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Calenick: A Cornish Tin Smelter, 1702 to 1891

R F Tylecote

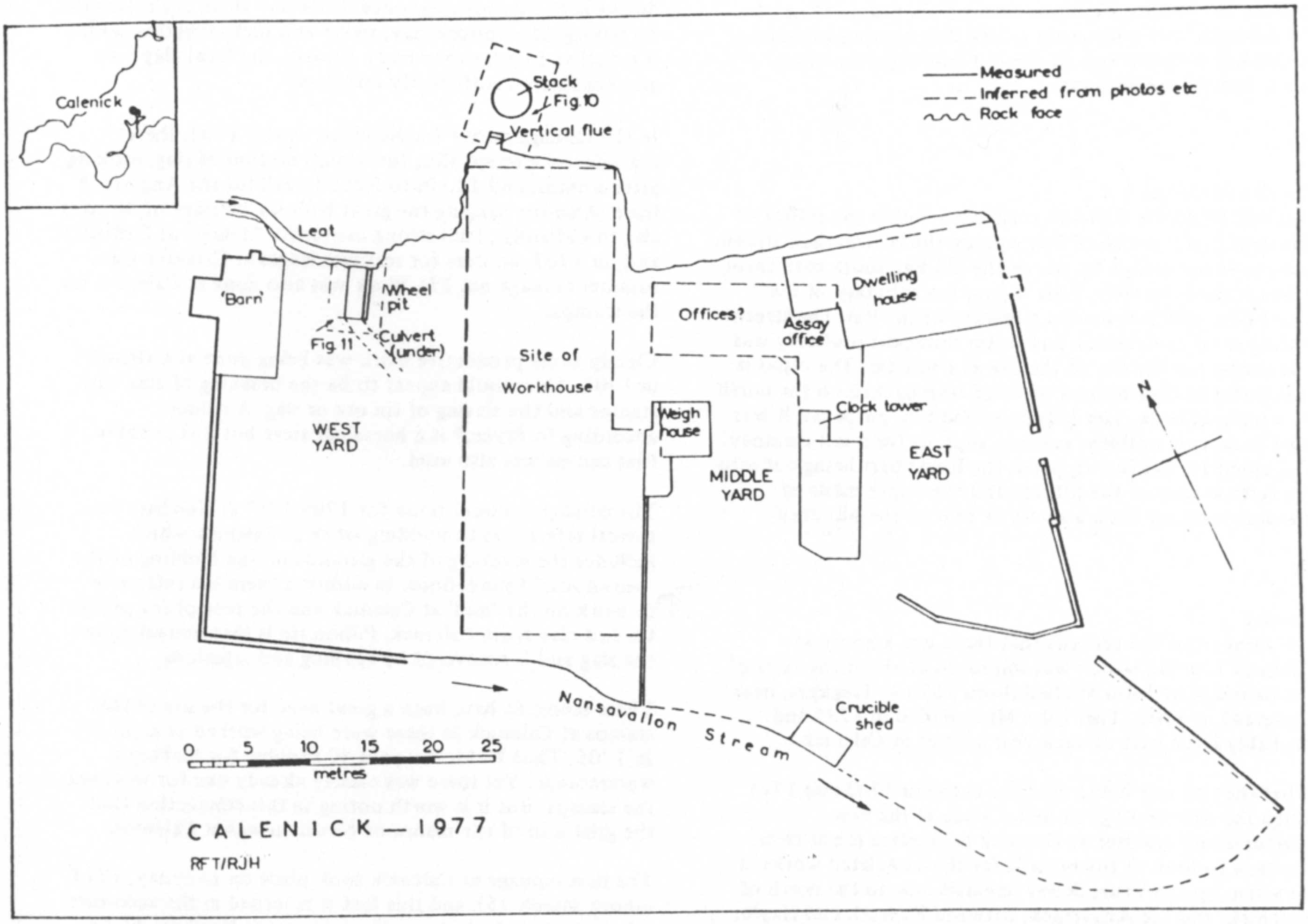


Fig 1 Plan of site of Calenick showing location of site in Cornwall and position of Figs 10 and 11.

Summary and Abstract
Calenick House, near Truro (NGR-SW 820 440) is the site of one of the longest-running tin smelters in Cornwall which became one of the first to introduce the reverberatory process based upon the patent of R Lydall.

Today it contains the remains of a tall chimney stack, the lower half of which has been cut into the vertical rock face, a mill-leat, a wheel pit, the works clock (in good working order) and a weigh-house.

In September 1977 a survey was made of the remains and an attempt was made to reconcile these with the archival material. The crucibles were examined and drawn, and some analyses of the slag and crucibles have been made.

It would appear that the site contained a blowing house, which continued in use into the 19th century. The opportunity has been taken to try and evaluate the inputs and outputs of the tin smelting reverberatory process.

I

Introduction
Tin smelting sites in Cornwall are not easy to find. Although tin smelting has been carried out in Cornwall for over 4000 years, the evidence on the ground is not very obvious. The early blowing houses have left very little slag, as they smelted richly dressed ores. The furnaces were primitive and simple, made of dressed granite; after their decline these blocks were put to other uses.

The larger reverberatory smelters which came into use at the beginning of the 18th century were mostly on sites which have now been converted to other industrial uses such as foundries or creameries. Some of the latest, such as that used between 1887 and 1931 at Seleggan, have literally been bulldozed to the ground, so today only a small amount of slag can be found where they used to be. The originally Cornish firm of Williams Harvey continued to operate in Bootle, near Liverpool. But this plant was also dismantled in the 1970s and the site is now scheduled for housing. This means that the only surviving primary smelter in Britain is that of Capper Pass on the Humber at North Ferriby with an output of 10,000 tons/year.

It is therefore fortunate that one smelter, that of Calenick, is available for examination as it was made into the garden of a private house. The house itself originally belonged to one of the partners of the works and became the manager's house. When the smelter ceased work in 1891 the house was preserved, and reconstructed to a certain extent to produce the handsome house that we see today. Most of the industrial buildings were pulled down giving a spacious garden but retained two of the old buildings, the clock tower and the weigh-house.

II

The site of Calenick

Calenick NGR-SW 820 440 is situated within the manor of Newham in the parish of Kenwyn on the Nansavallon stream just above the bridge by which the old Falmouth road from Truro crosses the river. This stream is a tributary of the Truro river which is itself a tributary of the Fal. The stream is tidal as far as Calenick and water transport probably was one reason for the use of the site as a smelter. The other is that it stands on a narrow piece of land backed on the north by a steep hillside. The hillside served two purposes; it was used to carry a mill-leat and as a support for a tall chimney. The chimney was in two parts; the lower part being cut into the vertical face of the hillside and the upper made of masonry, was set back a metre or two on the hill itself.

III

History

It is clear from the records that there was a house at Calenick in 1702 which was improved at about the time of the marriage of John Michell (born 1676 at Tregayes, near Ludgvan) in 1702. This John Michell died in 1735 and probably lived part of each year at least at Calenick.

What the site was being used for between 1702 and 1711 when the first coinage of metal made at the new reverberatory smelter at Calenick took place is not clear. We have to look at the records for the associated works at Newham on the Truro River one half mile to the north of Calenick, and for Angarrack, between Redruth and Hayle, to get a clue.

According to Barton and Henderson[1] Newham was in production from 1703-1711. Angarrack was established by Francis Moult in 1704 and was up for sale in 1783.[2] It would seem that by this time both these had given way to the newer works at Calenick which it would appear was in a more favourable position.

In 1703, amongst those mentioned in the accounts of the works at Newham were Robert Lydall, Stephen Sando, Here(ward) Nicholls, Michael Tonkyn and James Harrie.[3] The first is well known in association with Francis Moult as the patentee of a process of reverberatory smelting which he established at Newham in 1705.[4] Previously he had been involved in copper smelting at Neath in South Wales.In the Newham cash book[5] opened in 1702, F Moult is credited with 60 oz of silver at £16.10s. In the same book it is clear that large amounts of lead ore were being bought and lead sold (1703). In addition to the lead, silver and litharge was also being sold. It is clear from these entries that Newham was smelting lead and cupelling some of it at least to silver. It was not recovering all the lead from the litharge, probably because there was a demand from potters for litharge as a glaze.

In the building accounts for Newham[6] in the account book dated 1703-1717 we find a reference to the purchase of tin (ore) for the works at Calenick. At Newham itself stamps were being erected in 1703, clay ground, blowing house clay bought, and bricks made on the spot. In the list of utensils bought, we find tin moulds, a melting kettle, scales weights, tin marks (die stamps), stamp heads, grindstones, furnace iron ware, a ladle, anvil and redding (red ochre).

In the accounts for Angarrack 1704-05[7] there is a reference to buying Stourbridge clay, sieves and picks,together with a tuball and sledge (hammer). Clearly, the local clay was not considered sufficiently refractory.

In the coinage book[8] for Newham works, 1704, there is a reference to spauling (breaking) 60 tons of slag, looking after stamps, and £2.10s to Robt Lydall for the Angarrack lease. Also for hanging the great bellows, carriage of 36 tons slag to Callenick, (sic) strong canvas for 'deluers at Callenick' and, in 1707, an item for servants wages at Calenick (Midsummer coinage no. 13). Work was also done at Calenick on the stamps.

Clearly some productive work was being done at Calenick in 1704. This would appear to be the breaking of slag with stamps and the sieving of tin ore or slag. A deluer, according to Pryce,[9] is a horsehair sieve but it is possible that canvas was also used.

The coinage account book for 1709-10[10] at Newham has several references to building work at Calenick which includes the levelling of the ground and the building of the 'workhouse' foundations. In addition there is a reference to work on the 'mill' at Calenick and the receipt for pillion tin and clay from Calenick. Pillion tin is that remaining in the slag and is recovered by spalling and remelting.

There seems to have been a great need for the use of the stamps at Calenick as these were being worked at night.[11] In 1705, Thos Webb was paid 40 shillings for making a watercourse. Yet there was clearly already one for working the stamps. But it is worth noting in this connection that the grist mill of the manor of Newham was at Calenick.

The first coinage at Calenick took place on Ladyday, 1711 (about March 25), and this fact is recorded in the accounts relating to the Ladyday coinage No 33 at Newham.[12] At the rate of four coinages a year plus one in 1711 this would agree with the first coinage being at Newham in 1702.

At the coinage on Ladyday 1711, 30 'pieces' of tin weighing 8808 lbs were coined and the proceeds of £285.5.0 paid over to F Moult. This suggests an ingot weight of 294 lbs. In the same accounts are charges for the bassaning (?basining) of white tin (metallic tin) and the buying of cinders (slag or dross).

The four coinages from Ladyday to Christmas 1712 produced 460 pieces worth £4312 which is equivalent to £9.8s per piece.[13]

For 1716 we have a schedule of goods, utensils and stores at Calenick which shows that we had at that time a hall, a counting house, an assay office with a furnace, and two administrator's rooms together with kitchen, cellar and workhouse.[14] Also we have a middle yard which had iron and lead weights and a grindstone, and a west yard part of which was enclosed and part not enclosed, which contained the annealing furnace.

The workhouse had eight reverberatory furnaces with stacks

Fig 2 Photograph of the site from south of the bridge. Taken about 1925 and reproduced by courtesy of the Truro Museum.

braced with iron, and contained 'brows' (? brouse) and six flux tubs. There was a kettle house which included a fixed kettle and tackle (for hoisting the grain tin ingots?), seven tin moulds, a ladle skimmer, a 'puddle' and an old chest. There was also a smith's shop with a pair of fixed bellows, an anvil, a vise, wedges and two hammers. The 'utensils' included shovels, ladles, moulds, files, small tools and 12 tons of blowing house clay.

Further details of Calenick are given in the Ladyday coinage of April 1729.[15] Here we learn that tinstone (black tin) was received in various forms (slimes, leavings, rough etc).

Black tin ore was being received from a variety of tinners. A full assay was made of each offering and the results varied from 9 to 12¾ 20ths, ie. 45 to 63.7% of tin (pure tinstone contains 79% Sn). It seems that the price offered was a little less than that justified by the results of the assay. Was this the smelter's premium?

In the period 1730-41[16] we find that a considerable number of Windsor bricks were being bought. These were a red fire-brick from a seam of clay at Hedgerley near Windsor, which was well known in the Victorian period for firebricks etc. In addition, new stampheads were needed, lime, and blowing house clay. One suspects that this is a grade that was once supplied for blowing houses but which at this time at Calenick was used for other refractory purposes – perhaps for parging (patching) the reverberatories.

There is also an entry in the accounts about a refining furnace (? kettle), stampgrates, hog's lard (? for bellows), fluke iron, 'house' tin, culm (coal from Bovey Tracey, Devon) and for 'sifting 240 bushels of cinders' (slags).

In 1776, the partnership records[17] state that R Michell and Co were selling from Calenick, wool, sheep and barley, and that Thos Daniell was paying wages for the services of a thatcher. Michell & Co were general merchants and by the nineteenth century would also have operated the candle factory and ropewalk. But the Daniells, first Thomas, and then Ralph Allen, were the financiers. It is recorded that the building work was being carried out at Higher Calenick and paid for by Ralph Allen Daniell. This included mason's work such as repointing the barn, healing (roofing) and building a new dairy; 3000 'pins' were needed to secure the tiles or slates.

Furthermore, in 1781-82, a good deal of carpentry was being done, some of it on the wheel on which two 'vales' were required. Other items included a spok(ed) wheel for a barrow.

Tin dressing was not always as good as it should be since, in March 1792, Rbt Michell was writing to Capt Webster of one of the mines supplying black tin (and probably owned by Messrs Michell) complaining that his people 'are gone to be sad slovenly dressers' having produced a concentrate giving only 9½ parts out of twenty of white tin (47.5% Sn). The normal amount was about 63% Sn.

By 1800, Calenick was probably the largest tin smelter in Cornwall. There were 10 furnaces in 1794 and, in 1815, 2336 blocks of tin were coined equivalent to 389 tons if we assume 6 blocks to one ton.[18,19] The maximum capacity of the three moulds found at Calenick was 400 lbs (Fig. 12). But by 1818-20 the output had fallen to c. 1300 blocks, to rise again to 2702 in 1835.[20]

In 1805 there is a reference[21] to the use of 'chark'd coals'; this could be a reference to charcoal, but at this late date it is more likely to be coke. If so, this could not be used for firing the furnaces as a long flame fuel is needed, but it could have replaced the culm as a reducing agent.

Thatch was still being used for roofing in 1817. The furnaces were being lit with wood and furze in 1821, and both culm and coal (sea-coal) were being imported through Truro. Naturally a large amount of clay was needed, over 11 tons of sandy clay was brought in, and 13 tons of 'vouge clay' (sic) was 'raised' locally, some from Trewartha land.[22] This is a reference to clay from Vogue, near St Day.

The most surprising item in this period (1823) is a green blind for the blowing house.[22] This reinforces the feeling that all along, together with the reverberatory furnaces, a blowing house was continuing to work at Calenick. The co-existence of a blowing house and a reverberatory smelter was not unusual, as we see from Treyew and Carvedras.

A brass wire sieve was needed for flux. Whether this flux was iron oxide or lime we do not really know, but the former is the more likely from the slag analysis (vide infr). Stamp heads were clearly an item that often needed replacing, and just prior to 1793 Rbt Michell was obtaining them from Bristol.[23] But in that year he was writing to John Harvey of Hayle complaining that he was being charged too much and enquiring about Harvey's present prices. (He had been dealing with them previously). The parts comprised the heads, the iron grounds (anvils), and also plates for assay furnaces. Naturally, he was willing to return the old in part exchange. This may explain why only one possible head of an early type could be found on the site itself.

By the middle of the 19th century over-production was occurring, and the firm agreed to restrict output to 140 tons/month (= 5 tons/day) in 1863. In fact the actual output was only 54 tons/month.[24] After the death of R Michell in the 1860's, the scale of operations was reduced still further until, in 1891, the Calenick Tin Smelting Co was taken over with others by Consolidated Tin who closed it down together with the crucible works alongside.[25]

The Proprietors

The principal proprietors and shareholders of Calenick were at first the Michell, Lemon and Daniell families. Daniell also held shares in the associated works of Angarrack and Newham. John Michell died (at Calenick?) in 1735 and by 1776 Robert Michell was one of the main proprietors with Thos Daniell and others. By 1781 Ralph Allen Daniell appears and in 1792, Robt Michell is writing to Richard Michell in London (probably a brother) and to John Michell who was addressed as 'brother'. In 1794, Thos Daniell became one of the principals after he had succeeded into William Lemon's interests at Angarrack in 1760.

Angarrack was owned by Lemon from 1743, but by 1804 the principal partners were Bolitho and Carne, and Daniell seems to have transferred his interests entirely to Calenick.

Bolitho acquired an interest in Calenick in 1816 when Robt Michell Senior and Robt Michell Junior were in control, but by 1817 Robt Michell Senior had died. According to the tithe map of 1840 John Mitchell (sic) was the owner and occupier of Calenick. The interests of the Michell family in Cornish tin were much reduced by the death of Robt Michell Junior in about 1861.

IV

Results of the Survey

Buildings and Furnaces

The site today consists of a handsome dwelling house, a clock tower and connected buildings which now serve as garages; a small building which was clearly the weigh-house and entrance to the main workshop,and a 'barn' which has been converted into holiday living accommodation. On the south side near the river is a very small brick building known as the 'crucible shed' for no obvious reason (Fig. 1).

Existing maps consist of a map based on the 1;2500 Ordnance Survey map of 1889 and the tithe map of 1840. It was immediately clear that the scaled-up map based on the Ordnance Survey was not very accurate (not unexpectedly) but reference to the 1;2500 OS map itself showed that even that could not have been an accurate representation as it showed that the clock tower building made a right angle with the dwelling house which is now quite clearly not the case. It is unlikely that the line of the dwelling house has been altered in direction, although the house itself has clearly been altered in some details since 1889.

Other evidence exists in the form of photographs; one was published by Barton and shows the works from a point just SE of the bridge.[26] Another photograph was taken from a similar angle but further away (Fig. 2). This shows that near the main 'workhouse', were one short and one tall iron-bound square brick chimney.

Two other photographs, one of which is shown in Fig. 3, show the main chimney at the back of the site which was connected to the workhouse by a vertical rock-cut flue. (Fig.11). This chimney would seem to be about 21m (70 ft) high which, together with the rock-cut flue would give an effective height of 27 m (90 ft), and so make the system one of the most technologically attractive features of the works. At the bottom of the flue where it is cut into the rock there are signs of severe burning and it would seem that a furnace was positioned at this end of the workhouse – perhaps a roaster rather than a smelting furnace. The flue-and-chimney system seems to be too ambitious to have been originally provided for one furnace and perhaps was designed to take the fumes and provide the draught for all the eight furnaces which we know that the smelter had at its inception in 1711.

The third photograph (Fig. 4) was taken from the south side of the middle yard which lay between the clock-

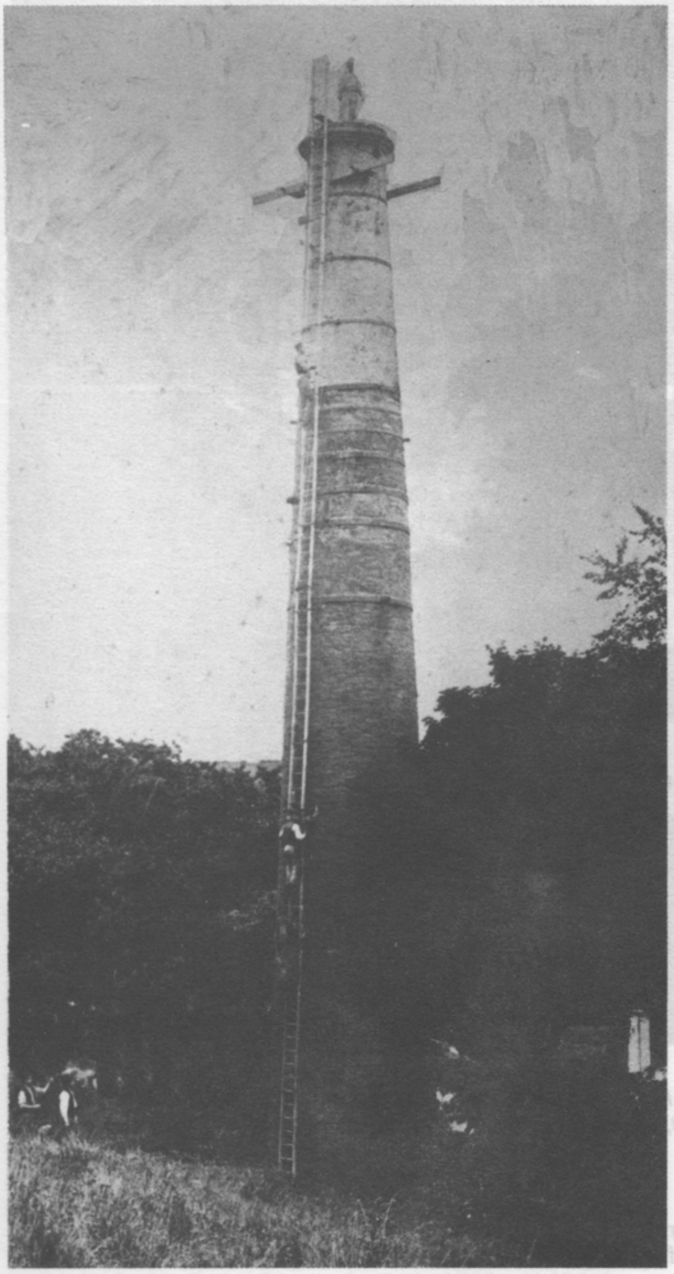


Fig 3 Photograph of the great chimney during demolition. Taken about 1880.

tower and the weigh-house and shows the workhouse on the left with the large chimney at its north end. It also shows the assay office in the top right corner, this building is identifiable by its bank of narrow tall chimneys heeded to give sufficient draught for the induced draught assay furnaces of the type shown by Pryce.[27]

The pile of bricks shown in the left foreground suggests that either relining or demolition was being carried out when this photograph was taken (c. 1880).

Water Powered Equipment

The wheel pit is situated between the workhouse and another industrial building now called 'the barn'. (Fig.1). It was served by a leat, the course of which is still clear, and which terminates 2.52 m above it. (Fig. 10). But it is not certain to where exactly it drained. A culverted drain leads away from the pit in a southerly direction which would intercept the west wing of the workhouse itself. Perhaps the west yard housed some other water-driven apparatus. Clearly the wheel would have considerable power; sufficient, perhaps to run stamps and bellows for a blast furnace. Before the advent of the stamps it might have powered a crazing mill for crushing the ore. (Fig. 5). Two mill stones which could have been used for this purpose were found on the site (Fig. 6). Both the stones found, and shown in Fig.6 are 'runners', ie. the top stones of pairs comprising bedstones and runners. According to Gordon Tucker[51] the simple type of dressing shown in Fig.6 is unusual. It is odd also that the arrangement shown by Agricola[52] and reproduced in Fig.5 lacks a bedstone. This surely must be due to a lack of understanding on the part of the engraver.

From the shape and position of the wheel-pit in relation to the leat above, it would appear that there would be sufficient water and head to power one large wheel 3.5 m diameter by 1.2 m wide, or several smaller ones. This assumes a leat 1.0 m wide supplied with water maintained at a depth of 1.0 m. According to data provided by Longland[28] such a system would be capable of giving 7.0 HP. This assumes a flow in the leat of 20 m/min. A depth of only 0.5 m would give half this power. A suitable speed for such a wheel would be about 6-10 RPM.

If we assume that the stamps had the first priority for the water available we can get some idea of the power required from Mulcaster[29] who, in about 1790, describes stamps in use in the north of England which had been introduced from Cornwall 50 years before. These stamps (Fig. 7) had 6 stems, 8ft high and 6 x 6 in square, made of timber and fitted with iron heads of 98 lbs weight. The total weight of each stem would be about 180 lbs. The water wheel shaft had 4 cams for each stem. If we assume that the shaft revolved at 10 RPM and lifted each stamp 0.5 ft, the power required by the set of 6 stamps would be 0.66 HP. If we assume an overall efficiency of 25% we would need 2.64 HP. Cook, Greeves and Kilvington[30] suggest that in the 19th century on Dartmoor, stamp wheels varied from 10 to 17 feet (3 to 5 m) diameter.

Thus it is clear that the power available at Calenick would be more than sufficient to drive one set of Cornish stamps, that it could have driven a set of bellows needing not more than 2 HP for a blowing house and that some power would be left over for other purposes.

The tithe map of 1840 (Fig. 8) suggests that the wheel pit discharged into the space between the workhouse and the barn building (west yard) and that there was a common tail-race parallel with the river and carrying on through other buildings at the south-east end of the site before discharging into the river just above the bridge. Perhaps the water served the crucible shop and was used for washing and puddling the clay. The building shown in the middle of the west yard was probably the blast furnace (blowing house), and wheels powered both stamps and blowing house bellows.

The Reverberatory Furnaces and Smelting Techniques

The eight reverberatory furnaces would probably be connected to the high chimney via a 'balloon' or common flue. This is normal practice today although the draught is assisted by fans. It would be possible to work a fairly large number of furnaces (more than 2 and less than 10) satisfactorily through a common flue. Additions made later would probably have separate stacks and this might explain the shorter ones that we see in the photographs.

Fig 4 Photograph from the middle yard of Calenick showing the chimney, 'workhouse' and weighhouse to the left and the assay office and clock tower to the right. Taken about 1880. (reproduced by courtesy of the Truro Museum).

The two sides of the workhouse building would probably be open or protected by some sort of lean to roof. The fireboxes and ash pits would be against the outside walls.

It is difficult to get precise figures as to the size of the tin smelting reverberatories of the early period; Pryce[31] says that they differed little from those used for copper but that the hearth was shallower. The copper furnaces were 6 m long by 4 m wide and 3 m high. The hearth was 3 ft above ground. His undimensioned figure is shown in Fig.9. Of course, copper furnaces worked very differently from those for tin as they mostly tapped molten sulphides (matte) rather than metal.

Hatchett (1796) when describing his visit to Calenick[32] where there were then 10 furnaces also says that they were smaller than the copper furnaces, 2 m high, and that the hearths were 23 cm deep, 2.10 m long and 1.10 m wide. The chimneys were 46 cm square inside and 12 m high. He also gives details of furnaces at St Austell and, from these two descriptions and that of Pryce, we learn the following:–

The furnaces smelted 300 to 250 kg of tin ore in 6 hours which resulted in an output of 175 to 200 kg of impure tin metal. At Calenick this required 49 lbs of culm coal as reducing agent and an unspecified amount of Welsh pit coal for firing.

At the end of the 6 hours, when additional culm may have been added to the charge, the whole contents were tapped into a granite trough or float at one side through (at St Austell) a 2.5 cm taphole. The tin was ladled out of the float or basin with an iron ladle into small moulds to form slabs or pigs weighing about 3/4 cwt for refining. This metal was then remelted either in a cooler reverberatory furnace or in a refining kettle. During this stage it was stirred and 'tossed' to oxidise out the impurities; it was then ladled into the large granite moulds which form slabs weighing 3 cwt suitable for coining. Three of these moulds were found at Calenick and the dimensions, as far as they could be obtained are shown in Fig. 12.

Clearly the moulds for the impure tin would have to be near the smelting furnace, but the kettles for refining could be elsewhere.

Details of the layout of furnaces, floats and moulds based on information from Hatchett for Calenick and St Austell are shown in Fig. 13.

The slag would be floating on the surface of the metal in the float (at about 1100-1200°C), allowed to cool and then be removed in the solid form. Charcoal would replace this to prevent rapid oxidation of the very much super-heated tin.

Percy[33] gives an analysis of the culm coal from Bovey Tracey (Table 1) from which we see that the ash content was only 2 to 3%, compared with 11-14% for Welsh coal. The ash would be mainly silica and alumina[34] and together with the gangue elements in the black tin would form the slag. A piece of black slag from Calenick was analysed with the results shown in Table 2. A tin content of 7.9% is by no means abnormal. Cornish slags have given values varying from 0.8 to 2.8% without showing evidence of metallic tin, while a slag recently anaysed from Dartmoor gave 13.5%, mostly present as tin oxides.

According to one analysis the tin content of ore used at Calenick was about 63%. Since pure SnO_2 contains 79% Sn this indicates a gangue content of only 19%, most of which would be present as silica. A charge of 300 kg of black tin would provide 58 kg of silica and would need 36 kg of culm with 3% ash content to smelt it, thus giving 59 kg of slag. Clearly then, the culm is not providing much slag volume and the composition of the slag reflects the gangue composition of the ore. Lime was not being added as a flux (as is done today). The sulphur content could have come from the culm but more probably from the sulphide of copper which appears in the slag.

The reference to 'redding' and 'flux tubs' suggests that some flux was being used. 'Redding' is one of the terms used for iron ore, which makes a useful flux when the ore is highly siliceous. The absence of other evidence we must therefore assume that redding was added as flux to bring the iron oxide content of the slag up to the 37% given in Table 2.

The output of metal at the first coinage at Calenick in 1711 is given as 4000 kg. If we assume that this represents a quarter's output and 80 working days this means only 50 kg tin/day. Clearly this was not a full quarter.

Four later coinages (1712) produced 460 pieces and, assuming 136 kg/ingot, this gives a normal output of $\frac{460 \times 136}{4}$ kg per quarter ie. 15,700 kg or 200 kg/day. This, according to Pryce and Hatchett, is the daily output (in 6 hours) of only one furnace between 1788 and 1796!

One can assume that the 1711-20 furnaces were smaller, but part of the reason is that all the furnaces (8 or 10) were not in use at any one time, since brick furnaces deteriorate very rapidly and need regular and frequent maintenance.

If we take the figures for 1815, when 2336 blocks, probably weighing 170 kg each and yielding a total of 400,000 kg of tin, were coined and assuming 320 working days, we get an output of 1250 kg/day. If one furnace was capable of smelting 300-350 kg of black tin producing 180 kg/day of 6 hours these 2336 blocks would represent the output of 6-7 furnaces. This seems more reasonable and therefore suggests that the original 1711 furnaces had less than half the capacity of those of 100 years later.

