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Crushing copper ore with stamps. Agricola Book VIII

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Contents

Fumes, flues, condensers and chimneys in lead smelting

D G Tucker

SUMMARY

Methods of condensing the fume from lead smelting are discussed in relation to Percy's treatise of 1870, and the wide variety of arrangements used in practice is illustrated by examples from the remains of English smelting mills. Questions are posed regarding the reasons for this variety.

INTRODUCTION

In the various accounts of lead smelting one rarely finds anything but a passing mention of the long horizontal flues that are nevertheless often the most obvious and striking remains of the lead smelting industry, especially in the North Pennine area. In some of these flues one finds large chambers; some flues are short and some are unbelievably long; some double back on themselves while some merely wander; all have chimneys, but what a variety of shape and size is found! All sorts of apparently-inexplicable features are to be discovered. Is there any kind of principle involved in these arrangements? Are there reasons for all the variations?

A reasonably thorough technical treatment of the subject is that by Percy.[1] A very brief summary of his account follows, which brings out the main points. The flues were partly for condensing the lead fumes for commercial recovery of the lead in them and partly for leading toxic materials such as lead compounds and sulphurous acid away from habitations and grazing land. The large chambers were to aid condensation.

The longest flues recorded by Percy are two at the Allen Smelt Mill, one 4451 yards and the other 4338 yards. The shortest known to me is that at Malham Moor Mill (Yorks, SD 883 661), about 30 yards; this mill when erected in the early 18th century smelted lead, but later went over to copper.

Long flues were also used in the tin, copper and arsenic industries, and a short note on this use is given in the Appendix.

A SUMMARY OF PERCY'S ACCOUNT OF LEAD-FUME AND ITS CONDENSATION

In 1778 Bishop Watson[2] showed that lead was sublimed during the smelting of galena, part adhering to the internal surface of the chimney and part escaping from the top of the chimney, poisoning the water and herbage on which it settled. He suggested that "this sublimed lead might be collected either by making it meet with water, or with the vapour of water during its ascent, or by making it pass through an horizontal chimney of a sufficient length", He quoted experience with a "horizontal chimney" on the side of a hill at Middleton Dale, which had been built to prevent adjoining pastures being injured by the smoke. It was, however, found to collect considerable quantities of lead.

The term "fume" means strictly the solid matter rich in lead, and does not include the sulphurous acid also given off. Both should be condensed.

Since the fume is very finely divided, it settles slowly, and this led to the use of condensing chambers in the flue between the furnace and the chimney stack. Settling is improved by inserting obstructions or partitions in the chambers to delay the flow through them. However, these chambers are not effective in proportion to their size, and so fine jets of water have been tried, or steam injected, to assist the settling of the fume in the chambers. But where space permits it, the long horizontal flue is most effective. A vertical stack is necessary at the end of the flue.

Apart from the methods mentioned above, the smoke can be forced through water by a fan-made draught, as in Stagg's condenser[3]; through faggots of brushwood continually soaked by jets of water, as in the installation on the Stokoe system at the Keld Head Mining Co's works in Wensleydale: through racks of pebbles and water-soaked coke filters as at Wanlockhead in Dumfriesshire, or racks of water-soaked pebbles as at the Eggleston Mill of the London Lead Co in Teesdale[3a]; or it can be mixed with steam and then condensed with water-jets as in the 1862 system of the Belgian engineer A Fallize, or of several earlier British patentees[4,5,6].

Lead fume varies mainly from grey to white in colour and from oxide to sulphate of lead as the dominant constituent. Black fume is reported from the fan-chamber when forced draught is used. The true sublimate often has finely-divided matter mixed with it, carried over mechanically by the gaseous current, and this accounts for much variation of colour.

The quantity of fume obtained in relation to the amount of lead smelted is very variable, depending on the type of ore and furnace. Many divergent figures are available, but a typical proportion of lead obtained from fume to lead obtained direct from the ore is 5 to 10%. The reverberatory furnace gives only a little less than the ore hearth, but the slag hearth gives much more.

ENGLISH PRACTICE IN RESPECT TO FLUES AND CONDENSERS

I have examined a large number of the smelting sites in England in the counties of Somerset, Derbyshire, Yorkshire, Durham and Northumberland, and shall discuss English practice mainly in relation to those sites of which I have personal knowledge.

There seems to be a very distinct regional difference in practice in respect to flues and condensers; Somerset and Derbyshire form the southern region and Yorkshire, Durham and Northumberland the northern region. The reason for the difference may possibly lie in the nature of the terrain.

Southern region:– Here the smelters seem to be on rather restricted sites and the flues obtain an adequate length by doubling back on themselves, perhaps several times. A straightforward and tidy example is at Charterhouse-on-Mendip (grid reference ST 506 560) where there are remains of eight parallel flues; (Plate 1); four of these were certainly joined in series, with what were probably small condensing chambers at the end of each loop. Such a system would have condensed most of the fume (ie. lead) but would probably have discharged the sulphurous gases into the atmosphere. A neighbouring smelter – St Cuthbert's (ST 545 505) – had an apparently much more random layout of flues. A single doubling back is found at Bradwell (Derbys, SK 174 808); a drawing of the arrangement has been published by the Peak District Mines Historical Society[7]. The Stone Edge smelter (Derbys, SK 334 670) has a rather wandering layout of flues, hard to follow on the ground, but again clearly drawn by the PDMHS[8]. The most complex system of all in this Southern region – indeed probably in the whole of the country – is that at Alport (Derbys, SK 223 648), where there were four different kinds of furnace, comprising two reverberatory and two blast furnaces. There were numerous condensing chambers, some with water showers. The complete layout was given by Percy and is reproduced here as Fig 1. This complex system covers a large stretch of steep hillside, and most of it is still clearly visible, some of the flues and chambers being practically undamaged.

Northern region:– Here the typical arrangement is a single long flue, often quite straight, running up the hills for some hundreds or thousands of yards to terminate in a prominent chimney. Condensing chambers are only occasionally found, and water-washed condensers in very few cases. There are only one or two cases of doubling-back of flues.

Two examples of water-washed condensers are Keld Heads Mill (Yorks, SE 077 910), mentioned by Percy, where a Stokoe condenser using forced draught was provided about 160 yards above the furnaces, and Grassington High Mill (Yorks, SE 025 663) where two small simplified Stokoe-type condensers were fitted. There are now no remains of the former condenser except for the walls of the wheel-pit and wheel-house; there are more substantial remains of the latter pair, their two-compartment arrangement being clear from the remaining walls of both the simple condensers, which did not (it is believed) use fans.

The Surrender smelt-mill (Yorks, NY 988 003) has a large heap of stone at one point in its now ruined long flue, and I thought this might have been a condensing chamber; but Clough[9] shows it as the ruins of an old chimney built before the flue was extended to its present length. This mill shows very clearly, in its ruins, how two flues from two sets of ore hearths join smoothly by "fusion" in what seems to have been the common manner. A different system of joining flues was, however, adopted at the Lintzgarth mill (Durham, NY 925 430) where two flues left the mill and were carried on a fine arched stone bridge across the stream and a road to enter a condensing chamber; (Plate 2); from the far side of this a single long flue ran for about 1.5 miles across the moor. Thus the condensing chamber acted as a junction box; its plan is shown in Fig 2. The vertical cross-section transverse to the flue direction was arched, with a height of about 9 ft above the floor level.

Another rather curious flue system deserves mention. The flue from the Keld Heads smelter, after passing through the Stokoe condenser, ran for no less than two miles up on to the moor beside the Cobscar smelter. (Yorks, SE 060 930). The latter had a flue only about 250 yards long; it may possibly have had a condenser in it, but more probably merely a condensing chamber, judging from the remains. The surprising thing is that the Keld Heads flue joined the Cobscar flue about 145 yards below the chimney, which both smelters shared. (NB. Clough[10] appears to be in error in this matter, for he says they had separate chimneys).

The notable northern case of doubling-back of flues, at Grassington High Mill, is indeed a flue system of great complexity by northern standards, although less so in comparison with the southern region. A diagrammatic layout of the flues, including the condensers, is shown in Fig 3. By suitable insertion of doors at junction A, the fume can be directed straight up the flue or via the first condenser. By insertion of a door at junction B, the fume can be directed around an extra half-mile of flue. By suitable operation of the doors at junction C, the fume can go straight to the chimney or round via the second condenser and an extra 400 yards of flue. The maximum flue length which can thus be obtained is just over one mile; the minimum is about a third of a mile. There were also arrangements for washing down the flues with water into settling pits from which the lead could later be recovered.

There was a much less complex zig-zag flue system at Castleside smelter, near Consett (Durham, NZ 078 485). It is also worth mentioning that over the border, in Scotland, the Wanlockhead Smelter (Dumfriesshire, NS 855 144) which continued in use until 1928, still shows clearly the flue system, which approached 1000 yards in length, coiled in two complete circles; remains of the condensers mentioned by Percy are also evident.

DISCUSSION

There are many puzzles in this subject, apart from that of the very great difference between the two regions. Why was there such an incredible variety of flue arrangements at a period in which mining engineers travelled widely and exchanged their opinions freely? One would have expected some standardization to appear; after all, there was a good deal of standardization in furnace design, ore dressing methods, etc. Clough[11] quotes performance figures for the condensers at Grassington High Mill as a yield of lead of 4 to 6% of the total lead smelted, and this must have been as much as (or more than) was recovered from the long flues. Yet the cost of the condensers in capital, maintenance and recovery of the lead must have been much smaller than that of a long flue – so why have the long flue; why not have additional condensers? Perhaps they had serious operating difficulties. It has been suggested that the long flues may have helped in obtaining adequate draught for the furnaces, but the truth is probably the reverse.

It is curious that there was only one really sophisticated installation – that at Alport. Was it successful? and if so, why was it not copied elsewhere?

CHIMNEYS

Finally, chimneys. The variety of shapes, sizes and styles is almost beyond belief. There are "typical chimneys", like factory chimneys, tall, slender and tapering, like that at Stublick in Northumberland (a round one, Plate 3 NY 841 611) at the top of the long flue from the Langley smelter, or that at Stone Edge in Derbyshire (a square-section one, Plate 4). There are huge, broad square towers like the keeps of castles, eg. that at the Surrender Mill in Yorkshire, or (huge and broad but not square) that at Alport in Derbyshire. (Plate 5). There are handsome round chimneys not like factory chimneys, (Plate 6), eg. that at Malham Moor in Yorkshire. The only one of the large ones readily explained is that at Alport; this had to be broad because four separate flues ran side-by-side up to it, and it contained condensing arrangements as well as a chimney vent.

APPENDIX

Flues in the tin, copper and arsenic industries

Long flues and special condensing arrangements were also used in connection with the production of tin and copper, but in a rather different manner. Although long flues may have been occasionally used in copper smelting (eg. the chimney and vestiges of the flue still remaining at Crew's Hole, Bristol, ST 628 732), it is believed that they were here used only to lead toxic material away from areas of habitation and not for the recovery of valuable metal. It was in the early stages of ore preparation at the mine that the main use of flues occurred, for the tin and copper ores, after preliminary dressing, were roasted in calciners to drive off sulphur and arsenic. Up to the middle of the nineteenth century the poisonous fumes were allowed to deposit themselves on the surrounding land, and compensation for wastage had to be paid by the mine companies. However, long flues were then introduced with an improved calciner, eg. the Brunton calciner[12], at one end and a tall chimney at the other. A very large proportion of the flue (typically 150yards out of a total flue length of 300yards) took the form of a labyrinth in which the arsenic, as arsenious oxide, was deposited and from which it could later be recovered as a valuable commercial product; indeed, after the slump in copper prices in the 1860's, the famous Devon Great Consols copper mine made arsenic its main business and the remains of this can be seen at the site (SX 425 733) – especially the very fine chimney and terminal flue. The flues extended to a total length of over a mile. Another good example of which extensive remains can be seen is at the old tin mine at Botallack in Cornwall (SW 363 333) where practically the whole labyrinth still exists. (Plate 7)

Some technical detail of arsenic extraction is given by Booker[13].

(based on a talk given at the Annual Conference of the Historical Metallurgy Group at Leeds, 25 September 1971 Professor D G Tucker is at the University of Birmingham)

REFERENCES

1 J Percy, **"The Metallurgy of Lead"**, John Murray, London, 1870, pp 434–458.

2 J Watson, **"Derbyshire lead ore"**, Chemical Essays, Cambridge, 1782, 3, p 240 and p 282.

3 J D Stagg, British Patent No 9920, 2 Nov 1843.

3a Percy (op.cit.) says in error that this mill was near Alston.

4 T Richardson, British Patent No. 12,246, 21 Aug 1848.

5 W Young and H B Young, British Patent No 12,256, 28 Aug 1848.

6 A Courage, British Patent No 959, 1859.

7 T D Ford and J H Rieuwerts (eds), **"Lead Mining in the Peak District"**, *Peak Park Planning Board*, Bakewell, 1968, p 74.

