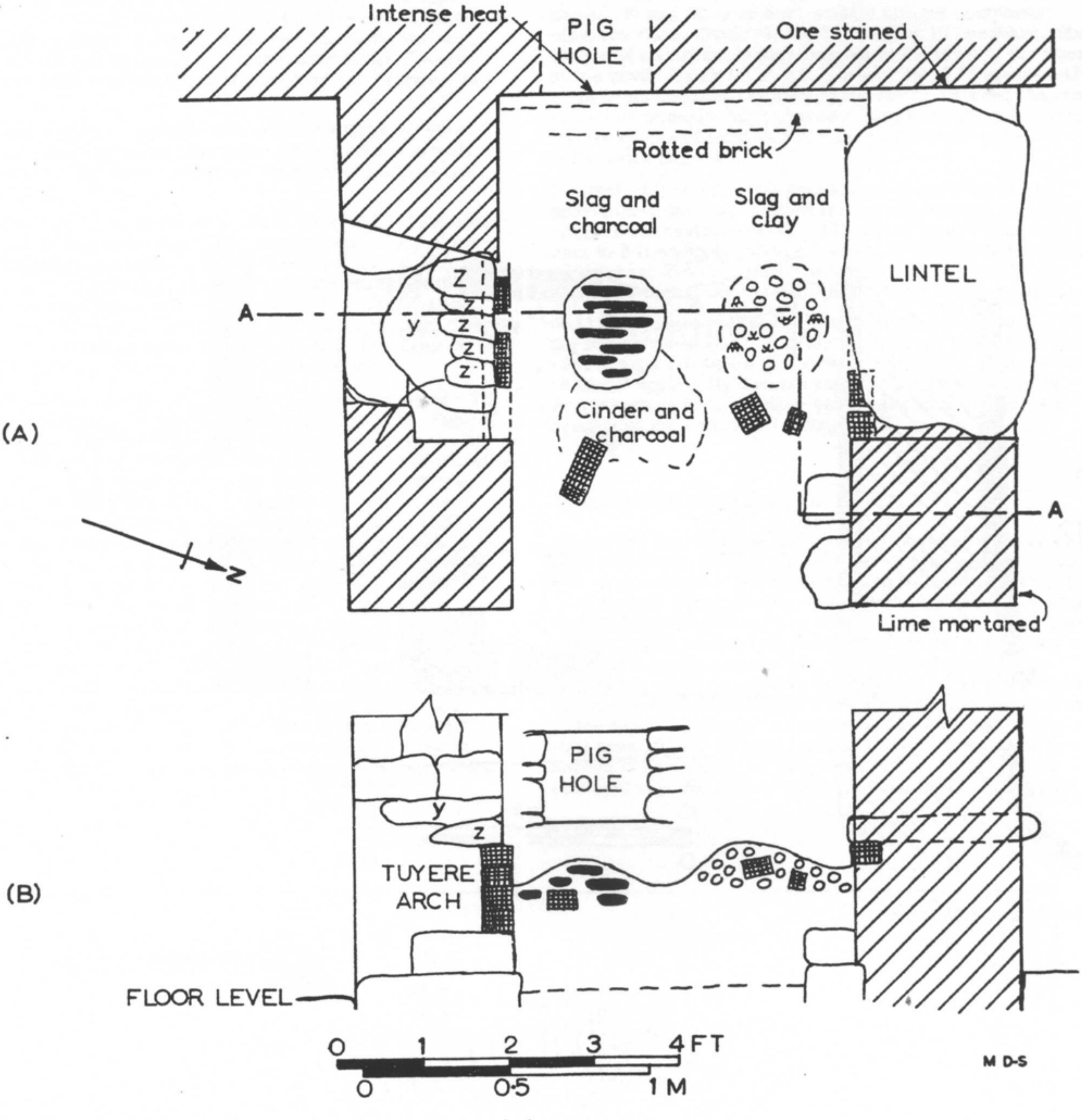


Fig. 3 — Hearth plan 18 in above floor and section on A-A

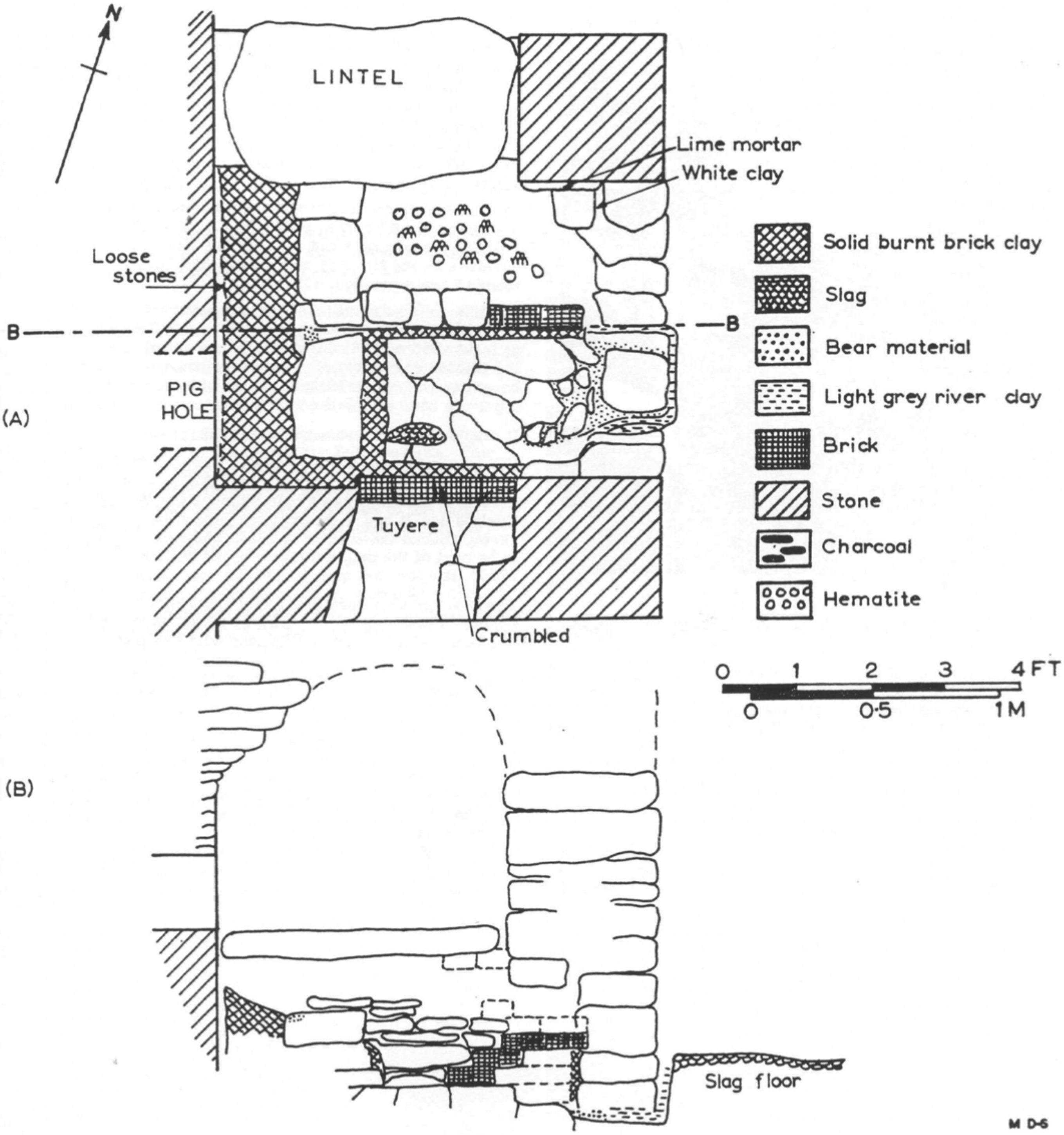


Fig. 4 — Plan 6 in above floor level and section on B–B

Fig. 5 — View of finery hearth from east (Scale: pig hole is 14 in wide)

only a soft yellow clay indicating that this floor was not trodden upon. At the eastern opening was much cinder and charcoal but no ore. At the northern lintel was much ore but nothing else.