The output figures and the anaysis give us a good idea of the quantity of slag made. As we see, 300 kg of black tin ore would give 60 kg of slag and 250 kg metal. So in a quarter producing 15,700 kg metal, 3,750 kg of slag would be produced. This would have to be stamped to recover the pillion-tin which would go back into the furnaces. This,

A—Axle. B—Water-wheel. C—Toothed drum. D—Drum made of rundles. E—Iron axle. F—Millstone. G—Hopper. H—Round wooden plate. I—Trough.

Fig 5 A crazing mill for grinding black tin (from Agricola, 1540).

together with the fire-box clinker, the coal, culm and the ore itself, would have to be moved around by the barrow women, who are mentioned many times in the accounts.

At Calenick the impure tin from the reverberatory furnaces would go to the kettles for refining. These would be made of cast iron and would be fired underneath with pit coal and need short chimneys.

These are possibly those seen in the photographs at the south end of the main workhouse (Fig. 2). The kettles would be provided with ladles and skimmers, and paddles for 'tossing' the tin in order to oxidise the impurities such as iron, cobalt, arsenic and antimony which would go into the dross. This would be high in tin and would be returned to the reverberatory furnaces, where the impurities would go into the slag.

The fuel for firing the reverberatory furnaces had to be a long-flame coal and not culm. It was usually a Welsh pit coal. The cost of coal for smelting is given by some figures that we have for Newham in 1703/04[35] where we find that the smelters received 45 weys totalling 135 tons at a cost of £186.3.4. between March 9 and May 25.[35] This works out at 135/76 = 1.78 tons/day. The total quarterly cost (Midsummer 1703) seems to have been £179.8.6. If we assume that this bought 43.5 weys (= 130 tons), and assuming 80 working days to a quarter, we get a consumption of 1.62 tons/day. If we can apply the same figures to Calenick in 1712 it shows that this coal consumption only produced 200 kg of tin; if we assume that out of 8 furnaces only 6 were actually working on any one day this means that each furnace consumed 275 kg of coals and produced 32.5 kg of tin, giving a fuel/metal ratio of 8.4. This may be compared with other metallurgical processes; the ratio for Welsh copper smelting in the 19th century was about 20, while that for the iron bloomery process was about 5.

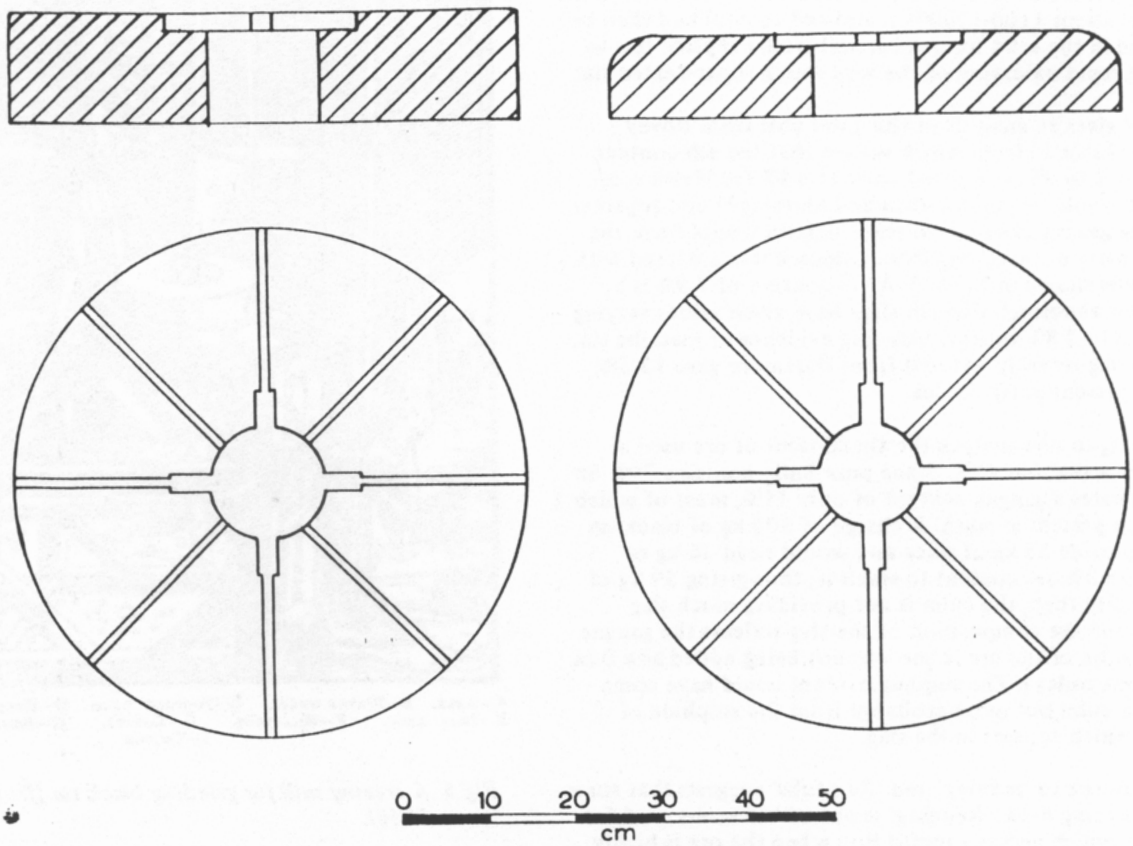


Fig 6 Two crazing mill stones from the site at Calenick.

The coal clinker produced would amount to about 12% of 130 tons = 15.6 tons/per quarter for the barrowwomen to move and no doubt sieve for any reusable pieces.

This may be compared with Dufrénoy's[50] description of Cornish reverberatory practice in about 1834. Three types of slags were produced:– A, the final rejected slag, poor in tin and amounting to c3/4 of the total; B, slag containing small prills of tin amounting to only 5% of the total which was stamped and C, a slag not greater than 10% in volume containing much metal which was recycled. The total rejected slag volume was not more than 12% of the charge.

Other figures given by Dufrénoy show that 1000 kg of ore required 1760 kg of coal to smelt it, and produced 1000 kg of tin. As this is over 100% yield, it is either inaccurate or does not take in account tin added to the charge as 'pillion' or recycled prills. At worst it represents a fuel/metal ratio of about 3 to 1 which gives the improvement expected in 100 years of experience. The furnaces shown by Dufrénoy are not larger than those shown in Fig. 13 and agree reasonably well in plan and section.

The transport of coal overland was expensive. It could be brought straight to the quay at Newham and one must conclude that this was also possible at hightide at Calenick, otherwise the move would not have taken place.

TABLE 1

Composition of Tertiary Culm Coal from Bovey Tracey (%) (After Percy)[33]

	'Brown'	'Broad-coal'
C	66.31	66.76
H	5.63	5.59
O_2	22.86	22.81
N_2	0.57	–
S	2.36	2.09
Ash	2.27	2.75
H_2O	34.66	2.21
% Coke	30.76	51.50

NB: The Broad-coal occurs in 1.2 m thick beds and yields a bright, hard, porous coke. (T Roy Soc 1862, p 1039-1086).

Comparison may also be made with the lead works built at Gadlis[37] in Flintshire in 1702. The workhouse measured 34 yards by 8 yards wide and had walls 5 yards high with another 5 yards to the roof ridge. In a drawing dated to

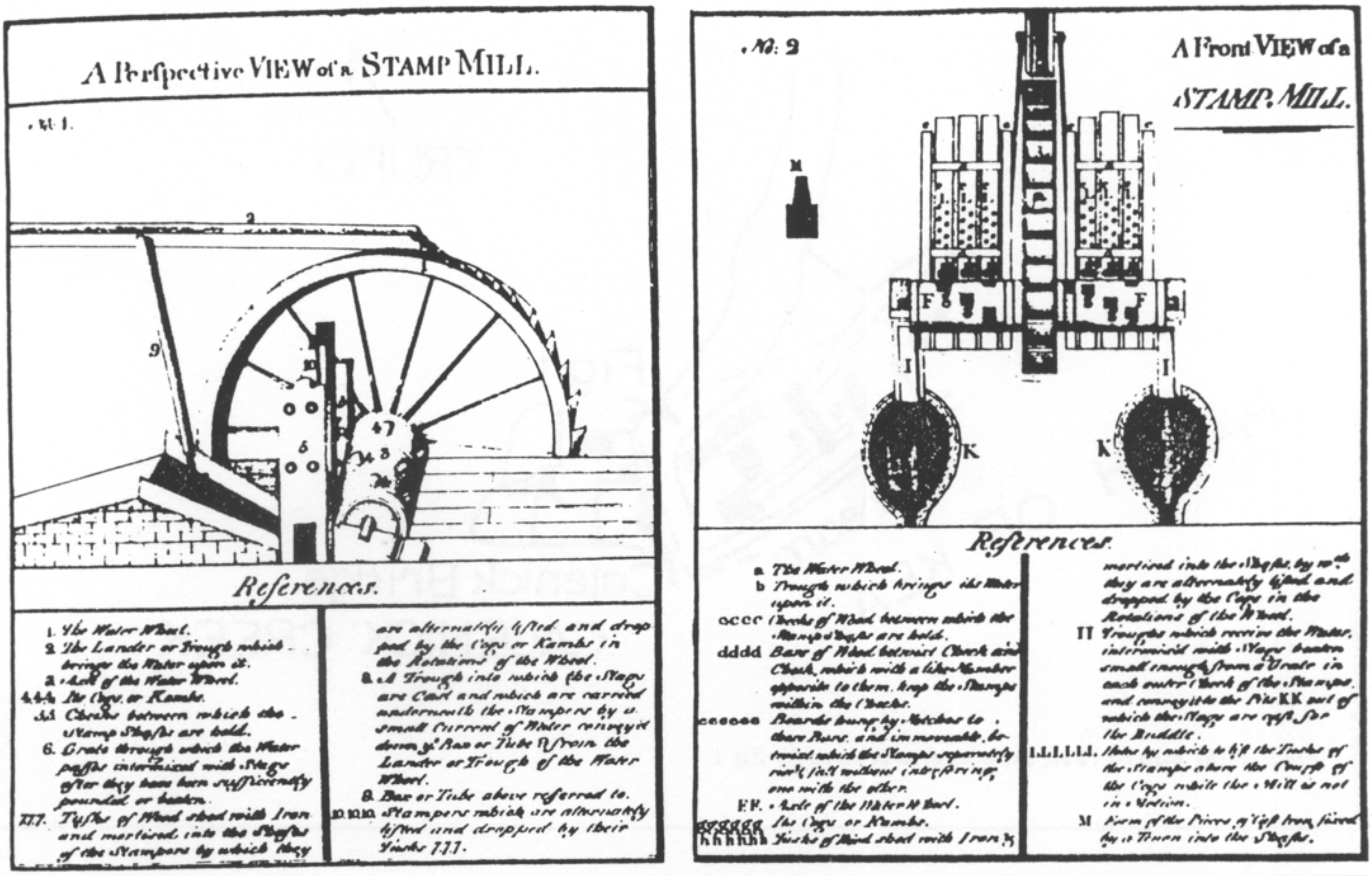


Fig 7 Stamps used for lead ore in the Northern Pennines and said to be based on those used in Cornwall (Mulcaster).

TABLE 2

Composition of unstratified black tin slag from Calenick (%)

FeO	32.6
Fe_2O_3	3.9
SiO_2	30.0
CaO	1.6
Al_2O_3	11.1
Mn	0.15
P	0.02
S	0.55
Sn	7.9
Cu	1.48
Pb	0.02
Sb	<0.01
As	<0.01
Rest (H_2O, O_2)	10.48
Total	99.82

1720 there are shown 13 chimneys which have a height exceeding the top of the roof by about 4 m, thus giving a total vertical chimney height of about 12 m. In 1706 there were four reverberatory furnaces, two refining furnaces and a slag hearth. In 1710 there were six refining furnaces, so that the 13 chimneys shown in a drawing of 1720 could be accounted for by the addition of various roasting and calcining kilns.

Flue dusts were pelletized with the aid of lime and added to the slag hearth charge. Windsor (red) bricks are mentioned in connection with the furnaces but in 1704 were found to be not as good nor as cheap as those made from local (fire) clays.

We do not know much about the method of working reverberatories in the 18th century. But, being large and brick-built, they could not stand discontinuous operation as the expansion and contraction that is involved causes the furnaces to crack. Therefore some sort of shift working was necessary.

We can get some idea of one way in which this could have been organised in the case of tin smelting from the records of the lead mill at Langley, Northumberland,[38] in 1802. This relates to the smaller ore hearths and the larger reverberatory refining furnaces. The former were worked

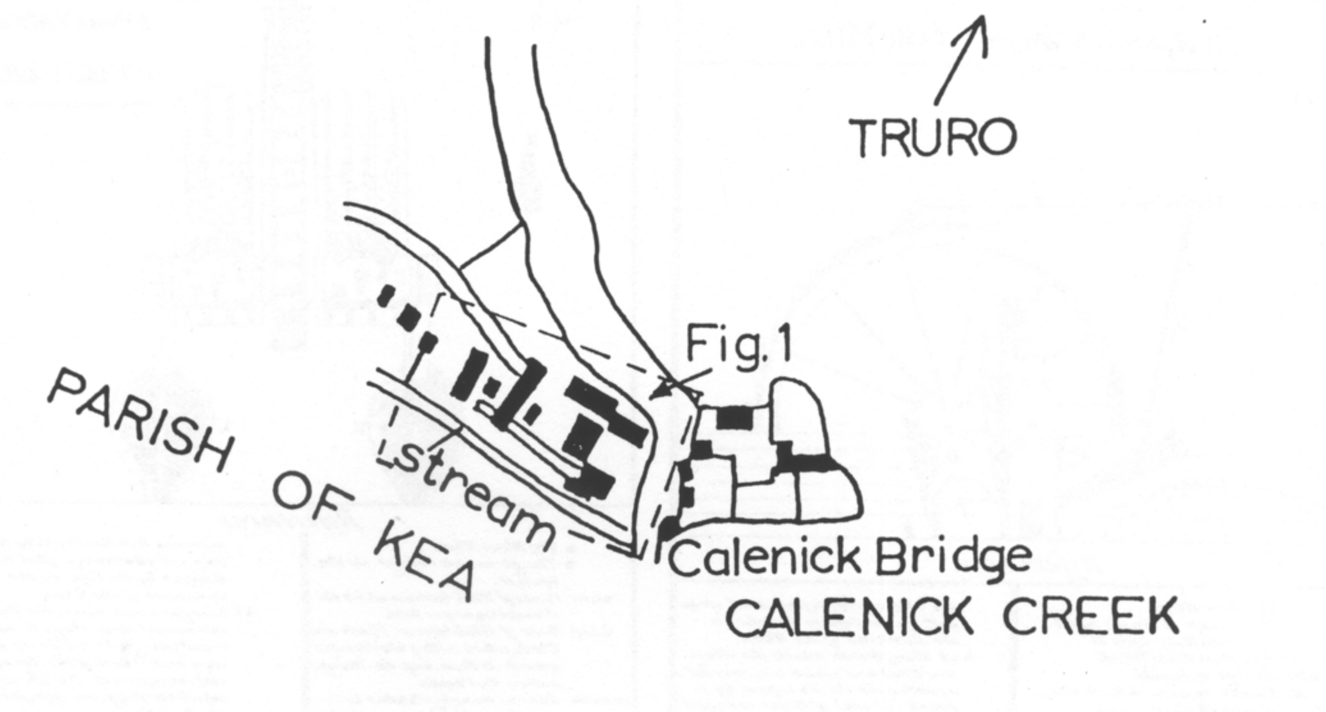


Fig 8 Tithe map of 1840, showing area covered by Fig 1.

by two men who did two 16-17 hour shifts and one half shift over a period of 2½ days (ie. a 42 hour week), when a second set of men took over. The hearths were therefore worked for 17 hours, cooled for 7 hours and then restarted, and worked in this way for 5 days with two groups of men. The larger, reverberatory, furnaces which were used for refining were worked continuously for 35 hours by three men. Two men would work one furnace each and the third would allow each of the others to get a rest, off and on, over a period of 35 hours in a week. In this way the furnace was worked for 35 hours before being allowed to cool.

This may be the manner of working the reverberatories at Calenick. If each smelt took six hours, six smelts could be done in a week of 36 hours; then the furnaces would be available for fettling.

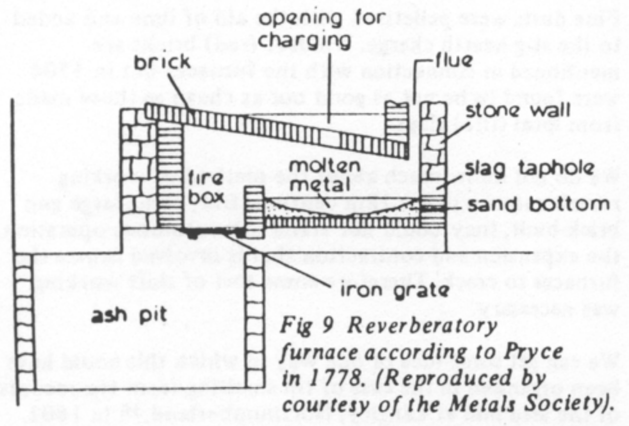


Fig 9 Reverberatory furnace according to Pryce in 1778. (Reproduced by courtesy of the Metals Society).

VI

Crucible Production at Calenick

One of the attractions of the site seems to have been a seam of clay suitable for crucibles.

Pryce[39] (1788) makes reference to a crucible manufactory 'at Truro' and it is fairly certain that this reference is to Calenick. It would seem that the clay was mixed with decomposed granite as grog. It seems that these crucibles were being produced for a little time before he wrote, and in 1766 a Mr Rosewarne of Truro had sent some for trial to the Committee for Chemistry of what was to become the Royal Society of Arts, who found them as good 'or rather better than any German crucibles.'[39]

Confirmation that crucibles were being made at Calenick, at least as early as 1787, is shown in a letter to a Miss Bevan of the Forest Co. (?Fore St) of Redruth complaining of the non-payment of an account for crucibles, which were delivered to W Bevan on the 25 January, 1787.[41]

In 1792, Robt. Michell was writing to Mr Richard Michell of London saying that he would be declaring a dividend on behalf of the Crucible Co. It appears that most of the proceeds was coming from the larger crucibles and that the smaller assay crucibles were not selling well. This would necessitate a change of contract with the Crucible Co, so it seems that R Michell placed a contract with his Crucible Co for some time ahead.[40]

Another letter to Mr Michell dated 1823 refers to the settlement of another account 'on behalf of the Calenick Crucible Co'.[40]

It seems that the Crucible Co at Calenick was financially independent but in some way related to the tinsmelting company. Both tin and copper assayers needed crucibles for their work and it is clear that this was the case at Calenick.

But there were others in the field. In about 1760, works at Pednandrea and Fore St. Redruth were established by John Juleff and these were still in business in 1957.[40] The official catalogue of the Great Exhibition of 1851 included J Michell of Calenick as a crucible manufacturer. But Juleff's had no competition in the 1861 exhibition, so it would seem that either Calenick had ceased making crucibles by then or else did not bother to exhibit.

It is clear that in 1766, black-lead (clay and graphite) crucibles were being made in England as well as the more usual clay ones. And it would seem likely that some of these were being made 'at Truro'.[42] Certainly black-lead pots were being made in 1815 at Calenick, as there was an advertisement in the West Briton referring to the difficulty that they had in getting satisfactory black lead (Graphite).[43] From this date (2.3.1815) they were able to supply black-lead melting pots of all sizes and of best quality, as well as their normal (clay) copper assaying crucibles.

It is well known that there was at least one English source of supply of graphite, that from Borrowdale, near Keswick in Cumbria. But the quality of this source, no doubt like others such as that from Passau in Bavaria, was variable and sometimes contained large amounts of iron oxides.[44] However, Percy[44] gives analyses from various sources including Keswick and Passau from which we see that the Borrowdale graphite had an ash content of 7 to 16%, the iron oxide content of which was from 7.5 to 12.0%. On the other hand the ash content of the graphite from Passau could go as high as 65%; but the iron oxide content of ash was in the range 0.5 to 12.6%. So it would appear that a good grade of Bavarian graphite might be superior to the best English graphite.

According to John Percy,[46] in 1865 Cornish crucibles were then made in two sizes which fitted into each other. The larger were 7.6 cm external diameter at the top and 8.9 cm high. They were coarse in grain and greyish-white on the surface. The ware was pitted with iron inclusions,. There external surface was reddish-brown and they were 'kiln-burnt' which seems to mean that they could be plunged into a hot furnace without cracking; but they softened at a white heat. The well known makers of these were Juleff of Redruth and Mitchell (sic) of Truro. Both were rapidly corroded by PbO but Mitchell's more so than Juleff's. They were made on a potter's wheel and a composition for Juleff's is given.

It seems that the clays came from Bovey-Tracey, Poole, St Agnes and St Austell, but clay from the latter was only added to the less refractory types.

Black-lead crucibles made from a mixture of graphite and

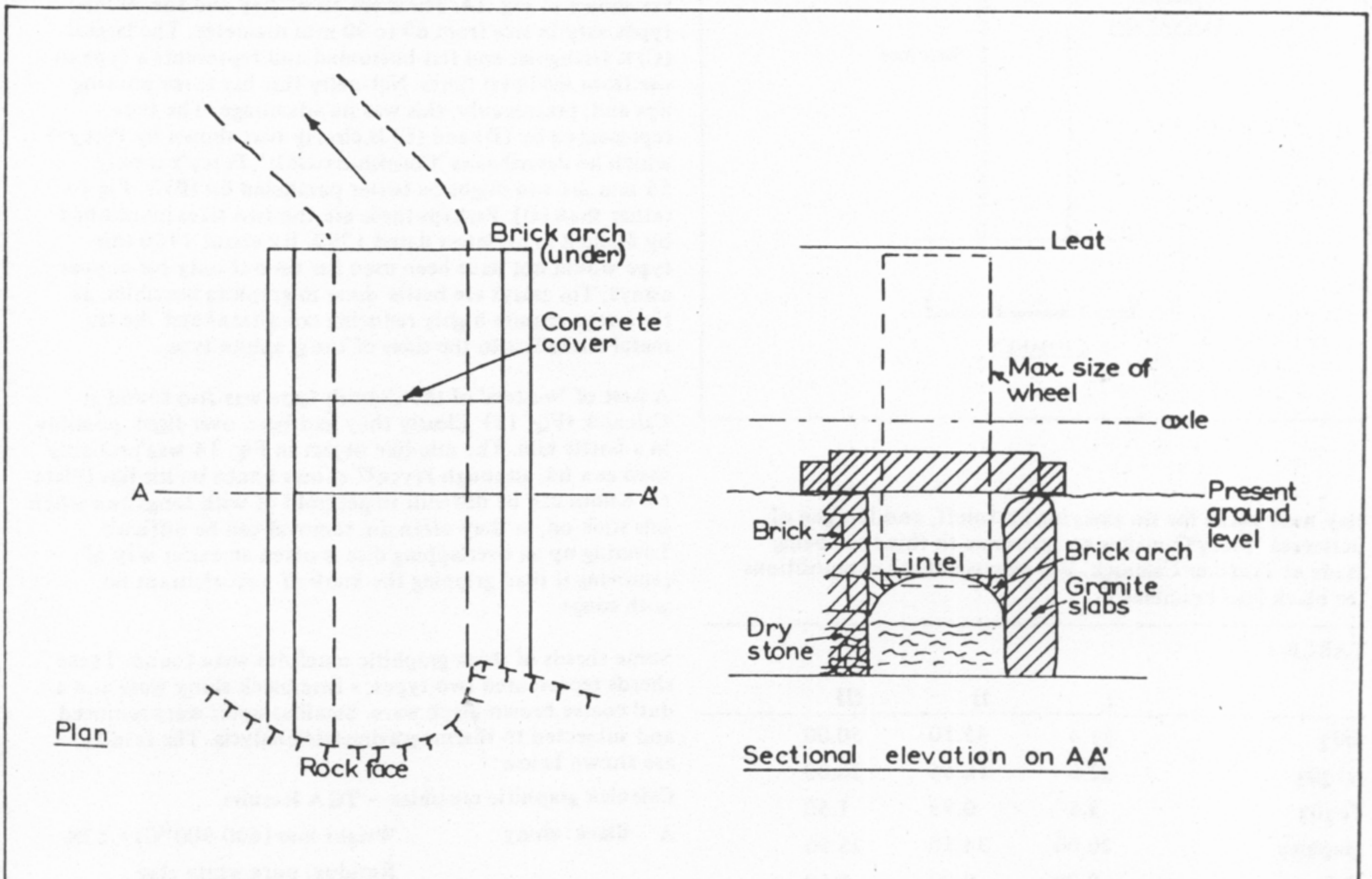


Fig 10 The wheelpit at Calenick showing position of race and maximum size of water wheel.

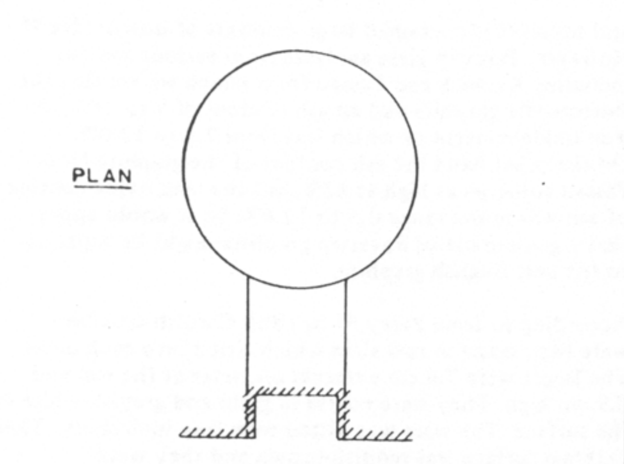


Fig 11 Existing flue cut in rock and chimney base.

clay were made for tin assaying by Juleff, and Morgan of Battersea. Percy[47] makes no reference to this type being made at Truro or Calenick. But he gives three compositions for black-lead crucibles: –

TABLE 3

	I	II	III
SiO_2	51.4	45.10	50.00
Al_2O_3	22.0	16.65	20.00
Fe_2O_3	3.5	0.95	1.50
graphite	20.00	34.50	25.50
CaO	0.20	0.00	0.50
H_2O & loss	2.90	2.80	3.50

(Compt. Rendu, 1867, **64**, 1093)

He also mentions that specimens from crucibles made by Morgan of Battersea were found to contain 48.34% graphite, so it is clear that there was at least one other grade with a higher graphite content.

According to Boon,[44] graphite was imported into this country from Passau but it is unlikely that this was of crucible grade, as the export of such quality had been prohibited from 1613 to 1805. It is therefore likely that the graphite used at Calenick in 1815 could have been German and that the release of this quality was the reason for the start of black-lead crucible manufacture there.

Some time during the 19th century the Calenick Works came into the possession of a family named James, of whom a Mr J James died in the early 1900's. This seems to have heralded the end of crucible making at Calenick and the stock-in-trade was purchased by Mr James's great-grandson, Mr W H Lake, whose wife was a Miss James of Calenick, and taken to the Chapel Hill pottery in Truro, recently owned by William Townsend Lake.

This pottery was recently bought by the Dartington Hall Trust. A brass crucible mould and some clay crucibles from it were in the care of Prof Charles Thomas of the Institute of Cornish Studies, Redruth and have kindly been drawn by R Penhallurick of the Truro Museum (see Appendix). They are now in the County Museum at Truro.

Finds of Crucibles at Calenick

During the last few years quite a lot of crucibles and crucible sherds have been dug up at Calenick. Those in good condition are shown in Fig. 14. These are all of clay and the circular types vary in size from 60 to 90 mm diameter. The largest (C) is triangular and flat-bottomed and represents a type in use from medieval times. Naturally this has three pouring lips and, presumably, this was its advantage. The type represented by (D) and (E) is clearly that shown by Percy[46] which he describes as 'Cornish crucible'; Percy's is only 55 mm dia and might be better paralleled by (E) in Fig 14 rather than (D). Perhaps these are the two sizes mentioned by Michell in his letter dated 1792. By about 1780 this type would not have been used for tin but only for copper assays. Tin assays are better done in graphite crucibles, as tin assays require highly reducing conditions and the tin metal sticks less to the sides of the graphite type.

A nest of 'wasters' of the Cornish type was also found at Calenick (Fig. 15). Clearly they had been over-fired, possibly, in a bottle kiln. The disc-like object in Fig. 14 was probably used as a lid, although Pryce[27] shows knobs on his lids (Plate 6). Knobs can be difficult to get hold of with tongs and when lids stick on, as they often do, removal can be difficult. Levering up an overlapping disc is often an easier way of removing it than gripping the knob of a recalcitrant lid with tongs.