8 **ibid**, p 113.

9 R T Clough, **"The Lead Smelting Mills of the Yorkshire Dales"**, pub. by the author, Leeds, 1962, p 116 and p 119.

10 **ibid**, p 96

11 **ibid**, p 79

12 B Earl, **"Cornish Mining"**, D Bradford Barton Ltd, Truro, 1968, p 92.

13 F Booker, **"Industrial Archaeology of the Tamar Valley"**, David and Charles, Newton Abbot, 1967, p 162 and p 249

ACKNOWLEDGEMENTS

I am grateful to my wife for much help in the field, to Mr and Mrs Roy Day for showing me the Crew's Hole site, and to Dr R F Tylecote for suggesting the inclusion of the Appendix.

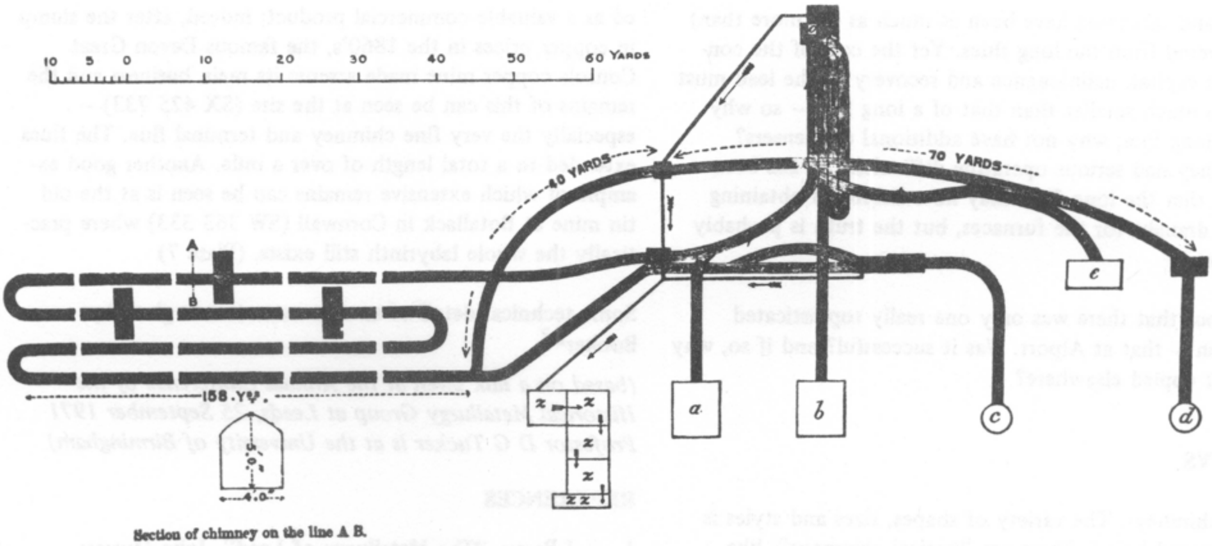


Fig 1 Arrangement of flues at Alport Smelt Mill, Derbyshire (from Percy)

a, b	reverberatory furnaces
c, d	blast furnaces
e	calciner
f, g, h, i, k	condensers using water showers or steam
l, m, o	combined condensers and chimney
y	arched chambers in the long flue x
z	lowest water pit, filled with cinders.

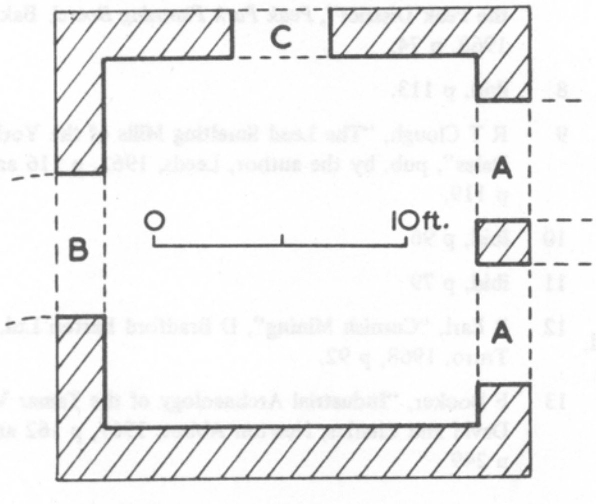


Fig 2 Condensing chamber at Lintzgarth Smelt Mill, Co Durham.

A	two flues entering over bridge
B	single flue leaving to run over moor
C	door for removal of condensate (fume).

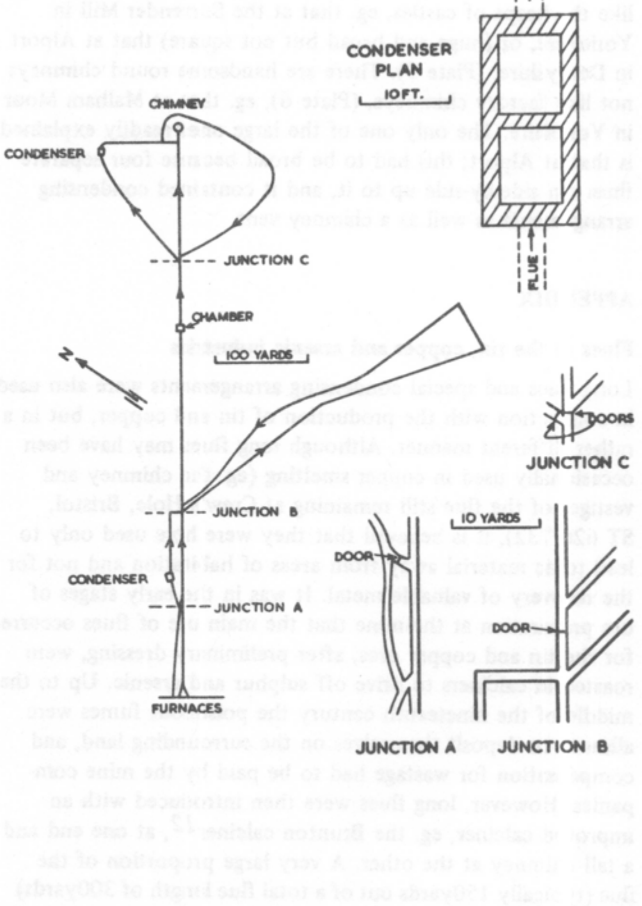
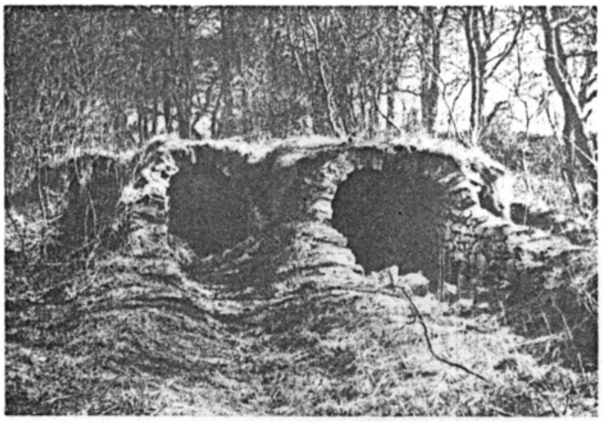
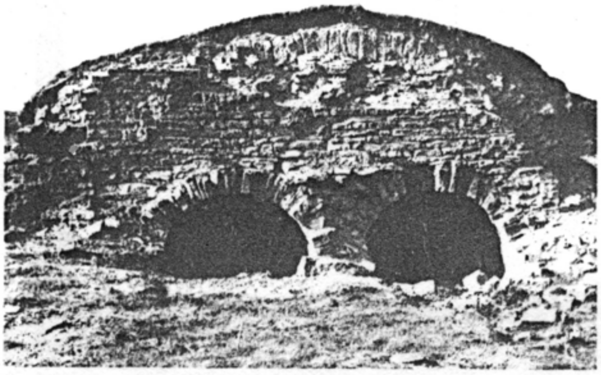
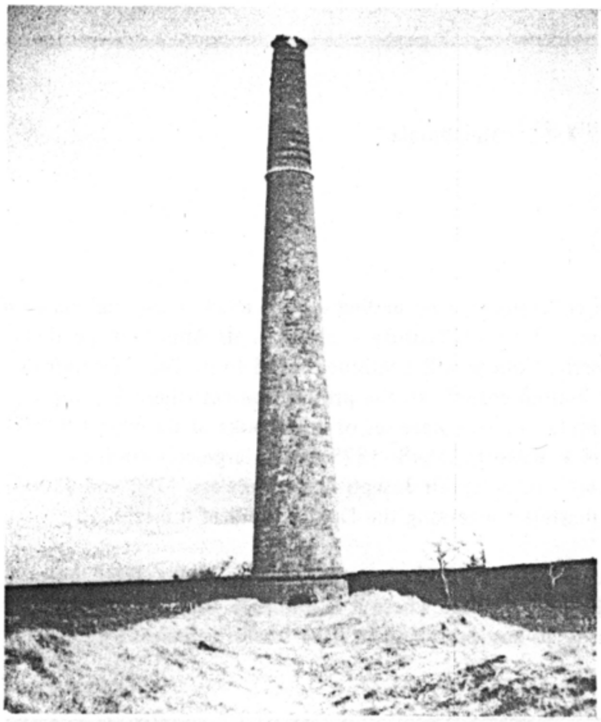
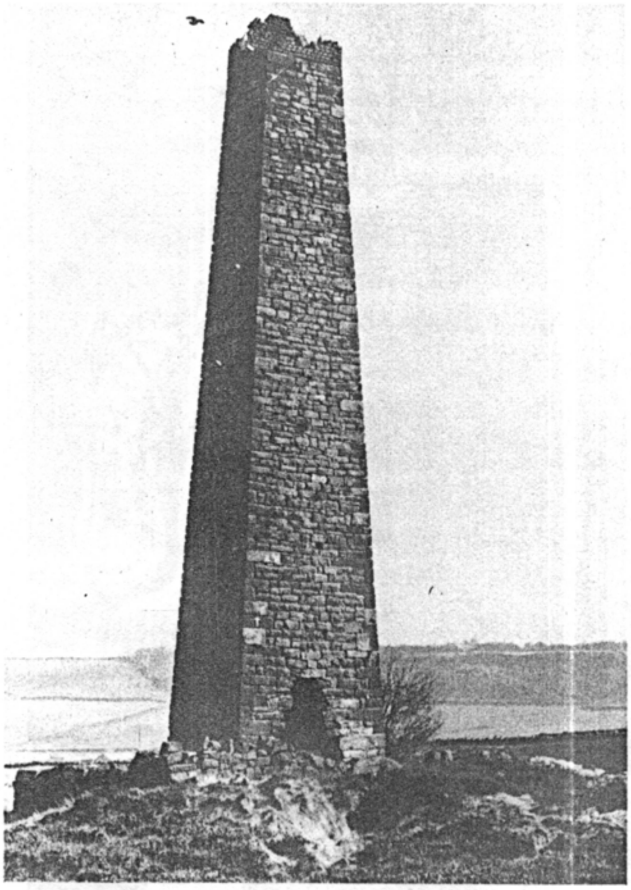


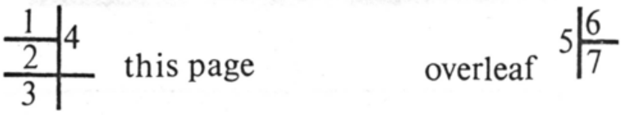
Fig 3 Details of the flue system at Grassington High Mill.