The presence of this ore is something of a puzzle as also is the absence of a chafery forge, that ought to be on the site, probably at the northern end of building B. The alignment of part of this section with the water-race suggests a water-wheel pit, a bellows, and large forge. The large amount of huge stones here suggests a solid chimney at one time. There might have been a tailrace passing under B and exiting in the beck near the present roadbridge. It would be a much better outfall than the present spot. As it is, the end of the present inefficient race narrows towards the back and is poorly (re)built of mossers, suggesting that a new process was begun that did not require the use of a chafery.

The levels and composition of the floor suggest that, at an early stage of site use, there was a bloomery or forge occupying the SE corner of building A. The whole of the walls at the southern end have stones with heavily burnt surfaces facing inwards, suggesting total rebuilding, using stones from a previous (?) furnace.

Documentary evidence shows that the site was at first in private hands, then belonged to the Cunsey Company until at least 1755, when it was made over at a valuable sum to the Duddon Company. Although Harrison, Ainslie & Co. bought up Duddon in 1818, the forge was only made over to a private band of locals in 1822 at a near-nominal amount.

It may still have been working in 1833.

If the use of iron ore in the hearth was to obtain partial oxidation of the cast iron, when was that process introduced here? Schubert intimates that, although the method was an English one, it had been forgotten until a Samuel Lucas re-introduced the method in 1804. The ramp and bin appear to be part of the original fabric of the building complex of 1718.

The site calls for further careful excavation to answer these problems and those of the chafery forge. Much of the ore has been left in situ in the furnace with this purpose in mind.

# Panningridge Furnace, Sussex: interim report on 1969 excavations

D.W.CROSSLEY

During the 1968 season the greater part of the plan of a furnace had been recovered, with, superimposed, traces of a later robbed structure, now seen to be a furnace, and an associated water-channel.

The aim of the 1969 season was to elucidate the relationship of these features and to trace and assess the means for operation of the bellows of the early furnace. Operations had to be completed in 1969 prior to the use of the site for drainage of the surrounding land.

The area stripped in 1968 was extended to the north, towards the dam, and to the east, towards the slag heaps investigated in 1967. The following features were recorded:

**Furnace 1**—The NE corner was traced, although only a small quantity of the core of the wall remained; the facing had been entirely robbed. To the north west lay the bellows-house floor, indicated by wooden sleepers and uprights remaining in situ, and by scraps of leather and nails of appropriate type lying on an uneven surface of small stones.

An overshot waterwheel was partially preserved in a timber wheel-pit immediately to the east of the bellows area. The wheel was only 12 in wide, narrow even for this period; its diameter was 12 ft, calculated from measurements taken on the spot. The wheel-pit lay at right-angles to the dam and was drained by a tailrace running southwards past the eastern side of the furnace.

This layout makes it clear that the arch in the east wall of the furnace, recorded in 1968, could not accommodate the bellows-tuyere. Its purpose appears most likely to have been an inspection aperture for use by the founder.

**Furnace 2**—Although the structure of the furnace itself had been completely robbed, a number of features from this period had survived.

The wheel pit had been built over the north-west corner of the early furnace: it was of similar timber construction to its predecessor, but the wheel itself was 6 in wider; the timber of the (overshot) wheel, however, was badly preserved, and distortion, apart from making this figure approximate, will hamper calculation of the diameter. The tail-race cut through the northern and eastern part of the early furnace, thence turning sharply to join the line of the channel from the early wheel. Water was fed, not directly over the dam as in period 1, but from the west, through a channel high in the spur linking the charging ramp to the dam. It had reached this channel from the pond through a further channel in the main dam itself, and it must be assumed that the marshy ground west of the charging ramp was the site of a penstock from which water could be run either to the wheel or down an overflow along the foot of the hillside west of the site. Contemporary with these features was a clear deposit of clay raising the dam and sealing the early wheel pit and bellows floor.

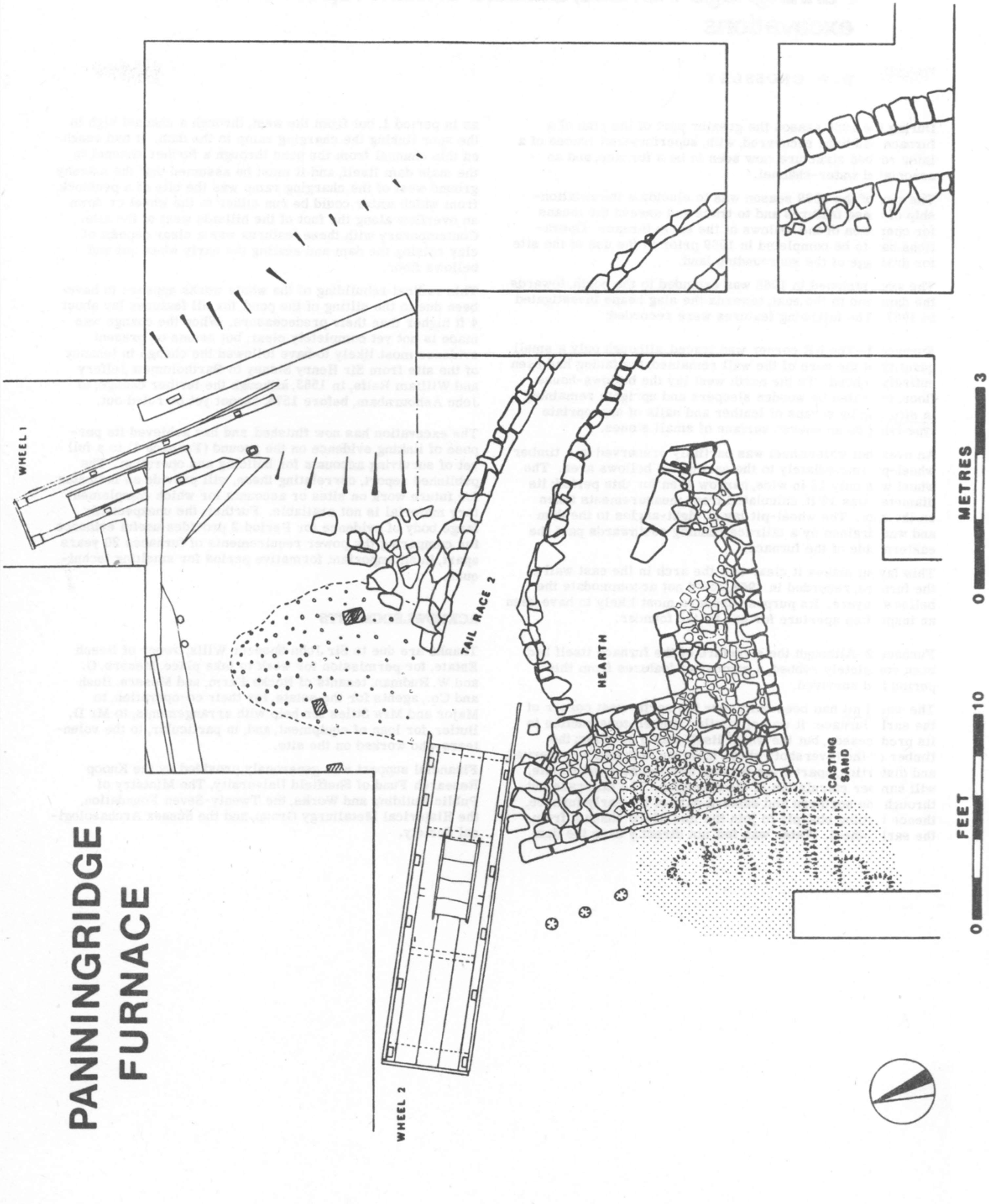
This radical rebuilding of the whole works appears to have been due to the silting of the pond, for all features lay about 4 ft higher than their predecessors. When the change was made is not yet completely clear, but seems on present evidence most likely to have followed the change in tenancy of the site from Sir Henry Sidney to Bartholomew Jeffery and William Relfe, in 1563, although the further change, to John Ashburnham, before 1574, cannot yet be ruled out.