Some sherds of thick graphitic crucibles were found. These sherds represented two types; a fine black shiny ware and a dull coarse brown-black ware. Small samples were removed and subjected to thermogravimetric analysis. The results are shown below:

Calenick graphitic crucibles – TGA Results

A	**Black: shiny**	Weight loss (600-900°C) = 52% Residue; pure white clay
B	**Dull: brown-black** (numbered 10 on base)	Weight loss (700-900°C) = 19% Residue; red-brown clayey material (iron oxides)

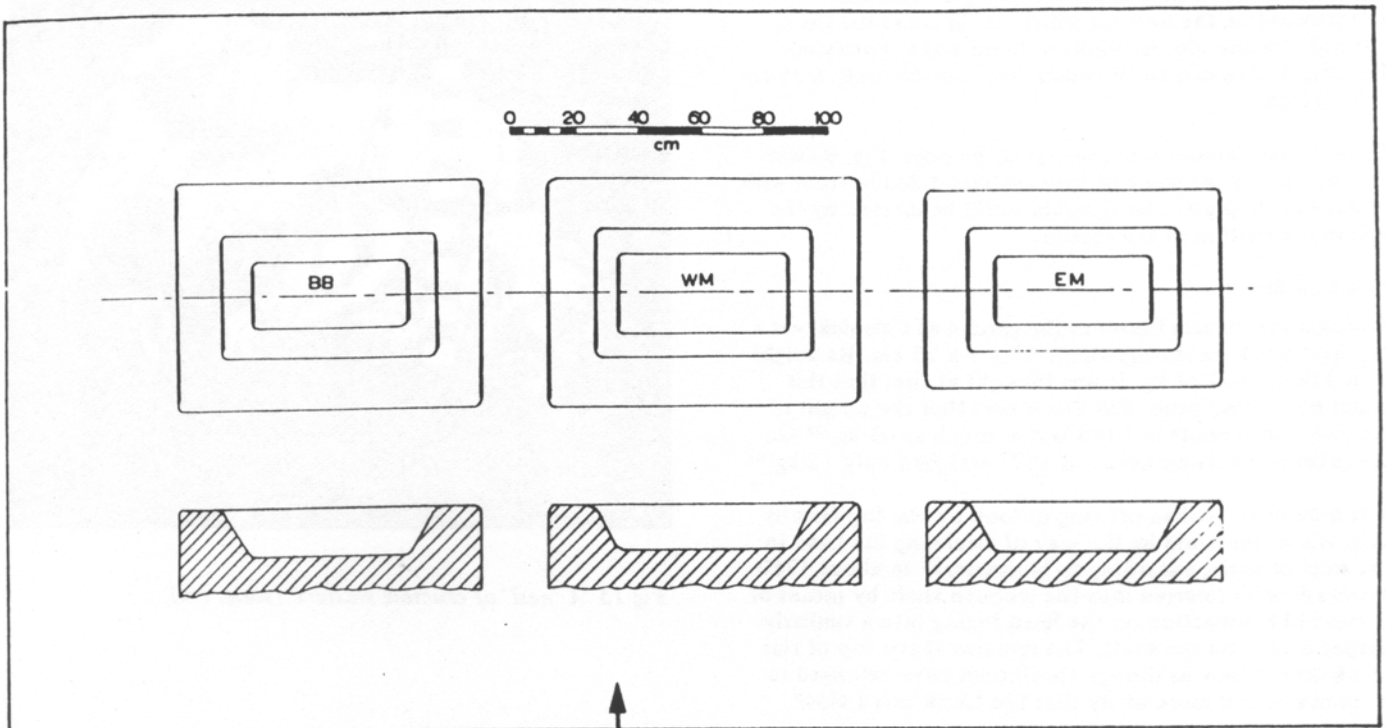


Fig 12 Granite moulds for tin blocks; still at Calenick.

It seems therefore that the shiny one represents the best quality, and is similar to that made by Morgans (Percy[47]) containing 48% graphite, while the brown one is of the lowest grade I shown in Table 3. The iron content would also be similar to that given for grade I.

The largest piece of graphite crucible found on the site appears to have had some experimental purpose (Fig. 16). It is in fact the lower half of a crucible with the bottom removed and a large opening at one side and a small hole at right angles to it. Opposite the small hole is a groove terminating about half way down. There is no contamination of slag or metal and it appears that the object was never used at all in contact with metal. It is of medium quality as far as the graphite content is concerned.

Conclusions

The historical evidence shows that clay crucibles were being produced at Calenick from about 1760. It is doubtful whether these were being produced from local clay, as clay was being imported to Calenick and it was well known that specially refractory clays were necessary.

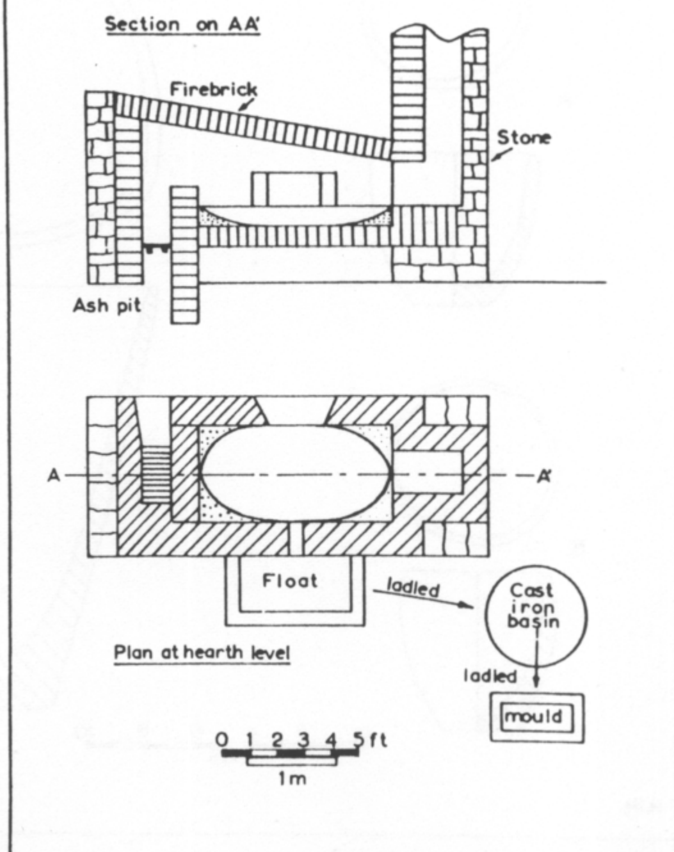
Graphite crucibles were being produced by about 1800, if not earlier. Calenick Crucible Co was one of two crucible manufacturers in Cornwall and closed down between 1851 and 1891.

APPENDIX

Crucibles

The collection of crucibles found at Lake's pottery, Truro, consisted of three medium sized triangular clay crucibles with a small 'J' stamped on the side (Fig.A, 2) and one waster. In addition there were two large triangular crucibles, one with a 'J' on and another of the round Cornish type (Fig.A, 1); there was also another smaller misformed Cornish crucibles. It is very probable that the 'J' stands for Juleff of Redruth.

Fig 13 Layout of smelting furnace and auxiliary processes based on Hatchett's description of Calenick and St Austell.



There was also one small round graphitic crucible that nearly fits the brass mould shown in Fig.B. This has a 'CC' stamped on the bottom which could stand for the Calenick Crucible Co. In addition there was a scorifying dish (Fig.A, 3) and a small round clay crucible only 6.35 cm (2.5 in) high.

The two-piece mould accompanying the pots (Fig. B) was used by forcing the top-half into the clay-filled bottom with a screw- or fly-press. The crucible could be ejected by the hole in the bottom of the mould.

Cast Iron Block

Amongst the objects found in the garden at Calenick was a cast iron block measuring about 17 x 7 x 25 cm. Its weight would be around 24 kg. It was thought at first that this might be a stamp head. But Pryce says that the weight of Cornish stamp heads in 1788 was as much as 63 kg.[48] On the other hand stamp heads of 1671 weighed only 18 kg.[49]

The head has a broken off ring or loop on the top (small) side. While this could be the way of attaching the head to the stem or shaft, according to Mulcaster[29] in about 1780 the heads were inserted into the wooden shaft by means of a tenon-like projection on the head fitting into a similarly shaped socket on the shaft. The remains at the top of this block do not look as though they could have belonged to a tenon and it is more likely that the block was a clock weight.

Fig 15 A 'nest' of crucible wasters. (scale, cm)

Fig 14 Crucibles found at Calenick.

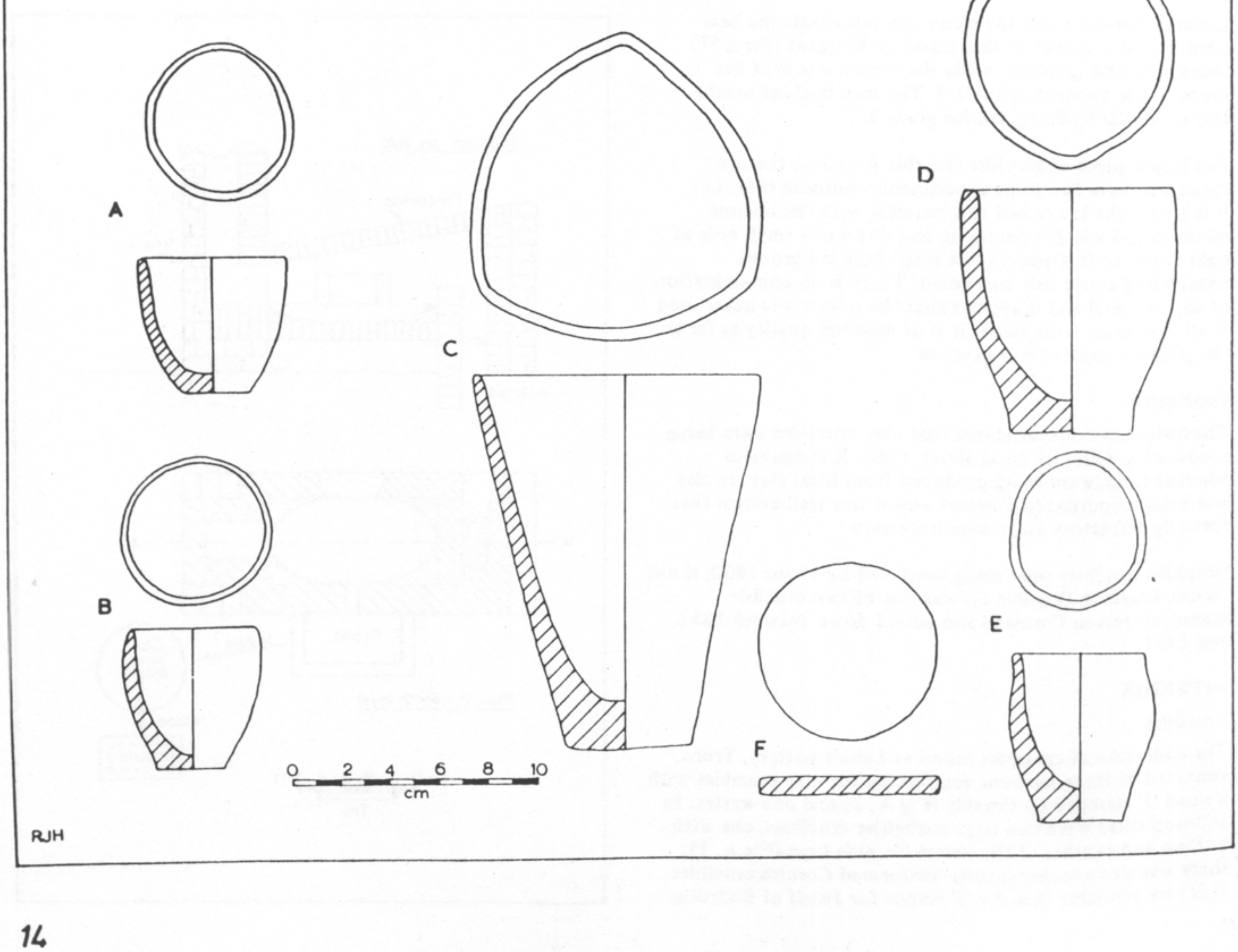
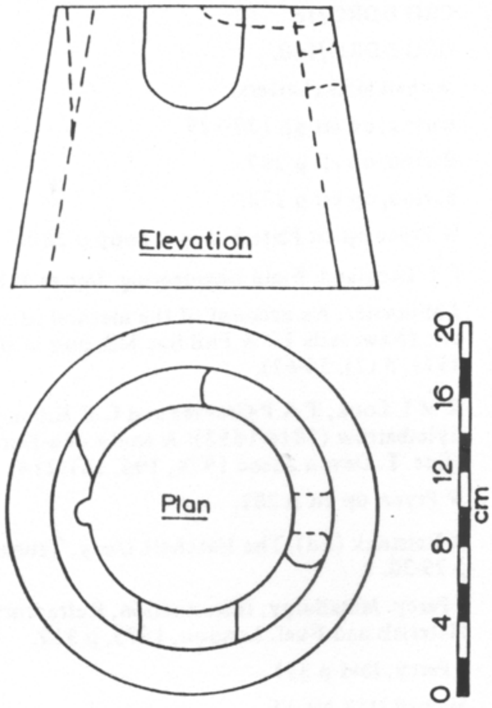
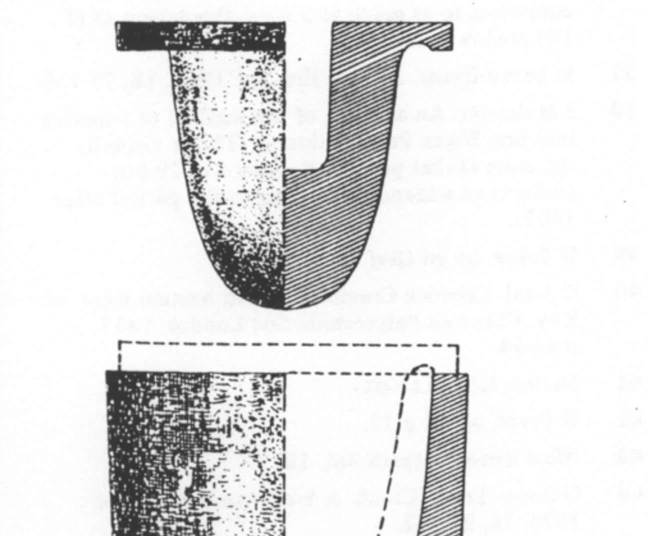


Fig 16 A modified graphite crucible from Calenick.





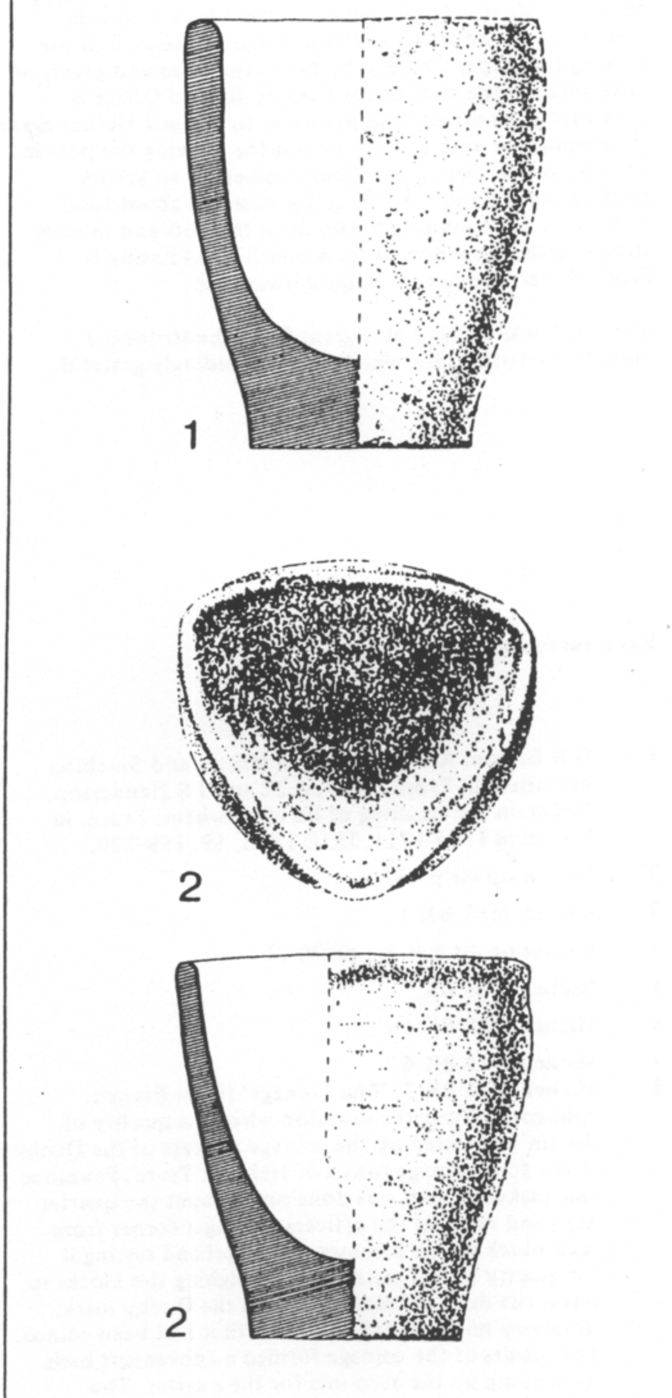


Fig A Crucibles and Fig B Brass mould from Lakes Pottery, Truro. (Kindly drawn by R Penhallurick of the Truro Museum).
Appendix

Acknowledgements

I would like to express my appreciation and thanks to the following for the help that they have given me with this paper:– to Mrs E K Pascoe of Calenick House for making contact with Miss M Michell of South Africa who is in possession of the Michell MSS referred to above, and for making this paper a reality by her enthusiasm and practical assistance; to the staff of the County Record Office at Truro for their efforts and patience; to Roger J Hetherington for helping me with the survey and for drawing the pots in Fig.14; to H L Douch and Tom Greeves for so kindly reading the MS and correcting my mistakes about local history; to R Penhallurick who drew the pots and moulds shown in the Appendix (Figs A and B); and finally to Prof Charles Thomas for helpful discussion.

The work was assisted by a grant from the Historical Metallurgy Society for which I am exceedingly grateful.

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3 Michell MSS BK 1.

4 Barton op cit Ref.1 , pp 20-21

5 Michell MSS BK.

6 Michell MSS BK 16.

7 Michell MSS BK 4.

8 Michell MSS BK 2. 'The Coinage' (from French, coin corner) was the occasion when the quality of the tin was tested by the coinage officers of the Duchy at the four coinage towns of Helston, Truro, Penzance and Liskeard. This was done on or about the quarter days and entailed the officers cutting a corner from each block with a hammer and chisel and testing it for quality and, if satisfactory, weighing the blocks to assess the dues and stamping with the Duchy mark. In theory no tin could be sold until it had been coined. The results of the coinage formed a convenient basis for making up the accounts for the quarter. The Coinage was discontinued in 1838.

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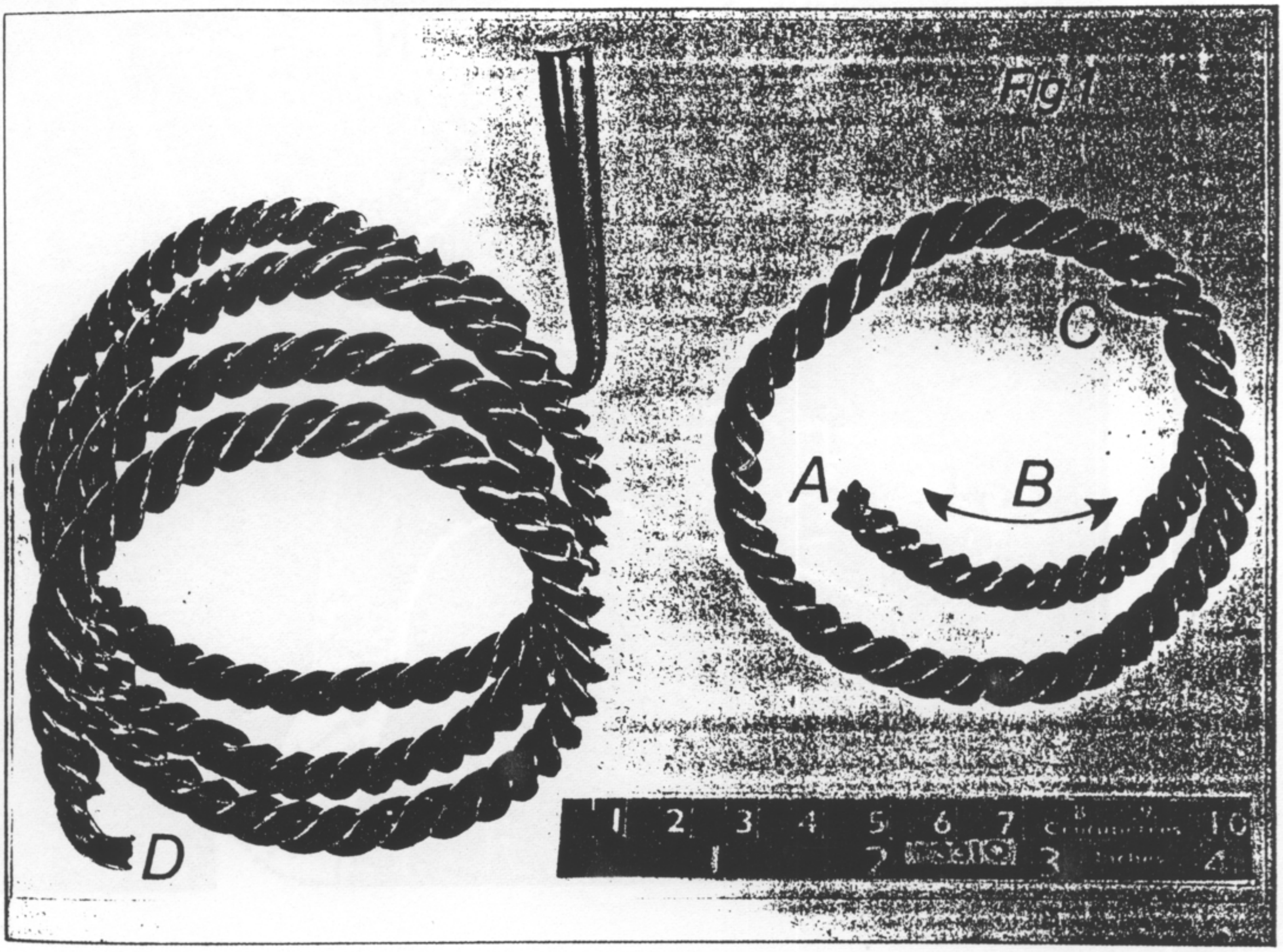
The metallurgical examination of a Bronze Age gold torc from Shropshire

Janet Lang, N D Meeks and I M McIntyre



Introduction
The gold torc (acc. no. A1747'73) illustrated in figure 1 was brought to the British Museum for examination in 1973 following its acquisition by Birmingham City Museums and Art Gallery. It was reported to have been found in Shropshire, but its exact provenance and the circumstances of its discovery are unknown.

In appearance, the torc is of the type discussed by Eogan (1967) and resembles the twisted bar torc from Castlemount, Dover (Maryon 1933 and 1938) in the British Museum (Department of Prehistoric and Romano-British Antiquities) and a similar one from Fresné la Mère in the Ashmolean Museum. The torc has a cruciform cross-section which has been twisted to form a helix and then coiled to form a spiral. Only one of the terminals survives. Its shape is that of a simple cyclindrical rod about 5 cms in length, tapering slightly towards the spiral section of the torc. The torc was damaged when found but the fact that the broken surfaces at C and D fit together exactly indicates that the two pieces were originally part of the same object. Restoration consisted of soldering the two halves together (see appendix) but before this was done a sample of the cross-section was removed from the broken surface at A for microscopic examination and a similar sample was also removed from the broken part of the spiral at D. The latter was replaced when the two halves of the torc were soldered together.

Composition of the metal
Analyses were carried out on the terminal and on the edges of the cruciform spiral using an independent X-ray fluorescence spectrometer. The method used was that described by Cowell (1977) and the results were as follows:

	Au %	Ag %	Cu %
Terminal	80.9	15.1	4.0
Spiral 1	82.9	13.6	3.5
Spiral 2	82.4	13.7	3.9
Spiral 3	81.6	14.9	3.6
Spiral 4	83.6	12.9	3.5

These results are in reasonable agreement with those obtained

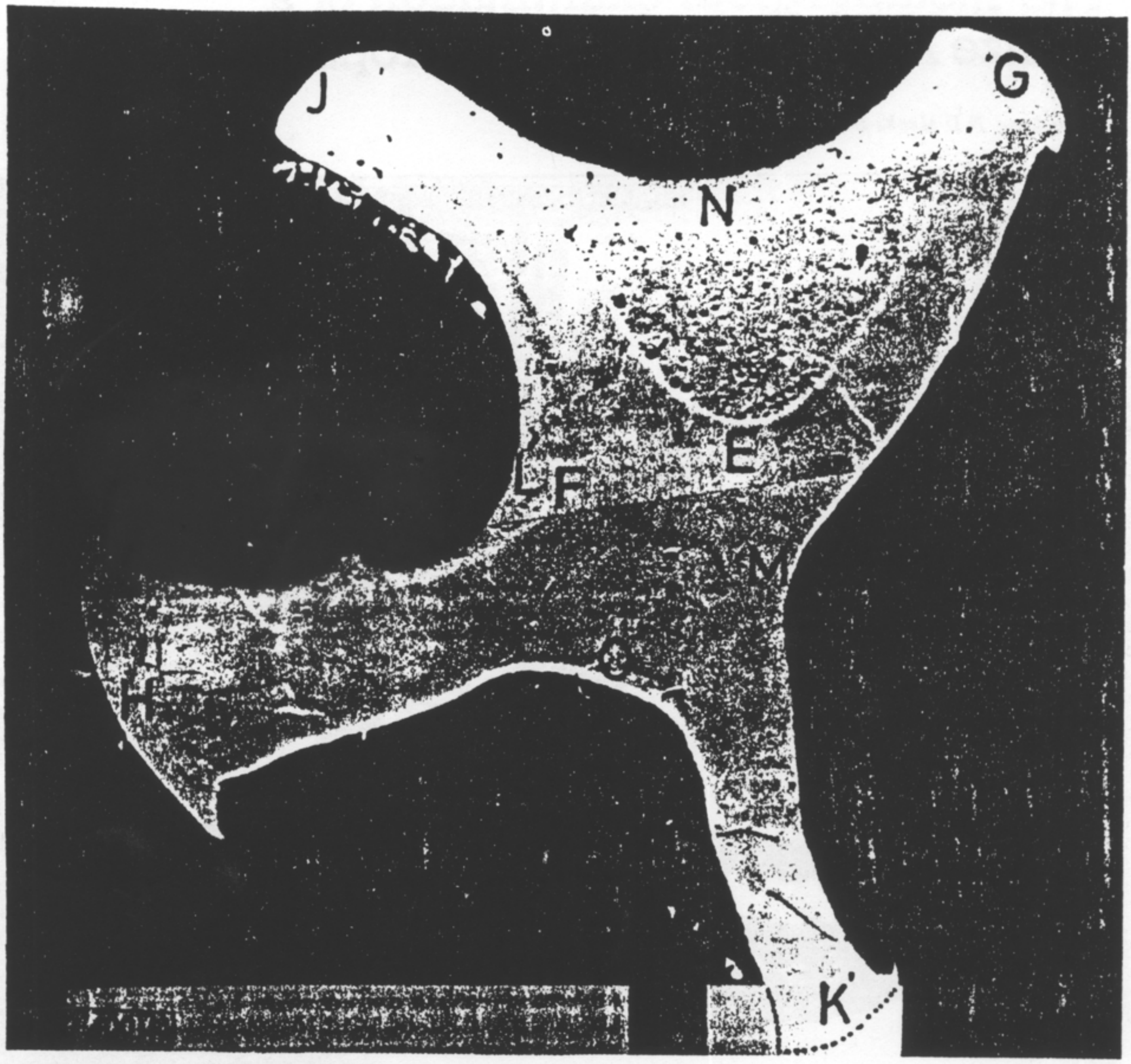


Fig2

for the body metal in the SEM, which are given below. The analyses of the terminal and spirals are sufficiently similar to suggest that the terminal could have been cast from the same melt as the bar used to make the torc. Unfortunately the geometry of the object and the dimensions of the XRF probe made it impossible to analyse the join between the spiral and the terminal. Hence, although visual examination failed to reveal any evidence for a soldered joint, it is not possible to say whether, in fact, the terminals are soldered on to the twisted section like those on the torc from Fresné la Mère or whether they are part of the original bar, like those on the Castlemount torc.

Microscopic examination

The cross section from A was examined by optical and scanning electron microscope (SEM) and also using the independent X-ray fluorescence spectrometer. The cross section from A is illustrated in the composite SEM micrograph shown in figure 2. Measurements of dimensions made using a graticule in a low powered optical microscope are listed beside the micrograph. The cruciform cross-section has rather bent arms of irregular thickness which have thickened 'mushroom' shaped ends. In the 'as polished' condition both cast and worked structures are visible on the cross-section. More details of the structure are revealed by electro-etching and the main body of the metal was found to consist of twinned, equiaxial grains, with an average diameter ranging from 0.8 mm near the centre of the section to 0.6 mm at the ends of the limbs, where the grains are slightly distorted. An infill of metal with an 'as cast' structure can be seen between three of the four arms of the cruciform section. The infill consists of large cored grains with rounded cavities due to gas porosity and shrinkage, which were particularly prevalent at the interface between the infill and the body metal. Some angular grains have grown from the body metal into the infill, showing that the torc was heated for some time after the infill was introduced. X-ray fluorescence analysis of the gold carried out in the SEM showed that the body metal contained 80.3% Au, 16.2% Ag and 3.5% Cu, while the infill contained 77.6% Au, 13.9% Ag and 8.5% Cu. According to the ternary liquidus diagram of Sistar (1967), these alloys have melting points of c.1040°C and c.1000°C respectively, and the infill metal can therefore be interpreted as a solder, or brazing alloy, with a melting point close to that of the body metal. The use of such an alloy for soldering would require good temperature control of the source of heat to avoid excessive softening or melting of the body metal. Semi-quantitative analysis of the grain which had grown into the cast region from the matrix shows a composition gradient with a definite increase in copper and a slight decrease in silver in the portion of the grain within the solder. The cross-section showed clearly that the torc was not made by soldering together separate strips of metal or portions of the same bar which had previously been split into four lengths, while remaining joined at the ends, a technique employed in the Yeovil torc. (*Maryon, 1938*)

The second sample, from position D, was examined in the SEM, without polishing. Solder was not present between the arms of this section. The grains are equiaxial, but smaller than those found in similar positions in section A. Distorted and undistorted grains can be seen at the broken surface and therefore the fracture exhibits both ductile and brittle features. X-rays fluorescence analysis of the section from D shows a gold-silver-copper alloy with composition similar to that of the body metal at A, but in addition, a small amount of nickel is present in the area immediately adjacent to the point from which the fracture originated. Nickel is completely soluble in gold and normally has a strengthening effect upon gold and its alloys. It is possible, however that in this case the nickel is associated with the presence of another trace element, such as sulphur, which has a markedly embrittling effect in gold. Unfortunately the detection of a small quantity of sulphur is difficult by x-ray fluorescence, since the sulphur Kα line produces a peak at 2.3 KeV and can be masked by the gold Mα peak at 2.12 KeV.

The solder which is visible between the arms of the cruciform section on Figure 2 can be seen with a low powered microscope to extend along the torc for several centimetres from the break at A (area B on Figure 1), but is not present elsewhere. Several partially melted fragments of metal which were probably pieces of solder can be seen close to the break at A, and their presence indicates that the heat applied during soldering must have been kept close to the melting point of the solder, 1000°C. No positive evidence for the presence of solder was found elsewhere on the torc. The folds and creases visible on the surface of the metal between the arms, which at first sight could be due to poorly adherent solder, do not show a dendritic structure and are more probably the result of the working processes used to shape the torc.