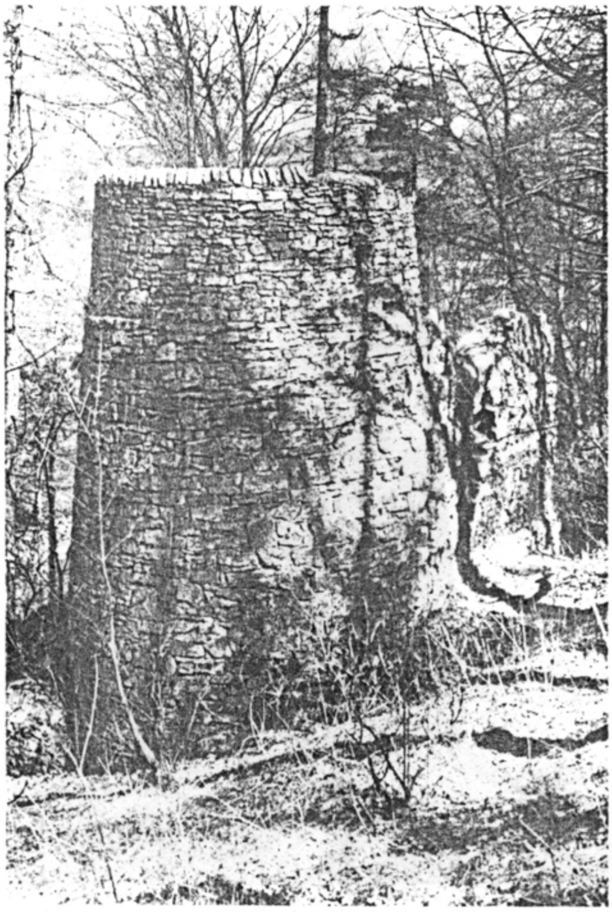


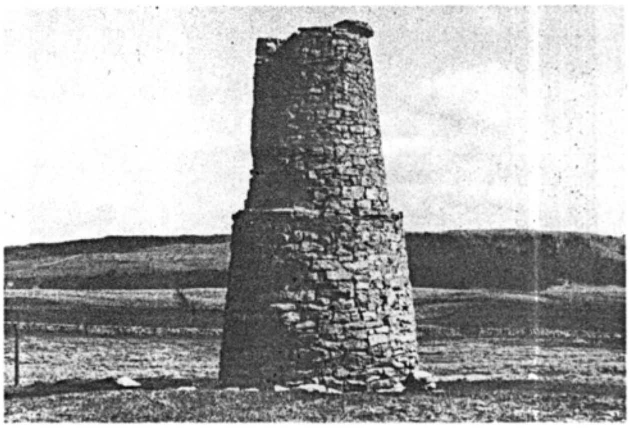


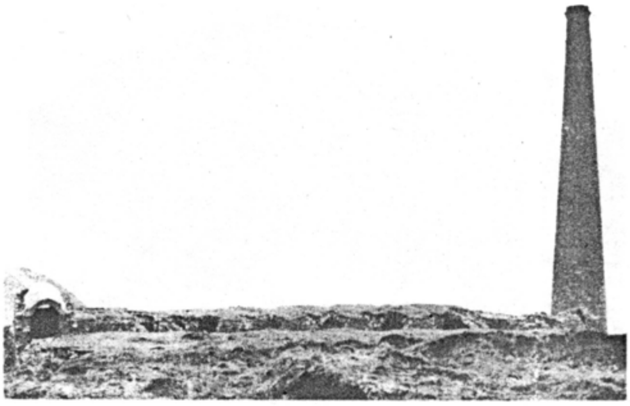


List of Photographs
(all taken by the author)

Plate 1	Parallel flues at Charterhouse-on-Mendip, approximately 6ft high by 3ft wide.
Plate 2	Condensing chamber at Lintzgarth Smelt Mill, showing where the two flues from the smelter entered. The long single flue left at the back of the chamber.
Plate 3	Stublick chimney, at top of a long flue from the Langley Smelt Mill, Northumberland.
Plate 4	Chimney at Stone Edge Smelt Mill, Derbyshire, base approximately 10ft x 13ft.
Plate 5	Chimney at Alport Smelt Mill, Derbyshire, height 34 ft.
Plate 6	Chimney at Malham Moor Mill, Yorkshire, 9ft diameter, height 20 ft.
Plate 7	Arsenic flues at Botallack tin ore roaster plant.







Robert Annan collection

July 1972 "Metallurgia"

The Robert Annan book collection. Mr Robert Annan, who has had a long connection with the Institution of Mining and Metallurgy and who is a Fellow of the Imperial College has presented to the Royal School of Mines his collection of books on metal mining and metallurgy. The collection, containing approximately 500 books and pamphlets, is one of the most comprehensive private libraries ever assembled in this field. It contains the printed works of virtually every important authority on all aspects of mining, from 1495 to the end of the 18th century, usually in fine examples of the first edition.

The collection has no ending date – much additional material brings it into this century – and it is Mr Annan's hope that Imperial College will continue to add to it. The collection is not limited entirely to the printed sources: there are, for example, the complete set of cost books of the Wheal Buller Mine at Redruth, 1848–1875, and a large collection of letters written to Sir Joseph Banks between 1793 and 1800 on matters concerning the Derbyshire lead mines.

The collection is being housed in the Lyon Playfair Library at Imperial College where it is available, under proper safeguards, to any persons who have reason to consult it.

Iron and steel manufacture on the Dee estuary of North Wales

P S Richards

The recent closure and subsequent dismantling of the Darwen & Mostyn iron and steel works of Mostyn, Flintshire, have resulted in a considerable change in the landscape. At the same time it presents the industrial archaeologist with an interesting study: the rise and fall of an important and specialised steelworks. This paper attempts to do this; it is hoped to follow it with a second paper on the surviving firm: Messrs John Summers & Company of the Hawarden Bridge Iron & Steel Works, Queensferry, near Chester. This industry has some unique features and well repays study.

HISTORICAL SURVEY

The Darwen & Mostyn Iron Company, originally the Mostyn Coal and Iron Company, was the first major iron works to be founded on Deeside. In the years just prior to its closure, however, it tended to specialise in the production of ferro-manganese and spiegeleisen. The firm started on its present site in the year 1800; there is no reliable documentary evidence for this date; unfortunately in the early days of World War Two a very patriotic manager of the works sent almost all the firm's records for salvage. It was founded in the middle of the French Wars when large quantities of iron were needed to make munitions; this seems a reasonable explanation for the start of iron manufacturing at this time. Its location on the Dee Estuary was strategically sound as it was away from the battle area. Its name in those days, the Mostyn Coal & Iron Company, reveals one of the reasons why it grew up where it did: the presence of nearby coal seams to supply the large quantities of fuel needed for the smelting process. On this site beehive coke ovens were constructed in order to reduce coal to coke and so make it suitable for furnace use.

Other factors helped to give rise to this industry. Together with the coal, clay ironstones, limestones, probably from the Trelogan Quarries about two miles from the river,[1] and water were all found in the vicinity and in close proximity to each other.[2] In addition, the works benefitted from the extension of the London & North Western railway line from Chester to Holyhead, which was completed by 1849.[3] But before that Mostyn provided a suitable shipping depot on the river Dee. This industry flourished and completely outshone similar concerns elsewhere, situated more inland, so much so that by the late 1840s a foundry and shipbuilding yard were flourishing here. The whole concern covered eight acres and it belonged to Messrs Eyton, local coalowners. This incipient iron industry formed the nucleus of what was to become a highly prosperous undertaking.[4]

The two basic raw materials for this industry were iron ore and coal. There was very little iron ore to be found in Flintshire. Such ores as there were occurred in the northern part of the county and usually in the lower parts of the carboniferous limestone and more rarely in the carboniferous basement beds. The ore developed chiefly as irregular flat pockets and veins.[5] The raising of clay ironstones from the coal measures of Flintshire has been extinct for so long that little information is available; the highest annual output was 1,050 tons in all Flintshire in 1859, but production ceased altogether by 1883. Percentages varied, but on average 30-36 per cent was metallic iron.[6] Since that date all ores used at Mostyn have had to be imported.

Although iron ore was in short supply it was some years before disastrous flooding put an end to local supplies of coal. The middle of the nineteenth century saw the hey-day of coal mining at Mostyn. The iron works were run in conjunction with coal mining and in the mid-1840s two steam engines were installed underground to pump out water from the seams in Mostyn Colliery which were between 1,200 and 1,400 ft deep.[7] In 1856 Mostyn Colliery, according to a mining engineer, could maintain an annual output of 100,000 tons of coal without any further expenditure of capital.[8] In 1859 400–500 men were employed in the colliery alone.[9]

In 1850 a new owner, J T Cookney, took over the mine and he immediately took full advantage of the geographical amenities of the place. A siding was built to link up his colliery with the adjacent Chester to Holyhead railway line, which had recently been constructed within a few yards of his property. He also expanded the shipping depot by building a dock and a wharf from which to export coal. The Hanmer and Englefield collieries also supplied fuel for the iron industry and enjoyed the advantages of proximity to railway and dock.[10] There was also a considerable export of coal.

By 1872 there was an iron industry at Mostyn on a considerable scale. Under the leadership of Joshua Lancaster the mine and iron works flourished. Changes, however, were imminent, but in order to understand the developments in the iron industry at Mostyn it is necessary to take into account certain technical improvements in the manufacture of iron and steel. These brought about its production on a great scale and effected the almost universal substitution of steel for iron. In 1856 Sir Henry Bessemer invented the process called by his name. This process, however, would only work successfully with non-phosphoric pig-iron. Bessemer had used haematite from Cumberland and Furness and to supplement this imports of ore from abroad were needed. In the years 1909–13, 67 per cent of Bessemer ore (ie. non-phosphoric ore) came from Spain, 10 per cent from Scandinavia and 10 per cent from Algeria. Robert Mushet discovered that phosphoric ores could be used in the Bessemer process if spiegeleisen and ferro-manganese were added to the wrought iron. Lancaster immediately saw the profits to be made from manufacturing these essential constituents of Bessemer steel, and ceased to produce pig iron. By this time local ores were exhausted, and the company had to import ores. In addition to those sources mentioned earlier, manganese ores came from Russia and South America.[11]

It would seem that without local supplies of iron ore it was uneconomic to produce pig iron here, and in order to use the extensive capital equipment profitably the works changed to the production of a more valuable product. This is an example of geographical inertia made possible by improved technology.

THE RAW MATERIALS

In a heavy industry such as the production of ferro-manganese the cost of the raw materials and their transport to the plant forms a high proportion of the cost of the finished article. There are four basic raw materials: air, limestone, fuel and the ore.

Because it is ubiquitous and does not have to be paid for there is a tendency to neglect the importance of air in any process. But turbo-blowers had to be installed and provided a blast for the furnaces of 40,000 cubic ft per minute. Over six tons of air were blown through the furnaces to produce one ton of manganese.

Limestone came from nearby quarries at Llandilloes. Originally it came by sea but in latter days it came by road. British Rail would have very much liked to have obtained this business. The firm would have liked them to have had it since it would have meant that the limestone would have been cheaper and easier to handle on the site.

It can only be assumed that ferro-manganese ores from India were originally used since it is known that the Mostyn Iron Company did have interests in the manganese ore area of the Central Provinces; there is, however, no documentary evidence to support this statement. In latter years ores came from a variety of sources: from 1959-64 over half the ore used was washed manganese ore from Tchia-Turi in Caucasia. This was exported from Poti on the Black Sea. The remainder came from west and south Africa, Malaysia, and amapa ore from Brazil. The use of Brazilian ores had to be abandoned because of high transport charges. The world price of ore at the source of mining or quarrying varies little: the price of ore at the blast furnace varies with transport costs and distance from the source.

Although the Darwen & Mostyn Iron Company controlled the port, which was originally built for the works and still is quite active, it was not, however, used by the works in its latter days When it was used, ships containing 7,000 ton lots anchored in Mostyn Deep and the ore was unloaded into lighters which were then towed into the harbour. One of these lighters lasted until 1963. There is ample and well proportioned space; the company's dock facilities take ships up to 2,500tons and 275ft in length. Up to 1950 imported ores were transferred direct from ships to site by means of modern electric grabbing cranes.[12] This port could not be used because the breaking of bulk was very costly and because of the policy of BIS Ore (who alone in this country are allowed to import ore) in using extremely large bulk ore carriers of up to 24,000 tons and over to reduce transport costs. Such vessels could not use the river Dee. The government have entered into long term contracts for the purchase of ore and their bulk purchases enable ore to be supplied to the iron and steel manufacturers much cheaper than they could buy it for themselves. When the river Dee proved too small for the ore carriers they came into Bidston Dock (and still do for John Summers) and were transported in British Rail's special hopper wagons. All the ore arrived at the plant already blended and dressed; sintering was unnecessary, and there was no sintering plant at Mostyn.

In the manufacture of ferro-manganese large quantities of coal are used – about twice the quantity used in pig-iron manufacture. This is because of the much higher temperature that is needed to smelt manganese ore than iron ore. Originally coal from the company's own mine was used, as has been stated earlier in this paper, and other locally supplied coal when it was necessary. The coal was reduced to coke in the beehive ovens on the site; these actually existed until 1940.

In the last years of its existence the firm had to buy its coal from the Coal Board – most of it came from Yorkshire and South Wales. The obvious source would have been John Summers who make their own coke; but for equally obvious reasons they were not allowed to do this. 2,000 tons of coke per week came to Mostyn by rail; road transport simply could not have handled that amount.