The excavation has now finished, and has achieved its purpose of linking evidence on the ground (Furnace 1) to a full set of surviving accounts for building and operation. The published report, correlating these, will provide an indicator for future work on sites or accounts for which complementary material is not available. Further, the unexpectedly large body of evidence for Period 2 provides useful evidence for comparing the power requirements of furnaces 20 years apart, in an important formative period for smelting techniques.

## ACKNOWLEDGMENTS

Thanks are due to Sir John Spencer Wills, owner of Beech Estate, for permission for work to take place, Messrs. G. and W. Rudman, tenants of Rocks Farm, and Messrs. Bush and Co., agents for the estate, for their co-operation, to Major and Mrs Stiles for help with arrangements, to Mr D. Butler, for loan of equipment, and, in particular, to the volunteers who worked on the site.

Financial support was generously provided by the Knoop Research Fund of Sheffield University, The Ministry of Public Building and Works, the Twenty-Seven Foundation, the Historical Metallurgy Group, and the Sussex Archaeological Society.



PANNINGRIDGE FURNACE

# Correspondence

## Excavations at Panningridge (Bulletin Vol. 3, No. 1)

The excavations appear to have revealed a structure similar to that found by Hallett and Morton at Sharpley Pool, Worcs (Bulletin No. 6 Jan. 1966, page 11—Fig. 1). At Sharpley Pool there were more remains of the tuyere arch than at Panningridge and the foundations of the pillar were uncovered.

The general layout of the charcoal blast furnace is shown in Fig. 2 from which it will be seen that the forehearth is at right-angles to the tuyere arch; this was an essential feature of furnace design. In addition the head and tail races were generally kept as far away from the molten pig iron as possible, and usually ran round the back of the furnace. This type of layout has been observed at all the furnace sites examined by the writer. From this information it is possible to ascertain the position of the water wheel and the type of action (i.e. overshot, undershot, or breast).

As at Sharpley Pool the stream at Panningridge appears to have been diverted from its original course around the furnace. The weakest part of the structure would be in the region of the pillar and, when the dam at Sharpley Pool burst, the furnace was destroyed at the pillar and the stream followed its new course through the furnace near the hearth. The similarity of the remains suggests that the pillar at Panningridge collapsed, leaving the back and side walls of the furnace intact. If this was so, suggested reconstructions can be attempted.

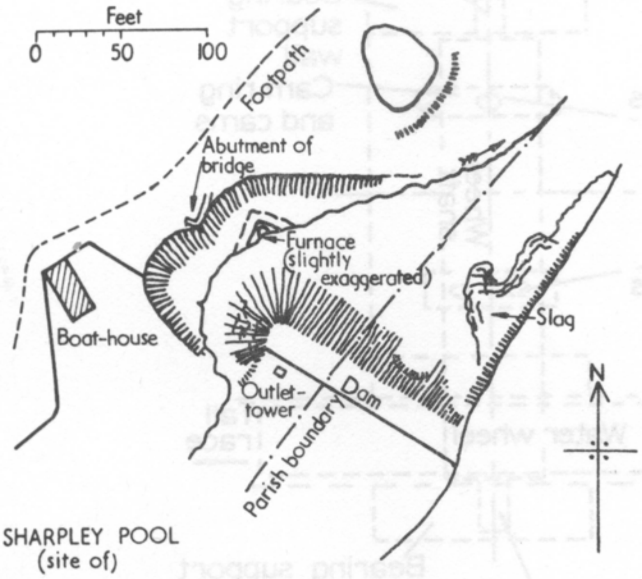
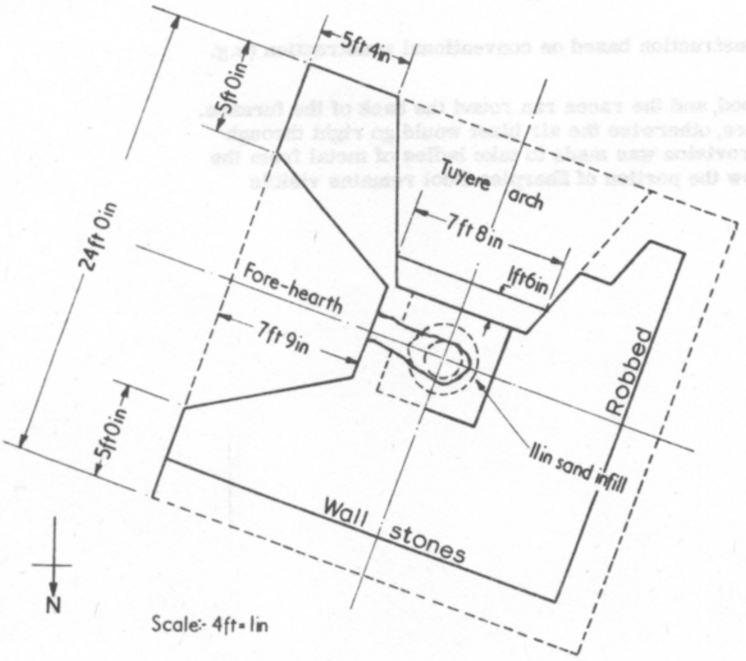
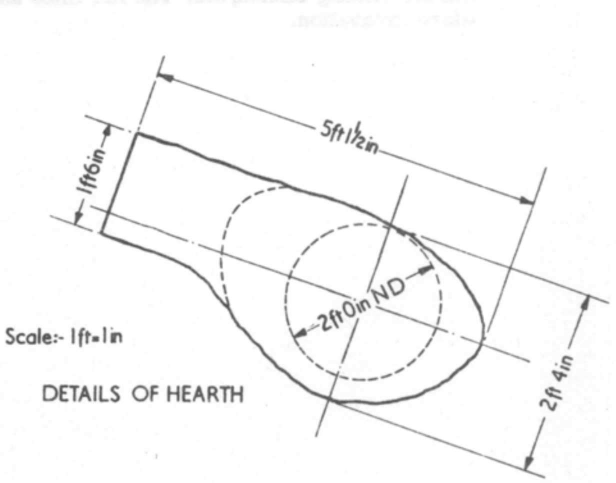


**Fig. 1 — Sharpley Pool: (a) general plan: (b) plan of furnace at tuyere sill level and details of the hearth (full lines show extent of excavated remains)**