There are four possible explanations for the presence of solder at the broken end of the torc. It might have been used to (a) repair a break in the torc which has since failed again (with loss of part of the torc), (b) attach the second terminal which has since been lost, (c) repair a split at the centre of the cruciform section (there is just such a split near the existing terminal, but no split is visible in the cross-section on Figure 2), or (d) strengthen the twisted bar, the arms of which are not all of equal thickness. There is no evidence which points conclusively to any of these explanations but whatever the reason for the presence of solder, the heating necessary for the soldering process resulted in grain growth within the metal, which had a weakening effect on the structure and may have been an important contributing factor in causing the subsequent failure at this point.

The Method of Making the Torc

The various methods of manufacturing torcs have been discussed in two papers by Maryon (1936 and 1938) and the examination of the torc from Shropshire suggests that the way in which it was made is similar to that suggested by Maryon for the Fresné la Mère and Castlemount torcs. In an attempt to throw some light on the practical aspects of making torcs of this type a model torc was made from square sectioned copper rod following Maryon's suggestions. A regular cruciform shape was first produced using a chisel, working longitudinally along each face of the square sectioned rod. The arms of the cross were then extended by hammering on an anvil, and finally the outer edges were hammered inwards and lightly burnished which resulted in a slight thickening and burring over. The torc was then twisted by clamping one end and twisting the other, which was gripped with a pair of pliers. The procedures were easily carried out and in general appearance the copper model was very similar to the Shropshire torc. The main difference was in the appearance of the ends of the arms which were much more angular and slightly facetted on the model torc, while those on the gold torc were rounded and even somewhat undercut. This suggested that perhaps another process, designed to straighten or give a more uniform cross section, might have been employed on the Shropshire torc and so, in an attempt to simulate the appearance of the gold torc, different lengths of the model torc were respectively swaged, drawn through a near circular die or rolled between two flat blocks of hard wood. The drawn and the rolled models resembled the gold torc most closely, on both the micro and macro scale, and either method could have been used, since both techniques were apparently known at the time *(Oddy 1977, Pietzsch 1964)*.

Summary

The torc from Shropshire was made from one melt of gold, containing approximately 81% gold, 16% silver and 3% copper. The suggested scheme of manufacture is as follows: chisel cuts were made into the four faces of a square-sectioned bar along its whole length, the arms of the cross formed in this way were flattened and extended somewhat by punching or hammering on an anvil and the outer edges were finished by burnishing and polishing. The torc was then twisted and possibly pulled through a die or rolled between two flat surfaces to make the section more uniform. Because the torc was not constructed by joining together separate strips of gold, the solder which was found near the broken end of the torc may have been used to effect a repair or to attach the second terminal which is now missing. The composition of the solder (77.6% Au 13.9% Ag and 8.5% Cu) was close to that of the body metal, and would have required a very careful control of temperature for its application.

Appendix

Restoration

Since this examination was carried out the torc has been restored in the Department of Conservation and Technical Services of the British Museum at the request of Birmingham City Museum and Art Gallery. This involved physically straightening the distorted and damaged area near the existing terminal, which was assumed to be modern damage, and similarly straightening other distortions along the length of the torc. The two pieces of the torc were soldered together using 'Silfos' silver brazing alloy which was subsequently gilded electrolytically. The same solder was also used to repair the torc near the terminal where the metal had been split. In the restored condition the terminal was found to lie across the diameter of the spiral, thus preventing the torc being worn. As a result the spiral was straightened and re-wound more evenly. Fuller details of the restoration are preserved in the files of the Department of Conservation in the British Museum.

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Cylindrical shaft furnaces of the early Wealden Iron Industry: circa 100BC to AD300

J Gibson-Hill

Introduction

Recent excavations of early Wealden iron working sites have uncovered two distinct types of smelting furnace which were apparently in use during the Late Iron Age and Roman Period. These finds consist of single examples of developed bowl or slag-pit furnaces from both Minepit Wood[1] and Pippingford Park[2], as well as groups of cylindrical shaft furnaces represented by the discoveries at Broadfield.[3,4] (TQ 258353) and Holbeanwood.[5]

Several possibly significant variations can be observed within the groups of cylindrical shaft furnaces, and the purpose of this paper is to discuss them, in relation to a chronological sequence provided by radiocarbon 14 determinations. This analysis is based on 70 cylindrical shaft furnaces, 58 from Broadfield, and 12 from Holbeanwood, which are thought to provide a reasonable body of information. Further discoveries of the other types of furnaces will be required, however, before they can be the subject of a similar study.

Wealden Furnace Typology

The 58 furnaces found at Broadfield span a period extending from the first century BC to the third century AD[6] and provide a unique opportunity to study localized variations in smelting techniques. These furnaces are divided into five types, as follows:

Type A (Wealden Type)

This is the earliest and most prolific of all the Wealden furnaces, dating from 190BC (radiocarbon determination of 2140 ± 80 bp and 2010 ± 60 bp at Broadfield); see Table 1 and consisting of a cylindrical shaft, approximately 1.25 metres high, with a slag-tapping bay. As with all the other furnaces, the shaft was lined with puddled clay, laid as a coil starting at the base, and smoothed by hand (reminiscent of a method used in the manufacture of pottery). Both coil and finger marks were clearly visible during the excavation and sectioning of individual furnaces. Where the slag-tapping bay (depression) met the superstructure, an aperture was cut known as the front arch. The sides at this weak point were often reinforced with sandstone blocks (see Fig. 1). The characteristic features are a hearth, level with the surrounding ground, and a free-standing superstructure. The 29 furnaces of this type found at Broadfield span a period extending from the late first century BC to the end of the second century AD. At Holbeanwood they occur in a third century context.

The advantages of using this design (as opposed to other smelting furnaces with slag-tapping facilities) were fourfold. First of all, it was an easier method of construction (the furnace at Minepit Wood required a wooden framework from which the superstructure could be formed and supported during construction). Secondly, the whole shaft could be used, whereas in the bowl furnace considerable space was wasted once smelting had begun.

Type B (see Fig. 2)

This furnace dates from the same time as the earliest examples of the Type A furnace, but was only in use at Broadfield for a limited period (exclusive to the later part of the first Phase at Broadfield (second century BC to c 43 AD)[7,8]. It differs from the 'Wealden' furnace in that the base of the shaft slopes toward the front arch, presumably to assist the flow of the semi-molten slag. Its characteristic feature is a slag-tapping bay, which is fan-shaped. Theoretically, this enables alternate tapping into each of the depressions, as shown in Fig. 2. The characteristic features consist of these alternate tapping facilities, a hearth inclined to the horizontal, and a free-standing superstructure. The modifications were probably an unsuccessful attempt to cope with huge quantities of tap slag.

Type C (see Fig. 3)

In this case, a row of either three or six furnaces was constructed, and was serviced by one large slag-tapping bay, instead of individual pits. The bay was divided by a series of ridges extending from the front arch of each furnace. In all other respects, this furnace is similar to Type B, from which it is thought to have been developed. The characteristic features of this variant are a group of three or more furnaces, arranged in a row, adjacent to each other, with alternate slag-tapping facilities, a free-standing superstructure, and a hearth inclined to the horizontal.

It is impossible to ascertain from the archaeological evidence whether or not the group of furnaces operated simultaneously. This arrangement did, however, offer the possibility of a substantial reduction in the manpower required for the operation of a similar sized group of dispersed furnaces.

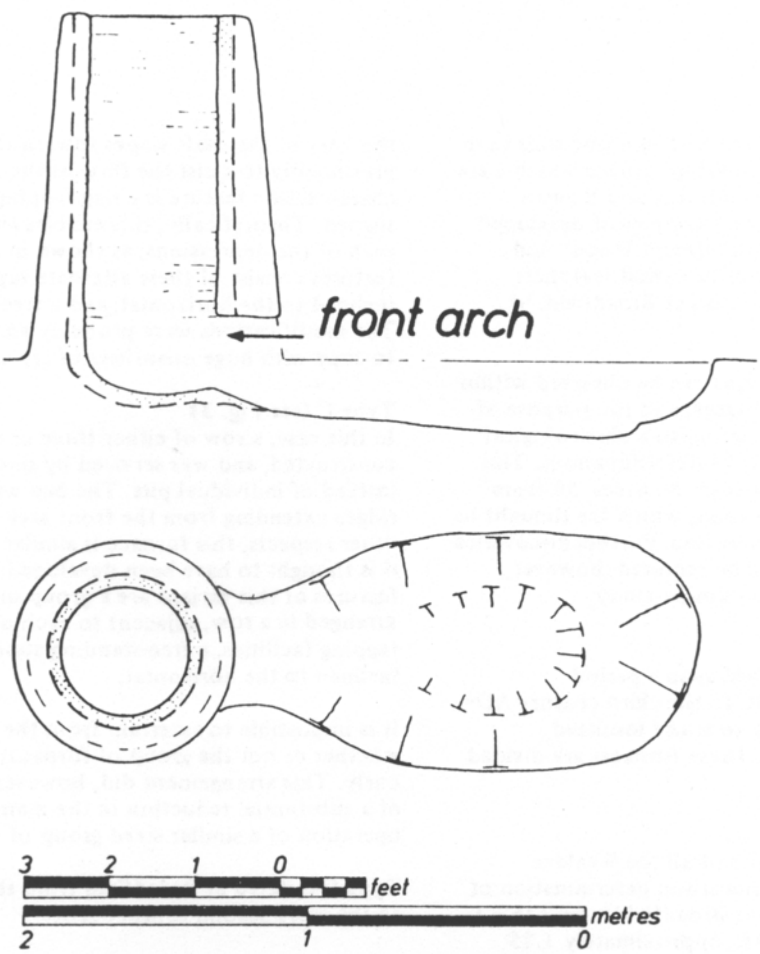
Type C is dated at Broadfield from the late first century AD to the early second century AD.

Type D (Ashwicken Type)

This type is superficially similar to the furnace described above, with several features clearly inherited from Types B and C. There is considerable variation, however, in the method of construction. (see Fig. 4). To construct this furnace, a rectangular flat-bottomed pit was dug and filled with a prepared clay insert. A group of three or six shafts, arranged in a row adjacent to each other, and a tapping bay were then both cut out of this base. A low bank was formed by piling surplus material around the furnaces. Thus this design increases the strength of the structure, and improves its thermal qualities. By using the low bank as a charging platform, the height of the shaft was increased beyond the level convenient for loading by an operator at ground level.

In common with all the following furnace types, the prepared clay insert and structure had a fine sandy texture, quite unlike the Weald Clay.[5] While it proved impossible to ascertain the exact origin of the material used, the purpose of this elaborate excercise may be partly explained as a successful attempt to remove natural inclusion of limestone, ironstone, sandstone and gravel found in the clay locally.

The characteristic features of Type D are a group of three or more furnaces, constructed in a row adjacent to each other, a superstructure supported by the clay insert out of which it was fabricated, and an inclined hearth with slag-tapping facilities. Type D dates from the late first century AD and occurs at Broadfield (as well as at Ashwicken) in a late second century AD context (radiocarbon 14 determination of 1920 ± 70, 30 bc., see Table 1).



Type A

Fig 1 Reconstruction of a free-standing shaft-type smelting furnace. Broadfield Type A

Type E (see Figs. 5 & 6)
This type is subdivided into larger (E1) and smaller (E2) furnaces. The clay insert is normally circular in shape, often being reinforced with large blocks of Tunbridge Wells sandstone.

This later variant is characterized by having up to one-third of the shaft set below ground level, into one side of a relatively deep slag-tapping bay. This method of construction increased the overall height of the furnace, without causing undue loading difficulties. The thermal properties of the furnace were also improved by having the combustion zone recessed below ground level. These furnaces were frequently relined, which caused either a gradual encroachment of the slag-tapping bay, or a change in the orientation of the shaft. The characteristic features are: a superstructure supported by, and fabricated from, a prepared clay insert; a flat hearth and up to one-third of the superstructure being beneath ground level.

The small furnace (E2) was in use from the late first century AD to the late second century AD. The larger variety (E1) first appeared during the second century AD and continued in use until the mid third century AD (Broadfield, radiocarbon 14 determination of 1840 ± 80, 110 bc, and 1900 ± 60, 50 bc).

Conclusions
The most common smelting furnace with slag-tapping facilities, in the Lowland Zone of Roman Britain, was the cylindrical shaft variety. This type offered distinct advantages over the contemporary developed bowl furnace.[8]

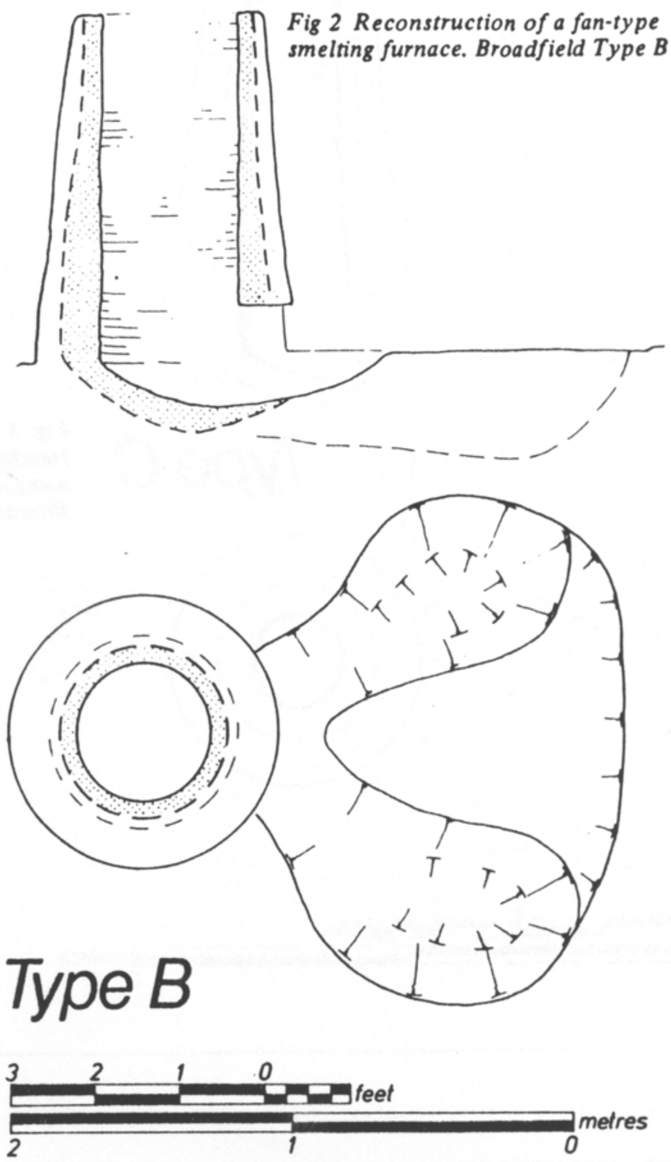


Fig 2 Reconstruction of a fan-type smelting furnace. Broadfield Type B

The cylindrical shaft variety was relatively easy to construct. The shaft was probably formed from clay blocks laid in a circle and lined with puddled clay, applied by the 'coil' method. The strength of the structure is indicated by the numerous relinings the original shaft. Finally, loading the straight-sided shaft furnace was a simple operation, which used the entire volume efficiently.

The cylindrical shaft furnaces are normally associated with both small and large scale industrial settlements, although four free-standing shaft furnaces (Type A) were recently discovered in an urban workshop.[9] Groups of Type D furnaces have been found, in a late second century context, at Ashwicken[10] and Stamford.[11]

Although the free-standing shaft furnace (Type A) is the most prolific variant, it has only been discovered in large quantities in the Weald, with 12 from the third century AD site at Holbeanwood[12] and 29 at Broadfield.[13,14]

The significance of the types described above lies in the differences in construction and size, which imply a change in techniques, manning and yield. It is accepted that some of the variants are probably nothing more than the manifestations of local preferences. Even so, Types A and D have exact parallels elsewhere in Roman Britain and, as a group, the Broadfield furnaces appear to represent a distinct series of improvements.[15] The results are probably both a reduction in the manning requirement and an increase in the yield.

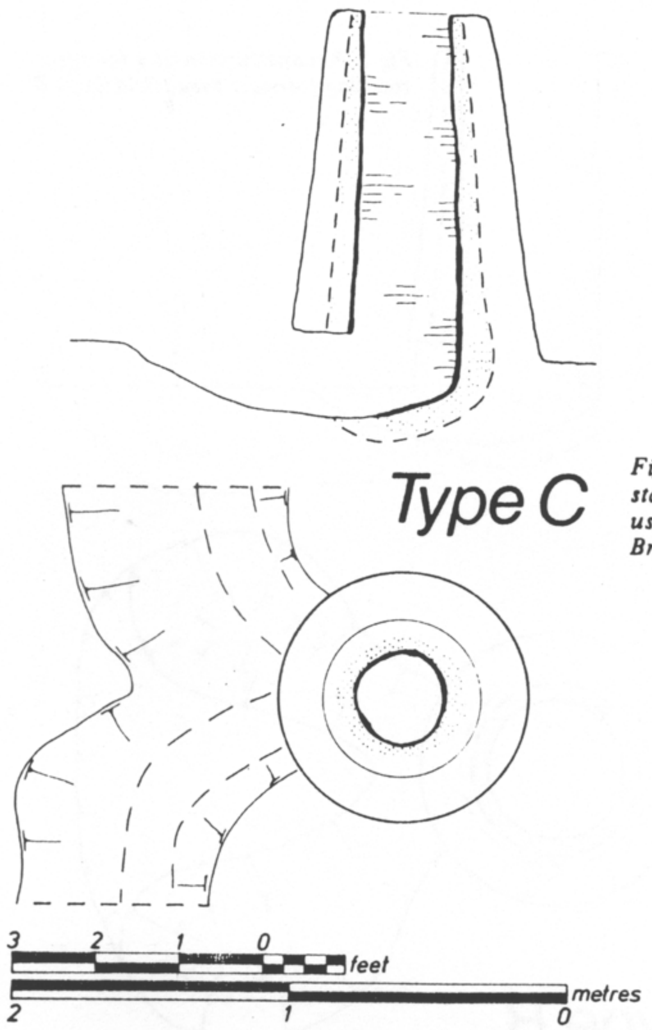


Fig 3 Reconstruction of a free-standing shaft-type smelting furnace using a common slag tapping bay. Broadfield Type C

TABLE 1

Carbon −14 determinations from Early Wealden Iron Sites

Site	Lab No	Age BP Years	Age-Calender Years (BP 1950)	Ref No
Broadfield 1	HAR 554	1900 ± 60	AD 50	3
Broadfield 2	HAR 970	2010 ± 60	60 BC	3
Broadfield 3	HAR 971	2140 ± 80	190 BC	3
Broadfield 4	HAR 972	1840 ± 80	AD 110	3
Broadfield 5	HAR 973	1920 ± 70	AD 30	3
Broadfield 6	HAR 974	1920 ± 70	AD 30	3
Broadfield 7	HAR 975	1920 ± 70	AD 30	3
Castle Hill	HV 2984	–	AD 60-90	16
Little-Inwoods	HV 2985	–	130 BC-70 AD	16
Minepit-Wood 1	BM 363	1949 ± 43	AD 1	1
Minepit-Wood 2	BM 267	1610 ± 150	AD 340	1
Pippingford Park	BM 685	1647 ± 60	AD 303	2

Fig 4 Reconstruction of an insert-type smelting furnace using a common slag tapping bay. Broadfield Type D (Ashwicken after Tylecote)

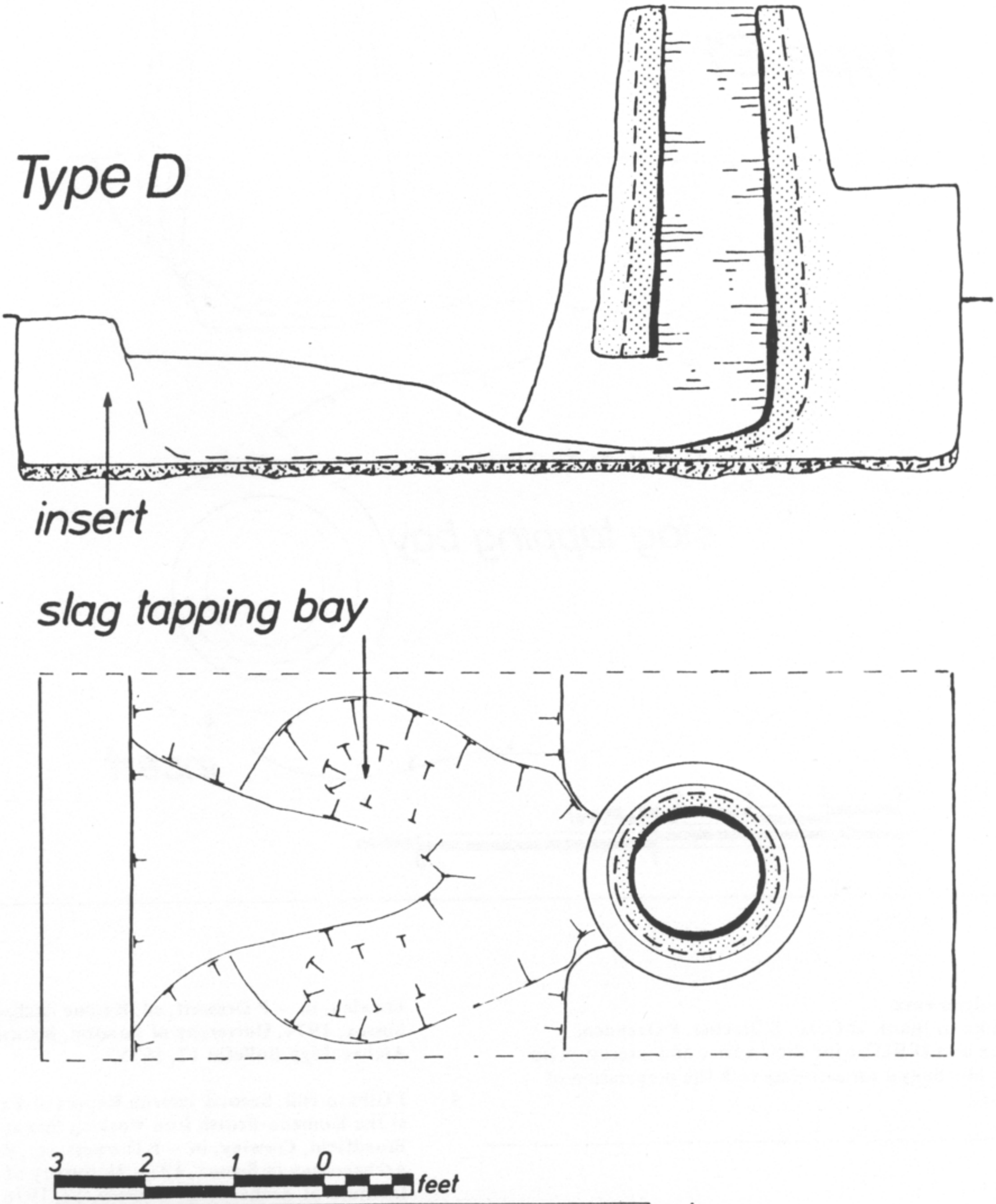
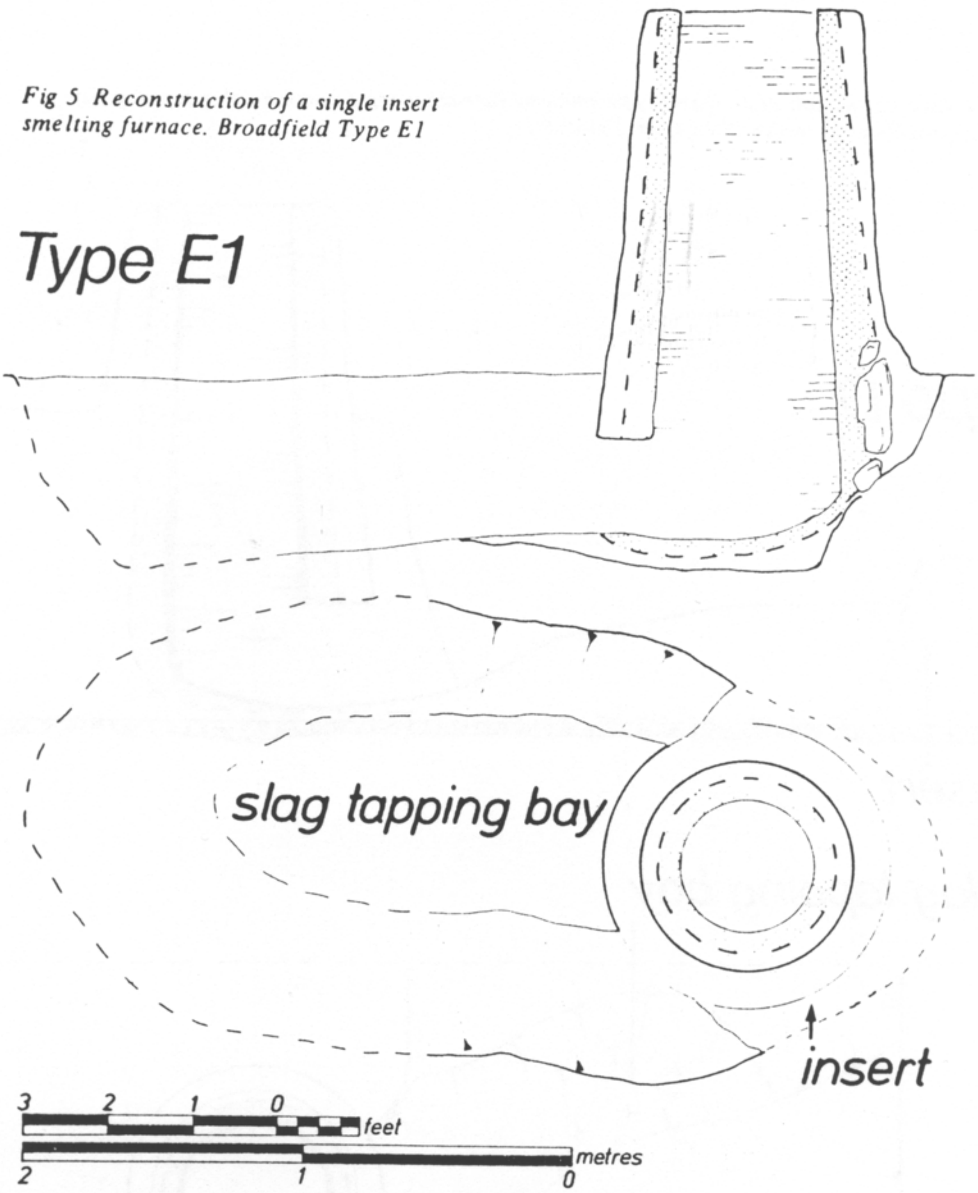


Fig 5 Reconstruction of a single insert smelting furnace. Broadfield Type E1



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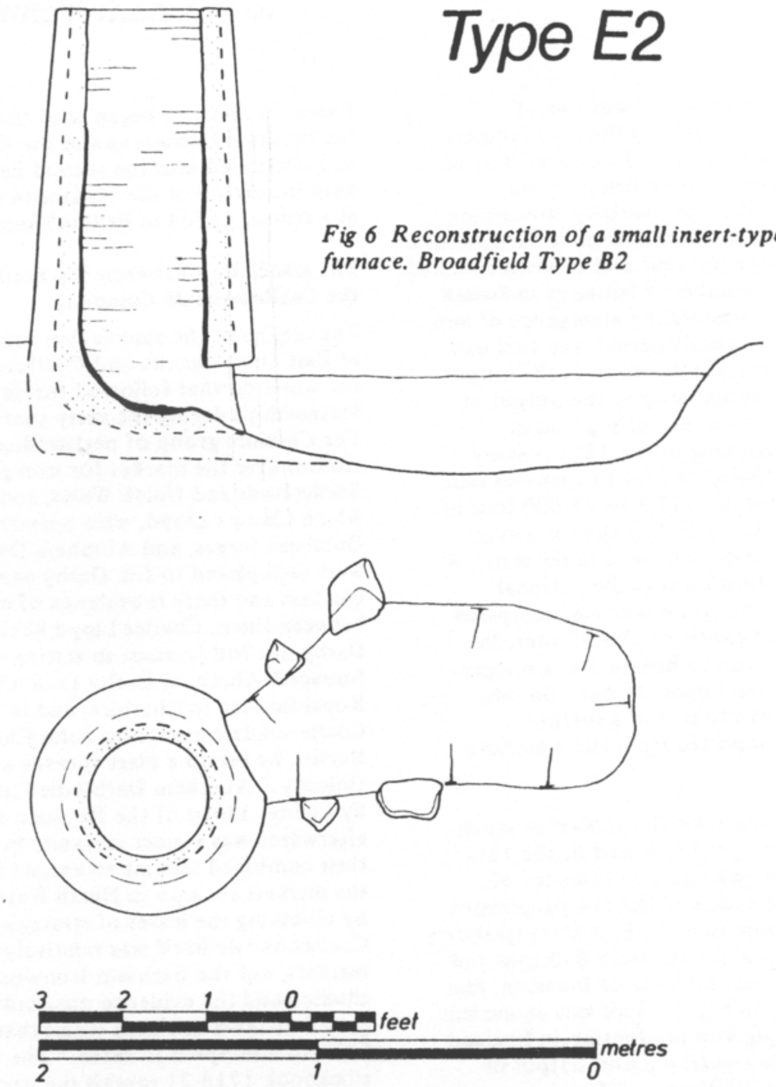

Fig 6 Reconstruction of a small insert-type smelting furnace. Broadfield Type B2

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The Iron Industry of East Denbighshire during the early Eighteenth Century: with particular reference to Bersham Ironworks

John T Turley

The first half of the Eighteenth century was one of technological progress and innovation in the iron industry of East Denbighshire at a time when traditional centres of the charcoal iron industry elsewhere in Britain were experiencing increasing problems, particularly concerning fuel supplies. Many charcoal blast furnaces once extinguished for one reason or another were not relit and often abandoned. Between 1653 and 1740 the number of furnaces in Sussex declined from 53 to 15,[1] and despite the emergence of new centres of iron making over the same period, the first half of the 18th century saw a general stagnation in the output of pig iron in Britain and an actual drop in the output of bar iron. Estimates of the total output of pig iron in England and Wales at the beginning of the 18th century vary from 18,190 tons mentioned in a list of furnaces sent by William Rae to John Fuller in 1717,[2] to 25,000 tons in 1720 a total quoted by T S Ashton[3]. For the following three decades pig iron production remained fairly static. A list of forges dated 1734[4] estimated that the national output of bar iron was 12,190 tons per annum, compared to a total that had been made earlier of 19,489 tons. In 1718, Russia's export of bar iron to Britain was a meagre 334 tons, but by 1750 the total import of bar iron into Britain from Russia was 27,954 tons, and a further 3,335 tons of pig iron were imported from the American Colonies.[5]

In this environment of stagnation which typified so much of Britain's iron industry during the first half of the 18th century, the progress made within the iron industry of East Denbighshire stands out as one of the few progressive aspects of a depressed situation. In 1720 East Denbighshire's annual output of pig iron was approximately 850 tons and this originated from the charcoal furnaces of Bersham, Plas Madoc and Ruabon (see map in Fig. 1). This was equivalent to some 3.4% of the annual pig iron production in England and Wales, By 1750 when the annual pig iron output of England and Wales was under 30,000 tons[3] East Denbighshire produced around 1350 tons of pig iron or 4.5% of the National total, the majority approximately 800 tons coming from the Bersham Ironworks. The relative increase in the importance of East Denbighshire as an iron producing region reflected both the closure of many charcoal furnaces in other parts of the country and the technical progress achieved at Bersham which allowed iron output to increase.