INDUSTRIAL ARCHAEOLOGY OF SPIEGELEISEN AND FERRO–MANGANESE PRODUCTION

In 1868–9 just before J Lancaster acquired these works two blast furnaces had been built to smelt the local ironstone.[13] Fortunately these furnaces could easily be adapted to produce spiegeleisen and ferro-manganese. Some few years later a third furnace was built, and production averaged about sixty tons per furnace per week.[14] There is some problem over these dates: another authority states that the first furnace (presumably producing spiegeleisen) began working on 9 December 1871. The second furnace was finished within a few months, the whole concern being completed in under twelve months. These new furnaces were of novel construction: coal was not used as a fuel. The steam was raised entirely by gas brought down from the blast furnaces in large wrought-iron tubes from the top of each furnace. This was an obvious economy. Coke had to be used in the smelting of the ore and was produced by sixty-four coke ovens which used the small coal of the colliery.[15] In 1872, 13,228 tons of haematite were smelted, and in 1873, 24,690 tons. The furnaces were in blast until 1876 and then came a period of depression. Local supplies of ore were inadequate (or non-existent?) for the needs of the Mostyn iron industry. Fortunately, however, foreign supplies could be cheaply imported into Mostyn Quay. Most of the ore, as has been shown, came from Spain and during the first six months of 1882, when the works re-opened after a short depression, 32,000 tons of ore were imported from this source. Most of the ore, as we have seen, was brought in by large steamers which discharged their cargoes into lighters in the Mostyn Deep. Ore could be transferred to lighters at the rate of 500–600 tons per day.

There were special facilities for steamers at the port of Mostyn. Steamers were favoured with a quick despatch and waiving of port charges, so much so that steam-boat owners were willing to accept a 1s less per ton for shipping ore to Mostyn than to other ports of the district.[16]

By the end of the 1870s this iron smelting firm was quite well equipped with workshops, weighing machines (to get the right proportions of ore and coke in the blast furnaces), locomotives, rolling stock, two steamers and five sailing vessels, and several houses were erected on the property. In 1884, 600 tons of spiegel and ferro-manganese were turned out per week.[17] In 1887 the company passed into the hands of the Darwen & Mostyn Iron Company who extended the plant in 1890, improved the port facilities and began to produce a special type of hard steel.[18] This firm remained in the hands of the owners until nationalisation took place in 1951. Perhaps, as future paragraphs will reveal, it was a pity the industry was ever denationalised.

From the closing years of the nineteenth century, however, right up until the works were denationalised in 1959 production was continuous. The 1860s, the 1870s and the early 1880s were the 'golden age' at Mostyn and the village earned the proud title of 'The Merthyr of North Wales'. At this time the collieries, copper and iron works employed over 3,000 persons.

On 22 July 1884 a tragedy occurred. Water burst into the workings of Mostyn Colliery, and the mine was completely flooded. Efforts were made to pump the water away but it was soon found to be of no avail since it was tidewater that had burst into the mine. Fortunately no human lives were lost. The neighbouring Eyton Colliery had also been flooded. Many men were put of work, and Mostyn never really recovered its former glory. Today with its iron works closed, but for its port, it would be well on its way to becoming a 'ghost town', a fate which has overtaken nearby Bagillt.

Soon after the time of this disaster, the Point of Ayr Colliery was opened, and this helped to save Mostyn from an even more serious decline. For sometime the Darwen & Mostyn Iron Company used coal from the Point of Ayr Colliery.[19] Since World War I with its mine flooded and coal from the Point of Ayr no longer suitable, it might appear as a 'stranded furnace'.[20] Despite this gloomy description this industry flourished as it was one of only four producers in Great Britain, the only one which produced ferro-manganese in Great Britain and nothing else (except for by-product gas); all other producers made this special steel as a by-product. It was under very capable management and flourished quite well.

INDUSTRIAL ARCHAEOLOGY PRIOR TO CLOSURE

During the second World War a comprehensive modernisation scheme for the whole works at Mostyn was decided upon. The plant then comprised two blast furnaces of the hand-charged type, only one being in operation during the war period, and the other kept as a standby. In 1945, a scheme was prepared in collaboration with consulting engineers to allow for a revised layout on a two-furnace basis, and adaptable to any future expansion. Each furnace was to be automatically charged and the handling of the materials from the incoming point to the furnaces was to be mechanised. To allow reconstruction to take place without interference with production, it was arranged for it to take place in two stages. Before the work commenced, Mr J H Storey, managing director, with Mr W Marley, consulting engineer and Mr A Bowie, works manager, visited the United States to view comparable installations and to make sure that the new schemes for Mostyn were at least as good as other modern installations. A direct comparison with plants elsewhere is impossible, of course, since the Flintshire works are unique in that ferro-alloys alone are produced. The effect of all these new installations was improved quality of product, reduction of manual effort, uniformity of operation, reduced maintenance costs, and conservation of materials.[21] In fact the result was a very much greater all round efficiency.

The site and situation are important. The site consists of 79 acres of ground; it was soft ground that had to be made up, ie. reclaimed and consolidated before it could be used satisfactorily. Such land would be cheap. The absence of company records does not permit us to say more. Even until very recently, however, the site caused problems: a few years ago a crane sank and damaged part of its base, which had to be replaced, at considerable expense.

The situation was excellent in the days when ships could get down the river Dee direct to the works.[22] Coal had been exported from the wharves: the Mostyn Coal & Iron Company had developed some new mines in 1877 and they hoped to be able to ship coal to the Mersey, saving they claimed, 6s per ton in transport costs. It is not known what became of this project.[23] Probably the whole idea collapsed with the flooding of the mines. As well as close proximity to road and rail their works were also conveniently close to the Merseyside ports for the ease of exporting manufactured products and importing raw materials when the Dee had silted up.[24]

The works were built to supply markets all over Great Britain, especially South Wales and the Midlands. There has not been any export of ferro-manganese for many years since British prices were usually and still are too high to compete with overseas producers. Mostyn was one of the four suppliers of manganese in the country and until June 1963, when they were broken up by the Monopolies' Commission, they formed part of the UK Ferro-manganese Association. Each firm

produced a quarter of the country's needs. The Darwen & Mostyn, in production for a whole year, had an output of 50,000 tons and produced ferro-manganese cheaper than the other members of the cartel. The other three manufacturers were able to sell their ferro-manganese at a loss as for them it was a by-product or sideline to their main concern.

Ninety per cent of the output at Mostyn was sent away by rail. The whole works were geared to the railway. Mechanised handling on the site made production as cheap as possible. In the years just before closure limestone was brought in by rail. Although this was more expensive than by road, it was cheaper in the long run since handling costs on the site were much lower.

Since February 1964 the plant has been idle. The works had functioned for seventy years and for most of that time had made a steady profit. The plant had been nationalised and modernised at national expense shortly before that date. Production at Mostyn had first been suspended in January 1963 and production restarted early in July of the same year. The company envisaged there would be continuity of employment so far as the foreseeable future was concerned. Redundant workers had been given their jobs back.

A large export order was secured in face of severe competition. The labour force at the works at the time of suspension was nearly 300 and that was reduced to about 100 workers who were engaged for a time on maintenance; about 130 of the redundant people had been taken on again.[25] This temporary prosperity was not to last long. The answer to this problem is one that does not seem to have been considered by industrial archaeologists. Mismanagement by inexperienced directors and the pursuing of unwise trading policies resulted in the official receiver being called in.

The company, who had acquired the iron works after de-nationalisation in 1959, that is six years after the passing of the De-nationalisation Act, were financiers who wanted quick and large profits. The outcome of this policy was that within a few years the company went bankrupt. To quote an eminent metallurgist (E Taylor Austin), the steel industry is a good bread and butter proposition but is certainly not one that brings large returns quickly.

All attempts to sell to firms in the metal industry failed and finally the plant was bought for scrap by T W Ward who have already dismantled the furnace and the ancillaries. When one considers that over one million pounds were spent in modernisation between 1950 and 1960 and one of the furnaces, now dismantled, was brand new and had never been blown in and that the new blowers, which had cost over a quarter of a million pounds, had only been in use for three months and at half blast at that, the tragedy of the situation is realised.

The firm closed finally on 4 April 1964 and all the staff were given a minimum of notice and the hundred and eighty who were discharged received no compensation. Of this number fifty were retained by Thomas Ward who took over the works. Twenty were placed in employment immediately by the local employment exchange (now the Department of Employment and Productivity) and about sixty made claims for unemployment benefits. It is assumed that the remainder found alternative work by their own efforts. Of those who registered as unemployed about twenty were placed, and seventeen found work during the first two to three weeks. One man was still registered at Holywell Employment Exchange in September 1968. The majority of those who were placed in employment were engaged by Courtaulds Ltd, John Summers & Co Ltd, Connah's Quay Power Station, the Royal Air Force Station Sealand and local building contractors. With the dismantling of the plant and the placing of the labour supply elsewhere a chapter in the iron and steel industry in Flintshire came to an unfortunate conclusion.[26] Mostyn has thus reverted to a residential area, and the iron works have become fields once more. First the mines closed, then the steel works, and now only the dock is left.

ACKNOWLEDGEMENTS

To J L Boyle, former works' manager and E Taylor Austin, FRIC, FIM, metallurgist for help in writing this paper.

REFERENCES

1 P T Williams, **The Industrial Industry of Flintshire**, MA thesis, Liverpool 1933, 158. These particular quarries seem to have been closed since they are mentioned neither in T M Thomas, **The Mineral Wealth of Wales and its exploitation** (1961) nor by H W Crellin, **Flintshire County Development Plan: Report and Analysis of the Survey**, Mold (1954).

2 G M Howe, **Wales from the Air**, Cardiff (1957), 31.

3 A H Dodd, **The Industrial Revolution in North Wales**, Cardiff (2nd edn 1951), 116.

4 **Chester Chronicle**, 2 November 1848, cited by P T Williams, op cit, 156.

5 W A Griffiths, **The Mineral Industries of Flintshire**, BA Liverpool (1940), 89.

6 **Ibid**, 92

7 **Chester Chronicle**, 5 June 1846, cited by P T Williams, op cit, 127.

8 C R Williams, **The Industrialisation of Flintshire in the Nineteenth Century**, MA Wales (1950), 147.

9 **Chester Chronicle**, 7 January 1859, 2 February 1857 and 30 October 1857, cited by P T Williams, op cit, 157. Iron rails were used at this colliery to connect the pit head with wharves on Dee Bank.

10 Ibid, 157-8.

11 C R Williams, op cit, 183.

12 A R Parkes, *'Production of Ferro-Manganese and Spiegeleisen – a reconstruction of the Mostyn Iron Works'*, **Iron and Coal Trades Review**, 1 December 1950, 804.

13 **The Flintshire Observer**, 23 February 1872, contains a detailed article on these furnaces. Quoted by P T Williams, op cit, 159.

14 Ibid, 159.

15 Ibid, 159.

16 R Meade, **Coal and Iron Industry of North Wales**, 1877 and 1822, cited ibid, 159.

17 **The Flintshire Observer**, 7 July 1882.

18 Ibid, 20 February 1890. Ed Bowen, **Wales**, 1957, 451.

19 Crellin, op cit, 26.

20 Abercrombie et al, **Deeside Regional Planning Scheme**, Liverpool (1923). Written at the time of a trade depression, it presents a very gloomy picture.

21 A R Parkes, op cit, 803–9, contains technical details of the improvements.

22 Customs Imports 1873–1900, PRO Customs 23/1–94 cited by J P Bethel, **The Dee Estuary – an historical geography of its use as a port**, MSc Wales (1952/3), 204.

23 **Mining and Engineering Record**, 14 April 1877, cited ibid, 205.

24 A R Parkes, op cit, 804.

25 **Daily Telegraph**, June 1963.

26 Personal communication to the author by R H Saunders Esq on behalf of the Welsh Office of the Department of Employment and Productivity.

Norfolk Foundries

Norfolk Foundries – Historical Survey. A historical survey of foundries in Norfolk is planned by the county's *Industrial Archaeology Society (Secretary: 2 Mill Corner, Hingham, Norwich, NOR 23X)*. The intention is to list all foundries from about 1800, survey their sites and photograph any remaining buildings. As information about the early ones is likely to be sparse, the Society will concentrate on the last hundred years. Eyewitness accounts of local foundry work and old photographs, diaries and other records are sought. Articles made in the foundries are to be stored at the Bridewell Museum, Norwich, where the results of the survey will eventually be deposited. Readers who can assist the Society are invited to write to the Secretary.

Apologies

Errata – 'The Early English Iron Patents'. The following errors crept into the above paper in Vol. 6 of the HMG Bulletin:

Page 10 Table 1

1670–80	6	45	51
1830–40	37	2416	2453
1840–50	87	4494	4581

Page 13 John Champion's patent should read number 2239.

Page 15 Patent omitted:

1832 6211 Moses Teague. Making and smelting pig iron.

Page 18 Patent omitted:

1850 13028 Thos.Walker. Manufacture of sheets of wrought iron.

The Redesdale Ironstone Beds

J E Hemingway

Professor J E Hemingway is in the Department of Geology, University of Newcastle upon Tyne. This paper was first published in the Magazine of the Geological Society of the University and we are grateful to the author and J G Baines the editor for allowing us to reproduce it here.