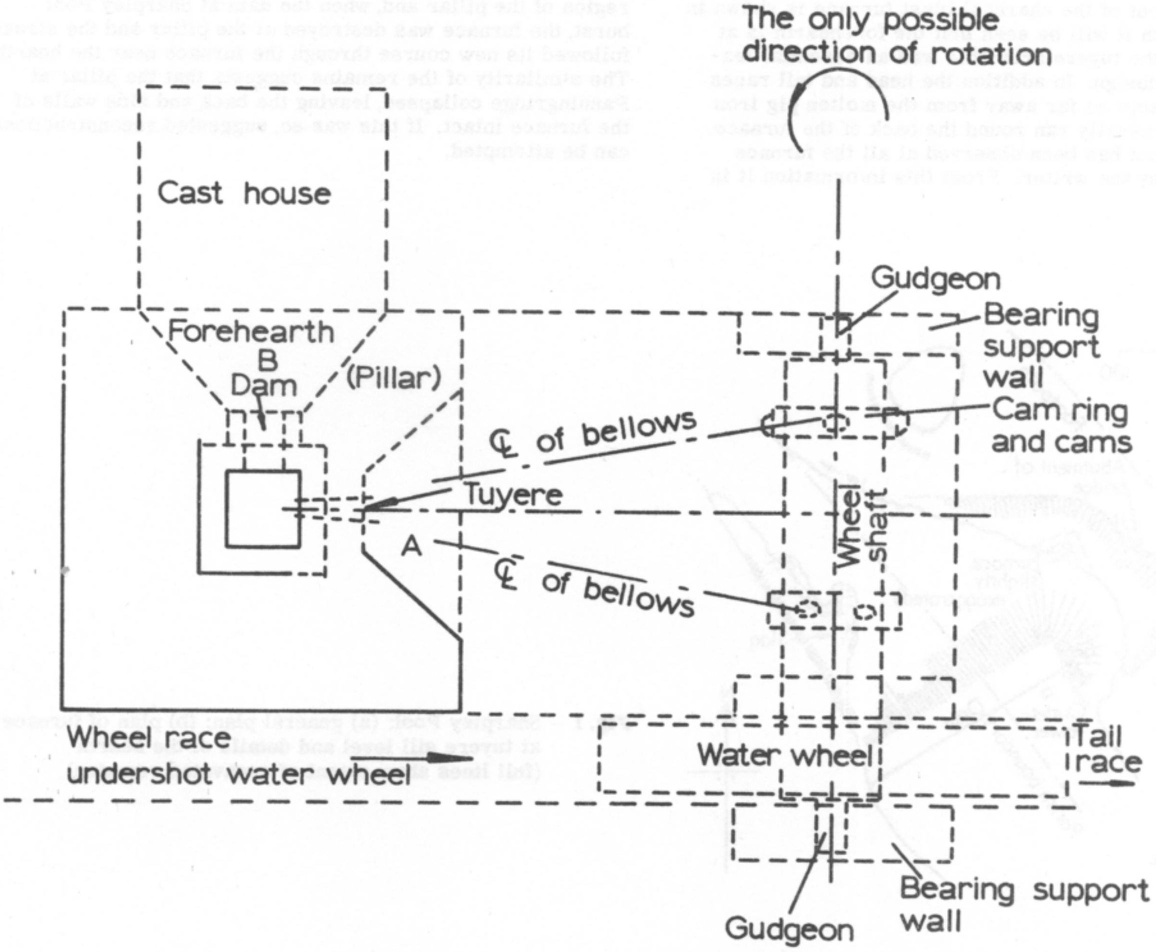


**Fig. 2 — General layout of charcoal blast furnace: reconstruction based on conventional construction (e.g. Rockley, Sharpley Pool, Charlcote, etc).**

**Note: Water was always kept clear of the pig bed, and the races ran round the back of the furnace. The cast house was at right-angles to the tuyere, otherwise the air blast would go right through the furnace. Sealed tap holes were not used; provision was made to take ladles of metal from the dam for casting cannon, etc. The full lines show the portion of Sharpley Pool remains visible before excavation.**

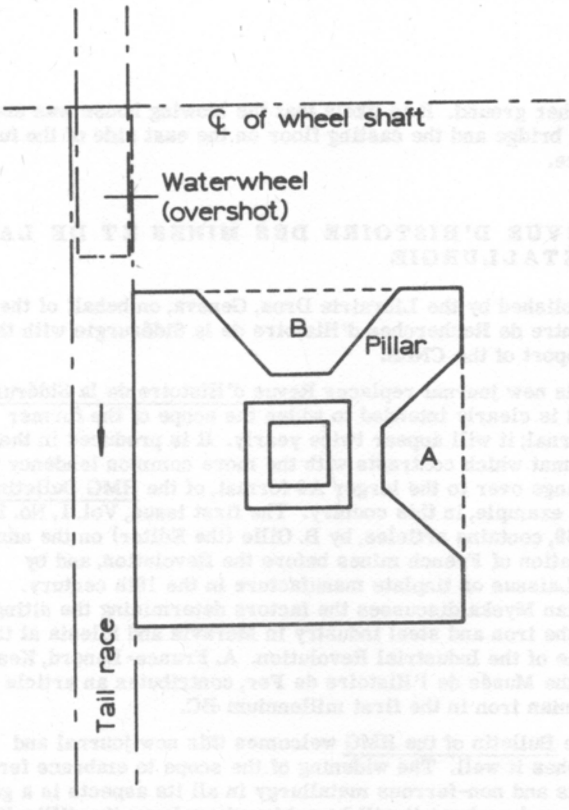


**Fig. 3 — Alternative position of water wheel**

If the conventional layout for charcoal furnaces is accepted, the position of the pillar at Panningridge would be as shown in Fig. 3, and the tuyere arch and forehearth either at A or B. If the arch was at A, the water wheel would be in the position shown in Fig. 2, i.e. the head-race running round the back of the furnace. In order that the cams on the wheel shaft should depress the bellows without tending to lift them, the direction of rotation would be as shown, and the wheel undershot. This means that the forehearth and pig bed would be situated at B.

If on the other hand the tuyere arch was at B, the waterwheel would be situated as in Fig. 3, and in order to obtain the correct direction of rotation it would be overshot. The sidewalls of the hearth and bosh would be supported by the inner square of the outer case. These walls seem to have disappeared, but the actual hearth should still be in place. This hearth structure would be of silica stone blocks which would probably show considerable slagging of the upper courses.

**G. R. Morton**

# Shorter Notes

## BAIRDS AND SCOTTISH STEELS LTD

This company took over the iron and steel interests of William Baird and Co. Ltd and the Scottish Iron and Steel Co. Ltd in 1939. It ceased operating at Northburn Works in 1966, and at Gartsherrie Ironworks in June 1967. The steelworks (four open-hearth furnaces, cogging and re-rolling mills) are now largely dismantled. The Gartsherrie Works were modernized in 1959-60, when a new 20 ft hearth mechanically charged blast furnace was built. A 6 ft × 102 ft single-strand sinter plant was installed, together with a new battery of 37 Becker coke ovens, new generating and blowing equipment, new ore stockyard, and a large range of ancillary equipment. The plant was commissioned and the furnace blown in 1960, and made about 5000 tons of merchant pig iron per week. Equipment was installed for oil injection at the tuyeres, but it was never fully commissioned. Gartsherrie must be the shortest lived blast furnace of the 20th century.

## CRALECKEN BLAST FURNACE, FURNACE, NEAR INVERGARRY (NS 025998)

This furnace worked from c. 1775 to about 1812. Up till now no serious work has been done on it, but Mr Hume and his colleagues in the University of Strathclyde expect to start work on it. The structure and casthouse are intact and in quite good condition, but trees are growing in the stack. There was only one tuyere and this seems to be still in position but largely buried. It is possible that the hearth is still intact and clearing of the rubbish and debris will provide some unique information.

The stream which provided the power is still there, and the remains of a pond. A large stone building behind the furnace may have been the charcoal store.

## SUSSEX BLOOMERIES

Our member, C. F. Tebbutt, informs us that two bloomery slag heaps have produced early medieval pottery which has been dated by Dr J. G. Hurst. The details are as follows:

1. Chantler's Farm, Hartfield (N.G.R. TQ 471388): The pottery is of the 12th or, at the latest, early 13th century.
2. Buxted (N.G.R. TQ 498225): The pottery is late 13th century.

These are believed to be the earliest known in the Weald after the Domesday reference to East Grinstead.

## DARKHILL IRONWORKS, COLEFORD, GLOS.

D. E. Bick is studying the history of this site connected with the Mushet family. He would be glad of any information; his address is 13, Rotunda Terrace, Cheltenham, Glos.