Factors leading to Technological Progress in the Iron Industry of East Denbighshire during this period

The reasons that account for the progress in technique and output made within the iron industry of East Denbighshire during the first half of the 18th century owe little to geography. In terms of indigenous resources the region had no particular advantage compared with other areas that were similarly endowed, and its geographical position was such that it was relatively poorly placed to serve national needs. The answer lies instead in a series of coincidental occurrences which brought East Denbighshire from the backwaters and into the mainstream of new developments within the iron industry.

These occurrences began with the association between the Bersham Ironworks and the Coalbrookdale Company, and continued into the second half of the 18th century with the arrival of the Wilkinson family into Denbighshire at a crucial period in Britain's industrial history.

The association between the Bersham Ironworks and the Coalbrookdale Company

The origins of the association between the iron industries of East Denbighshire and Coalbrookdale can be traced to the situation that followed the demise of the Foley Partnerships during the early years of the 18th century. The Cheshire group of partnerships had considerable control over the market for iron goods in the Welsh Borderlands and North Wales, and its collapse left a void which Charles Lloyd, who operated the Mathrafal and Dolobran forges, and Abraham Darby of Coalbrookdale were well placed to fill. Darby and Lloyd were both Quakers and there is evidence of early business links between them, Charles Lloyd having loaned money to Darby in 1708 to assist in setting up the Coalbrookdale furnace.[6] Abraham Darby took a half share in the Vale Royal furnace in Cheshire, and in 1715 with his Coalbrookdale associates John Chamberlain and Thomas Bayliss, he set up a blast furnace at Dolgaun, near Dolgelly.[7] Abraham Darby died in 1718, but the lease by Charles Lloyd of the Bersham Ironworks shortly afterwards was almost certainly in part an outcome of their combined scheme to extend Quaker control over the markets for iron in North Wales and the Borderlands by obtaining the leases of strategically placed ironworks. Coalbrookdale itself was relatively remote from these markets, but the Berhsam Ironworks was more conveniently situated and the evidence does indicate that Bersham gained markets in North Wales that Coalbrookdale had hitherto attempted to serve. "The Coalbrookdale stockbook 1718-21 reveals the names of ironmongers at Wrexham and Oswestry who were served from Coalbrookdale. In Wrexham were Mary Speed, Joshua Eddows, Thomas Acherley and Joseph Buttall; in Oswestry Evan Guyn. Elizabeth Felton and Owen Hughes . . . By 1722 names of Wrexham as well as Chester ironmongers had disappeared from the Coalbrookdale lists. Evidently Bersham was then catering for the "Potts, kettles, bakestones, skillets etc."[8]

In 1727, following the failure of Charles Lloyd's operations, the Bersham Ironworks was disposed of to John Hawkins, a son-in-law of Abraham Darby.[9] Through his wife Ann, John Hawkins also had shares in the Coalbrookdale Company, together with Richard Ford, another son-in-law of Abraham Darby, Thomas Goldney, and Abraham Darby II, who entered the partnership in 1728.[10] Our knowledge of events concerning East Denbighshire and Coalbrookdale during this period derives from the correspondence between Richard Ford and Thomas Goldney, (See Ref 9) and the letters indicated that the link between the Coalbrookdale Company and the Bersham Ironworks became complete when Ford and Goldney began to finance the operations of John Hawkins at Bersham in 1732. "I have advanced him (John Hawkins) upwards of £150 and hope it will not be long before we are in blast", wrote Ford to Goldney in February 1733.[11]

East Denbighshire 18th Century Ironworks Map

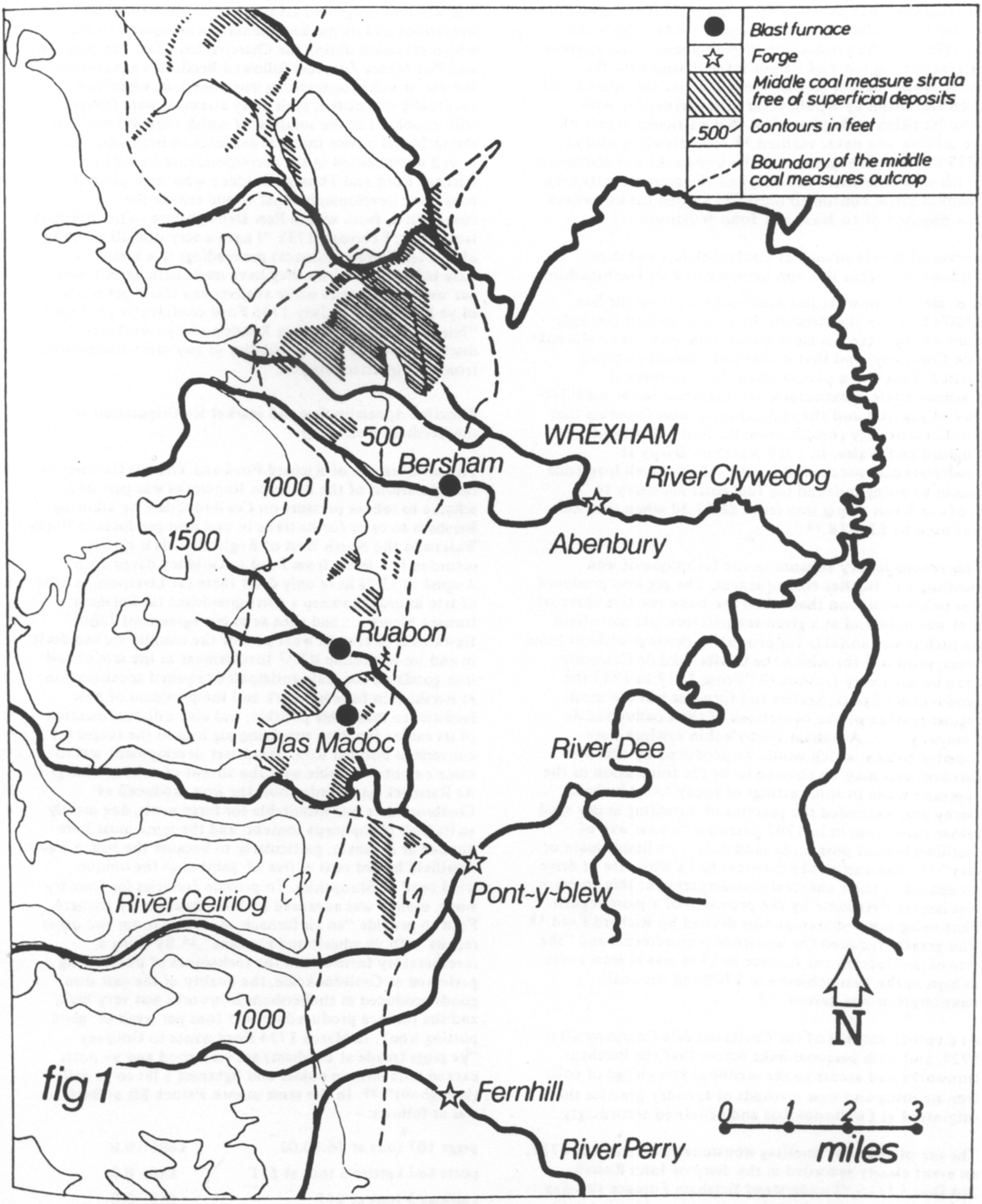

fig 1

By February 1735 they had advanced £1,500 to John Hawkins, of which Abraham Darby II contributed one third.[12]

The reason for the continued involvement of the Coalbrookdale Company in the iron industry of East Denbighshire was part of a marketing scheme designed to release the Coalbrookdale Ironworks for foundry work concerned in the production of Newcomen steam engines by transferring most of its pot trade destined for the North Wales market to Bersham.[13] It was anticipated that Ford and Goldney would enter into partnership with John Hawkins at Bersham, but that particular aspect of the scheme was never realised.[14] John Hawkins died in 1739 but the management of the ironworks was continued by his wife Ann and son John, and the arrangements with Coalbrookdale continued until 1753 when the ironworks was disposed of to Isaac and John Wilkinson.

Technical developments at Coalbrookdale and their application within the iron industry of East Denbighshire

It is clear from what has been said that from the late 1720's to 1753 the Bersham Ironworks in East Denbighshire was operated in close association with the Coalbrookdale Company, and that earlier links almost certainly existed. This was a period when the ironworks at Coalbrookdale spearheaded developments in the manufacture of pig iron and the techniques of iron founding that would eventually revolutionise the iron industry of England and Wales. In 1709 Abraham Darby at Coalbrookdale successfully used coke to smelt ironstone and in so doing reduced the fuel costs necessary to produce 1 ton of pig iron from £6.13.3d when charcoal was used to £3.1.1d.[15]

This revolutionary advance in the technique of iron smelting had further consequences. The pig iron produced was richer in silicon than when the more reactive charcoal fuel was used and at a given temperature was more fluid As such it was suitable for producing castings without blow holes, products for which the Coalbrookdale Company soon became very famous.[16] "From 1719 to 1737 the production of pots, kettles and furnaces was the most regular feature of the operations of the Coalbrookdale Company .... Abraham Darby's thin castings were superior to any which would be produced by charcoal furnaces and may be claimed to be the foundation of the common trade in thin castings of today".[17] Abraham Darby also extended the practice of moulding in dry sand rather than loam in in 1707 patented "a new way of cast iron bellied pots... in sand only... without loam or clay".[18] The early coke furnaces had a slow rate of drive compared to their charcoal counterparts but this problem was largely overcome by the provision of a more regular blast using horse-driven pumps devised by Richard Ford.[19] This greatly reduced the ironstone requirements and "the rate of production per furnace in 1736 was at least twice as high as the best achieved in 1709 and the coal consumption was halved."[20]

As a virtual outpost of the Coalbrookdale Company after 1727, and with personal links before that, the Bersham Ironworks had access to the technical knowledge of coke iron smelting and new methods of foundry practice that originated at Coalbrookdale and benefited accordingly.

The use of coke for smelting ironstone at Bersham in 1721, an event clearly recorded in the diary of John Kelsall; 3rd Dec. 1721:- "I understand Bersham Furnace this day ceased blowing with charcole and went on blowing with coakes for potting",[21] was a direct outcome of personal links between the Coalbrookdale Company and Charles Lloyd, and it meant that the iron industry of Denbighshire was second only to that of Coalbrookdale in utilising the new process. By the middle of the 18th century every blast furnace in East Denbighshire was using coke in preference to charcoal for iron smelting, and at Bersham in particular a profound change had taken place in the form of its operations and its market orientation compared to that which prevailed during the Charcoal Iron Era. The Ruabon and Plas Madoc furnaces followed Bersham's example in the use of coke for smelting ironstone but, while they eventually succeeded, their early attempts were fraught with problems in the solution of which they did not have the technical advice that was available to Bersham. This is well documented in the correspondence between Richard Ford and Thomas Goldney who were pleased to see any developments that would reduce the competition from within East Denbighshire to the Bersham Ironworks; February 1732 "I have a very dismall account of Ivie (at Ruabon furnace) proceedings in a blast . . . I am told ye most iron they have made hath been 3 tons per week and that as white as silver can scarse get it out of ye hearth".[22] In July 1736 Ford confidently predicted "Ivies furnace is at hand at Ruabon and ye workmen discharged, there is no possibility of any more competition from that quarter this year".

Function Specialisation and Market Re-Orientation at the Bersham Ironworks

The involvement of Richard Ford and Thomas Goldney in the operations of the Bersham Ironworks was part of a scheme to relieve pressure on Coalbrookdale by allowing Bersham to cater for its trade in cast iron products in North Wales and the North West of England. This is clearly recorded in a letter from Ford to Goldney dated 18th August 1733 "I have only dealt there (at Liverpool) a little of late in order to keep a correspondence till Bersham furnace blows . . . and then as in our agreement John Hawkins is to take in what part of the country he can deale in and we to decline it".[23] Involvement in the sale of cast iron goods on the scale anticipated required specialisation at Bersham in foundry work and the provision of new facilities to make this possible, and also a discontinuation of its earlier function supplying pig iron to the forges for conversion into bar iron. This latter development was to some extent inevitable with the advent of coke smelting. As Raistrick has pointed out, the iron produced at Coalbrookdale was unsuitable for forge work, due mainly to its high phosphorus content, and the same must have applied at Bersham, particularly so because the North Wales Coalfield lacked coal as free of sulphur as the unique 'clod coal' of Shropshire. To provide facilities for foundry work, money was advanced to John Hawkins by Richard Ford to provide "an air furnace, moulding room and other repairs with ye wheele and Furnace".[24] By using a reverberatory furnace and the techniques of iron casting perfected at Coalbrookdale, the quality of the cast iron goods produced at theBersham Ironworks was very high, and the furnace produced up to 5 tons per week of 'good potting iron". In March 1734 Ford wrote to Goldney "ye piggs (made at Bersham) are very good and ye potts exceed ours both in colour and lightness 5 lbs to ye gallon throughout".[25] In the same month a stock list at Bersham was as follows:–

piggs 107 tons at £6.10.0d	£695.10.0.
potts and kettles 6 tons at £11	£66. 0.0.
castings 5 tons at £11	£55. 0.0.
goods sold	£100. 0.0.

Ironstone 60 dozens at 9/–	£27. 0.0.
Coakes and coles	£20. 0.0.

Among the dead stock was listed boxes and patterns value £50, sand and loame value £10 and buildings which included moulding rooms and a carpenters' shop. These facts seem to confirm that by 1734 the Bersham Ironworks had been fully adapted to foundry work, specialising in the production of high quality castings. Its earlier links with iron forges and through them with the iron trades of the Stour Valley and the West Midlands had either been severed, or substantially reduced, and it was catering increasingly for the growing market for cast iron goods in North Wales and the North-West of England, a trade focused on Liverpool and, to a lesser extent, Chester.

Confirmation from documentary sources that similar developments occurred at the other blast furnaces in East Denbighshire during this period is less certain, but it does appear that the Ruabon furnace followed a similar course of development, but with less success than at Bersham as the letters referred to earlier indicate.

The Plas Madoc furnace on the other hand, operated in association with Pont-y-blew forge and in 1729, as the disbursement book of Thomas Cupper indicates,[26] it still used charcoal as a fuel; July 23. 1729. "received from Mr Maddocke £200 . . . of ironstone and cordwood delivered to the use of the furnace and forge". The destination of the bar iron produced would initially have been the traditional market in the Stour Valley, but it is likely that as the century progressed an increasing proportion would have been marketed locally. By the middle of the 18th century Plasmadoc was also using coke as fuel, but whether its links with Pont-y-blew forge continued at that time is impossible to say with certainty.

Sources of Fuel and Raw Materials

By the middle of the 18th century coal had largely replaced charcoal as a fuel in the furnaces of East Denbighshire, and the use of charcoal was mainly limited to small amounts added to increase the rate of drive of the coke furnaces. The demand for charcoal in East Denbighshire at this time came from the forges, and, with the fall in total demand by the iron industry as a whole, supplies of timber within East Denbighshire and adjacent areas were adequate for their needs.

Ruabon parish with its drift-free exposures of Middle Coal Measures, particularly in the Rhosllanerchrugog and Acrefair districts, was the main source of ironstone, as it had been in the previous charcoal iron era, and with introduction of coke smelting the ironmasters turned to the same localities for their coal supplies. The use of both coal and ironstone from the Gardden Estate in Rhosllanerchrugog by the Bersham furnace in 1723 is detailed in the Kelsall Diaries,[27] 20.12.1723 "I was very busy copying out a large deed about the purchase of the Rhose and in getting a deed made from T Harvey to convey the same to master". 20.12.1724 "Edward Davies and I went to the Rhose to see the coalworks and went down one of the pits". Later when John Hawkins operated the Bersham furnace he also made use of the coal and ironstone of the Gardden Estate, as the following extract from a letter by Richard Ford indicates: "The progress of Bersham Furnace hath in some measure been retarded for two months, being occasioned by Ivie preferring a bill out of ye exchequer against Jn Hawkins for keeping possession of Gardden Estate after Thomas Harveys decease".[28] In 1757 the Brandy Colliery, also in Rhosllanerchrugog, supplied 1412 courses of coal and 110 dozens of ironstone to Plasmadoc furnace,[29] sufficient for over one third of the requirements of the furnace,and the remainder came from the Plas Bennion estate of Edward Lloyd, also in Ruabon parish, and pits leased in Christionydd Kenrick township, from 1830 onwards.[30]

Conclusion

From the sources available it is reasonable to conclude that during the initial phase of the Coke-Iron Era, which lasted until the middle years of the 18th century, East Denbighshire grew in significance as an iron-producing region. This was a direct outcome of the use of coke as a blast furnace fuel, initially at the Bersham Ironworks and subsequently at Ruabon and Plasmadoc furnaces. The new fuel freed the ironworks from a total dependence on the increasingly scarce and expensive supplies of charcoal and this gave the iron industry of East Denbighshire a significant competitive advantage over other iron-producing regions, which lacked access to the new technology. This early and successful use of coke in East Denbighshire stemmed directly from the close personal and marketing links between the Bersham Ironworks and the Coalbrookdale Company, which was responsible for so many of the early advances in coke-iron smelting.

The iron produced by the use of coke, however, was less suited to conversion into bar iron than the pig iron produced by charcoal furnaces, but its chemical properties made it ideal for the manufacture of cast iron goods. This fact, together with the technical advances in iron founding introduced into the Bersham Ironworks from Coalbrookdale, led to a significant change in the character of the Bersham Ironworks and its market orientation. The traditional practice of producing pig iron for conversion in the forge into bar iron for sale to the iron trades of the Stour Valley and the West Midlands was almost certainly discontinued at Bersham, and its pig iron was cast instead into a variety of foundry products that could be marketed locally, in North Wales and the North-West of England. The arrangements made with the Coalbrookdale Company that alone could produce cast iron ware of comparable quality gave Bersham a considerable advantage in these markets, a situation which continued until the introduction of canals, and a more widespread use of coke after 1753, brought increasing competition from other iron-producing regions.

Evidence concerning the Plasmadoc and Ruabon Ironworks during this period is more limited, but what is available could suggest that they too developed along similar lines to the Bersham Ironworks, but without the technical assistance that Bersham received from the Coalbrookdale Company. Plasmadoc furnace was worked in association with the Pont-y-blew forge and thus the output of bar iron from East Denbighshire continued, but probably for an increasingly local market as the former trade between East Denbighshire and the West Midlands declined.

The developments outlined above all occurred within a framework of industrial location within East Denbighshire which was determined by the requirements of the charcoal-iron industry. The Bersham, Plasmadoc and Ruabon ironworks each operated blast furnaces that had been converted to use coke as a fuel in place of charcoal, and each owed its siting to the need for centrality in relation to once essential supplies of charcoal, easy access to ironstone and a convenient water-power site. The advent of coke smelting did not lead to an increase in the number of

blast furnaces in East Denbighshire or to any change in the location of existing concerns. The need for water power continued and the furnaces were already sited near to drift-free Coal Measures outcrops, the continuing source of ironstone, and now also the origin of the coke on which the furnaces depended for fuel.

APPENDIX A

STATISTICS RELATING TO THE IRON INDUSTRY OF EAST DENBIGHSHIRE

1. **Hulme, W E, Statistical History of the Iron Trade. Trans. Newcomen Soc. Vol IX 1928-1929.**

Appendix 1, pages 21-23. A list of ironworks in England and Wales in 1717 based on the Mss of John Fuller, Gunfounder, Heathfield, Sussex.

The list of furnaces records under Denbighshire, "Place maddock", annual output 300 tons, Ruabon, annual output 250 tons and Bersham, annual output 300 tons.

The list of forges records under Denbighshire, "Pontablew" (Pont-y-blew) annual output 200 tons. Under Flintshire is recorded Abbenhirry which probably refers to Abenbury forge in Denbighshire, annual output 70 tons.

Appendix 2, pages 24-25. A list of forges in England and Wales contained in an anonymous pamphlet published in 1736 entitled "The Interest of Gt Britain in supplying Herself with Iron: impartially considered".

Under Denbighshire is recorded Pontablue (Pont-y-blew) which has made 200 tons of iron per year but now makes 150 tons, and Wrexham (Abenbury) which has made 80 tons of iron per year but now makes none.

Appendix 3, page 27. A list of forges in England and Wales 1750.

Under Denbighshire is recorded "Pontablue', annual output 200 tons and Wrexham, annual output 80 tons.

2. **An account of charcoal blast furnaces which have declined blowing since the year 1750 owing either to want of woods or the introduction of making coak iron. Jan. 1st 1788.**

Boulton & Watt Collection, B'ham Ref. Lib.

Under North Wales is listed as follows:

Bersham furnace – worked by Wilkinson, down.
Ruabon furnace – worked by Rowlands, down.
Plasmadoc furnace – worked by Rowlands, down.
Conway furnace – worked by Bridge, down.
Aberdovey furnace – worked by Kendall, down.

One coke fired blast furnace is recorded at Bersham.

3. **An account of the coak furnaces now in work in Great Britain with an estimate of the quantity of pig iron they may be supposed to make at each of them weekly upon an average of 52 weeks in a year. Dec. 25th 1791.**

Boulton & Watt Collection, B'ham Ref. Lib.

Hawkins Average (Average Ann. Output per Work) c. 1750	Counties	No of Works	Average Annual Output per Work (Tons)	Total Annual Output for each County (Tons)
1400	Shropshire	23	1352	31096
1400	Glamorganshire	7	1352	9464
800	Yorkshire	8	730	6240
700	Lancashire	1	624	624
500	Cheshire	10	320	520
500	Derbyshire	9	520	4680
500	Staffordshire	15	520	7800
500	Cumberland	1	520	320
850	Monmouthshire	5	832	4160
750	Brecknockshire	2	780	1560
800	Denbighshire	1	780	780
1000	Scotland	12	1040	12480
			TOTAL	80704

4. **From a List of the different ironworks in England, Wales, Scotland and Ireland to the year 1794.**

Boulton & Watt Collection, B'ham Ref. Lib.

Name	Proprietors	Occupiers	Coak Furnaces	Forges Fin.	Forges Chaf.	Rolling Mill	Built
Bersham	Mr Myddleton	J Wilkinson				1	1788
Abenbury	Mr Travis	J Wilkinson			1		
Pont-y-blew		Mr Rowland		2	1		
Llyn-On	J Jones	Mr Rowland		1	1		1764
Gwersyllt		Ainsworth- & Hayton		1	1		1781 (wire mill)
Bodfari		Eyton & Son		2	i		
Mathraval		Smithman & Co		2	1		
Ruabon	R Myddleton	Jones & Rowland	1				1790
Brymbo	J Wilkinson	J Wilkinson	1				1796

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The story of 11|14% Manganese Steel Rails

Basil H Stonehouse

This narrative was to have been written jointly with Herbert Stead, formerly General Manager of the Trackwork Department of Edgar Allen Engineering Ltd, but with the latter's tragic death just before Christmas 1970 it fell to the writer to carry out this work alone; so this is, in effect, a memorial to him. It is not only Bert Stead's efforts over many years in the usage of 11/14% manganese rails in the trackwork field I would mention, but also the toil of many men not least those who actually made and rolled the steel and that was no light task for it was, and is, one of the most difficult of all qualities to manipulate.

The beginnings of the story go back to the time of Henry Bessemer with his invention of the type of steel which carries his name. Ever since man first melted metal he has always tried to improve on the finished product firstly, perhaps, to remove its inherent brittleness and then to get it to resist abrasion and corrosion better, and by these means to get it to last longer, and it is really with these latter factors with which we are concerned in 11/14% manganese rails. Apart from Bessemer's original work on the making of the steel, beyond all doubt, it was the work of the late Sir Robert Hadfield which started the use of abrasion and wear-resisting steels. Beginning in 1878, and culminating in the taking out by him of patent no 11833 in 1896, his work revolutionised the use and demand for these steels. He would probably have been the first to admit that his early work was inspired to quite a degree by experiments carried out about 1862 in Hadfield's Bessemer plant which served the steel foundry at that time. His work was principally concerned with manganese additions to such steels to remove porosity, which had been a bugbear with earlier metal produced by both the Bessemer and Siemens processes, and consisted of adding ferro manganese in varying proportions to decarbonised iron. The ferro manganese he used contained about 7% carbon and 80% manganese, resulting in steels with a carbon/manganese ratio of about 1 to 10. He found that steels with manganese additions between about 2.5 and 7.5% were extremely brittle but, when the figure was raised to 10% and above, the same steel became very tough, as proved by the much improved tensile and elongation characteristics.

The best results were found to be obtained by water quenching the steel from about 1000°C, which is the practice used today, to give the typical austenitic structure but, of course, in the case of the rail, the finishing rolling temperature was used to avoid any reheating. This treatment therefore, as we said, gave a steel which was very tough and ductile and it also had a great advantage as far as rails were concerned in that it hardened rapidly to a Brinell figure of about 550 when cold worked by the rolling action of railway wheels.

The first rails were rolled in Leeds by a firm called Walter Scott & Company Ltd, whose address at that time was Balm Road, in the Hunslet area. It appears that the firm of Scott had originally come to Leeds from Newcastle and in 1888 had acquired the Leeds Steel Works Company, and this amalgamation was fully operational by 1900. The plant for those times would now be termed an integrated one as there were blast furnaces, a Bessemer steel plant with converters up to 10 tons capacity and cupolas for re-melting such cold iron as was also required. The mill consisted of a cogging, roughing and finishing stands, the latter being 32" which meant that rails, up to 108 lbs/yd in weight, could be rolled. This new company obviously developed their rail rolling capacity very well and were not averse to trying out new qualities from time to time. Their rolling mill manager at that time, and we are now speaking of the period 1911/1913, was a Mr Borrowdale, whose son, Herbert, had joined Edgar Allen in 1913 as Railways Department Assistant – later becoming Chief Draughtsman in 1925.

Knowing his father's penchant for trying such new qualities, he persuaded his chief, Mr Brian, to enquire if Scotts would be interested in producing this quality of rail for Edgar Allen, who had obtained an exclusive licence to manufacture in this country in 1912 from the Manganese Steel Co of New York.

Scotts must have met with only limited success as about 1913 they ceased to produce. Whereas the Workington Co, who had also been approached earlier, had met with some success, and their continuing perseverance produced the results we shall read of in the following pages of our story.

At this stage a gentleman's agreement was reached between Allens and Workington that the latter would roll exclusively for them, against the blandishments of Hadfields in the period between and after the wars.

The Workington Iron & Steel Company came into existence as an amalgamation of the Derwent and Moss Bay Iron and Steel companies in 1909, and this company came under the United Steels Companies' banner in 1918. Manganese steel itself has over the years been made by all the conventional methods of steelmaking, ie, Open Hearth, Acid Bessemer, Tropenas and Basic Electric Arc. As far as Workington was concerned, both the Open Hearth and the Acid Bessemer processes were used originally to produce the steel but the latter soon predominated and shortly after the first World War, that process superseded the Open Hearth, as by then the Open Hearth furnaces at the Derwent Works had been closed down.

In those days casts produced in the Bessemer plant were small averaging some 3 tons each and for rail production purposes a maximum of 2 casts for each rolling was the order of the day. Demand was not high with the 85 lbs/yard rail/bullhead section predominating, this section being used by the various home railway companies of that time. The small casts involved did produce some degree of flexibility in that the small orders of those days could be coped with relatively easily.

In 1934 came the first big change towards increased production when Workington put down their new Bessemer plant and produced casts of an average weight of some 19 tons, but only 2 casts were made and rolled at a time. This was decided not only by the average size of order but, more important, the fact that high manganese steel was still one of the most difficult qualities to roll. The rolling rate per hour was very low which meant that, in the shift which was allocated to its production, the total output was equally low so overall tonnage was lost on a shift-to-shift output basis.

At this time, other developments also started to take place at Workington. The old coal-fired soaking pits were replaced firstly by a regenerative and later on by a recuperative soaking pit plant which meant that a much better control of the ingot heating process could take place and this, of course, was a vital factor when rolling the steel. During the 1939/45 war the plant which was to affect production most of all came into operation, that being the installation of a 20-ton Electric Arc Furnace at Workington. This at first worked in conjunction with the Bessemer plant, the idea then being to duplex steel to improve its quality but this phase of operations did not have a long life and very soon the arc furnace came into its own, working on a straight selected scrap melting basis. The improvement in quality and control of electric over Bessemer steels proved most marked in the case of 11/14% manganese products and by 1950 this had become the standard method for its manufacture. Notwithstanding this improvement at that time the average number of casts produced for each rolling was still only 2 and it was not until the late 1950's that the number of such casts began to increase up to the present time when the spectacular figure of 9 per rolling has been achieved. This has meant that production over the years has moved away from being a specialist operation to a regular routine affair, but the quality was still by no means an easy one to roll.