DISTRIBUTION

The Redesdale Ironstone Beds are restricted at outcrop within an area of approximately 6.5 x 4 kms on the valley slopes of the lower River Rede and its tributary Broomhope Burn in mid-Northumberland. The ore-bearing beds do not appear to extend far beyond this, though shales with increasingly calcareous but fewer nodules may extend for some kilometres at this horizon.

METHOD OF WORKING

The ironstones are essentially nodular ores occurring in shales and were worked extensively, but not very profitably in the mid-19th century. Originally this was by quarrying: the beds were cut or blasted from the escarpment, left throughout the winter months to frost, after which the ironstone was hand-picked from the enclosing shale. This form of extraction extended along the outcrop for a distance of about two kilometres, through the Steel and Broomhope royalties. A third area, the Redesdale Village royalty was less extensive.

Pillar and stall working replaced the early opencasting as the thickness of the overburden became too great for ready removal. The rate of extraction was inevitably much reduced by this form of mining and it is said that as much as 80% of the bed was left as pillars. Nevertheless, by 1871, when working was mainly underground 20,948 tons of ironstone were raised, an output which fell to 13,889 tons in 1873. The iron produced from the Redesdale Beds was "of a very excellent description"[1], but this was not sufficient to resist economic pressures possibly under the additional impact of cheaper Jurassic ores as well as the increased mining costs. Production finally ceased in 1876.

Today the workings are almost entirely grassed over, though the sites of some of the adits are clear. Two incomplete sections remain, in Hareshaw Burn and in the Steel royalty, the latter having been recently improved in order to ease examination.

FIELD EVIDENCE

The Redesdale Ironstone Beds form the uppermost unit in the Scremerston Coal Group of D_1 age of the Northumbrian Basin. They are approximately 30 feet (9.1m) in thickness and are typical of much of the iron-rich parts of the Carboniferous system in Britain, and particularly of the Coal Measures. They are dominantly shales with subsidiary concretionary siderite mudstones – the clay ironstones of an older terminology. As such, ironstone contributes less than 10% of the entire sequence, though this is difficult to determine accurately.

The most distinctive horizon in the Ironstone Beds is the so-called 'Shell Band', a highly fossiliferous ironstone which occurs in the middle of the Ironstone Beds. It was recognised and so-named by the miners and was used by them to subdivide the beds into an upper and lower 'plate' or shale.[2] Its thickness usually varies from 5 to 12 cms of which the upper centimetre, particularly where the bed is thickest, is a shelly limestone free from siderite.

The Shell Band is the lowest and most distinctive of four fossiliferous horizons. The remaining three are shales, each 2 to 5 cms thick, with a rich fauna of crinoids, brachiopods, bryozoa and their associated shell debris. They are separated by unfossiliferous shales and occur through the 50 cms of beds above the Shell Band. Only random ironstone concretions occur in the upper fossiliferous horizons.

The ironstone occurs as beds of scattered, discontinuous concretions. These 'lines' (beds) of nodules, in the limited field evidence now available, are not necessarily either regular or persistent in their distribution. In size the concretions now seen vary in major diameter from 1 to 35 cms and some were said to reach a weight of 50 lbs.[3]

In external form the concretions, other than the Shell Band, show great variation. Some of the smallest (1 cm diameter) are near-spherical: the commonest, of median size (25 cms major diameter) are flattened to discoidal or to triaxial forms. Others, clearly compound, are mamillar. Two other forms are highly distinctive: one is an aggregate of spheroids (each 3-4cms diameter) attached to and developing from a major concretionary nucleus. Each of the minor protuberances shows septariate cracking and together they present a compound pustulate form. The second type presents what is said to be a unique external form, simulating the wrapping round of individual layers, each about one millimetre thick and up to 1 cm wide. These appear to originate at the edges of a flattened triaxial concretion and grow towards the middle of the larger faces. The final concretion is built to about 20 cms major diameter. There is no internal evidence of such an aggregated structure. Each of the distinctive concretionary forms together with the beds of larger concretions appear to have some local stratigraphic significance, though the field evidence is limited.

There is no clear pattern of distribution in the size of the concretions or in the ratio of length and/or breadth to thickness. Some concretions, not necessarily the thickest are sparsely distributed in a bed, others are relatively abundant: some beds are septariate, others are not so. Most are relatively rough on their outer surface but the detailed relationship of the shale to the ironstone cannot be determined at outcrop.

PETROGRAPHY

The typical concretion of Redesdale Ironstone is a felt of interlocking anhedral siderite crystals averaging 5μ in diameter, with some interstitial clay. It usually shows a mosaic texture with a tendency to grumulous recrystallisation.

Pyrite is ubiquitous, occurring in disseminated aggregates, at times framboidal, and making up about 1% of the rock. Shell debris, probably ostracodal and at times pyritised, together with angular detrital quartz, are rare. Coarse sparry calcite fills the septariate fissures, with crystalline clay occupying the apex of each crack. In all, however, there appears to be little in these concretions that differs from the majority of British, nodular iron ores.

By contrast the Shell Band is distinctive in the delicacy of preservation of its fauna, as well as by its texture. Calcite, dominantly organic, makes up about 50% of the rock and varies in adjacent specimens both in amount and in the phylla preserved in it.

Crinoid columnals and plates are abundant and invariably occur as single calcite crystals with well-preserved internal microstructure.

Brachiopod debris as well as whole shells is preserved in great delicacy, with the imbricate anterior structure of the shell unbroken and the punctae at times filled with siderite. In most cases the shell microstructure is preserved in prismatic and foliated calcite. Originally hollow producted spines are abundant and occur in finely foliated calcite, without recrystallisation.

Gastropods of several genera, and usually recrystallised, with ostracods, foraminifera and bryozoa are frequent.

Thick-shelled debris, each fragment replaced by single or few calcite crystals, probably represent crushed aragonitic lamellibranchs.

Some of the shells are bored, as by filamentous algae, gastropods or sponges: others are encrusted with serpula and bryozoa.

Ecologically this fauna undoubtedly represents a thriving and mixed community developing on and in a clay substrate in essentially an open well-oxygenated, low energy environment. The larger individuals suffered from the attack of predators and occasionally from parasitic growths. There is no evidence of abrasion and lateral transport appears to have been minimal.

The fauna is set in a matrix of turbid fine-grained (4µm) siderite with minor interstitial clay. Pyrite occurs throughout the matrix and in some of the recrystallised shells but it never exceeds 2%'

All hollow shells and in particular gastropods, ostracods and productus spines are infilled, usually with coarsely crystalline siderite (to 20µm). Where such infilling is complete it usually culminates in a scalenohedral fringe of siderite succeeded by an overlying single calcite crystal and more rarely coarsely crystalline clay. These forms of preservation present good 'way-up' criteria.

An outstanding textural feature of the Shell Band is the frequent development of "Stromatactis", aggregates of coarsely crystalline calcite, even single crystals filling one-time cavities in the siderite matrix. These may attain, in random section a length of 3mm, though they are normally less than 1mm. They usually lie below the larger shells and vary from a regular oval form as seen in section, parallel or subparallel to the overlying shell to highly ramifying and even bifurcating forms. Invariably however two characters are developed. The cavities are always lined by a fringe translucent prismatic siderite to 60µm, with scalenohedral terminations and which predates the calcite. Further, the drusy rim of prismatic siderite is always separated from the shell debris by a layer of turbid siderite of matrix type, which may be as thin as 10µm. These druses in no case replace any shell material. Even delicate ostracod valves remain upstanding, though with the film of siderite matrix and the succeeding zone of prismatic siderite.

It would appear that the sequence of mineral infilling of the stromatactis vugs was identical with that of the hollow shells and the two were most probably paragenetically synchronous.

Stromatactis structures have frequently been described from fossil reefs where they were originally regarded as organic or the mould fillings of dissolved organisms. Other suggestions include a development along planes of shear failure during creep, slumping and compaction (Schwarzacher 1961). They have not previously been recognised in ironstones.

THE ORIGIN OF THE IRONSTONE

The origin and emplacement of nodular iron ores in relatively concentrated form in both marine and non-marine sediments has long been a source of discussion and will probably remain so. Nevertheless, some general observations, in so far as they affect the Redesdale Ironstone Beds, may be made.

It is generally agreed that goethite, ferric oxyhydroxide α FeOOH is the principal weathering product of iron-bearing minerals. The grains of limonite are transported in a dispersed, particulate form or absorbed on mineral grains and particularly on clay minerals. This allows a large amount of iron-bearing hydroxides to be trapped within the oxidised surface zone of the sediment. Without further concentration they would remain dispersed on lithification of the sediments to form a typical non-concretionary ferruginous shale. Their mobilization, essential to preparatory concentration, may be made possible by the presence of CO_2, with the consequent formation of a soluble bicarbonate. The production of CO_2, whether in sediments of marsh, inter-tidal flat or marine environment, is made possible by the decomposition of plant material. This was demonstrated by Hickling[4] in his work on the devolatilization of coals, when he concluded that the production of CO_2 during this process preceded that of the now more familiar CH_4. Although this referred only to the maturation of coal seams, it must be borne in mind that coal constitutes only 1/500th part of the organic matter trapped in sedimentary rock. Disseminated plant debris which is abundant in what was originally and significantly called the Carbonaceous Division of the Carboniferous of the Northumberland Basin (now the Scremerston Coal Group) would yield during diagenesis a steady supply of CO_2 to percolate upwards as carbonic acid. This would necessitate a thick oxygenated zone below the sediment-water interface.

Such a process would slowly continue until precipitation was initiated. Undoubtedly the increasing concentration of iron-bearing constituents of the upward-moving interstitial liquors, displaced by the continuing compaction of the sediment, would favour this. It would however be promoted by an upward change of pH. It has long been claimed that the production of ammonia from decaying nitrogenous tissue would raise pH, but it would not appear to have been more than marginally effective. It is significant that siderite deposition in the four shell beds of the Redesdale Ironstone Beds is concentrated in the lowest bed, the Shell Band, the upper three shell beds being essentially concretion-free. Such selection of siderite deposition cannot therefore be due to the chemical control exercised by the products of decaying tissue, which would doubtless be common to all four shell beds. It has nevertheless long been appreciated[5] that initial nucleation is critical. Once this is established a concentration gradient would support continuing growth until the available dispersed supply of the metallic ions was substantially reduced if not exhausted.

The pH of a sediment is known to be raised by felspar decay on weathering and carbonation. Although no large supply of feldspar is available in the shales, it is always possible that a single grain transported with the terrestrial quartz could, on its breakdown, initiate nucleation. It is perhaps not without significance that a feldspathic sandstone immediately overlies the Ironstone Beds.

The occurrence of concretions in beds, rather than randomly distributed does however support the view that the initiation of bulk precipitation is controlled either by a bedding plane or a surface approximating to a bedding plane rather than by random precipitation of the above processes. The former would necessitate a minor mineralogical or physical variation within a bed: alternatively the presence of an advancing "front" crossing the plane of the bedding and initiating precipitation when an adequate concentration is attained. The significance of a single horizon in concretion development is emphasised by the admittedly rare wrap-round. structure, the individual wrappings of which being clearly initiated on the equator of the concretions.

Once initiated, crystal growth would continue within the heavily watered sediment as long as a concentration gradient was maintained. It would result in trapping some of the mud within the growing carbonate and would continue until compaction of the host shale reduced the pore space between the grains and terminated further supply. As deposition continued the advance of the rising zone of reduction would, with the small amount of entrapped water and bacteriological breakdown, produce the small amount of disseminated pyrite now observed in the ironstones.

Continued compaction would flatten the concretions by expelling the interstitial liquors from them. Their early sucrosic texture would develop to a denser intercrystalline mosaic, a reduction in volume of the originally heavy watered mass which led to forms which are now predominantly flattened. Where this was inadequate to adjust the shrinking volume to the established equatorial framework, syneresitic cracks cut the concretion near-normal to the bedding and both radially and concentrically.

Within the Shell Band the siderite and clay, shrinking by recrystallisation within an established shelly framework left cavities which were preferentially roofed by the larger shells, on which were left a film of the original siderite mud. The closing phase in mineral diagenesis was the crystallisation of coarser siderite in the hollow shells and round the inner surfaces of the stromatactis cavities, probably as the final residuum of the mother liquor was squeezed from the slowly lithifying concretion. Only when this was exhausted did coarse calcite and clay finally crystallise in any remaining available space.

NOTES AND REFERENCES

1 Bell, L. **Rep. Brit. Assoc.** for 1863 (1864) p. 740.

2 The **'Shell Band'** is the only vestige of the original ironstone terminology that has survived. This is particularly regrettable in view of the known vigour and directness of mining nomenclature. It would appear likely that, in common with comparable ironstone successions in Yorkshire and Derbyshire, each distinctive nodule bed would have been given its own specific name.

Large tips of the Shell Band remain on the Steel royalty. It is likely that this bed, because of its large calcite content was used as a flux in smelting and this was surplus to requirements.