## WOOLPITCH WOOD FURNACE, MONMOUTH

P. G. Rattenbury and H. W. Paar have been studying the remains of this early furnace (N.G.R. SO 487048). It consists of the remains of a square stone-built blast furnace below a steep slope above which are the remains of a storehouse, no doubt serving the furnace by means of a 'bridge'. The storehouse remains indicate a building about 57 × 20 feet. According to 'Archaeology in Wales, 1964', there is evidence of a bridge which connected the charging platform with higher ground. It is likely that the blowing house was under the bridge and the casting floor on the east side of the furnace.

## REVUE D'HISTOIRE DES MINES ET DE LA MÉTALLURGIE

Published by the Librairie Droz, Geneva, on behalf of the Centre de Recherches d'Histoire de la Sidérurgie with the support of the CNRS.

This new journal replaces Revue d'Histoire de la Sidérurgie and is clearly intended to widen the scope of the former journal; it will appear twice yearly. It is produced in the A5 format which contrasts with the more common tendency to change over to the larger A4 format, of the HMG Bulletin for example, in this country. The first issue, Vol. 1, No. 1, 1969, contains articles, by B. Gille (the Editor) on the administration of French mines before the Revolution, and by F. Laissus on tinplate manufacture in the 18th century. Milan Myska discusses the factors determining the siting of the iron and steel industry in Moravia and Silesia at the time of the Industrial Revolution. A. France-Lanord, Keeper of the Musée de l'Histoire de Fer, contributes an article on Iranian iron in the first millennium BC.

The Bulletin of the HMG welcomes this new journal and wishes it well. The widening of the scope to embrace ferrous and non-ferrous metallurgy in all its aspects is a good aim and we hope it will be achieved; we know the difficulty of obtaining a balance of contents only too well.

## CORRIGENDA

The following corrigenda should be noted to Vol. 3, No. 2 of the Bulletin: Page 58 (Morton and Wingrove)

> Table VI should read: Table IV Visual Examination of representative samples of slag.
>
> The group letters require further clarification:
>
> A. Charcoal blast furnace, c. 1560-1600
> B. Charcoal blast furnace, c. 1650-1700
> C. Coke furnace, cold blast, c. 1770-1850
> D. Coke furnace, hot blast, c. 1850
> E. Modern.

Page 68 E. E. White should be included in the list of members present.

Page 47 First paragraph. For 'would' read 'wound'.

Page 54 For 'assoicated' read 'associated'.

## HONORARY TREASURER'S NOTES

### Back Numbers

Back numbers of the Bulletin are now available; certain early issues that had gone out of print have now been reprinted. They may be obtained from the Honorary Treasurer, C. R. Blick, 147 Whirlowdale Road, Sheffield S7 2NG, price 5s. each (post free)

### 1970 Conference

The date of the Annual Conference for 1970 (see p. 1 of this issue) has now been decided as the weekend of 4-5 September 1970; it will be held in Swansea. All enquiries should be sent to the Honorary Treasurer at the above address.

# Abstracts and Book Notices

## British Isles

**Roman ironworks in Britain** H. F. Cleere (Brit. Steel, 1969, March, 6-9) Ironmaking sites were widely distributed across the country, but the main concentrations were in the Weald of Sussex and the Forest of Dean. Various types of furnace were used for the smelting operation. In the Holbeanwood type, bellows were used for blowing, while the Ashwicken type used natural draught. It is conceivable that Britain was a major producer of iron for Gaul, Germany, and Spain.

**Bonawe Ironworks, Argyll** (Indust. Archaeol., 1969, 6, May, 193-195) The iron producing furnace belonging to the 18th-century iron works complex at Bonawe, near Taynuilt, Argyll, is described. It is stated that these works are perhaps the most complete charcoal ironworks surviving in Britain. The furnace, a massive square structure built of local stone, was supplied with blast by two water-driven bellows and iron ore was brought in via a small jetty on Loch Etive. Charcoal came from the nearby storehouses. The furnace had a capacity of about 750 tons per annum. Photographs of the furnace during reconstruction and the terminal for importing ore and exporting pig iron, are shown.

**Further observations on the Bowling Iron-works** C. Dodsworth (Indust. Archaeol., 1969, 6, May, 114-123) The origin and early history of the Bowling Iron Co. is discussed and the expansion during the war with France due to the trade in iron guns, is mentioned. The company's eventual decline from the 1860's onwards was due to competition from mild steel and the impending exhaustion of its coal reserves. The most interesting feature of the Bowling ironworks, namely the transport network, is described and an 1831 map of the tramroads serving Bowling is shown. The evolution of the railway network is described and an account of the narrow-gauge system is given. The 1871 map of the works shows the location of the coking area, blast furnaces and casting pits, rolling and forging sections, steam-hammer forge and engine department. (10 refs.)

**Excavations at Rockley Smithies, a water-powered bloomery of the sixteenth and seventeenth centuries.** D. W. Crossley and D. Ashurst (Post-Medieval Archaeol., 1968, 2, 10-54). The final report of an excavation that has been the subject of various interim reports in recent issues of the Bulletin.

**Fall Ings, Wakefield: Some notes on an 18th Century Foundry.** W. L. Norman (Indust. Archaeol., 1969, 6, Feb., 74-79) A brief account is given based mainly on 1792-1808 papers, with some newly-drawn plans of buildings.

**Costs in other days:** Records reveal Economic Background to an Early Nineteenth Century Foundry. C. McCombe. (Foundry Trade Journ., 1968, Oct. 10, 581-586). Attempts to reconstruct something of the day-to-day running of a small jobbing foundry at Workington about 150 years ago.

**Some Minor Metal Products of the EBA in Ireland.** P. Harbison (J. Cork Hist. Arch. Soc. 1967, 72, 93-100). Describes flat axes, awls, and spear heads and point out the existence of cakes of copper slag 10-20 cm dia. and 1 cm thick in 3 Irish hoards. Concludes that the smith separated copper from the slag as part of his activities as a travelling salesman.

**Mining and Metallurgy in EBA Ireland.** P. Harbison (North Munster Antiq. J. 1966, 10, 3-11). Lists EBA stone moulds from Ireland and suggests that some rough flat axes may be ingots for working.

**Casting a bell for Exeter Cathedral, 1372.** J. M. G. Scott (Trans. Devon. Assn. 1968, 100, 191-203).

## Europe

**The Norman forges in 1794.** G. Richard (Rev. Histoire Sidér., 1968, 10, (3), 251-310) [In Fr.] Reports on the forges, cannon foundries and manufacturers of the departments of Eure and Orne are reproduced and reviewed. Overall production figures for 1772, 1789, 1794 and 1802 are tabulated.

**Problems of mining technique in the Middle Ages.** B. Gille (Rev. Hist. Min. Mét. 1969, 1, (2) 279-296) [In Fr.]. There are other documentary sources than Agricola's 'De Re Metallica' for the understanding of the mining techniques of the Middle Ages. Mining regulations, on which the author quotes 26 publications, illustrations, of which some come from the XV and XVI centuries, and actual excavations. The last are less easy to interpret, if there have been pre-and post-mediaeval workings, but mines exist which it is known were abandoned in the XIV century, i.e. at the time of the Great Plague, and in some cases, there is architectural evidence. By such studies and comparisons, shaft-sinking, with and without lining, man-ways, working places, hoists, airways, lighting methods, tools, haulage and drainage can be identified, and the beginnings of application of mechanical power. Much, however, remains obscure, and the study of written sources, especially mining regulations, linguistic studies and actual excavation of mediaeval sites will help to make it more concrete.