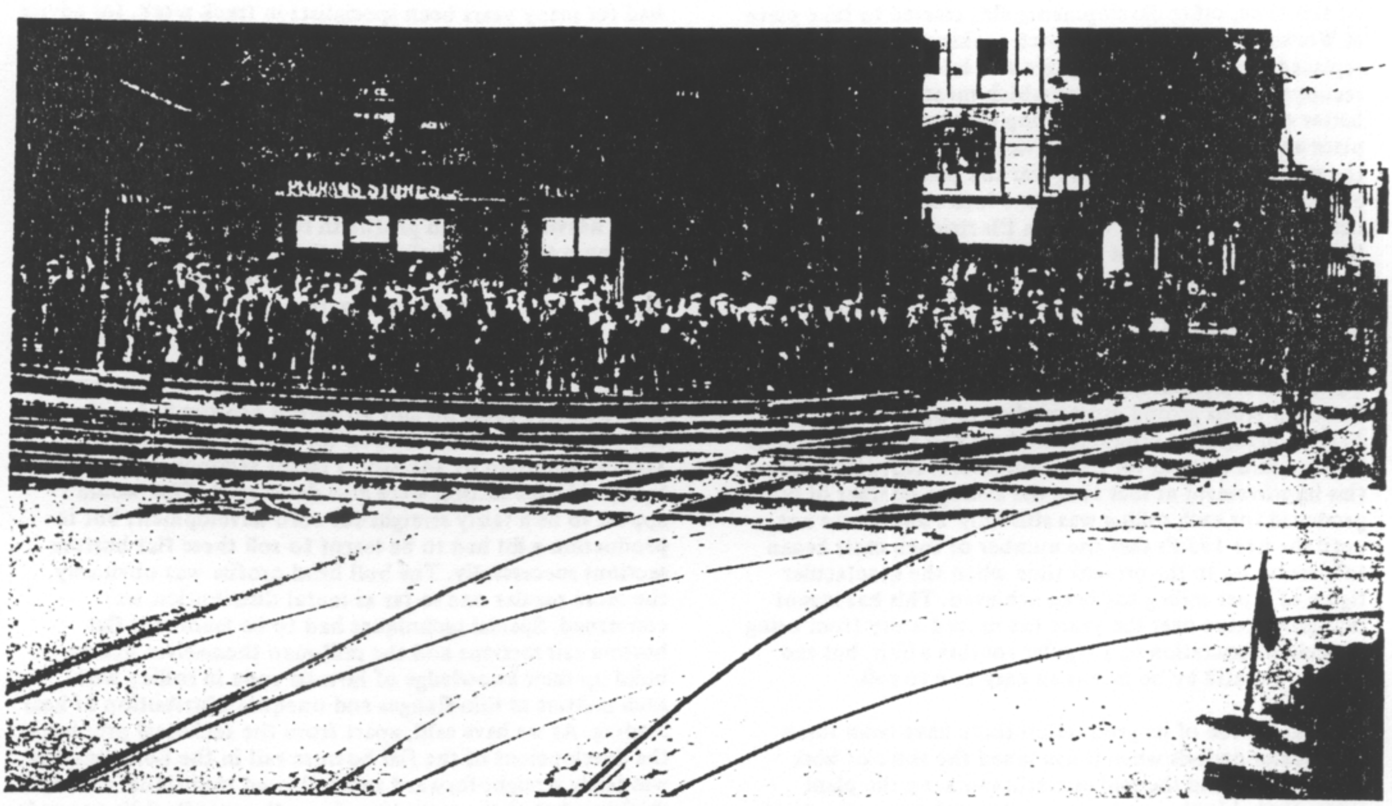
Over the period of its production there have been some spectacular periods when it has taxed the skills of both the engineers and the mill operators to keep the plant going. Probably the most spectacular and un-nerving time was during the change over from steam to electric mill operation in 1949, especially in the case of the finishing mill; at that time the foundations on which the old steam engine was standing had to be exposed so that the new bed for the electric motor and drive could be installed. The trouble was that the old steam engine bed rested literally on slag and the risk was that when rolling a tougher product, as 11/14% manganese, the engine drive might move, which would mean that the mill would be totally out of commission for 6 months. It speaks volumes of the courage of Mr Douglas Wattleworth, the then General Works Manager, that he agreed to carry on with the rolling of high manganese steel rails during that critical period. After the mill change over was accomplished, other plant improvements followed, in particular the reconstruction of the water quenching bosh to accommodate rails of 60 ft length, the new standard length, rather than the older 45 ft length. At about that time also the high speed saw for the cold cutting of the rails was re-sited at the present finishing banks. This was not carried out without some argument as to where the best site would be. Some thought that the cutting operation should be away from the finishing banks and that the saw should have its own crane, etc. Others thought that this piece of equipment should be placed in the vicinity of rail production and this latter view finally prevailed. At the same time the re-siting of it gave the engineers a chance to dismantle and rebuild this rather ancient piece of plant which had been bought originally from Messrs G Brown Bros, Limited, Portrack Lane, Stockton-on-Tees, in 1890.

So far we have dealt mainly with the technical aspects of the production of 11/14% manganese rails and although undoubtedly full of interest to technical readers there is obviously an equal weight of interest in the commercial field. The first rails produced in 1913 were for the home market and the main section used was the same as ordinary quality rails at that time, ie, the 85 lbs/yard bullhead profile. The first railway in this country to use a manganese steel in their rails was the Southern Railway. At that time they had approached Messrs Edgar Allen, who had for many years been specialists in track work, for advice in respect of built up points and crossings, and undboutedly, what is now the Southern Region, owe a lot to the advice, help and production they were able to give them. As time went on it was found that a heavier rail was needed and the 95 lbs bull head section was adopted and this again was rolled in high manganese steel. Following the introduction of this section it became apparent that there was a case for using heavier bull head profile in tunnel work, etc, where minimum time was likely to be available for the engineers to re-lay track and where corrosion was likeliest to be at its highest, and in this connection, the 100 lb bull head section came into use and was successfully rolled at Workington.

The first flat bottom rails for the home railways were rolled in 1937 these being 60 and 90 lbs/yd profiles but as the flat bottom rail was developed for the home railways, the 100 lbs, followed by the 109, 110 lbs sections, and, in 1968, by the 113 lbs section were also developed. This would appear to be a fairly straight-forward development but in production a lot had to be learnt to roll these flat bottom sections successfully. The bull head profile was obviously the more regular one so far as metal distribution was concerned. Special techniques had to be learnt for flat bottom rail sections and the mill men themselves had to build up their knowledge of how to cope in rolling with such matters as thin flanges and unequal distribution of heat loading. As we have said, apart from the technical problems the development of the flat bottom rail in the home market was fairly straight-forward and followed traditional railway thinking, but at the same time from the middle 30's onwards, when trading conditions were difficult, it was felt that there was a good market in overseas countries for the sale of the quality concerned and it is particularly due to Messrs Edgar Allen that this field was tackled.

In the period 1927 up to about 1955 it was in South America where they achieved their greatest success this, in no small way, being due to the energies of their agents in the countries involved. We think, in particular at this time, of the Argentine Railways who became very interested in the quality and over the years, as finance was available, purchased useful tonnages. In 1953 India became interested and the railways were quoted for the 90 lb FB section. In 1956 Australia came into the picture and, in that year, New South Wales was quoted for the 109 lbs/yd profile, this offer being made to try and get business and to avoid the cost of cutting new rolls. In that same year Queensland was tendered in respect of their 80 lbs/yd profile. By the end of that year as a result of the activities of rail rollers, manufacturers and agents, the biggest overseas order ever to be secured by Edgar Allen came to fruition and New South Wales ordered 1000 tons in the 109 lbs section, these rails to be used on curves in heavily worked areas. At about that time the interest in South Africa was beginning to develop in respect of 11/14% manganese and South African railways were tendered for switches in their 80 and 96 lbs/yd profile. At the same time Portuguese East Africa was tendered for their 60 lbs/yd profile. Other countries who had had their interest stimulated in the product were Pakistan for their 60 lbs/yd PR profile and Burma for their 80 lbs/yd rail and, in Europe, our Dutch neighbours, who were always to the fore in new developments, were tendered for their NP 46 section in high manganese steel. There is little doubt that it was at that time in no small measure due to Edgar Allen's keenness, that orders from overseas were forthcoming at reasonable prices.

One of the most interesting developments of all was the development of the guard rail for the Brussels tramways. It is probably not commonly known that up to 1932 this rail had been rolled by the Americans for Brussels but obviously



TYPICAL TRAMWAY JUNCTION CONSTRUCTED OF MANGANESE STEEL.

The photograph shows the Fitzalan Square (Sheffield) junction after 12 years' service and after 13,500,000 tramcars had passed over it. The previous layout, constructed of carbon steel, was worn out in three months.

due to the fact that tonnages were limited, and also due to the undoubted difficulties the Americans experienced in manufacturing the steel, as the electric arc furnace was only just beginning to supersede the open hearth for quality steel, the price they had wanted to charge Brussels had become exorbitant. The proposition was put to Workington to see if they could roll it and great credit is due to the then roll designer, Mr Stanley Armstrong, that he agreed to have a go in the 28" finishing stand. After some slight modifications of profile a trial rolling was put through and success was achieved but at a fairly high cost in defectives, and up to 1957, the year following on the Brussels Exhibition when the tramways started to be taken up, this particular profile, the most difficult ever to be rolled in high manganese steel, only had to be modified twice. Whilst we are still on the subject of the export market it is equally not generally known that the Japanese were at one time interested in high manganese rails and in 1929 they were quoted for a 60 lbs/yd FB section but no development proceeded from this. At that time it was merely a question of the Japanese seeking information on both the quality involved and the rail profiles currently being used because it is certain at the present date the Japanese can manufacture and roll high manganese rails.

In the home market one or two interesting examples of the use of high manganese steel come to the writer's mind. The first was that, as early as 1928, the Southern Railway used the quality in flat bar form for the production of the 95 lbs bull head fishplate for insulating purposes on third rail track. The second example of its use, in rail form, was the GPO Mount Pleasant Underground Line where a slightly modified 35 lbs/yd rail was produced and some 90 tons were ordered in the January of 1934. The wearing properties of this quality of rail are amply illustrated by this installation for as far as we know the track, to this date, has never had to be renewed. Another interesting application has been the use of the rail in switch and crossing form on Southend Pier where very, very little maintenance has been required since the installation of this track. In this case marine corrosion would have been the vital factor. There is one other interesting application of this quality which came about after the war and that is its usage in steelworks practice where heavy axle loads in such places as hot metal tracks and other similar areas were involved. The high axle loadings and curves involved caused heavy wear with normal quality rails. In this field we must particularly pay credit to the United Steels Companies and to what is now Scunthorpe Division of BSC who adopted the quality almost universally for the sort of sites mentioned above, in spite of its relatively high cost compared with ordinary trackwork. Since then BSC, in their Welsh and North East coast works, have adopted this quality for hard worked areas where high axle loads and side cutting of rails is likely to take place.

TECHNICAL ADDENDUM

R E Sherwood Managing Director Engineering
Edgar Allen and Company Limited and B H Stonehouse

As is well known steel production at the Workington Iron and Steel Company's plant was through the Acid Bessemer process, utilizing liquid Northwest Coast hematite iron. The first steel rails were rolled on 13 August 1877.

High Manganese Steel was made by the same process and the first 11/14% manganese steel rails were rolled on 12 July 1913.

In 1950 Workington switched all production of high manganese steel over to the Basic Electric Arc furnace process. Average analyses from representative casts by each process were:

Element	Acid Bessemer	Electric Arc
Carbon	1.32%	1.21%
Silicon	0.164%	0.175%
Sulphur	0.010%	0.012%
Phosphorus	0.068%	0.058%
Manganese	12.90%	12.38%

Because of its properties, high manganese steel which is difficult to roll, is required in sections which tend to be the more complicated. Great care is necessary in the initial heating of the ingot for rolling with the necessity to keep the finishing temperature of the rolled rail high enough to ensure its vital austenitic structure on water quenching.

This called for particular expertise from the rolling production teams.

Edgar Allen supplied high manganese rails first to the London Underground railway in 1913, one layout being still in operation 15 years later after carrying trains at the rate of 998 per day.

Rails supplied to the Indian railways, at Bombay, in 1928 were only replaced 24 years later.

More recently, considerable tonnages of heavy flat bottom section rails have been supplied to the Argentine and to Australia, the latter for use in curves on heavily worked stretches.

The Historical Metallurgy Society Limited

The Historical Metallurgy Society has been incorporated as a company limited by guarantee. Now entitled The Historical Metallurgy Society Limited it was registered on 8 August 1979 – No. 1442508. At the Extraordinary General Meeting held on 7 September 1979, at The University of Sussex, Falmer, Brighton, members noted this and approved the resolution that the Society as presently constituted be dissolved and that all members of the Society be invited to join The Historical Metallurgy Society Limited and that all assets and liabilities of whatever nature of The Historical Metallurgy Society be transferred to The Historical Metallurgy Society Limited and that thereafter The Historical Metallurgy Society be dissolved.

The Extraordinary General Meeting also approved that the Officers and Committee Members, appointed at The Historical Metallurgy Society's Annual General Meeting on 12 May 1979, continue in office as appointed.

President:	Mr M M Hallett
Chairman:	Mr F A Batty
Hon General Secretary:	Mr C R Blick
Hon Treasurer:	Mr I J Standing
Hon Editor:	Professor R F Tylecote
Hon Production Editor:	Mr R Day

Committee:
Mr P R White and Dr P Swinbank
Mr M S Darby and Mr S D Coates
Dr P T Craddock and Mr R C Dyer
Miss A Chatwin and Mr W K V Gale

Representatives of the Society on other bodies

Royal Anthropological Society:	Mr B E B Fagg
The Metals Society:	Mr M M Hallett
Council for British Archaeology:	Mr D W Crossley

The carbon reduction of fully oxidized chalcopyrite (copper) ores

W Rostoker and M Sadowski

Summary
It has been generally supposed that ancient copper smelting of iron-containing sulfide ores followed some crude version of the matte smelting process. Since this would necessitate a multi-stage procedure only at the end of which metallic copper would emerge, it seems unlikely to have been the first method. A process is described and analyzed whereby the ore can be smelted to metal in a simple two-stage process which in empirical terms would not require a technology much different from the carbon reduction of oxidic minerals. It is suggested that this earlier process may have fallen into disuse because the matte smelting approach, as practiced, offered a route to the recovery of precious metals and accordingly displaced the older process.

Introduction
While native metal and oxide (and carbonate) minerals were the earliest sources of copper, they represent a very small proportion of available mineral forms of copper. It is inescapable that the bulk of extracted copper throughout history and as far back as 2000 BC[1,2] was derived from the sulfide minerals (ores). The major deposits of copper sulfide ores of the world represent predominantly the mineral chalcopyrite whose ideal formula is $CuFeS_2$. Actually, chalcopyrite can exist over a range of compositions and can be associated with other copper-iron-sulfur compounds,[3] as well as pyrite, FeS_2 and pyrrhotite, FeS. However, the smelting reactions to produce the available copper are similar.

Oxide and carbonate ores yield metal by a simple reduction with carbon (charcoal). Actually the carbonate ores calcine to oxides during the heating up period. The reduction can proceed at temperatures well below the melting point of copper (1083°C) and with very little CO in the combustion gases. Note that the reduction is not by solid carbon but by the monoxide gas combustion product. Despite the low reduction temperatures, the copper metal remains disseminated and unavailable until the furnace temperature fuses both the metal and the rock to form two immiscible liquids which collect at the bottom of the furnace or crucible. The slag liquid being lighter floats. When solidification occurs the separation is easy and efficient provided that the slag has a low viscosity.

Sulfide minerals cannot be reduced directly by carbon monoxide. A two-stage process is necessary. The first stage is roasting by which the sulfide reacts with the oxygen of the air to form the gases SO_2 and SO_3 leaving a residue which, when roasting is complete, is a conversion to oxides or sulfates. The conversion oxides may then be reduced as would mineral oxides. The sulfates calcine to oxides as with carbonates. This is not so simple withchalcopyrite because complete roasting (conversion to oxides) leaves both the copper and the iron potentially reducible. The alloying of copper and iron is not advantageous. There is limited inter-solubility and the excess iron floats as a solid on top of the pool of liquid copper which inhibits good pouring. The soluble iron in the copper can degrade the formability and also can degrade its casting qualities (as a bronze).

It has generally been supposed that the early methods of sulfide conversion to metal were crude versions of contemporary matte smelting. Matte smelting represents a sequence of separate operations: (a) partial oxidation (roasting) so that some of the iron in the mineral is converted to oxides; (b) high temperature, liquid/liquid separation of a copper-enriched molten copper-iron sulfide (matte) and a slag containing the iron oxide, mineral associated rock (gangue) and added mineral rock ingredients (fluxes); (c) a progression of matte roasting and liquid/liquid separations so that the iron content of the matte is progressively reduced and finally eliminated; (d) oxidation of molten copper sulfide to oxide and the reduction reaction: $2\ Cu_2O\ (molten) + CuS\ (molten) \rightarrow 5\ Cu\ (molten) + SO_2$.

Until the development of the matte converter in the late nineteenth century AD, step (c) meant a long series of casting matte, crushing it, oxidizing partially, remelting and re-slagging off the iron oxides formed. Agricola[4] lists five roasting/smelting steps until copper emerges. It is important to realize that only at the last smelting operation does copper metal appear. Previous to that only slag and molten copper-iron sulfides appear and neither of these possess metallic properties or characteristics. It would seem therefore unlikely that the ancient smelter working empirically would have pursued this tedious route without some stimulus other than a search for common metals.

In a recent paper[5] it was proposed that matte smelting evolved from gold recovery procedures. Hoover, p.407[4] in footnotes analyzing the charging of a 16th century copper smelting furnace, details the addition to the first three operations of lead slags, lead ore, hearth lead and litharge. All of these would produce a descending stream of molten lead to which precious metals (gold and silver) would partition and segregate. The lead otherwise serves no function in copper smelting. If lead washing for precious metals was the primary and initial function, then copper enrichment and ultimate self-reduction of the matte would be the incidental outcome – although the priorities may have changed with time.

In our own work[5] we have shown that it is possible to produce a deformable grade of copper with good recovery without producing matte and involving only two stages: (a) a 'dead' roasting operation to a total conversion to both copper and iron oxides; and (b) a smelting operation at a about 1200°C. Subsequent to publication it became clear that the smelting operation was in reality a carbon reduction selectively of the copper to metal leaving the iron oxides in the slag. This is a much simpler process and it was proposed that it may well have preceded the matte smelting approach but fell out of favour when the precious metals recovery system was developed. It seems that the carbon reduction of dead-roasted chalcopyrite was discovered also by Tylecote, et al at about the same time.[6] With further search of the literature one finds that carbon reduction of dead-roasted chalcopyrite concentrates in an electric furnace has been a contemporary practice for many years in a plant in Austria.[3,7,8,12]

This present paper summarizes continued work to explain the nature of the reactions involved, the factors that control the temperature of the smelting operation, the quality of the copper and the efficiency of recovery. The intention was to assess whether such a process could reasonably have been discovered and efficiently regulated by an empirical approach and simple furnacing.

Experimental Materials and Methods
Chalcopyrite flotation concentrates were supplied through the courtesy of the Arizona Bureau of Mines (Tucson) in the form of a powder whose particle sizes were less than about 150 microns. An analysis of the concentrate is given in Table I.

The concentrate powder was roasted in shallow (¼in deep) stainless steel pans using an electric box furnace, an air atmosphere and limited venting through sight and thermocouple ports. The roasting was isothermal and was continued for 15 hours although the SO_2 smell was gone much earlier. Roasting below 800°C was done in one single stage. Roasting at 800°C produced dense caking or agglomeration that prevented complete oxidation. Accordingly, equilibrium was achieved by roasting first at 500°C and then at 800°C.

TABLE I

Analysis of Chalcopyrite Concentrates (Weight Percentages)

Chalcopyrite	71.0%
copper (24.6)*	
sulfur (24.8)**	
iron (21.6)**	
Acid Insoluble (primarily silica)***	10.4%
Limestone***	0.9%
Pyrite (by difference)****	17.7%
iron (8.2%)**	
sulfur (9.5%)**	
	100.0%

*Water soluble after 500°C sulfating roast. Agrees with the Arizona Bureau of Mines certification of about 25% Cu.

**Computed from ideal chemical formulae for chalcopyrite and pyrite.

***After 800°C roast which converts copper and iron to acid soluble oxides.

****Pyrite identified by X-ray diffraction as a major component. Chalcopyrite represents the strongest diffraction pattern.

Smelting was performed in a gas-fired furnace of a type commonly used for non-ferrous melting. The blended charge was packed in a clay-graphite crucible without a lid. Charge weights – roasted ore, carbon, fluxes – were about 1000 grams. Temperatures were monitored with an immersion thermocouple. From beginning of heating (cold) to pouring, the time period was usually less than 60 minutes. The charge was poured as soon as complete melting was observed and the slag was obviously fluid. With appropriate flux additions the crucible emptied completely on pouring into a cast iron mold. With a fluid slag, the molten metallic copper separated cleanly to the bottom of the mold. Nevertheless, the solidified slag cover was crushed to examine for unseparated copper beads (prills).

The components of the smelting charge were:

- fully oxidized roasted concentrates (designated roasting temperature)
- carbon in the forms either of graphite powder or crushed wood charcoal
- silica sand
- tricalcium phosphate as a chemical or as bone ash

The products of roasting and smelting were identified primarily by X-ray diffraction analysis. The copper metal was analyzed for iron by spectroscopy and by metallography.

Products of Roasting
Dead-roasting was conducted at temperatures between 400°–800°C. The time of 15 hours was considered more than adequate to oxidize the sulfides because re-roasting samples produced no change in weight. Moreover, the weight change after 500°C roasting was measured as 15.5% which compares favourably to a computed 15.3% weight change based on the initial compositions in Table I.

Roasting produced a very distinct sequence of colour changes according to temperature. As the result of the 400°C exposure, the dead-roast was a 'brick' red very similar to 'set' copper (high oxygen metal). The 500°C roasting produced a deeper red; the 600°C .darker red tending to purple; 700° and 800°C produced a black product. To one familiar with the products of oxide copper smelting, the 400°–500°C roast product would be very suggestive of a particulate copper product that could be consolidated by melting.

X-ray diffraction analysis results are summarized in Table II. The red colour of the low temperature roast product is actually due to the hematite or 'rouge'. The copper sulfate can be quantitatively removed by water leaching and evaporation yielding a copper content closely in agreement with the certification by the supplier. Copper sulfate dissociates to CuO or Cu_2S on heating above about 650°C with the evolution of SO_3. This is evident when 400°C roast is re-roasted at 700°C or above. Calcium sulfate was identified in the 700° and 800°C roast products by hot water solution and evaporation.

The apparent conversion of Fe_2O_3 to Fe_3O_4 is not reasonable on the face of it. No such simple dissociation is possible under the conditions of roasting in air. However, the X-ray diffraction pattern is appropriate to not only Fe_3O_4 but to all related spinel phases (the lattice parameter was not precisely appropriate to Fe_3O_4). The answer seems to be that the roast product is the spinel $CuO.Fe_2O_3$ or $CuFe_2O_4$ which is stable in air at the roast temperature[9,10], and has a diffraction pattern very close to the related spinel $FeO.Fe_2O_3$ or Fe_3O_4. Note that both $CuFe_2O_4$ and Fe_3O_4 are magnetic and the black roast product is magnetic. Since both CuO and Fe_2O_3 are nominally produced by roasting in air, it is reasonable to expect that they would interdiffuse to form a stable intermediate phase appropriate to the pseudo-binary oxide system $CuO-Fe_2O_3$ and the roast product represents an equilibrium point in the two-phase field ($CuO+CuFe_2O_4$).

Products of Smelting
Depending on conditions or factors to be described later there are two immiscible liquids or three. One is liquid metallic copper with three solute variables: iron content, sulfur and/or oxygen content. All of the copper products were pure enough to tolerate cold rolling to at least 50% reduction in thickness.

The second product of smelting is the slag which is black and very high in iron content. The solidified slag is predominantly fayalite which is an intermediate phase in the $FeO-SiO_2$ system and corresponds to the formula: Fe_2SiO_4 or 2 $FeO.SiO_2$ and the composition 70 w/o FeO. Fayalite itself melts congruently at 1200°C but there are two close eutectics on either side which melt about 20/30°C lower.

Some of the slags were strongly ferromagnetic and X-ray diffraction analysis showed intense lines of Fe_3O_4. In this case since the slag contained less than 1% Cu, it is reasonable, to interpret that this phase is magnetite which is not unknown in copper smelting slags.

A third product of smelting which appeared as a thin layer separating the solid copper from the solid slag was a copper sulfide matte. It was not always there. As will be discussed later this depends on the level of reducing condition or carbon addition. The reaction:

$$CaSO_4 + 2\ Cu \rightarrow CaO + Cu_2S + 3/2\ O_2$$

will produce Cu_2S when the oxygen partial pressures is reduced to 6.9×10^{-8} atmos. The Cu_2S dissolves in the molten copper up to a limit of about 1.8 w/o S at 1200°C but separates out on cooling first as globules of liquid Cu_2S floating out, then as primary crystals of Cu_2S and finally as $Cu-Cu_2S$ eutectic. The reaction: $4\ Cu_2SO_4 \rightarrow Cu_2S + 5\ O_2 + SO_3$ is also thermodynamically feasible.

TABLE II

Mineral Conversion Products by Roasting in Air

Roasting Temperature °C	Compounds Identified by X-ray Diffraction Analyses
400	$CuSO_4$, Fe_2O_3
500	$CuSO_4$, Fe_2O_3
600	$CuSO_4$, Fe_2O_3
700	CuO, Fe_2O_3, Fe_3O_4*, $CaSO_4$
800	CuO, Fe_3O_4*, $CaSO_4$

*Somewhat different lattice parameter.

Slag Control

The purpose of the slag is to form a low melting liquid, immiscible with copper that holds the rock components and the iron in a form that resists reduction to metal. The slag must not only have as low a melting temperature as possible, but at that temperature it must have good fluidity so that the metallic copper settles out cleanly and efficiently.

Basically the slag should be of the fayalite composition which in the present case required the addition of silica to the smelting charge. Improved fluidity and some reduction of the slag melting temperature is achieved by additions of wood ash (largely lime and potash) or by additions of bone ash (whose primary constituent is tricalcium phosphate). For most of the smelting experiments the flux additions were: 13% silica plus 8% tricalcium phosphate (chemical). Substitution of the chemical phosphate by bone ash 9-10% gave the same slag behaviour. With this formulation a fluid slag could be poured at about 1130°C provided that the carbon addition was sufficient to eliminate the magnetite.

Carbon Control

The amount of carbon added to the charge governs the outcome of the smelting operation in several ways. These can best be understood in terms of the lowering of the partial pressure of oxygen necessary to make certain reactions proceed (1150°C):

$CuO \rightarrow Cu + 1/2\ O_2$	$P_{O_2} = 5 \times 10^{-3}$ atmos.
$4\ CuSO_4 \rightarrow 2\ Cu_2S + SO_3 + 5\ O_2$	$P_{O_2} = 1.302 \times 10^{-7}$ atmos. (800°C)
$CaSO_4 + 2\ Cu \rightarrow CaO \times Cu_2S + 3/2\ O_2$	$P_{O_2} = 6.9 \times 10^{-8}$ atmos.
$2\ Fe_3O_4 \rightarrow 6\ FeO \times O_2$	$P_{O_2} = 1.5 \times 10^{-10}$ atmos.
$2\ FeO \rightarrow 2\ Fe + O_2$	$P_{O_2} = 2.5 \times 10^{-13}$ atmos.
$Fe_2SiO_4 \rightarrow 2\ Fe + SiO_2 + O_2$	$P_{O_2} = 4.7 \times 10^{-14}$ atmos.
$CO_2 \rightarrow C + O_2$	$P_{O_2} = 4.4 \times 10^{-18}$ atmos.

These relationships represent an order of reducibility. With sufficient carbon all of these reductions are possible because carbon reduces the partial pressure of oxygen below required levels. Note that incorporating FeO in a fayalite slag significantly increases its resistance to reduction to metal.

The level of reduction achieved in the smelting operation is regulated by the proportion of carbon added to the charge. In order of increased amount of carbon, the following events are additive:

1. Reduction of copper to metal
2. Generation of copper matte (limited by the amount of $CaSO_4$ or $CuSO_4$,
3. magnetite eliminated from the slag (lower slag viscosity),
4. Reduction of fayalite to iron (dissolved in the copper).

In the present experiments carbon existed as graphite in the crucible. However, after the first run with a crucible the carbon was less accessible to a charge and its contribution was seen only if the smelting operation was continued at temperature after all melting was accomplished but pouring was delayed. Carbon mixed with the charge provided the main control. The carbon could be either graphite powder or crushed charcoal with no noticeable difference in outcome.

There was enough carbon in the crucible, even after several runs, to reduce most of the copper and produce yields of more than 80%. However, for more than 95% recovery a carbon addition is necessary. When there was sufficient carbon to generate a small amount of matte, the copper recovery was always high. A carbon addition of 8% (graphite or charcoal) gave a consistently high yield of copper (in excess of 95%).

The iron content of the copper depended on the level of carbon addition. Some smelting results are summarized in Table III. In the temperature range of 1150°–1200°C copper is capable of dissolving about 4% Fe. Iron which is reduced and which is in excess of that saturation value will collect and float on top of the copper. High-iron copper shows dendrites of iron throughout the microstructure. This product has a limited formability. The iron content accounts for more than 100% recovery of copper.

The pouring temperature per se is not an obvious factor in copper recovery and iron reduction. When the carbon has been exhausted at any temperature, the reduction processes cease. In our experiments time was also a factor because of the late carbon contribution of the crucible. Pouring temperature is a factor in fluidity. One can always achieve higher fluidity at higher temperatures but constraints of air supply rates make fluxing the preferred approach.