3 Lebour, G A. On the geology of the Redesdale Ironstone district. **Trans. N England Inst. Min. and Mech. Eng.** 1873, **22**, 111–128.

4 Hickling, G. The Geological History of Coal. **Proc. S Wales Inst. Eng.** 1931, **46**, 911–951.

5 Tomkeieff, S I. On the mode and origin of certain kaolinite-bearing nodules in the Coal Measures. **Proc. Geol. Ass.** 1927, **38**, 518.

Metallographic examination of 16th century armour

A R Williams

Throughout the Middle Ages, from the fall of the Roman Empire up to the 16th century, the dominant figure in medieval warfare was the armoured knight. A body of knights, mounted on specially bred warhorses strong enough to carry them, armed with lance and sword, and trained from boyhood in their use, could sweep aside any opposition.

The cost of equipping and training knights was very high, however, and they formed a social as well as a military elite.

Initially, they were protected by chain-mail, which was proof against most weapons until the 11th century. At about this time, the (wooden) crossbow made its first appearance. The simplest types were simply wooden bows which could be drawn with two hands, but their effectiveness against mailed opponents led to their widespread adoption, despite their slow rate of fire. Indeed, the Lateran Council of 1139 banned their use in warfare, except against the infidel.

In the latter half of the 13th century, the famous national weapon of England, the longbow, came into use, and its deadly effects were demonstrated on Scots, French, and others. With "bodkin" points, arrows from the longbow (a much larger bow than usual, whose use needed much training) could penetrate chain mail readily.[1]

These developments triggered off an "arms race", plate armour being developed to resist the missiles of crossbows and longbows. Mixed chain mail and plate suits came into use about the middle of the 14th century, and complete plate suits at about the end of that century.

These represented a real advance in metalworking, being articulated and closely-fitting to protect the body. Contrary to popular myth, they did not reduce the immobility, a typical 15th century suit of plate armour weighing some 50—60 lb was by no means an excessive burden for a trained man. The problem is not entirely clear, but it would seem that the longbows and existing crossbows were ineffective against it. The English archers at Agincourt probably having to aim at the (partly-armoured) horses.

In the 15th Century, two new missile weapons, the handgun and the steel crossbow (which needed a small windlass to draw it) appeared and their arrows were probably capable of piercing plate armour.[2]

The acme of armour was reached in the 16th century, when it was produced on a large scale (Henry VIII ordering 3900 suits at a time)[3] but improvements in firearms forced armour to become heavier, and by 1600 it was passing out of use.

In a recent article[6] G W Henger described the analyses of a large number of iron samples from various dates, including five pieces of plate armour. Three of the samples, including two of the earliest, consisted of wrought iron carburized on one or both surfaces. The other two, later in date, were of a more steel-like composition. He suggested that these may have been made by an indirect (blast furnace-finery) process. One sample, the earliest, was a piece of Italian armour plate of about 1400 AD and resembles my specimens A and B.

THE METALLOGRAPHY OF SOME PLATE ARMOUR

As part of my work for an MSc thesis I examined some fragments of 16th century armour, very kindly made available by the staff of H M Tower of London.

	Average thickness
Specimen A	
Date ~ 1580 *(Italian)* part of an arm-defence	0.057 in
Specimen B	
Date ~ 1620 *(English)* part of an arm-defence	0.065 in
Specimen C	
Date ~ 1520 *(English)*	0.023 in

RESULTS

Specimen A *(Fig 1)*

Four samples (about ¼" square) were cut from the piece of armour, as shown. They were mounted separately in bakelite or acrylic resin and then polished and etched for microscopic examination. The hardness of these sections was also measured, as being much less unreliable because of the heterogeneous nature of the metal than a surface reading would have been.

Sample A1 *(Fig 2)*

This sample was obtained by cutting through a rivet-hole and the folded edge of the piece. It will be observed that the surface which was on the inner side of the armour (and was subsequently folded over to make the rim) is largely ferrite in structure with some inclusions of pearlite near the surface, (probably < 0.1% C increasing to 0.2%). The outer side of the armour has much more pearlite, present as distinct grains as well as inclusions between the grains. Near to the surface the grains show distortion due to having been cold-worked. (Probably about 0.45%C).

Sample A2 *(Fig 3)*

This sample was obtained by cutting a section from the plain edge of the piece. The slag inclusions are conspicuous and the middle of the sheet consists of large grains of ferrite with smaller grains at the front surface with pearlite inclusions. (Middle <0.1% C. Front surface 0.15-0.2% C).

Sample A3 *(Fig 4)*

This was obtained by cutting a section out of a side edge of the piece. The larger part of the sample is again seen to be ferrite with considerable pearlite in the front surface (Depth approximately 1/100 in) and some in the rear surface. The grains of ferrite show some lateral distortion, but not much, due to some cold-working. (Probably < 0.1% C in middle, increasing to about 0.3% C at front surface and to about 0.15% C at rear surface).

Sample A4 *(Fig 5)*

This was also obtained by cutting a section out of a side edge of the piece. Again, there is some slight distortion of the ferrite grains in the middle of the piece due to some cold-working (but this armour has been principally shaped while hot). The carbon content here is 0.1-0.15%. Towards the front surface it increases to about 0.45%.

Hardness Tests: *(Vickers Pyramid Hardness Tester)*

Sample	Area	Readings (HV)
A1	Turned-over rim	211, 201
A	Sheet below rivet hole	180, 196
A2	Sheet near edge away from rim	165, 158
A3	Piece from edge	180, 163, 179
A4	Piece below A1 (away from rim)	176, 168

The higher readings for sample A1 are probably due to work-hardening. The average of the other readings is VPH = 170. This compares with a typical value for mild steel of 130, carbon content 0.25%.

Specimen B *(Fig 6)*

Date about 1620 (probably English).

Three samples were taken, one being a section through a rivet.

Sample B1 *(Fig 7)*

This was obtained by cutting a section from the edge of one of the longer sides of the piece. The structure is largely ferrite (< 0.1% C) with a marked reduction in grain size towards one surface. This corresponds to the outer surface of the armour and more pearlite is present (about 0.3%C). Much corrosion is evident and some splitting has begun.

Sample B2 *(Fig 8)*

This was obtained by cutting a section through the lower rim of the piece at a point where a rivet had been inserted. The photograph therefore shows the cross-section of this rivet. The photograph of this (unetched) *(Fig 8)* shows how the slag inclusions have flowed during the forging of the rivet. After etching it could be seen that the structure was principally ferrite with some pearlite inclusions (perhaps 0.15% C).

Sample B3 *(Fig 9)*

This was obtained by cutting a section from one of the short (edge) sides of the piece. Slag inclusions will again be observed running parallel to the surface of the plate. Some 4/5 of the thickness of the sheet consists of a ferrite structure with some pearlite (perhaps 0.15% C) and about 1/5 of the thickness (the outer surface of the armour plate in fact) consists of a much finer-grain ferrite structure with conspicuous dark inclusions of pearlite (about 0.3% C).

Hardness Tests

Sample	Area	Readings	
B1	Upper edge of piece	(outer)	170
		(middle)	156
		(inside)	114
B2	Cross-section of rivet		197
B3	Side edge	(middle)	98

Specimen C *(Fig 10)*

Probably English about 1520.

This specimen was kindly analysed by Mr Birkhead (Chief Metallurgist, Mather and Platt Ltd).

Radiography was initially carried out but this yielded no positive information, except to show variations in thickness.

Microscopic examination of taper sections showed the plate to be composed of two layers, forge welded together. *(Fig 11)*. Slaggy material was visible at the interface. The two layers were of distinctly different chemical composition, the inner one being almost pure iron, and the outer one having the appearance of a medium carbon steel, with a micro-structure indicative of fast cooling after hot working (grain boundary ferrite in a matrix of very fine pearlite). Carbon diffusion had occurred across the interface.

Spectrographic analysis was carried out on the outer surface only, due to the difficulty of obtaining an acceptable 'burn' on the inner one. The results are given below:

Carbon	0.29%
Silicon	0.14%
Manganese	0.04%
Sulphur	0.061%
Phosphorus	0.071%

This is a wrought iron, unusually high in sulphur and carbon, although carbon contents of this level are not unknown in wrought iron, giving them 'steely' characteristics.

Tensile testing a sample of the plate gave an unsatisfactory result due to the difficulty of accurately measuring the original cross-sectional area.

Hardness tests carried out on the inner and outer skins indicated approximate tensile strengths of 27 and 30 tons per square inch respectively.

(NB: The tensile strength of a typical mild steel (0.25% C) would be about 30 tons per square inch).

Sample C1 *(Fig 11)*

About three quarters of the thickness of the plate consisted largely of a ferrite structure (about 0.1% C). The front surface was largely pearlite with some ferrite between the grains (about 0.5% C). The fairly sharp demarcation of this portion of the structure makes it more probable that it has been made by forge-welding two layers together, rather than by the surface carburisation of a sheet of wrought iron, (which would lead to a more diffuse grain-boundary).

Hardness Test *Area – Middle (in ferrite) – 84*

It was not possible to take a variety of hardness measurement on the section of Sample C because of its small thickness.

CONCLUSIONS

All three samples consist basically of wrought iron, which was shaped by hammering, and then surface-hardened.

Specimen A seems to have been carburised considerably on the front (0.2% C) surface, and to a lesser extent on the rear. Traces of laminations make it possible that a sheet of wrought iron might have been folded in two, hammered, and then carburised on both sides.

Specimen B has been carburised (0.3% C) on the front surface only, but the regularity probably makes it deliberate.

Specimen C shows such a marked difference between the high-carbon (0.5% C) front and the ferrite rear surfaces that it is possible that two sheets were welded together before shaping.

The case-hardening of small articles (files) is described by Theophilus, probably about 1100, and of suits of armour by Della Porta in 1589.[4]

Sword-blades were made by laminating strips of low-carbon and high-carbon iron[5] but I have not yet found any evidence for the application of this technique to armour.

Finally, it is conjectural that the development of the blast furnace in the sixteenth century caused different methods of making armour to be developed, but this problem needs much further study.

ACKNOWLEDGEMENTS

My thanks are due to Mr Russell Robinson of HM Tower of London, who very kindly supplied me with some scraps of armour.

REFERENCES

1 Oman, C. **The Art of War in the Middle Ages**, II, 59, and Pope S, **Bows and Arrows**, 1962.

2 Payne-Gallway. **The Crossbow**, 1903.

3 **Letters and Papers of Henry VIII**, vol. XIV, Pt. 2, p 782.

4 Theophilus. **De diversis artibus**. Bk 3, XVII–XIX (Trans. Dodwell p. 72) 1961.

Della Porta. **Natural Magick** (1589) facsimile reprint of translation, 1957, Bk 13.

5 J W Anstee. **Technology of ancient glass and metal.** Nature 1956, 178, 1430.

6 G W Henger. Bull. HMG. 1970, 4, 45–52.

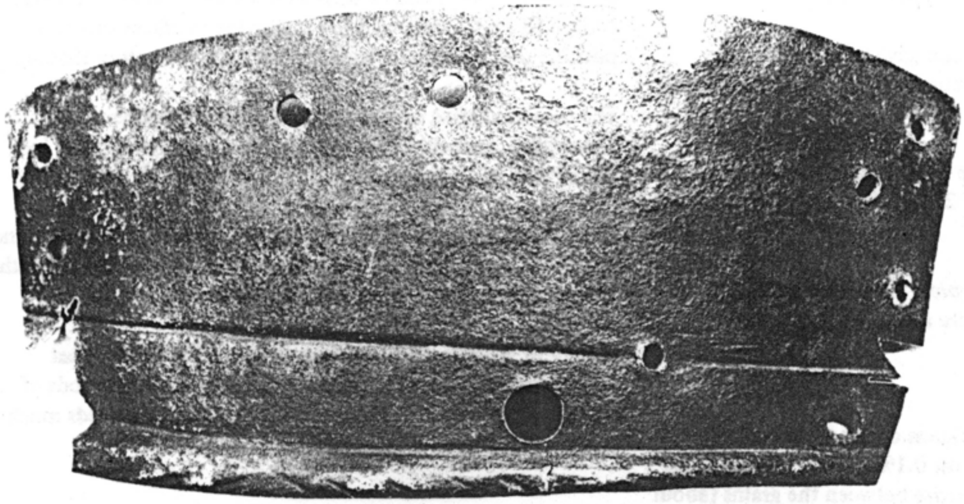


Figure 1 – Specimen A (approximately full size)