**[The economic condition of] forges in Normandy in 1811.** G. Richard (Rev. Hist. Min. Mét, 1969, 1, (2) 151-232) [In Fr.]. In 1811, the French Ministry of the Interior carried out an investigation of the iron making industries to examine the effect thereon of the industrial crisis of that year. The interrogation reports on three districts of Normandy have survived; they show declines in production of varying degrees of severity since 1789, although the continental system had given them considerable shelter in 1802-1810, and production had increased during that period; it is concluded that this protection had been the downfall of the ironmasters leading them to neglect technical improvements, such as the use of coke and of the puddling process. Even after the fall of the Empire they were still protected by customs barriers, and the Industrial Revolution was a long time coming. The paper concludes with 66 pages of very detailed questioning of 15 ironmasters in Eure, Orne and Eure-et-Loir, in 1811-1812.

**Unpublished documents on the first blast-furnace at Klus (Soleure).** P. L. Pelet (Rev. Hist. Min. Mét., 1969, 1, (2) 129-150) [In Fr.]. The economic and political reasons for the setting-up of this establishment in Switzerland with French and Swiss capital, during the Napoleonic wars, in 1810-1813, are given. A long detailed description by Benjamin Dellient, a Swiss technician, follows: the furnace though solidly built seemed low by the technique of the time. The shaft was only 18', the throat 2'6" and the bosh 7'. The hearth was 16" wide at bottom. Dellient considered the bellows, driven by a rather small waterwheel, to be themselves too small, and working too fast for a reasonable life. He also considered the furnace to be badly run, not that the technical management was incompetent, but for other reasons he would put in a report which has not survived. The whole plant was spaciously and solidly built and the enterprise extravagantly run; with changes in economic and political circumstances, bankruptcy was very near in 1815, and only avoided by financial sacrifice and perseverance.

**The recovery of Le Creusot, 1836-1848.** J. B. Silly (Rev. Hist. Min. Mét., 1969, 1, (2), 233-278) [In F.]. When Le Creusot went bankrupt in 1833, the assets were bought by a consortium of creditors, with some of whom the banking family of Seillère soon formed an arrangement to re start the works. The brothers Adolphe and Eugène Schneider had a part in this arrangement, and technical control passed to the former. There were several years of technical development, and diversification of production, notably into machine building and locomotive construction before the concern reached its full stature as primarily concerned with heavy iron and steelwork for the engineering industries and, very notably, for railway companies in which it had considerable holdings. The Seillère bank advanced much money during these operations, but at the end of them, the Schneiders and their associates were the majority shareholders, and the company was among the leaders of the industry.

**100th Anniversary of the Development of the Blast Furnace in Bohemia.** Ivo Kruliš (Dějiny věd a techniky, 1969, 2, (2), 102-111). The growing need for raw iron led everywhere to an increase of volume in blast furnaces. When this logical measure went beyond a certain limit it led to a significant decrease in output. Metallurgists in England, France, and Germany had similar experiences to that in Bohemia. At Kladno, blast furnace 4 started work in January 1900. The furnace was 28 m high with a bosh diameter of 8.0 m and a capacity of 778 $m^3$. In the first quarter of 1901 the furnace produced 9525 tons of Thomas (basic Bessemer quality) pig iron; furnace 3 during the same period, with the same ore and a volume of 450 $m^3$ produced 9674 tons. The 328 $m^3$ greater volume of furnace 4 was not utilised. The author investigates errors in the dimension of the construction of furnace 4 based on Pawlov's measurements and their relationship of blast-furnace profiles. The furnace was too high by 2 m and the throat and bosh too wide by 1 m. In spite of some changes (e.g. more powerful blowing engines) the output of furnace 4 remained unsatisfactory, and it was rebuilt in 1912/13. Its volume was reduced to 514 $m^3$ and the rest of the principal dimensions were in accordance with Pawlov's formulae.

**Iron working on the Southern Frankenalp near Kelheim.** K. Schwarz, H. Tillmann, and W. Treibs (Jahresbericht d. Bayerischen Bodendenkmalpflege, 1965/6, 6/7, 35-66). This is a report of an excavation of an area of woodland at the junction of the Danube and the Altmühl. It was undertaken in order to determine the periods of working of the underlying iron ores by thousands of pits of various shapes and depths. The pits were of three types. The first and shallowest were about 15 m wide and up to 7 m deep; they had been back-filled with the debris of later dug pits. These belonged to the late La Tène period. The second type were funnel shaped, 4-5 m diameter on the surface, caused by the collapse of the shaft collars. The shafts themselves had been about 2 m dia. and had been dug to a depth of over 12 m; they appear to have had vertical walls. These were dated to the Early Middle Ages. The third type were dug in spaces left between the others and are dated to the late mediaeval period.

There were also charcoal-burning pits, the bottoms of which were covered with charcoal embedded in clay to a depth of 0.2 m, and a date for the charcoal gave AD 835-1015. The sand below was burnt to a depth of 10 cm. Several slag heaps indicated that smelting took place on the site, but these were not excavated. Most of them were cleared in the 18th century for reworking. In 1940, four furnaces were found; one of these was dated to the La Tène period and the other three were mediaeval. The ores worked were nodules and boxstones from the Upper Cretaceous horizon which are widespread in the Upper Pfalz area.

**Early iron mining in the northern Alpine Foreland.** H. Frei (Jahresbericht d. Bayerischen Bodendenkmalpflege, 1965/6, 6/7, 67-137). This is a wider treatment of the same theme as the above paper by Schwarz. Frei describes the main areas in S. Germany where these 'pitfields' occur and discusses in greater detail the minerals mined and the slags produced. The pits are found in the Upper Miocene and Pleistocene sediments. Sample areas have been surveyed and sectioned. In some cases circular shafts and pits up to $1\frac{1}{2}$ m have been cut through and into layers of nodules; in other the shafts have been timber-lined to give an internal cross-section of $2 \times 1\frac{1}{2}$ m. The construction of the timbering is discussed in detail.

Many of the sites contained parts of furnaces and tuyeres. The slag analyses from Grubet in Landkreis Aichach show the expected compositions of bloomery slags. They contain about 8% Mn and 0.5% $P_2O_5$. Ores were also analysed; they were mainly limonitic with 64-78% $Fe_2O_3$, 10% $SiO_2$, 3% $Al_2O_3$, and very little lime. A full petrographic analysis was carried out.

These two papers probably represent the most detailed and authoritative work available on early iron-mining techniques and the ores won.

## America

**The 1st iron and steelmaking concern in Brazil (Aracoiaba-Brazil Estado, and Ipanema Brazil Vice-Reinado e Imperio)** J. F. Junior (Mineracao Metalurgia, 1969, 49, Jan., 3-9) [In Port.] An historical note on the production of iron in Brazil in the early 19th century.

**Canada's historic first iron castings.** H. Miller (Canada Dep. Mines, Inf. Circ. 1C209, 1968, Dec., pp 81) An investigation is described on the origins of iron founding in Canada based on Les Forges Saint-Maurice (1738-1883), near Trois-Rivières, Quebec, where very pure bog-iron ore was smelted in a charcoal-fired blast furnace to produce high-quality castings notable for resistance at red-heat temperature and to corrosion.

## Metallographic Examination

**The first Sheffield Plate.** J. A. Charles. (Antiquity, 1968 42, pp. 278-285). A Minoan dagger, dating from the middle of the second millennium B.C., showed good workmanship and was subjected to detailed metallurgical examination. The blade was of high-purity bronze with a 13.1% Sn and had been worked and annealed, with final cold-working of the cutting edge. The handle had been secured by three rivets of pure copper capped with pure silver. The interface between the two metals showed the silver-copper eutectic formed by diffusion at high temperature. After the silver coating, the rivet had been cold-worked with a high degree of skill, the whole process exactly corresponding to Sheffield plating discovered over two thousand years later in 1743.

**Further notes on the shaft-hole pick-axe from Khurāb, Makrān.** C. C. Lamberg-Karlovsky. (Iran, 1969, 7, 163-168). Describes a metallographic examination and analysis undertaken by Heather N. Lechtman of the Laboratory for Research on Archaeological Materials, M.I.T., Cambridge, Mass.