Some comparative experiments were performed with alumina crucibles instead of the clay-graphite crucibles. See Table IV. The only significant difference is that the pouring temperatures out of alumina crucibles was generally 50-100°C higher for adequate viscosity. This probably reflects the dissolution of the crucible by the molten slag.

reduction procedures familiar to oxide ore treatments represents a much simpler process than any reasonable modification of the matte smelting process. Considering the discovery of a process for metal recovery from sulfide ores by empirical means, this dead-roast reduction method would seem likely to be discovered before matte smelting. Unfortunately discoveries of matte and slag fragments at ancient smelting sites do not permit a distinction in actual process because each produces essentially the same slag. Matte is present also in both (though a minority component and probably discard in the dead-roast reduction process).

The smelting process can be operated at temperatures below 1200°C when proper flux additions are made. In this respect any furnace that could reduce oxide copper ores to metal could also operate the dead-roast reduction process (although

TABLE III

Factors which Influence the Iron Content of the Copper

Run No	Carbon Added, %	Pour Temp °C	Copper Recovery, %	Fe in Copper, %	Notations
48	6	1218	69	0.03	
72	7	1129	93	0.28	
50	10	1130	79	0.16	
56	12	1209	104	4.3	Fe metal also segregated
47	16	1160	98	2.5	Fe metal also segregated

TABLE IV

Comparison of Clay-Graphite and Alumina Crucible Influences

Run No	Carbon, %	Pour Temp °C	Copper Recovery, %	Crucible	Notations
14	16 (charcoal)	1344	120	Alumina	Fe dendrites in Cu
16	16 (graphite)	1304	121	Alumina	Fe dendrites in Cu
47	16 (graphite)	1160	98	Clay-graphite	Fe segregation
15	7 (graphite)	1327	105	Alumina	
80	9 (graphite)	1136	93	Clay-graphite	Fe dendrites in Cu
70	7 (charcoal)	1143	80	Clay-graphite	No Fe dendrites

For most of the smelting runs, 800°C roast was used. However, a number of runs were made with 500°C roast in which the copper was associated as a sulfate rather than the oxide and spinel. The copper recoveries seem to be less with the 500°C dead-roast product (Table V). The copper sulfate dissociates during the heat-up period (one can smell the SO_2 or SO_3 when the unfused charge reaches about 700°C in the crucible). Generally, there is more matte above the copper (molten Cu_2S) when 500°C roast is used which may account for the lower recoveries of metal.

Summary

Copper can be reduced in a single smelting operation by carbon from fully oxidized (dead-roasted) chalcopyrite mineral with high recoveries and a product low enough in iron and sulfur to permit substantial cold forming in excess of 80% reduction in thickness. Roasting to a point where SO_2 is no longer evolved and smelting with carbon

the fluxing might be different). For a chalcopyrite ore concentrate from Arizona, flux additions of about 13% silica and 8% tricalcium phosphate allowed slags which were molten and very fluid at about 1130°C. Presumably the flux proportions would depend on the degree of mineral beneficiation and on the identity of the gangue for different ores. The silica, intrinsic or added, is ncessary to form the low melting fayalite slag. The tricalcium phosphate, most probably as bone ash, still further reduces the pouring temperature and increases fluidity. Wood ash – rich in lime, potash and silica – will also serve as a flux with pouring temperatures which are below but nearer to 1200°C.

The proportion of carbon is critical. Too little carbon results in low copper recovery and too much carbon brings on a high iron content in the copper and in further excess generates segregated iron which is not very separable from the copper. A copper recovery of about 95% and an iron

TABLE V

Comparison of Smelting Results Using 500°C and 800°C Roast Products

Run No	Roast Product	Carbon %	Pouring Temp °C	Copper Recovery, %	Notations
1	500°C	0	1320	88	80 min run, no fluxes
28	500°C	12	1143	85	59 min run
83	500°C	11	1180	69	40 min run
51	800°C	10	1195	93	39 min run
81	800°C	9	1125	82	42 min run
73	800°C	6.5	1130	96	66 min run

content of less than 0.5% can be achieved with a carbon addition of about 8% by weight (either charcoal or graphite). Carbon additions of more than 12% will bring down more than 1% iron (soluble or segregated).

Except at low carbon additions, a small amount of matte (Cu_2S) is formed and appears as a silvery, brittle crust on the cast copper. The absence of a thin crust of matte usually correlates with a poor copper recovery because it represents a low level of available carbon. The existence of sulfur and copper in a slag cannot be taken to signify a matting operation as has been suggested.[11]

The dead-roast reduction by carbon could be operated in crucibles with a kiln or pit furnace or in a shaft furnace in continuous operation. It requires no air supply, fuel and temperature limits which represent any changes from pre-existing oxide copper ore smelting technology.

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News from Canada

FORMATION OF METSOC HISTORICAL METALLURGY COMMITTEE

Canada is an industrially young country. Has there been time yet to develop a significant metals' history?

Members of CIM METSOC believe so, citing as examples:

Atlas Steel's continuous caster . . . which pioneered the process in North America.

Dofasco's BOF vessels . . . first in North America, second in the world.

The Pidgeon Magnesium process

Nickel flash smelting at Inco Metals Co., Copper Cliff.

The contribution of Savard & Lee to Q-BOP steelmaking technology.

The world's first commercial continuous copper smelting and converting plant at Noranda Mines Ltd.

The world's first TBRC process for nickel at Sudbury.

And many other 'firsts'.

Accordingly, METSOC has authorized the formation of an Historical Metallurgy Committee which aims to develop interest and provide a focal point for Canadian metallurgists concerned with industrial archeology and archeo-metallurgy.

The founding committee has members with broad interest in Canadian metallurgy. They are:

Dr P J Mackey, Noranda, Chairman. Prof. Ursula Franklin, University of Toronto. Dr J E Dutrizac, CANMET. Dr P Tarassoff, Noranda. Prof. W M Williams, McGill University. P Stubbs, Dofasco.

Initial objectives of the committee include a review of repositories of metals' history and contact with other national historical metallurgy groups. Another goal will be promotion of the recording of processes and equipment which may soon become obsolete, but which have historic associations.

The 'recently obsolete' process is especially liable to pass unrecorded. Industry is understandably anxious to replace 'antique' equipment and technology. When new processes appear, there is rarely time to record formally the old techniques or to preserve such records as photographs, drawings, films, etc. The subject is often put off till later – and later never comes.

Pioneering processes are developed by pioneering people. We are fortunate in Canada to have many of these 'elders' still with us. The Historical Metallurgy Committee would like to help to record and convey our senior members' experiences to the current membership.

The Chairman would be delighted to hear METSOC members' ideas on committee activities, goals, etc. If you have something to say or contribute, please contact: Dr P J Mackey, School of Engineering, Laurentian University, Sudbury, Ontario, Canada P3E 20.

The St Maurice Ironworks: The St Maurice Ironworks, in operation between 1729 and 1883, are located near Three Rivers, midway between Montreal and Quebec city. The archaeological and historical research program is part of a Parks Canada site development plan. The summer of 1979 will end the excavation program.

The major components of this industrial village have been excavated, with more than 60 buildings located. Most reports are in French. Many have appeared in the Parks Canada Manuscript Report Series, and all are available at the Parks Canada Research section documentation centre in Quebec city. These include a variety of historical reports, excavation architectural report, studies on plant remains, a faunal analysis, a magnetometer survey report and a metallurgical study. Reports are complete on the blast furnace and moulding techniques. Structural studies on the two chafery forges are complete and a proper synthesis on wrought iron manufacture is forthcoming. The more important industrial artifacts have been restored and may be examined at Parks Canada labs in Quebec city. A report on the tools and products of the St Maurice Ironworks is forthcoming.

Domestic components have been dealt with in a series of site reports, while pertinent information to all individual buildings is indexed. Reconstruction of objects found in situ is continuing. Analysis is viewed as an end product related to an integration of technological change and local behaviour. All of the excavation has been video taped and some tapes have been edited (in English) for loan. For more information write to: Pierre Nadon, Project Director, PO Box 10275, Ste-Foy, Quebec, G1V-4H5.

Excavation Reports

MEDIEVAL BLOOMERY FURNACES IN SIBERIA, USSR. Since 1976 archaeologists at the University of Kemerovo have been paying attention to metallurgical monuments in the Kurey and Kos-Agac steppes extending to the southeast of the Altai range, where suitable ore resources enabled smelting of iron in the Early Turkish period in the second half of the 1st millennium AD. Several types of furnaces were found near Pasanta, Cagan-Lzun and Kuray in the district of Kos-Agac. One of the most interesting types is the earth-built furnace of a prolonged plan (125 cms x 35 cms) and about two metres high. At a height of more than 100 cms above the hearth bottom, 20-22 clay tuyeres were inserted into the front wall. The furnace evidently operated with induced draught. As it is known, multi-tuyere furnaces were used in the 13-14th century in the ancient Bolgar region on the Volga river. They were believed to represent a sort of primeval blast furnace. But according to the excavator, Mr Zinyakob, Siberian furnaces served for making blooms.

CPSA

M V Sedova (Mrs): Jaropolc Zalesskiy. Moskva 1978. Results of excavations of an ancient Russian hillfort from the 10th-13th centuries AD. Bog iron ore pieces and 'blooms' were found in huts of the later period. Blacksmith's tools (tongs), sheet scissors, forged semiproducts (pp 72-73). An appendix has been written by Mrs L S Khomutova and it deals with the results of metallographic investigation of 66 iron objects. The level of the local blacksmith's technique cannot be considered as very much developed: slaggy iron, slag in welding seams, simple techniques both in wrought iron and steel prevail (64%). Marquenching was common.

CPSA

Conference Reports

THE BASIC PROGRESS IN THE CENTRE OF EUROPE

100 years anniversary of the application of the S G Thomas patent in iron works of Bohemia, Moravia and Silesia.

On 12th May 1979, a special symposium was held at the National Technical Museum, Prague. This was devoted to the 100 years' anniversary of the first basic blow realised on the Continent. The importance of the S G Thomas' patent in the last decennia of the 19th century and the beginning of the 20th century was a considerable one, since the composition of the Bohemian iron ore resources with their elevated phosphorus content, especially in the Ordovician zones SW of Prague, made the use of the classical Bessemer process problematical.

As the history of the basic process on the territory of present Czechoslovakia is interesting enough for the complex understanding of the technological and economic development of the work of Sidney Gilchrist Thomas, summaries of the three papers read at the opportunity of the above mentioned symposium are reproduced below. The session was introduced by a short biography of S G Thomas, prepared by R Pleiner.

The Basic process in Bohemia

Jan Koran

In the late 1870's there were three iron works in Bohemia that were interested in the introduction of basic Bessemer process. Two of them, the Prazska zelezardska spolecnost (Prague Steel Company) at Kladno and the Fusternberg Iron Works (since 1880 the Bohemian Coal and Steel Company) at Kraluv Dvur, had a sufficient raw material basis as the Barrandien Ordovician ore had a higher content of phosphorus and could be used for the production of basic Bessemer pig iron. The third plant, Teplicka valcovna a Bessemerova hut (Teplice Rolling Mill and Bessemer Iron Works), was buying pig iron as it was economically better to process iron with higher phosphorus content supplied by the iron works at Peine near Hannover. The Prague Steel Company obtained the licence for the basic Bessemer process directly from Thomas in 1879; it is worth mentioning that first blows on the Continent were carried out at Kladno (Prague Steel Company) between the 11th and 13th May, 1879; this comes out of the day-books of the plant. The trials were presumably successful but – curiously enough, the method was not practically introduced until 1882. K Wittgenstein, director and joint owner of the Teplice Rolling Mill, purchased the respective licence in 1880, and in the same year the method was introduced at Teplice. To fight his competitors, represented primarily by the Bohemian Coal and Steel Company, he bought by the end of 1880 the licence for the whole territory of Bohemia so that the Bohemian Coal and Steel Company could not use it. The latter purchased the licence for the remaining parts of the Austro-Hungarian monarchy; however, the licence could not be practically used as K Wittgenstein bought the Bohemian Coal and Steel Company in 1884 with all its iron plants. Since that time, basic Bessemer pig iron for the Teplice Rolling Mill was produced in blast furnaces at Kraluv Dvur.

The Basic Process in Moravia and Silesia

Oldrich Bohue

The Vitkovice Iron Works obtained the right to use Thomas's patent by purchasing the respective licence 'for a moderate sum of money' from Massenez, director of the iron works at Horde, who was authorized by Thomas to grant his licences in Germany and the Austro-Hungarian Empire. P Kupelwieser, general director of the Vitkovice Iron Works, visited Middlesborough where, accompanied by P Gilchrist, he saw the new method, and immediately after his return to Vitkovice basic bricks were manufactured there and a melt of pig iron with medium phosphorus content was made. According to Holz (Stahl und Eisen, 1902, 1) the first blow of this type took place in Vitkovice in July, 1879.

Vitkovice Iron Works used the local iron ore and the iron produced there contained 0.3 to 0.5 per cent phosphorus. This was not good enough for the classical basic Bessemer process. Thomas's patent was used for dephosphorization of steel that was prerefined in the Bessemer converter. This duplex method was used at Vitkovice till 1890, when the Thomas converter was replaced by a basic open-hearth furnace.

For the duplex steel production in both acid and basic converters a special mixing mechanism was invented at Vitkovice and an optimum composition of iron was found so that the iron temperature enabled a good de oxidation by ferromanganese and an excellent steel quality could be reached.

At Trinec, too, the classical basic Bessemer process was tested in 1885 before the duplex Bessemer method in the converter – basic open-hearth furnace, was introduced.

Three years later, however, the method was abandoned as there was no ore near Trinec suitable for this kind of iron production and the importation of phosphorus iron or iron ore very expensive.

Although the licence for production of classical basic Bessemer steel was not in fact used, the basic process of iron production was economically important for both Vitkovice and Trinec iron works, as it was possible to use iron with a medium content of phosphorus for the production of high quality steel without having to import expensive high quality ores from abroad.

The technical and economic significance of the basic process

Antonin Hrbek

The basic Bessemer process played an important role in the history of Czechoslovak metallurgy as this technology made it possible to use the Barrandian ores.

A detailed analysis is made of both the technical and economic conditions limiting the expansion of basic Bessemer process in particular countries. These conditions included, first of all, raw material reserves, quality of material produced and economy of production. Starting from this the author proves that all along the basic Bessemer process was a specific feature of iron works situated along the Franco-German border and in the Kladno region of Bohemia. In the other centres of metallurgy the technology was developing from the acid Bessemer process to the basic open-hearth furnace.

Despite many attempts to improve the technology (reduction of bath temperature, addition of ore, CO_2, H_2O and O_2 blowing) the basic Bessemer process could not surpass the basic hearth furnaces in steel production. It was only pure oxygen blowing that turned the technical development back to basic converters, however on a qualitatively new and higher level. This makes us appreciate highly the pioneer invention of Thomas and Gilchrist who influenced for such a long time the development of steel production.

Letter to the Editor

Dear Sir,

The authors of a very interesting paper on the socketed axe from Eskilstuna, Sweden, E Hermelin, E Tholander and S Blomgren in HM No 2 1979, write that this axe, for typological reasons, has been dated to the period of the first four centuries AD.

On the territory of Poland the socketed axes are typical for the Lusation Culture (Central, South and Western Poland), dated by archeologists to the Hallstatt period (VIII–VI cent. BC), and for the Baltic tribes inhabiting North-Eastern Poland which may be dated to first Cent. AD.

Among 16 socketed axes of both types which I have investigated, one, found in Jezierzyce near Dzierzoniow[1,2,3,4] presented an identical structure and chemical composition, including micro-probe analysis, as the axe from Eskilstuna.

Both axes include layers of high-nickel-cobalt-arsenic. My recent studies[5,6] sustain my earlier hypothesis[7,8] that high-nickel – so called 'meteoric' – was smelted from the ore to produce the famous – but up to now unidentified – Chalybean steel.

The socketed axe from Jezierzyce belongs to the Lusatian Culture (VIII–IV cent. BC).

I would be very grateful if the authors would present their opinion on the dating of the Eskilstuna axe.

Prof dr hab Jerzy Piaskowski
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Book reviews

PERSIAN METAL TECHNOLOGY 700–1300 AD.
James W Allan. Oxford Oriental Monographs No 2, Ithaca Press, London for the Faculty of Oriental Studies and the Ashmolean Museum, Oxford. 1979. £12.50, 152 pp. Index and bibliography. 8 Plates.

Dr Allan is assistant keeper in the Department of Eastern Art in the Ashmolean Museum. This book is based on his DPhil thesis. It attempts to answer in a scholarly and original way questions on metals technology from published works of the period. The treatment deals with individual metals: – mercury, gold, silver, copper and copper-base alloys, tin , lead , zinc, iron and steel and niello. The damascening of swords and the making of armour is discussed.

There are several maps and many tables including a select vocabulary of technical terms. The last table contains analyses of objects from Stockholm, the British Museum, the Louvre, the Ashmolean and some recent excavations. There is an appendix by A Kacznoryyk and R E M Hedges on the Elemental Composition of Medieval Persian Metal Objects. The results are tabulated and comprise in all 64 analyses for, in most cases, 10 elements. These were done by X-ray fluorescence using the 'Isoprobe' which is non-destructive and 'sees' an area on the surface only 0.01cm^2. Two scrapings were made (0.001 cm deep) in the same spot and if these did not differ by more than 5% no further scraping was made.

Naturally with such a small area of analyses, difficulties were found with lead. They found four classes of alloy: –

1) true brasses, 2) leaded 'gun-metals' (Cu-Zn–Sn–Pb). These are perhaps more like high-tensile brasses rather than leaded gun-metals where the Sn is normally > the Zn, and resemble certain Roman alloys, perhaps made from scrap metal.

The third, small group, had a lower lead content than the second. But again there was less Sn than Zn. The fourth (one specimen only) was a simple leaded bronze with no zinc.

It is concluded that the high lead contents were mainly for ease of working, lower melting points, and hardness. Analyses revealed that one suspected Ag inlay was tin. Tin plating, sometimes with high levels of Ag was often used.

This is very useful work on a little discussed subject. It is complementary to H E Wulff's book on the Traditional Crafts of Persia published in 1966 which dealt with the techniques that are still being practiced today. Together, these two books should be in the library of all who need to be informed on Near Eastern Metal Work.

There are some points where I would take issue with Allan. For example his description of solidification of a 'wootz' steel to make metal suitable for damascening. But this is still a much debated area, and the author as a non-metallurgist has produced a most acceptable book.

R F Tylecote

STEPHEN LEWIN AND THE POOLE FOUNDRY. Russell Wear and Eric Lees. 101 pp £3.75 hardback, £2.75 soft cover. Pub. jointly by the Industrial Railway Society and the Industrial Locomotive Society. 1978.

Stephen Lewin (1822-1913) is quite widely known among locomotive historians for the small railway locomotives, some times with geared drives and launch-type boilers, built at the Poole foundry in the period 1874-78. This work, whilst dealing fully with this aspect also describes the foundry itself and its history in considerable detail, the agricultural and marine products, and the biography of Lewin and his associates. The work is fully referenced, and amply illustrated with photographs, drawings, and plans.

H Paar

THE APPLICATION OF THE CHARCOAL BLAST–FURNACE SINCE THE END OF THE 16TH CENTURY TO THE PRODUCTION OF CAST OBJECTS DIRECT FROM THE BLAST-FURNACE AND THE LATER RE-MELTING IN REVERBERATORY AND CUPOLA FURNACES UP TO THE MIDDLE OF THE 19TH CENTURY. Carl W. Pfannenschmidt.

(Die Anwendung des Holzkohlenhochofens seit Ende des 16. Jahrhunderts zur Erzeugung von Gusswaren erster Schmelzung und die spatere zweite Schmelzung in Flamm- und Kupolofen bis Mitte des 19. Jahrhunderts).

Report of the Special Committee of VDEH 9.007 (Fachausschussbericht des VDEH, 9.007). Dusseldorf: Verein Deutscher Eisenhuttenleute, 1977, 207 pp. 67 illustrations) 54.– DM.

As the lengthy title of the book would suggest it includes a very widespread field. Based on a very complete bibliography of 420 references, the author has succeeded in giving a full review of iron production beginning with bloomeries and ending with blast-furnaces and the introduction of coal. This is followed by the development of reverberatory, cupola and re-heating furnaces. In keeping with the title of the book, the review of the production of bloomery and pig iron is rather concentrated. The author is right in considering the bloomeries with shafts of the La Tène and Roman periods as predecessors of the primitive bloomeries in the late Middle Ages which developed via the 'foot blast smelters' (supply of air through treadle bellows) to the 'Stuckofen' or blast furnaces of the 14th century. The oldest smelter using water power has been documented for the year 1197 in Sweden and was worked by Cistercians. These were particularly active in this field, starting in England (1128) and penetrating through Germany (1237) into Austria. In the French Alps, the Carthusians and in Moravia (1215) the Premonstratensians were beginning to work iron. The latter used water power in about 1269.

Besides the supply of artificial blast by water-driven bellows: the addition of lime as a flux, served to define the difference between bloomeries and Stuckofen furnaces (1311). The supply of blast from water-driven bellows has been documented from 1395 in the 'Markische Kreis'. In pig iron furnaces, a piece of iron (a lump, a pig of forgeable iron) could be produced as well as what the Germans called a 'Floss', ie. cast iron. The increased production demanded a wider basis of raw material and energy which, apparently, offered less problems for ores than for charcoal and water power. Legal rules and regulations about the right to use water (1443) and the compulsory introduction of iron smelting only at certain periods because of fuel shortage were introduced in the 'Siegerland'. The direct production of pig iron ended with the 'Floss' furnace with a narrow hearth casing in order to reach higher temperatures. From now onwards cast iron was produced, but had to be 'fined' to produce forgeable iron.

Cast iron 'as smelted' had been used since the middle of the 15th century, especially for the casting of solid shot (Germany since 1415, England since 1497), and cannons and guns were produced in Germany (1445) and in England (1543) following the casting of bronze. But cast iron was also used for fire-backs (1497), domestic ovens (1519), gravestones and plates (1541), water pipelines (1445), pots and even church bells (1434). Agricola was aware of domestic stoves in the Eifel Hills. Whereas foreign casting and smelting masters had frequently been called to England, the English iron industry begins to assume a dominant part from the middle of the 16th century.

A continuous mass production of cast iron became possible only with the construction of blast furnaces. Their development (in Germany first in a rectangular form with 'Long corners'; in England with a circular cross-section) is the main subject of the author. The much better availability of bibliographical references in England and the more progressive recording of industrial-archaeological monuments, especially by the Historical Metallurgy Society, compared with the present state in Germany, is worth mentioning. The chance of finding after 1500 AD sufficient documents about the detailed methods of iron production, its organisation and economics, ie. prices, wages, position of workers etc can be realised probably only in individual cases.

The box-type blast (1621) and later on the cylinder type blast (England 1763, Germany 1788), the introduction of coal and the heating of blast air are shown to be milestones in the development of blast furnaces. The author also mentions more local inventions of the 18th century such as the waterdrum blast, the use of dry wood and peat for firing the furnaces.

The progress in the use of coal in Europe (in England since 1709) is shown in great detail and it is emphasized that cast iron produced in this way was used for a long time only for cast objects. A reduction of coal consumption could be achieved only by the use of hot air blast (England 1829). The reverberatory furnace, well suited for the casting of metals (ie. for bell casting) could be further developed for the melting of iron (1766) only with great difficulties. These reverberatory, blast or 'English cupola furnaces' became necessary because there was not enough cast iron available from coal-heated blast furnaces for the casting of large size products and it became evident that the amount of iron from re-melting could be much greater. What was understood later on by the term 'cupola furnace' happens to be a smaller shaft furnace to re-melt broken cast iron or to improve it. The development of the cupola furnace from the blast furnace is obvious. It appears that the smaller crucible cupola furnaces were invented by Réaumur.

As the author himself stresses, it is difficult, if not impossible, to follow exactly the developments shown or to record them in a correct chronological order. Nevertheless, the reader will gratefully acknowledge the effort of the author to produce a European synopsis. But this is rather difficult because of the often defective documents and old records which are given different weights by the experts. (Thus, the business books kept by English companies have been preserved in a much more complete state than the commercial books and ledgers in Germany).

The frequent citations of old documents and records renders a continuous reading of the book difficult, although this becomes rather unneccessary in view of the thorough analysis and the critical comments in the wealth of bibliographical references.

G Weisgerber

(Translated from 'Der Anschnitt' and reproduced by permission of the Editor).

IRON AND MAN IN PREHISTORIC SWEDEN Helen Clarke (Ed and transl). 157 x 235mm 180pp. 119 figs (half-tones and diagrams). 8 col. plates. Jernkontoret, Stockholm, 1979, no price stated.

This valuable publication comprises six essays: The first iron in Sweden and Sweden's first industrial society, both by Wilhelm Holmqvist, Prehistoric iron production, by Inga Serning, Blacksmithing in Prehistoric Sweden, by Lena Thålin-Bergman, Iron and iron economy in Sweden, by Åke Hyenstrand, and Linguistic evidence for early iron production, by Karin Calissendorff. The term 'prehistoric' is used in a wide sense, some contributions covering the medieval period.

Homqvist's contributions, in brief and popularised style, note the appearance of imported iron in Sweden in the sixth century BC, the lengthy interval before home-produced iron appears in graves in Öland from late in the first century BC and the subsequent tradition of iron grave-goods in cauldron burials. He surveys the activities of workers in ferrous and non-ferrous metals at Helgö, whose position he notes both in the trading pattern of the Baltic and within its local economy.

Inga Serning makes a substantial contribution, surveying current knowledge of iron smelting in Sweden between 380 BC and the late Middle Ages. The summary table and diagram on pp 70-71 are particularly useful. It is valuable to have a clear exposition of the place of the pit-type shaft furnace in early Swedish iron smelting, making it quite plain that the distribution of this form extends from the Continent into Scandinavia. Dr Serning makes some modifications to Henry Cleere's 1972 classification of bloomery-furnace types, emphasising the importance of structural form and giving slag-separation a subsidiary role. Lena Thålin-Bergman's wide-ranging survey comments on the position of the early smith in society, on his equipment, his techniques and his materials. There is some disagreement with Dr Serning's contribution over when iron was first smelted in Sweden, Thålin-Bergman suggesting that firm evidence is lacking before the first century BC.

Åke Hyenstrand points to the growth of iron smelting in the early Middle Ages, as an accompaniment to colonisation in areas such as Småland, northern Skåne and southern Halland. He emphasises the inter-relationship between settlement, industry and early trade routes, and suggests models to fit the Swedish evidence. Karin Calissendorff's survey of linguistic evidence is also useful for the historical geographer, examining place-name indications for mining, smelting, smithing and the use of water-power and timber in iron-working.

The collection is of convenient size and is very well produced: Dr Clarke and the publisher are to be congratulated on the result. There is an excellent bibliography to accompany the Harvard-style references in the text. Unfortunately there is no index. It is to be hoped that arrangements can be made to make the book easily available in this country. Meanwhile enquiries should be made to the translator at University College, London.

D W Crossley

FROM BRONZE TO IRON. Jane C Waldbaum. The Transition from the Bronze Age to the Iron Age in the Eastern Mediterranean. Studies in Mediterranean Archaeology 54 - Goteborg, 1978, 106 pp, diagrams, charts.

Historians of technology as well as archaeologists may profit from this valuable book, bringing statistical evaluation of practically all important iron objects and assemblages from stratified sites in the 12th-10th centuries BC in Eastern Mediterranean including Palestine, Syria, Cyprus, Greece, Crete, Aegean Isles, Anatolia and Egypt. The topic is divided into six chapters as follows: I, Introduction;

II, Distribution of Iron in the Eastern Mediterranean in the Bronze Age; III, Distribution of Iron in the Eastern Mediterranean: 1200-900 BC; IV, Comparative Distribution of Iron, Bronze, Gold, Silver, and Lead in the Eastern Mediterranean: 1200-900 BC; V, Raw Materials, Mining and Metallurgy in the Eastern Mediterranean: 1200-900 BC; VI, Conclusions. Appendix. Notes. Abbreviations. Bibliography. Index of Place Names. General Index. – Mrs Waldbaum compares the occurrence of iron in the relevant areas with the historical background marked through the decline of main civilisations and formations. She is with good reasons sceptical as to the often claimed Hittite strategical iron monopoly and to the dominating influence on the use of iron exerted by eg. the Dorians and Philistines. On the other hand the author seems to be inclined to underestimate the role of Anatolia, where the most ancient and most progressive metallurgical tradition can be attested. At the end of the existence of the Hittite confederation deliberate making of iron was known already in many neighbouring countries, however, the quantative rise of production proceeded very slowly: in the 12th century iron could be met with in all relevant areas, during the 11th century its use made a considerable progress, and in the 10th century iron had become a widespread technical metal. A very sympathetic feature of Mrs Waldbaum's book is the full comparison with the simultaneous frequency of non-ferrous alloys, gold and silver enabling us to understand the importance of iron in different categories of artifacts during ages which really has involved an enormous work. The development of the technology of iron in the Near East was very slow because the recognition of the most suitable properties of the new metal took up much more time than in other areas where mere adoption of the already developed technology may be supposed.

CPSA

THE SEARCH FOR ANCIENT TIN Eds A D Franklin, J S Olin, T A Wertime. A seminar organised by Theodore A Wertime and held at the Smithsonian Institution and the National Bureau of Standards, Washington DC, March 14-15 1977 (Smithsonian Institution Press, 1978). viii + 63pp, 26 Figures, 23 Tables, 27.5 x 21.5 cm. Soft covers (no price given).

This is a collection of nine papers, with an introduction by T A Wertime, and centres round a discussion of the origin of tin used in the earliest tin-bronzes of the Middle East.

Wertime (pp1-6) summarizes the known evidence for sources of tin in Egypt, Turkey, Greece, Thailand and the Sudan.

H Mckerrell (pp7-24) stresses, by means of analyses, the dramatic appearance of tin bronzes in Britain at ca.2200 BC, coinciding with the appearance of early thin-butted axes. He compares evidence from the Near East.

J A Charles (pp25-32) discusses metallurgical and mineralogical aspects of the use of tin and tin bronze.

P S de Jesus (pp33-38) covers historical and other evidence for tin sources in the Ancient Near East.

K T M Hedge (pp39-42) discusses sources of tin in India. These should certainly be investigated more thoroughly.