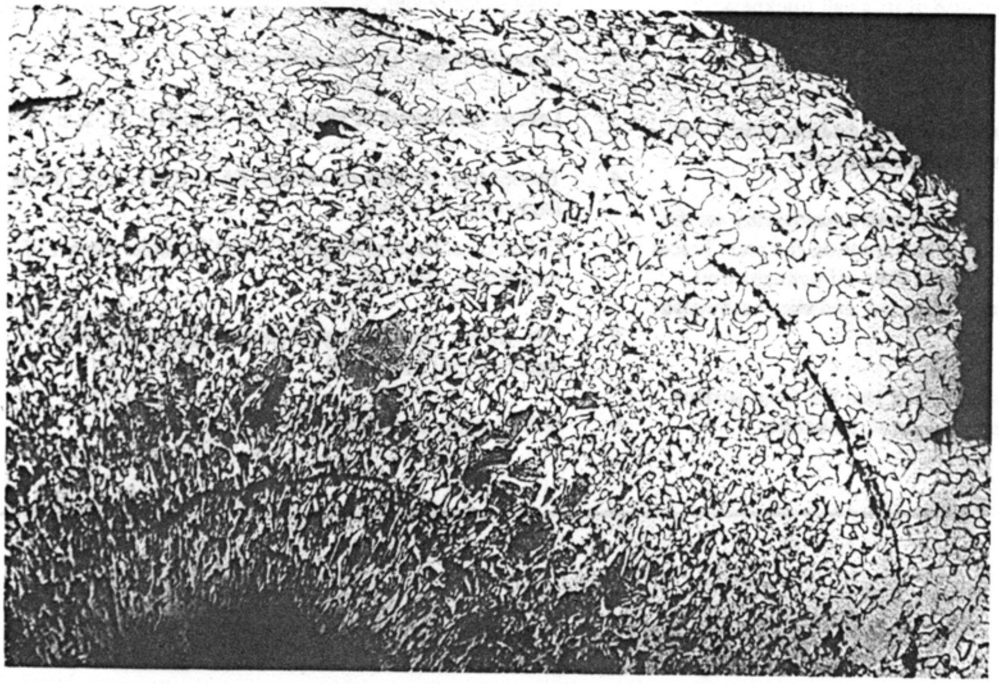


Figure 2 – Specimen A1 **X95**

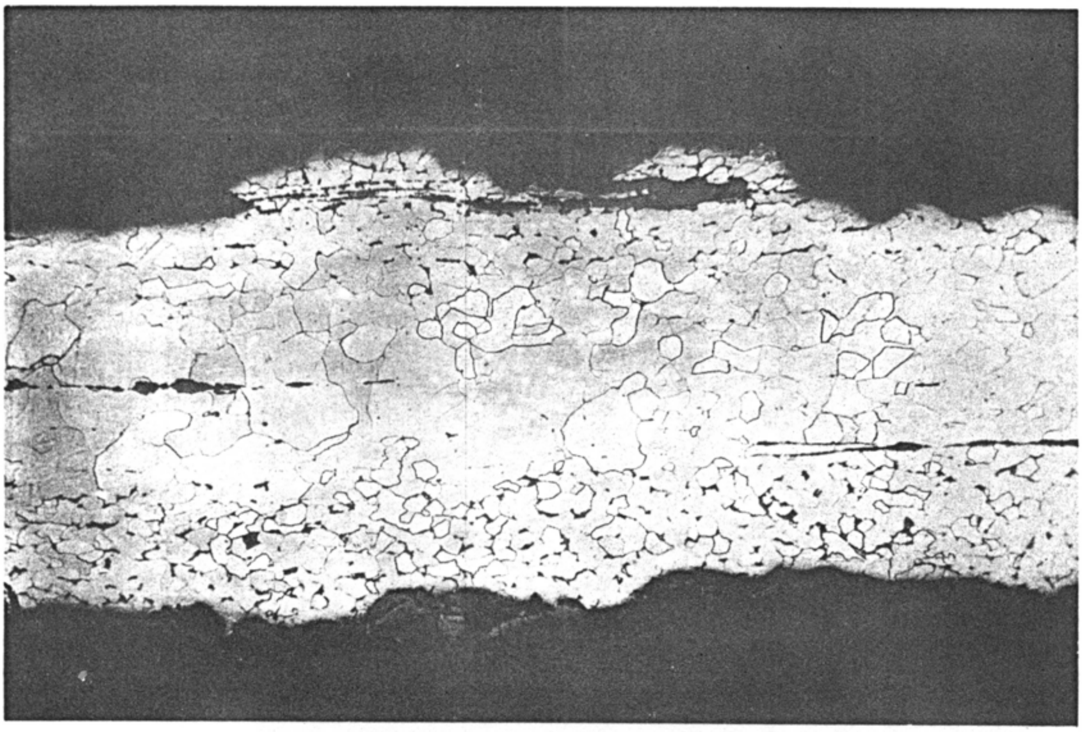


Figure 3 – Specimen A2 X95

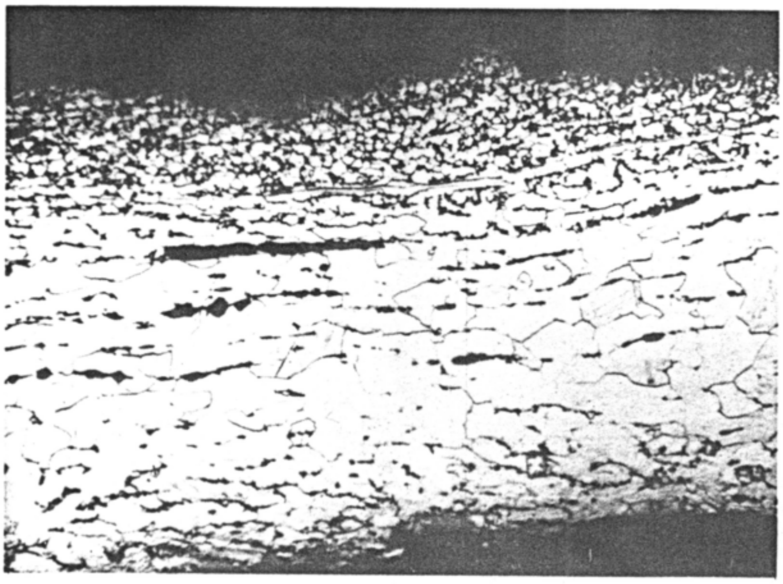


Figure 4 – Specimen A3 X140

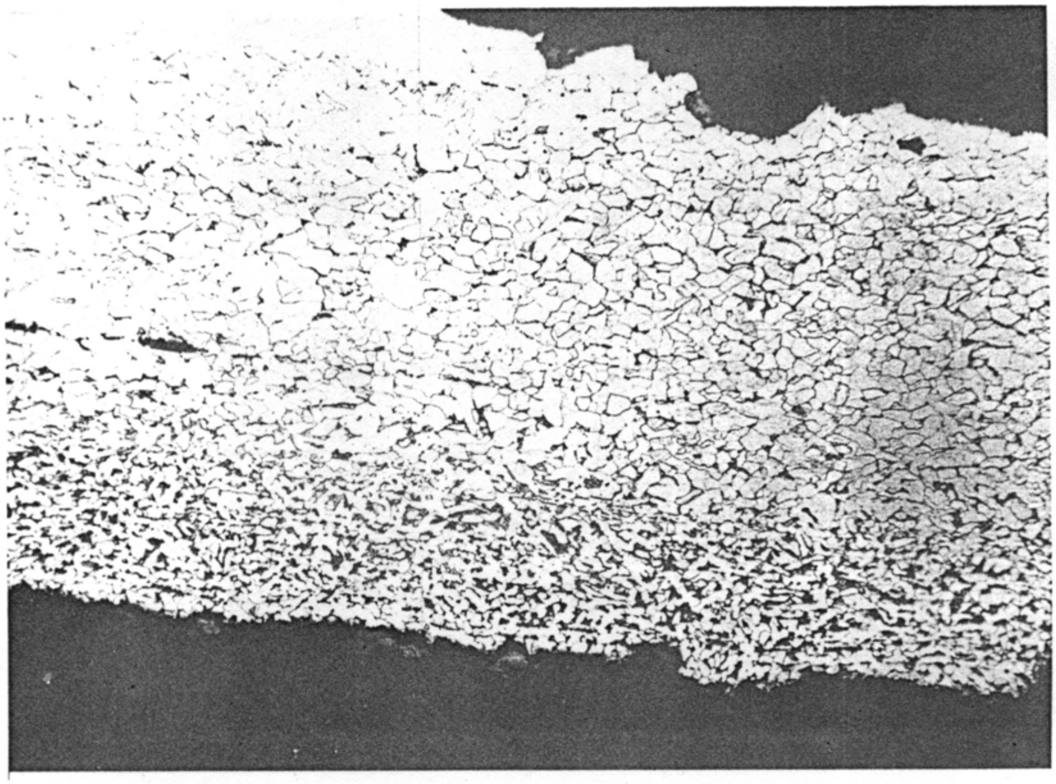


Figure 5 – Specimen A4 **X100**

Figure 6 – Specimen B1. **Full size**

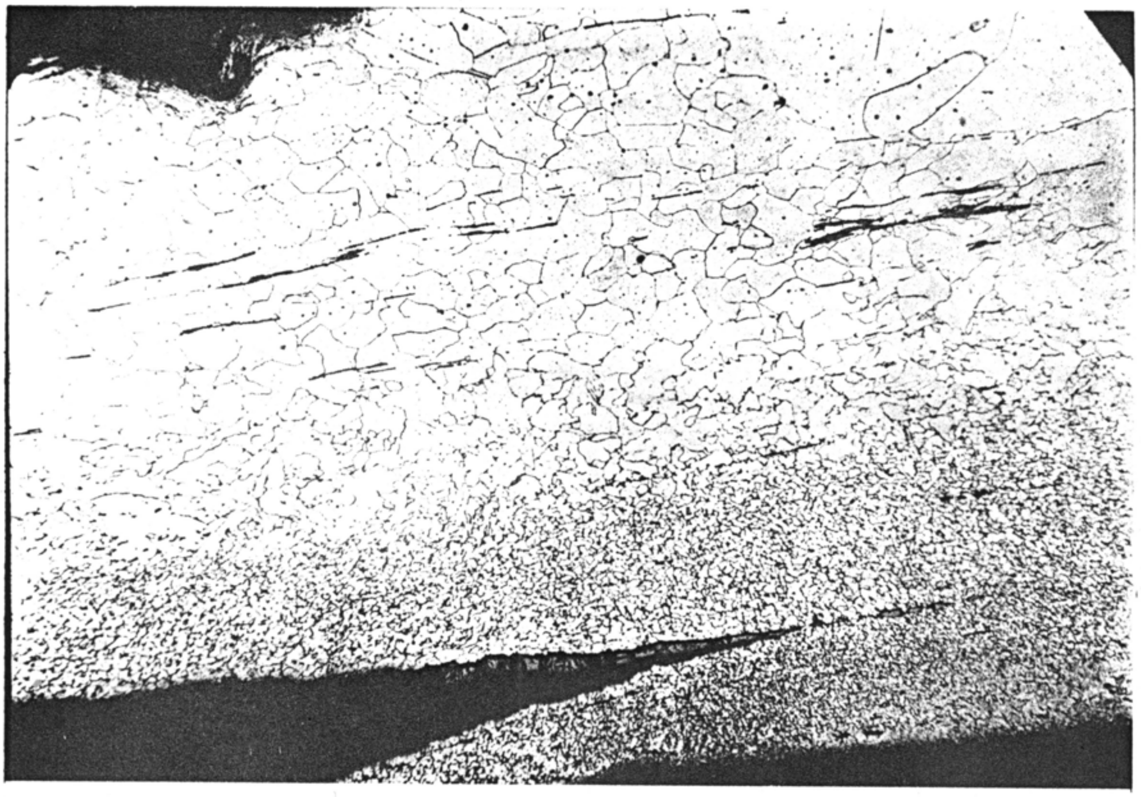


Figure 7 – Specimen B1. The outer surface is at the bottom. X100

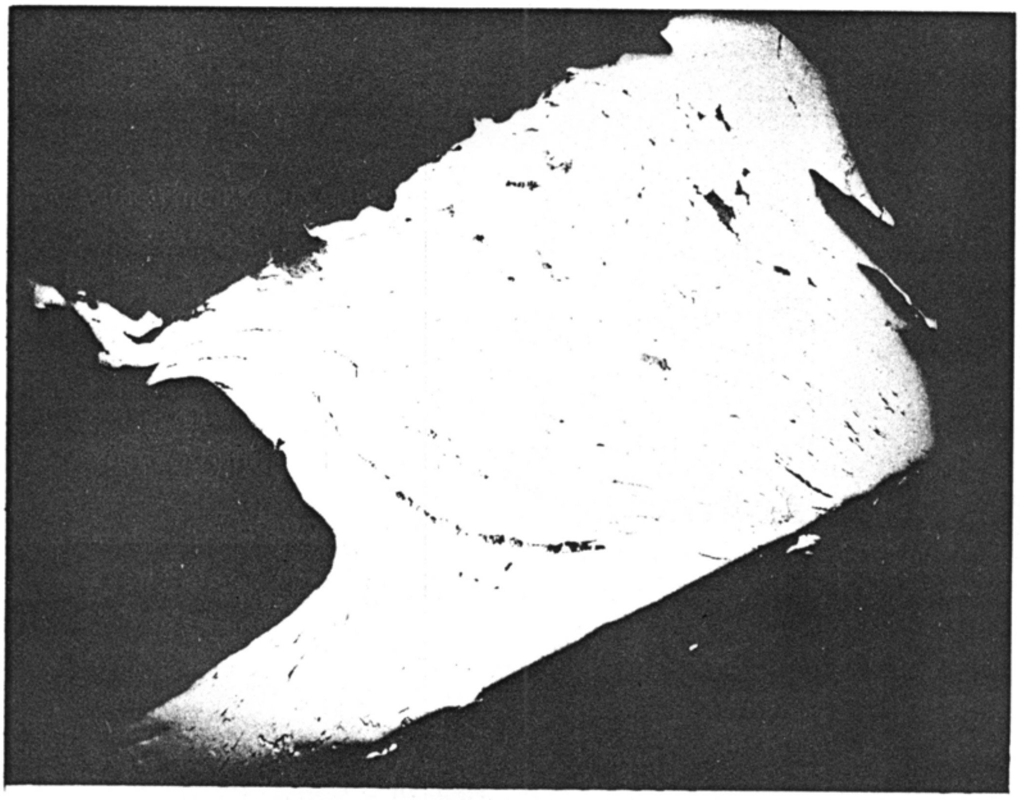


Figure 8
Cross-section of rivet in B2 (unetched)