**Metallographic examination as a museum aid. An examination of two pure copper flat axes.** H. H. Coghlan and George Parker (Borough of Newbury Museum, Newbury, Berks. 1969).

## Biography

**Some early West Midland Ironmasters.** M. Schofield (Iron Steel, 1969, 42, June, 191-192) Richard and Thomas Foley of Stourbridge, William Wood of Wolverhampton, John Wood of Wednesbury and others of the family are briefly discussed.

**The period of Abraham Darby III.** M. Schofield (Steel Times, 1969, 197, March, 199-200) The work of A. Darby III at the Coalbrookdale works from 1768 is described.

**Mark Firth—steelmaker extraordinary.** F. Collingwood (Steel Times, 1969, 197, April, 231) The founding and early work of the Sheffield steel manufacturing firm is described.

**James Foster and tinplate manufacture in Shropshire. 1822-1826.** N. Mutton (Iron Steel, 1969, 42, April, 88-92) Details of the construction and operation of this short-lived Midlands tinworks are given.

# Book Notices

### 'Industrial Archaeology of Derbyshire', Frank Nixon. David and Charles Ltd, Newton Abbot, 1969

Derbyshire is a county rich in industrial remains, and the author, who is a distinguished engineer working in Derbyshire and also a member of the Historical Metallurgy Group, has produced a book worthy of the subject. It is a sound and detailed survey of the industrial archaeology of the county, presented in an extremely clear manner, and is indeed a model of what any such book should be.

The opening chapters deal with the county as a whole and especially its geology, while further chapters describe the exploitation of mineral wealth, the evolution of engineering, communications, textiles, industrial housing and other industries. The second part of the book is occupied mainly by a gazetteer which describes the remains of interest in each locality, forming a very detailed guide book to the whole county.

Members of the Historical Metallurgy Group will naturally be most interested in the chapter on the exploitation of mineral wealth, though there are numerous other references dealing with the individual industries. One of the few misleading sentences occurs at the beginning of the section on cast iron on page 52, where it refers to blast furnace temperatures as being high enough to melt ore so that it could be run off into moulds. This might better be worded to the effect that the temperatures were high enough to smelt the ore, with the formation of liquid iron of high carbon content, and molten slag, both of which were tapped from the furnace. The references to slitting mills on pages 51 and 55 also would hardly enable the reader to comprehend their functions.

One might have expected to find under the description of Alfreton some mention of the experimental work of Bunsen and Playfair, which led to the development of the Bunsen burner.

Reviewers invariably bewail the absence of maps. There are, in fact, two maps in this book, one showing the geology and one the railway system. Whilst these give a general picture of the county, there might indeed have been a case for a map to illustrate the gazetteer section. The author can fairly rejoin that as an example of his detailed care all the principal points described carry with them the Ordnance Survey grid reference.

These minor comments in no way affect the value of the book. It is an outstandingly good description of the county and will be found of the greatest use as a general source of reference, particularly by those living in or near Derbyshire who have the opportunity to visit the sites. This is a book that will be equally useful in the library and in the field.

R. F. T.

### Iron Working in Ancient Greece, Radomir Pleiner. National Technical Museum, Prague. 55 pp. 17 figs. (No price stated).

Any work by Radomir Pleiner on the prehistory of iron may be expected to be an authoritative statement by an acknowledged expert. With his latest book he moves south, having a already produced standard monographs on the Czech lands and 'Germania Magna'.

He has used two main sources for his study: references in classical authors and archaeological reports. The former are scattered and difficult to interpret, whilst the latter tend to vary widely in accuracy and detail. Most important, very few smelting or smithing sites have been excavated, and those not by experts in the subject. Pleiner is therefore to be commended for having produced a coherent story from such inadequate material. He deals in a masterly way with the coming of iron to the Greek lands and then discusses its technological development.

On the jacket is a reproduction of a painting from a black-figured vase of the 7-6th century BC. This shows a smith and his helper working at a shaft-type furnace which could be a bloomery (smelting) furnace or a smithing furnace. The main problem is that it seems to have a large crucible sitting on the top of it; and it is difficult to reconcile this with iron working but it is just possible that it is a removable top and that the outlet for the gases is through the wall at the back of the furnace as in the furnace from Gyalar in Hungary, a model of which was for a long time on view in the Science Museum, London.

Pleiner proposes a technological classification into the following periods:

| | |
|---|---|
| Pre-Iron Age | Sporadic use of imported iron (14th-12th Cents. BC.) |
| Proto-Iron Age | Use of limited amounts of imported iron (12th-18th Cents. BC.) |
| Early Iron Age | Introduction of iron smelting and development of the smith's craft (8th to 6th Cents. BC.) |
| Fully developed Iron Age | Great increase of use of iron and increased sophistication of metallurgical skills (5th cent. BC. onward). |

One point that emerges strongly from the book is that the Greeks were not innovators in the field of metallurgy, despite their significant contribution in other fields of human progress and endeavour. They were taking over techniques from other civilizations, without seeking to develop or extend them. This may be due in part to the relative lack of iron ore in Greece: technological development appears to have been greater in the Celtic lands to the north, where ore was abundant and large and highly concentrated ironmaking centres were set up. Moreover, it seems likely that ironmaking spread around rather than through Greece from its Near Eastern heartland (although the author does not favour the view of Foltiny that knowledge of ironworking came into Greece from the north). It is to be hoped that Pleiner will turn his attention to the great Roman industry of Noricum in his next book.

However, no student of the prehistory of iron can afford to disregard this closely reasoned and well documented account of iron in Greece. It may perhaps leave more questions unanswered than it answers, but it is to the credit of Pleiner that his knowledge of the subject is so profound that he has been able to point out exactly what is known and how much more work needs to be done.

H. F. C. & R. F. T.

### 'The Rise of the Entrepreneur', J. W. Gough. Batsford, 1969, pp. 325, 50s.

The title of this book rather obscures the author's purpose, which is to present a series of brief outlines of industrial development in the 16th and 17th centuries, placing his emphasis, if not always as fully as might be expected, on the individuals responsible for investment and innovation. By implication he reflects Nef's belief in the importance of this period in terms of industrial change, but both in his brief assessment of the idea of an early 'industrial revolution' and in his refusal to exaggerate developments in his chosen industries Dr Gough accepts the current view of this period more as one of interesting precursors to the greater scale of changes of subsequent centuries.

A significant proportion of this book is concerned with mining and metallurgy, and each section collates the published materials without significant recourse to primary sources. Indeed this is a product of a well kept card-index rather than of original research, but if its purpose is to provide a series of signposts to some of the less accessible literature it may be judged a fair success. However, a greater element of re-interpretation might have been expected, and is really required to balance the lengthy precis, many barely disguised, from others' work. It is in the stated approach of the title that this re-interpretation might lie, but in fact there is little rigorous examination of the motives and pressures behind entrepreneurial involvement, and the summaries are merely shaped so as to include the names of landowners or industrial tenants at appropriate intervals, their actions and control over events rarely being examined in detail. In the section on ironmaking, for instance, the interests of the groupings among the Wealden ironmasters, obvious from published work, are hardly discussed, and the treatment of the Willoughbys' ironworks in Warwickshire relies on the older articles by Pelham rather than on Dr R. S. Smith's thesis and the published extracts covering iron and, appropriate to another chapter, the Nottingham glass works.

Dr Gough's work on the less familiar field of Scottish gold mining is more valuable, in that his sources are less accessible and deserve wider knowledge: it is, however, annoying to have to search for the references in a consolidated set of footnotes set at the end of the book. This blemish, and an index covering persons and places, without topics, are balanced by a presentation which is generally of a good standard.