Sources for and trade in Bronze Age tin are discussed by J D Muhly (pp43-48). He believes the importance of the metals trade is exaggerated by prehistorians.

R Tylecote (pp49-53) discusses 'Early Tin Ingots and Tinstone from Western Europe and the Mediterranean', in a very useful summary of present knowledge. The importance of the Early Bronze Age tin slag from Caerloggas in Cornwall (Cornish Archaeology, 14, 1975, 35-38) cannot be overemphasised.

I R Selimkhanov (pp53-58) covers the meagre Caucasian evidence and stresses that there are no known deposits of tin ore in the area.

Finally, G Rapp (pp59-63) puts forward the results of research into trace element patterns and cassiterites and tentatively suggests that there are strong regional differences.

Among such a wide range of material it is possible to pick out only a few points for comment.

Much is made of the recent discovery of cassiterite in the eastern desert of Egypt.

Strangely, one still finds suggestions (pp 2 and 33) that stannite and wood tin are relatively common in Cornwall yet the former was not considered to be of economic importance and the latter is 'comparatively rare' according to a report of 1956 (Dines, **Metalliferous Mining Region of South-West England, HMSO, Vol I, 20**).

A possible link between the exploitation of tin and that of gold is worth investigating more fully in likely areas, as the required mining techniques are very similar.

McKerrell believes that metallic tin rather than cassiterite was added to copper to form bronze while Charles and Tylecote think otherwise. In view of the density of both tin ore and metal I feel it is far more likely that metallic tin was used.

McKerrell's data relating to Early Bronze Age bronzes in NE Scotland is particularly interesting. He believes that local Irish and Scottish copper was mixed with tin from South-West England. He remarks that there is a distance of some 800 miles by sea from Cornwall to Aberdeen. He might also have remarked that it is not much further from Aberdeen to the central European tin deposits of the Erzgebirge (via the River Elbe). Indeed, these central European deposits are hardly mentioned in this volume, yet they contain extensive alluvial tracts (Quellmalz, Wilsdorf and Schlegel, nd, **Zinn in Natur Geschichte Technik**, 18-19).

The vast alluvial resources of tin in Cornwall and Devon appear to be discounted by de Jesus (p.33), yet these could have been readily worked in prehistory. Moreover, Muhly (p.44) believes that alluvial tin leaves no evidence of its exploitation – this is manifestly untrue as very distinctive heaps of waste material must be left behind (as in SW England). Similar heaps can be produced from the exploitation of alluvial gold (eg. in N Spain or Romania) and we have already mentioned a possible link between gold and tin. Indeed, surface evidence of relatively small-scale alluvial workings will probably be more visible than traces of small-scale shaft mining.

Muhly also states (p.44) that lode tin was inaccessible to the ancient prospector. This cannot be true - the technology of deep shaft mining (viz Ai Bunar, Rudna Glava) was probably in existence at least one thousand years before tin began to be exploited. Also, much rich tin occurs in decomposing granites (eg SW England) which are soft and easily worked with primitive tools. It is more important to consider whether or not prehistoric societies needed to exploit lode tin when abundant alluvial sources were readily available.

The volume contains some minor errors. The caption to Table 4 (p.12) is humorously wrong. It purports to list finds of tin objects in the Caucasus, but should read 'British beaker-associated metalwork shown by analysis to be tin-bronze', as is given in the list of Contents. The shading of the tin mining area on Fig 1 (p.7) should be extended eastwards to cover S Devon. Fig 4 (p.35) precedes Fig 3 (p 36). On P.50 illustrations of ingots 6 and 7 are missing from Fig 1.

It is a pity that the convention of bc and BC is not used for uncalibrated and calibrated radiocarbon dates, respectively. Also, there is some inconsistency about the use of the terms 'Near East' and 'Middle East'.

But these do not detract from the usefulness of the book as a whole, and one hopes that it will stimulate further research. As Wertime says (p.viii) 'negative evidence still dominates', but this should act as a spur rather than a rein. There is still much ignorance about the nature of tin ores, mining, concentrating and smelting processes, and of the distribution of the finished metal. I suspect that many of the answers to problems of Near Eastern tin will be resolved if more attention is paid to fieldwork in Central Europe, SW England and Iberia.

Tom Greeves

Abstracts

GENERAL

J A Charles: From Copper to Iron – the Origin of Metallic Materials. *J of Metals, July 1979,* **31** *(7), 8-13.*

The author holds the view that the development of copper extraction techniques and the subsequent appearance of bronzes and early ferrous alloys were probably based on close observation by prehistoric metal workers of the subtle phenomena in their furnaces and their awareness of the differences of the minerals they sought as starting materials, and this paper presents the arguments which support this viewpoint. It is clear that native copper and gold were the first metals to be exploited. By contrast with stones, these metals would be shaped by hammering. Hammering also hardens and eventually cracks the metal. However, the use of fire was already part of the technology for cracking and flaking stone, and might have been used in attempts to separate intimately associated natural copper and rock. This could have led to the observation that hammering hot metal is easier, and that copper hardened by being hammered cold could be softened again by heating. The discovery of melting and casting techniques would follow.

General copper mineralization occurs with natural copper, and the firing of green malachite in a charcoal fire easily produces sponge copper, which agglomerates or melts if the temperature is high enough. Thus early melting and smelting probably went together, and there is no need to consider the discovery of smelting as an abrupt event. The use of a flux to melt mineral gangue and facilitate the separation of copper would probably be discovered as a result of the association of iron oxides, particularly limonite available from the gossan or 'iron hat', with copper deposits, and this in turn would eventually lead to the development of iron smelting. The occurrence of occasional iron artifacts in the earlier Bronze Age fits with these theories, and there is considerable evidence that the mining and smelting of iron ore continued to be associated with the earlier copper activity for a coniserable period.

The development of copper-arsenic alloys is probably due to the increase in arsenic content in many copper deposits with increasing depth below the surface, the traditional smelting technique giving an arsenic content of 3-7%. The development of copper-tin alloys may have followed the successful use of stannite, which looks like primary high-arsenic copper ore, for producing a copper alloy, or may have followed the use of an iron gossan flux containing tin. In either case, it seems that cassiterite quickly became the raw material for the introduction of tin, being added with a flux to the surface of molten copper under charcoal. Tin bronzes replaced arsenic bronzes probably for several reasons: the loss of arsenic on smelting, and associated difficulty of controlling the arsenic content of the alloy; more ready availability of cassiterite; and the toxic nature of arsenious oxide fume.

The extensive replacement of copper alloys by iron and steel may have arisen as a result of scarcity of raw materials on the scale required for a continuous expansion of population and civilization, but was probably delayed by the early inability to produce an iron with a sufficiently high carbon content to approach the hardness and strength of wrought bronze.

APG

J F Healey: Mining and Processing of Gold Ores in the Ancient World. *J of Metals. Aug 1979* **31** *(8) 11-16*

The Greeks and Romans exploited both alluvial and reef gold. The earliest placer deposits, 7th century BC were weathered auriferous ore carried down from Mt. Tmolus by the rivers of Asia Minor. Grains of ore were collected in sheepskins spread out in the river, and later in perforated troughs. No sophisticated processing was required to produce 'white gold'.

Greek/Egyptian ore processing and refining techniques (cupellation and cementation) were first described by Diodorus Siculus (after Agatharcides) and Strabo in the first century BC. Experiments by Johnson Matthey and Co simulating these techniques produced gold 93.5% fine. The addition of lead and tin, however, inhibited the reaction.

Gold and silver were alloyed to produce electrum. X-ray fluorescence, neutron activation analysis electron probe micro analysis, and photon analysis show that the alloy differs from other ancient varieties in containing a variable but substantial percentage of copper and traces of iron. The effect of cold-working on this ternary alloy and its physical properties are examined apropos coin production.

The occurrence of gold as a trace element in silver may

help to identify the geographical origins of ore sources. The presence of copper in electrum could help to group coins according to different melts. Finally the unexpected hardness of electrum has an important bearing on establishing the chronology of certain coin hoards.
Author

L Biek and J Bayley: Glass and other vitreous materials. *World Arch 1979,* **11** *(1), 1-25.*

Discusses glasses and other vitrified products such as glazes and enamels particularly those containing lead. Differentiates between slags and fuel ashes. RFT

V Daniels and M W Pascoe: *Archaeological detective work. Metallurgist and Materials Technologist, 1979,* **11**, *277-278.*

Research workers generally wish to examine archaeological objects which have not been tampered with by modern individuals, but most museum visitors like to see attractive, restored, whole objects. Unfortunately the processes of restoration and conservation may interfere with the results which may be obtained by scientific examination.

The information typically provided by visual, X-radiographic and metallographic examination, and by elemental analysis, is outlined. Problems of detecting fakes are briefly discussed. Many techniques for the restoration of corroded objects are liable to produce changes in structure so that metallurgical evidence is lost. Yet it is often very difficult to avoid further corrosion during storage unless some way can be found to stabilise the objects. Careful consideration must be given to storage conditions, as illustrated by the photograph of lead coins stored in boxes that were made with acetic acid containing glue. Certain woods and textiles can also be harmful to lead. Wool, and certain dye-stuffs accelerate the tarnishing of silver, but there is, as yet, no completely satisfactory technique for protecting the polished metal from tarnishing by the hydrogen sulphide in the atmosphere. References are given to souces in which detailed consideration is given to these problems. APG

I A Kinnes, P T Craddock et al: Tin plating in the Early Bronze Age; the Barton Stacey Axe. *Antiquity, 1979,* **53** *(208), 141-143.*

This flat axe dated to about 2000 BC contains 12% Sn and 0.15% As. The authors have decided that the tin-rich layer 0.04mm thick, is due to deliberate tinning rather than any of the other possible alternatives such as preferential corrosion or tin-sweat.

The plated areas contained 25% Sn and 75% Cu showing considerable diffusion of copper into the tin during plating. This was probably done by prolonged heating with the surface covered with tin or tin oxides in a reducing atmosphere. Dipping is discounted. RFT

W A Oddy: Hand made wire in antiquity: a correction. *Masca J (Philadelphia), 1979,* **1** *(2), 44-45.*

Claims that a block-twisted wire is more likely to have two helical creases than the four previously claimed. RFT

P T Craddock: Copper alloys of the Medieval Islamic World – Inheritors of the Classical tradition. *World Arch 1979,* **11** *(1), 68-79.*

Plain and leaded brasses, and ternary alloys of Cu-Sn-Zn. Some more unusual alloys are compared with alloys from medieval Europe and China and the writings of some alchemists and technologists. RFT

BRITISH ISLES

S M Smith: The Construction of the Blists Hill Ironworks. *Ind Arch Rev, Spring 1979,* **3** *(2), 170-178.*

Commercial production of wrought iron ended in 1976 when Thomas Walmsley and Sons Ltd, ceased their operations at Atlas Forge, Bolton. The Ironbridge Gorge Museum is to reconstruct and operate a wrought iron manufactory at Blists Hill, using equipment from the Atlas Forge, as a permanent tribute to the skill of the ironmaker and the memory of Reg Morton, the first honorary curator of the Ironbridge Gorge Museum. This paper presents the nature of the intended reconstruction and discusses the manning and material requirements for its operation. APG

S M Linsley: Excavations at the Allensford Blast Furnace, Northumberland, NZ079503. *Ind Arch Rev, Spring 1979,* **3** *(2), 193-198.*

A brief progress report with excellent photographic illustrations. APG

H Cleere: Roman Sussex – the Weald. In: *Archaeology in Sussex to AD 1500. Council for British Archaeology, Research Report 29. London 1978, 59-63.*

Different types of Roman smelting sites of Weald as viewed from their economic and political background. The Western group was directed rather to civil needs. Eastern plants having had an access to naval ports had close economic relations with the Roman Classis Britannica. CPSA

Barrie Trinder: The First Iron Bridges *Ind Arch Rev, Spring 1979,* **3** *(2), 112-121.*

The paper re-examines the contributions of the many personalities who played a part in the promotion, designing, financing and building of the Iron Bridge over the Severn.

It was more than ten years before any other major structure was made in iron, but two and probably a third, were erected in Europe, and following the great flood of February 1795, a number of major bridges in the West Midlands were replaced by iron structures. Optimism about iron bridges reached a peak about 1800, but was soon tempered by the failures of Thomas Wilson's bridge at Staines, Middlesex in 1803, and his bridge at Yarm, Yorkshire in 1806. The use of iron for bridge building in the early 19th century has been documented for Scotland but still awaits review, for England and Wales. APG

R Hartridge: Excavations at the Prehistoric and Romano-British site at Slonk Hill, Shoreham, Sussex. *Suss Arch Coll 1978,* **116**, *69-141.*

Contains a note by R F Tylecote on crucibles and copper-base alloy remains dated to the EIA and Roman periods. Both copper and 10% tin bronzes were found, and the crucibles were hemispherical or conical. RFT

J R Harris: Attempts to transfer English steel techniques to France in the 18th century. *Business and Businessmen. Liverpool Univ Press, 1978, p.199-233.*

Despite the attentions of French observers and the actual transfer of some English workers, the attempts were largely unsuccessful due to the failure to realise the essentials, such as the need to import phosphorus-free iron, to be able to make good crucibles (skilled men needed) and have available plentiful supplies of cheap coal. RFT

A T Arnott and M Sayer: Beam engines in blast-furnace blowing. *Industrial Archaeology Review, Autumn 1978,* 3, *29-44.*

Describes the evolution of the blowing tub, worked by a water-wheel, to replace leather-sided bellows in the mid-18th century; then the application of a steam pumping engine to recirculate the water over the waterwheel; and finally the direct coupling of the steam engine to the blowing tubs well before the end of the 18th century. More detailed treatment is given to the subsequent improvements in design and performance, based on the use of Watt engines, with double-acting tubs, and then the addition of a flywheel by the mid-19th century, as blast pressures rose from 2-3 up to 4 lbf/in^2 and high-pressure steam engines came into use. The reason for the flywheel-end of the beam being curved upwards in a 'rhinoceros' horn'-shape is fully explained. Developments are followed right up to the final cessation of manufacture of beam blowing engines before 1870. DGT

F Celoria: Some specimens of early telegraph cables in the Science Museum. *Industrial Archaeology Review, Autumn 1978,* 3, *54-64.*

Describes in some detail the Euston-Camden Town wood-insulated 5-wire 'cable' of 1837; two quill-insulated wires of 1842-5, one of galvanised iron and one of copper; a copper-wire underground cable of 1844, with lead sheath; early gutta-percha cables of 1849 and 1856; and cast-iron and ceramic conduits of this period. Includes scanning-electron-microscope examination of copper wires from a cable of the 1860s, showing die-marks. DGT

D A Jackson, T M Abrose et al: Excavations at Wakerley, Northants. 1972-5. *Britannia, 1978, 9, 115-242.*

This report describes one of the biggest excavations of Late Iron Age and Roman iron smelting and ancillary furnaces to take place in Britain in recent times. The site lies on the Northants ore-field and the work was carried out in advance of open-cast ore extraction. Dating is from the 2nd century BC to the 3rd century AD. It embraces trench-type furnaces (channel hearths) containing charcoal used either for roasting ore or for charcoal making. The furnaces fell into 3 types:– Type 1 was a bowl smelting furnace 20-30 cm deep 60-130 cm daimeter – some with furnace bottoms in situ (1st Century BC). Type 2 was a sunken shaft furnace in pits 40-75 cm diameter with an arch 35 cm high with its top at ground level. No slag tapping was possible from this type, and the shafts were 30-40 cm diameter with an inward upwards taper and often relined. These Belgic types may shed some light on the method of inducing slag fall in North European slag-pit types. Type 3 was a surface mounted shaft furnace provided with slag tapping facilities. This is a familiar type found at Holbeanwood, Ashwicken and Pickworth.

Round ore-roasting hearths similar to those at Bedford Purlieus and Great Casterton were also found. The ores come from nodular beds outcropping on the site containing 77.7% Fe_2O_3.

The usual range of copper-base and iron objects were found and qualitative analyses are given of the latter. RFT

R E M Hedges and C J Salter: Source determination of iron currency bars through analysis of the slag inclusions. *Archaeometry 1979,* 21 *(2), 161-175.*

Three groups of currency bars from three separate hoards were analysed for the distribution of 17 elements in their slag inclusions. There is a clear statistical discrimination between the three groups which can be attributed to the different ore sources. Thus chemical analysis of slag inclusions in wrought iron can be used to trace the different sources of iron artefacts, at least within the context of the geology of southern England. Author

M J Hughes: British Middle and Late Bronze Age metalwork: some reanalyses. *Archaeometry 1979,* 21 *(2), 195-202.*

While analyses were being carried out by atomic absorption spectrometry on some British Bronze Age artefacts not previously analysed, for comparison with the large body of optical emission spectrographic analyses published by Brown and Blin-Stoyle, the opportunity was taken to re-analyse seven bronzes which formed part of their programme. There was in general fairly good agreement between the two techniques for the same objects except for the percentages of lead, which showed some severe discrepancies. As a result, it is suggested that the lead percentages found by Brown and Blin-Stoyle should be treated with some caution. For bronzes which they report as containing above about 4% lead, it is only safe to assume that they are leaded bronzes since they could in fact contain up to 3.5 times or even more of the reported percentage of lead. LBA bronzes in Britain therefore contain a proportion of material which is actually much more heavily leaded than previously suspected. Author

EUROPE

B Hansel: Raw copper finds from Heligoland. *Der Anschnitt 1979,* 31 *(4), 146-149. (In German).*

The finds consist of blister copper in the shape of plates and plano-convex ingots 15-20 cm diameter totalling 65 kg in weight and averaging greater than 90% Cu. Similarities are noted between the composition of the Heligoland ores and the copper, apart from the iron and chromium contents. But C-14 age determinations of the charcoal inclusions in the plates gives a date of 660±120 BP which suggests that some at least of these finds are of medieval date. No mention is made of any slag and it would appear that the ore was not smelted on the island but elsewhere, and the presence of metal is the result of ship wreck. RFT

A Hauptmann and R Slotta: Remains of mercury mines at Almaden. *Der Anschnitt, 1979,* 31 *(2-3), 81-100 (In German).*

One of the very few papers on this subject. Deals with the period from Roman times to the early 20th century. Discusses the geology of the ore-body. The ore mined is a Cinnabar (HgS) impregnated quartz with 6-7% Hg. There is also some native metal as prills in the rock, which collects in channels. After Roman and Islamic working, the Spanish state took over until 1545 when it was leased to the Fuggers. 45,000 trees were used for timbering. In 1790, the state operated with German help. This period produced stone-lined shafts and had hand-pumps for drainage. In 1785 an oil-fired steam engine was installed, to be followed by steam operated stamps after 1871. According to Le Play (c. 1845), more than 1000 tons of Hg had been extracted since 1827 by 700 miners from 3 levels.

In 1646 there were two Bustamente furnaces – a type brought from Peru. This type continued in use until the 1920s. These furnaces consist of closed roasters, the mercury vapour from which rises and passes through arches to rows of aludels which are fired clay pots open at both ends. The mercury condenses in these and flows through holes in their walls and runs down hill into receptables and the fume goes up hill to chimneys. An improved version of this furnace was introduced from Idria in the 18th century. No fluxes were used but care was taken to recover the Hg from the fines by placing these on top of pre-roasted material. RFT

G A Voznesenskaya: The technology of blacksmithing by the Eastern Slavs in the 8-10th century AD. *Sov Ark 1979 (2), 70-76 (In Russian).*

Romny culture ironwork from the fortified settlement at Gornal. There were a wide variety of types including the use of high carbon steel made by cementation, the cementation of the final artifact and the welding of iron to steel. The edge tools were examined metallographically and the photomicrographs indicate ferrite, ferrite + pearlite, and martensitic structures. Hardnesses are not given. RFT

V V Ruben: A casting mould from Kozyrka XV. *Sov Ark 1979 (3), 249-258. (In Russian).*

A Greek trinket mould dating from the 6-5th century BC.

RFT

W H Waldron: A Beaker workshop area in the Rock Shelter of Son Matge, Mallorca. *World Arch, 1979,* **11** *(1), 43-67.*

Finds include half a two-piece sandstone mould, copper and bronze, tanged spearhead and arrow-heads, pins and other objects. Bronze awls were cast vertically in sheet copper moulds. Dating was 2000-1400 BC with 2 phases.

The crucibles had slag/dross on the inside which proved to be copper and not bronze (Early phase). The awl had 10% Sn with oxide and slag and showed signs of slight deformation (Later phase). Other objects of the later phase were a bronze bead (5-10%Sn), a pin (6-7%Sn).

RFT

Z Hensel: Metallurgical researches on IX–XII century. *Materiał Zachodniopomorshie 1975 (ed 1978),* **21**, *61-93. (In Polish).*

Metallographic examination of 68 iron artifacts from early medieval levels at Wolin, Northern Poland. Among cutting tools there appear simple wrought iron blades, iron-to-steel welding in different schemes was applied as well. Tools are poor in phosphorus, nails show an extremely varying phosphorus content. Iron vessels were made of iron with elevated phosphorus content (0.742%). The use of ores rich in phosphorus increased towards the High Middle Ages. CPSA

J–R Maréchal: Origin and evolution of ferrous metallurgy in the Paris Basin. *100^e Congres national des Societés savantes. Archéologie. Paris 1975, 31-44. (In French).*

The volume has appeared with a considerable delay. The article by Mr Maréchal represents a survey of iron slag sites of North-Central France. Comments on ore resources and iron bars of the La Tène type. CPSA

J Piaskowski: Further metallurgical researches on early iron from West Pomerania. *Materiał Zachodniopomorskie 1973 (ed 1976),* **19**, *173-191. (In Polish).*

Investigation of several Hallstatt-La Tene iron pins and of a set of Migration Period knives etc, from a settlement near Lubieszewo. CPSA

C Baglu and A Morley: Enamelled iron advertising signs: posters in amber. *Indust Arch, Winter 1978,* **13** *(4), 354-363.*

Porcelain enamelling on cast iron was developed and practised in Central Europe in the early 19th century. Benjamin Baugh started an enamelling business in Bradford Street, Birmingham in 1857, and production of enamelled signs reached a peak before the 1914 war. The second World War virtually put an end to production. Cast iron and wrought iron were the materials of the plates until the 1920's, when Armco produced a steel sufficiently free from defects to be used for the purpose. The techniques of enamelling are briefly described. A short list of selected iron sign manufactures and some of their clients is given at the end of the article.

APG

J Bouzek: The origins of the Iron Age in Central Europe. *Zeitschrift fur Archäologie 1978,* **12** *9-14. (In German).*

The author is inclined to ascribe engraved ornaments on the late Bronze Age Artifacts to the first use of steel cutting implements. Thus the first use of iron in Central Europe might be presupposed during the Ha_2 – HB_1 period. CPSA

G J Varoufakis: Examinations carried out on three spearheads of the 7th and 6th centuries BC. *Metalleiologike metallourgika chronika, 1973,* **10**, *23-34. (In Greek).*

The Greek version of the same author's contribution published in Archiv fur das Eisenhuttenwesen, 1970, **41**, 1023-1026. CPSA

J Emmerling: The technology of Roman Swords from Buchhein. *Alt-Thuringen 1978,* **15**, *92-102. (In German).*

Two swords from the Romano-Barbarian cremation cemetery at Buchhein (distr of Finsterwalde) were examined metallographically. Sword no. II 10.104 c, ritually bent, was welded together from 4 rods. Soft steel in both edges. Punched marks. Sword no. 10.104 b: a special kind of ornamental pattern-welding based on folding iron-and-steel strips which served as inlays. Both edges show structures low in carbon. CPSA

W Gaitzsch: Roman tools. *Stuttgart 1978, 81 pp, 46 figures. (In German).*

A nice booklet presenting a survey of Roman blacksmith's tools from Romano-provincial towns in Germany. Remarks on smithies, hoards of iron objects, Roman terminology relating to tools and handicrafts. CPSA

J Piaskowski and Z Hensel: Metallographic investigations of iron objects from the cremation cemetery at Kryspinow, commune of Lizski, province of Krakow. *Sprawozdania Archeologiczne 1978,* **30**, *175-186. (In Polish).*

Eight analyses of Roman period artifacts from Kryspinow, southern Poland. Mainly heterogeneous steels left in heated state. CPSA

M Slivka: Medieval metallurgy and blacksmith's craft in Eastern Slovakia. *Historica Carpathica 1978, 9, 217-263. (In Czech).*

Evidence concerning medieval metallurgy and iron working in the East of Slovakia during the 13th-17th centuries. Excavations of smithies at Zaluzany (14th century), L ubovna and Kapusany (both of the 17th century date), all in castles. Metallurgical examination of wrought iron nails from the castle of Trebisov. CPSA

A R Williams: Medieval Material for Armour. *Materials Science Club: Bulletin No 56, December 1978, 22-29.*

Measurements of the armour plate thickness which was increasing after 1550. The hardness of the average armour breast plates was low in the course of this period. Resistivity tests. CPSA

A R Williams: Medieval metalworking – Armour plate and the advance of metallurgy. *Chartered Mechanical Engineer No. 56, December, 1978, 109-114.*

The metallurgical examination of protective armour has found in Mr Williams an experienced explorer in the last few years. The present paper deals with eight samples of European armour ranged chronologically from the Roman period up to the 17th century. Hard steel was used for making luxurious pieces since the end of the 15th century. Metallurgical comments on the medieval bloomery and blast furnace process, hardening etc, remarks on prices of armour on hand from selected examples.
CPSA

ASIA

Anon: Small iron belt found in the tomb no.2 at Ch'eng-ch'iao in Liu-ho, Kiangsu province. *Laogu (Peking), 1974 (2), 119.*

The remnant of a small iron belt (5 cm long) was found dating from the late Spring-Autumn period. The find supports the statement that towards the end of the 6th century BC at the latest, the Chinese were able to obtain comparatively pure pieces of iron (though far from the first quality) suitable for further manufacture of iron implements by application of as low a temperature as 800°-1000°C. Up to that time China had only known – similar to other slave economy states in the Near East and Egypt – iron implements of meteoritic iron.
After R Fellner (CPSA)

Huange Zhanyue: The problem of the origin of iron metallurgy and application of iron implements in China. *Wenwu (Peking) 1976 (11), 56-59.*

The author concludes from ancient literary reports and hitherto known findings that the late Spring and Autumn period (about 6th century BC) could be considered as the earliest era of iron metallurgy in China.
After R Fellner (CPSA)

Anon: Scientific determination of Li Chung. *Wenwu (Peking) 1976 (9), 56-59.*

Two adzes with iron blades and bronze handles dating from the Western Chou period are fully described. Recent analyses prove the meteoric origin of the iron.
After R Fellner (CPSA)

Anon: Iron implements found in the burials at Min-ch'ih, Honan province. *Wenwu (Peking), 1976 (8), 45-61.*

The burials date to the Northern Wei period (385-534 AD) but some of the 4195 excavated iron implements seem to be of a more ancient origin. As to the material used three types of cast iron (white, gray and mottled iron), malleable cast iron obtained by annealing, and wrought iron are reported. The most interesting material however is steel having originated in the process of decarburization of cast iron, grey low-silica iron and cast iron with spheroidal graphite.
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R Waranghkana and N Seeley: The bronze bowls from Ban Don Pa Phet, Thailand: an enigma of prehistoric metallurgy. *World Arch 1979,* **11** *(1), 26-31.*

Metallurgical examination of 5-15 cm diameter bowls from SW Thailand. The walls were only 0.3-0.5 mm thick and the alloy was 23% Sn. The structure was mainly martensitic beta with some residual alpha and it was quenched from 520°C. The hardness was 120-180 HV. They were probably finished by grinding and the alloy was chosen because of its resemblance to gold. The dating was 500-0 BC and they bear comparison with the later Korean bowls. RFT

AMERICA

A Sauver: Metallurgical Reminiscences. *J of Metals, June 1979,* **31** *(6), 20-27.*

This is the text of a lecture given in October 1936 and first published in 1937. The reminiscences cover the period from June 1889, when the author graduated, until about 1905. After a short period in the chemical laboratory of the Pennsylvania Steel Company he moved to the Illinois Steel Company in Chicago, where he was soon given a room to himself, 'supplied with an old-time microscope, and instructed to study the structure of steel and the ailments to which his flesh is heir'. This event marked the introduction of metallography in the iron and steel industry in the USA and this was soon followed by the first experiments in the field of radiography.

However, this work was brought to an abrupt end in 1896 with the appointment of a new Company President, and life became difficult until he was invited to join the teaching staff of Harvard University in 1899.

However, starting with the Carnegie Steel Company in 1896, metallographic work was taken up more and more by industry, and the early arguments on the metallography of iron and steel are vividly recalled. APG

TECHNIQUES

K Stransk, V Souchopova (Mrs) and K Ludikovsky: Trial bloomery smelts in shaft furnaces in the region of Blansko, Moravia (In Czech). *Slevarenstvi, 1978, 26 (11), 464-467.*

New trials with the smelting of iron ore in the slag-pit type of the bloomery furnace were carried out at Blansko.

Parameters of the most successful smelt: shaft height 100cms slag-pit depth 35 cms, hearth diameter 38 cms, highest temperature 1220°C (forced draught), ore: a mixture of rich Indian ore and poor local ore 6:1, ore/fuel ratio 1:1, fuel: commercial beech charcoal, duration of the smelt 3 hours 25 minutes; yield: bloom of heterogeneous iron with carbon content varying from traces up to more than 2% C. The output was 13% of the ore content. CPSA

K Ludikovsky: The state of archaeological field studies in Moravia. In: *International Symposium Mechanization of the Archaeological Fieldworks. Chojnice 15–17. IX 1977. Archaeologica Baltica 3, Łodz 1978, 79-103.*

The application of the proton- magnetometric prospection in archaeology: bloomeries of Sudice. Block-diagrammatic projections of measured anomalies. CPSA

J Piaskowski: Examination of Early Iron Objects: Part I – Purpose and Methods. *Irish Archaeological Research Forum 1977, 4 (1), 13-22.*

The author proposes some basic ways leading to a certain standardization of methods used in the metallographic research of ancient iron objects, simultaneously presenting his view on the identification of early techniques as revealed by polished samples. With regard to the extreme complexity of features revealed by microscopical observations and to the techniques mastered by early smiths this standpoint seems to be rather simplified. Unfortunately, the author does not respect numerous discussions which have already appeared in the respective literature.

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