D. W. C.

**Dynasty of Ironfounders. The Darbys and Coalbrookdale. Arthur Raistrick. David and Charles: Newton Abbot. 1970. xvi + 308 pp., 30 illustrations. 105s. (84s. before 1. 7. 70)**

Messrs David and Charles have done yet another valuable service for the industrial archaeologist, and in particular for the historical metallurgist, in reprinting Raistrick's classic work on the Darby family, which has been out of print for far too long. Of course, some of the author's views have been subject to revision as a result of the work of many people in the seventeen years since it was first published; however, the imposing mass of data that Raistrick assembled and marshalled so well to tell a fascinating story still inspires nothing but admiration and awe.

The reproduction of the new reprint is excellent, even of such difficult subject's as Farington's pencil sketch of Coalbrookdale facing p. 108. Perhaps the only point that merits the slightest comment is the comparative bulk of the book, as compared with the original edition, owing to the fact that a heavier grade of paper is necessary for satisfactory photographic reproduction by lithography. However, this is a nugatory disadvantage, and far outweighed by the advantage of having 'Raistrick' available again. The attention of readers is drawn to the fact that the book is available up to the end of June this year at the concessionary rate of four guineas.

H. F. C.

**Sources for the History of the Science of Steel: 1532-1786. C. S. Smith (ed.), 6 × 9¼ in, xv + 358 pp, 1968, Society for the History of Technology, and MIT Press**

Of all the dull works of scholarship, 'Source books' can be the dullest. So far, however, from this being the case with this volume: it is a most fascinating work. The aim of the editor—a most modest description of the part Professor Smith has played—is to illustrate the gradual change from 1532 to the end of the 18th century of knowledge of the nature and consitution of steel. This period of some 250 years saw a progressive evolution of ideas from a state of utter ignorance of the causes of things to one so firmly founded that on it the modern science of ferrous metallography could be built.

Extracts from ten books are included, the most important of which now appear in English for the first time. Even those who have fondly imagined that they were not unacquainted with the history of metallurgy will discover books, often of the greatest rarity, of which the very name was unknown. The earliest item reproduced 'Stahel und eysen' is from an anonymous pamphlet of eleven pages first printed apparently at Nuremberg in 1532 AD. No more than a collection of recipes for the successful hardening of steel, its tempering and decoration for armour and similar purposes, this is a purely empirical treatment devoid of a shred of theory.

The last extract, by three of the foremost scientists of their day 'On the different metallic states of iron', demonstrated beyond doubt the fundamental importance of carbon in determining the properties of steel and cast iron. Despite its title, the allotropy of the metal had not yet been realized.

Between these limits the gradual development of knowledge is illustrated from publications from France, Sweden, Italy, and Germany. Progress was clearly affected by the state of scientific knowledge of the time and in its turn reacted on this. Those parts of this book concerned with the age of belief in phlogiston and the caloric fluid have their profound significance to the student of the history of science in general. Two chapter headings from Bergman's 'De analysi ferri' published at Uppsala in 1781 are indicative of the state of scientific thought at that time: 'The quantity of reducing phlogiston sought by experiments in the humid way', and 'The quantity of caloric matter in iron'—an early groping for the concept of free energy?

The magnitude of the changes resulting from these centuries of research, often carried out under conditions of the most extreme difficulty, cannot be better exemplified than by a couple of quotations, one from the first, the other from the latest of the editor's extracts.

1532 AD (p. 9): 'First, how iron is to be hardened. . . ' Take the stems and leaves of vervain, crush them, and press the juice through a cloth. Pour the juice into a glass vessel and lay it aside. When you wish to harden a piece of iron, add an equal amount of man's urine and some of the juice obtained from the little worms known as cockchafer grubs. Do not let the iron become too hot but only moderately so; thrust it into the mixture as far as it is to be hardened. Let the heat dissipate by itself until the iron shows gold-coloured flecks, then cool it completely in the aforesaid water. If it becomes very blue, it is still too soft'.

1786 AD (p. 311): 'This ... experiment ... made plain (1) that the changes which soft iron undergoes in its conversion into steel are uniquely due to the action of the charcoal and not to that of any grassy substance which heat could disengage from it; (2) that those changes are not in the nature of calcination. . . ; (3) that it is the substance of the charcoal itself which, in combining with the metal, augments its weight, changes the colour of its fracture, occasions the black stains made on its surface by acids, gives it fusibility and makes it more combustible in free air'.

We are indebted to Professor Smith for a book of quite outstanding interest which it would be impossible to praise too highly.

F. C. T.

**Wealden Iron. A monograph on the former ironworks in the counties of Sussex, Surrey and Kent. Ernest Straker 8½ × 5½in, 488 pp, 1969, David and Charles Reprints, 105s.**

During the 2nd and 3rd centuries AD and in the late medieval and early modern periods, the Weald of Kent, Surrey and Sussex was the premier ironmaking area of the British Isles. Visitors to this beautiful agricultural area nowadays find it difficult to conceive that at two periods of our history this was, in effect, the 'Black Country' of its day. Only a few hammer ponds, now frequented by coots and mallards, and evocative place names such as Furnace Farm and Cinder Field, give any indication of its industrial past.

The first study of the industrial history of the Weald was that of the Reverend Mark Antony Lower, in the early part of the nineteenth century, who published the results of his studies in an early volume of the 'Sussex Archaeological Collections'. However, it was the work of Ernest Straker that properly established the significance of the Weald in the industrial history of this country.

Ironically enough, when his great work on 'Wealden iron' was first published in 1931, he was in a way a prophet without honour; his book commanded no great sale, and was in fact remaindered not long after publication. Until David and Charles brought out the present reprint, as a result of the greatly increased interest in archaeology since the second world war, secondhand copies of the book were being quoted at as much as 12 guineas per copy.

'Wealden iron' represents a lifetime's study of the industry on the ground. Straker was not primarily an excavator, although he did carry out limited excavations on a number of sites, but rather a field archaeologist in the tradition of Crawford. The book begins with an historical and explanatory section, dealing with iron in general, the technological aspects of the industry, and chapters devoted to such specialized subjects as gunfounding, firebacks, and the financial implications of the industry as illustrated by surviving documents. The main interest of the book, however, lies in the second part, which is a gazetteer of sites over the whole Weald on which traces of industrial activity had been observed and recorded. This section is illustrated with maps and photographs, and the maps in particular indicate the thoroughness of Straker's investigations.

It is all too easy, at a distance of 40 years, to criticize the author for imperfections in his work. He was in no sense a metallurgist, and he relied for his technological section very heavily on those with technological training. However, at that period, all too little had been learned, either by archaeologists or by metallurgists, about the subtle differences in practice that applied at earlier stages of development of the industry. For this reason, many of Straker's comments on the technology must be viewed with caution, and accepted only after checking against the more recent work of people such as Tylecote and Pleiner.

Some of his descriptions of sites may appear at the present time to be somewhat naive. For example, several sites are described as having been worked in the pre-Roman period on the basis of a very few sherds of pottery, which in the light of the considerable amount of study of Romano-British coarse pottery in the past two decades can now confidently be described as Roman.

However, the book should be judged as a whole rather than by its parts. This was the pioneer study of an industrial region, whether in this country or anywhere else in the world, and as such it paints a remarkable picture of a great industry. Anyone concerned with the modern iron and steel industry who has any feeling at all for the historical heritage of his industry can read it with profit, for it gives a masterly survey of the Wealden industry in all its aspects. It is perhaps a most fitting tribute to Straker that the current survey of the Wealden industry that is being carried out by the reviewer and Mr D. W. Crossley is being based entirely on the work of Straker; points of detail may well be changed and corrected, but the basic picture that he painted so well in 1931 needs no retouching or amendment. David and Charles are to be congratulated on their acumen in selecting this great work as one of their excellent series of reprints.

H. F. C.