X25

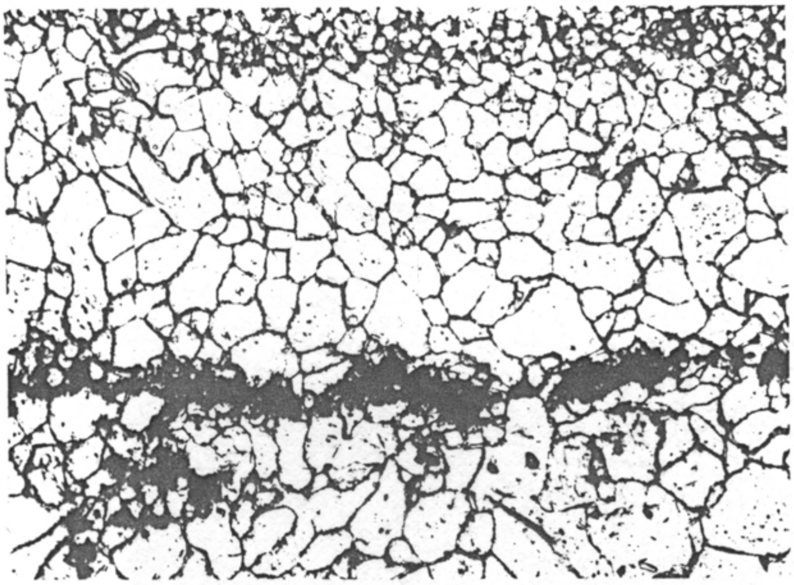


Figure 9 – Sample B3 X400

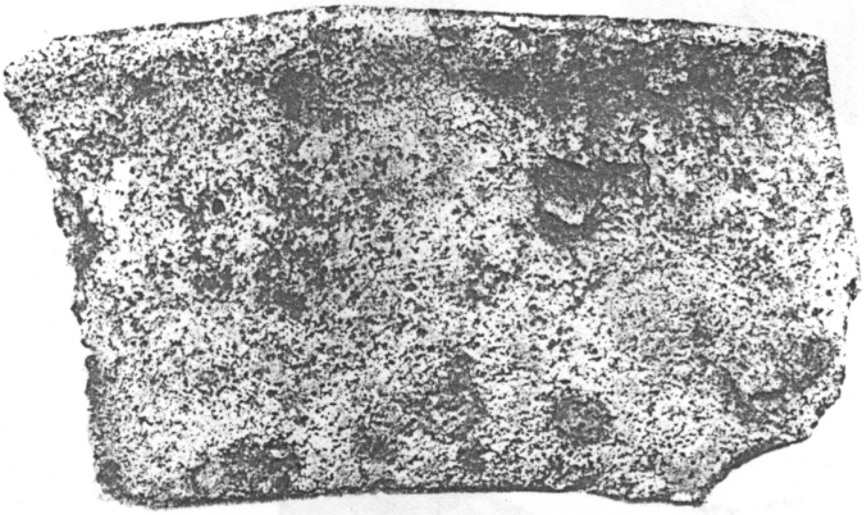


Figure 10 – Specimen C Full size

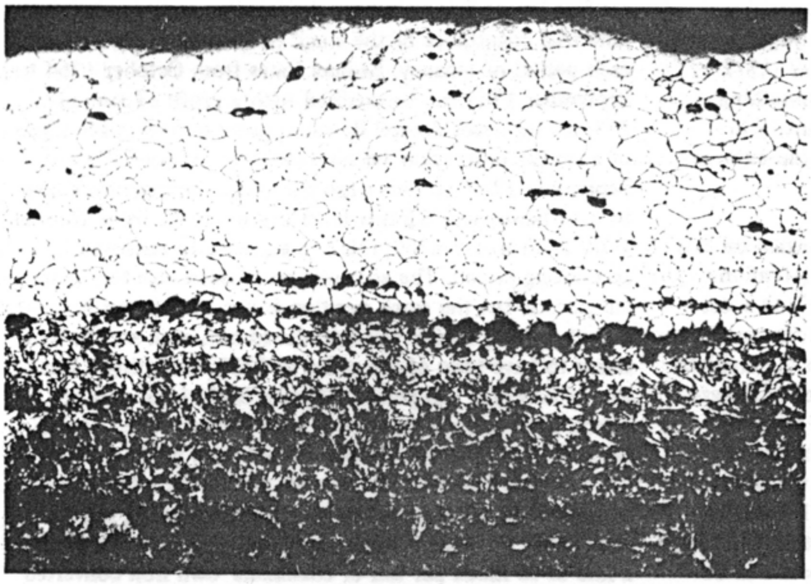


Figure 11 – Sample C1 (outer surface below) X80

Abbeydale steel

Crucible Steelmaking at Abbeydale. Sheffield City Museum Information Sheet No.2, 4pp, 1972 (available from the Museum for 6p including postage).

This leaflet gives a short but useful description of the operations of the crucible process of steelmaking as it would have been carried on at the Abbeydale Industrial Hamlet. It has some worthwhile illustrations, including a view of the interior of the Abbeydale crucible shop.

There is a brief introduction to the Abbeydale Shop, a description of crucible manufacture and an outline of the operations from charging to casting, together with suggested further reading.

To those to whom old Sheffield steelmaking is something of an enigma this leaflet is likely to prove of considerable interest since there are few easily accessible sources of such information.

An eighteenth century steelmaking enterprise: the Company of Cutlers in Hallamshire, 1759|1772

(Being an appraisal of Volumes 47 and 48 of the Cutlers' Company Archives)

K C Barraclough

R E Leader, in his **"History of the Sheffield Cutlers' Company"**, published in 1905, devoted about a page* to an enterprise undertaken by the Company from 1759–1772 to produce steel for sale "at a price if possible something below the common market and yet to bring a gain to the Company something more than equal to answer the expense of the trust and the interest of the capital".

This information was all that appeared to be available on this project but it was recently brought to the attention of the writer by Mr W G Ibberson (a Past Master Cutler and a descendant of the original Master Cutler involved in the enterprise) that a so-called "Furnace Book" existed in the archives of the Company. This proved to be a day-book of considerable interest; tantalisingly, it gave no records of sales. By courtesy of Mr R T Doncaster, present Senior Warden of the Company, however, it was discovered that there was still a further account book, which turned out to be a ledger. By careful study of both records a much clearer picture has been obtained; certain matters still require inspired guesses to be made, since the styles of book-keeping varied considerably from one period to another over the fourteen years (and were in all cases rather strange by modern practice). Nevertheless an insight can be gained into Sheffield steelmaking at a very early period from which no other detailed records are known to exist.

From this study it can now be attested that the Company's activities not only covered the production of blister steel by the Cementation Process but that cast steel was made by the Huntsman Process under their aegis, so that the reference in Leader's History to consultation with Huntsman may well have had some bearing on the matter. Furthermore, it appears fairly clear that the scale of operations on blister steel increased over the period and operating costs on two sizes of furnace can be evaluated with some degree of certainty.

It is, incidentally, just 200 years since the furnace ceased operations under the direct control of the Company so that it is felt to be most appropriate to publish these findings at this particular time.

In 1759 a cementation furnace was erected at a cost of £550. It was operated for the Company for three and a quarter years by Joseph Ibberson and under his care the venture made a profit of £212. Subsequently, at a meeting on 26th February 1763** it was decided that the furnace should henceforth be run on an annual change of management. George Greaves held control from January to August 1763 and made a profit of £71. The next tenant was Joseph Hancock and between October 1763 and September 1764 a debt of £38 was incurred, but it was during this period that the "New Furnace" was built and no steel appears to have been produced from November to April or even May. The position then becomes confused since it is not clear whether the profits or losses take true cognizance of the stock transferred at the end of each period of tenancy. Samuel Bates from October 1764 to September 1765 can be credited with a profit of around £75; his successor Joseph Bower appears to have made a loss of a similar proportion on his year from October 1765 to September 1766. At this stage the annual arrangements seem to have lapsed and William Birks was in charge from October 1766 to February 1769; this is a particularly confused accounting period. The accounts are divided into two separate periods but the stock position is not clear at the transfer; a further £100 capital was introduced but, even so, the loss seems to have been of the order of £200, indicating a true loss of £300 for this period. Thomas Beely took over in March 1769 and was in control until August 1772. Under his care, the venture succeeded in making a profit of £288 – the accounts are very clear for this period. As we shall see later he changed the mode of operating, becoming largely what could be called a "hire converter" – that is, charging at a rate of so much per ton of customers' own iron converted into steel, rather than by buying iron, converting it and selling the steel so made.

At this stage the accounts close and, as indicated by Leader, late in 1772, the furnace was rented by the firm which had become the major customer in Beely's time, Messrs Watson, Raynor and Turner.

If the present assessments of the profits and losses are correct, since the furnace was eventually sold in 1784 for £200 and since the day book refers to interest paid on an annual basis and in some cases to rent of furnace the overall venture must have been more or less self supporting and possibly not so unsuccessful as Leader made out; in fact, the reason for the adandonment of the project by the Company may not have been the financial one but merely that the experience of Beely had shown that hire operating was the way to make a profit and that this was against the original intention of the Company to produce steel for their members.

The main value of the accounts, however, at this point of time, is the insight they give into the technical details and costs of the processes operated. It is unfortunate that the standard of book-keeping varies so much in the detail given. Those relating to the activities under Ibberson and Greaves and finally under Beely are capable of more reasoned interpretation than the remainder but it is worth discussing each set in turn.

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* *Appendix I gives the text of pages 174-5 from Volume I*

** *The minutes of this meeting are given in full as Appendix II.*

JOSEPH IBBERSON – 1759-1762

The iron used was Swedish throughout, the most popular grades being "double-bullet" or "0-0" and "GL", their costs, delivered British port, being £22 and £21.10.0 respectively. Some cheaper material, "CDG" at £20.10.0 and "AOK" at £19.13.0 per ton, was also used. The material was all supplied via one or other of the Hull factors, Joseph Sykes or Samuel Wordsworth. Some of the earlier supplies came from London, the carriage from there to Hull, by sea, being 3/9d per ton. The iron then travelled from Hull to Tinsley along the canal at a cost of 10/0d per ton, the final road transport from the Canal Wharf at Tinsley to the furnace at Scotland Street in Sheffield costing 2/6d per ton.

Complete details of the iron shipments are not available, but the road transport charges from Tinsley over the period total £17.6.8, which indicates a total of around 139 tons. At the end of the period there was some 10 tons 4 cwt of iron still in stock; 128 tons 8 cwt of steel had been sold; a further ton remained in stock together with 4½ cwt of slit steel. Thus a figure of 129 tons of iron converted to give around 130 tons of blister steel is as near the mark as we shall reach.

Total costs for the period are £3391.5.9. The value of the stock remaining is given as follows:

	T c q lb	
Steel at the furnace	1. 0. 0. 10	£ 24.17. 6
Slit steel	4. 2. 0	£ 6. 1. 6
0-0 Iron @ £21.15.0	1.13. 3. 4	£ 36.14. 9
AOK Iron @ £19.13.0	8.11. 0. 4	£168. 0. 9
TOTAL		£235.14. 6

The working costs therefore for the production of 129–130 tons of steel were £3155.11.3, with the stated profit of £212.6.11 the selling price was £3367.18.2 which indicates a figure of just over £26 per ton (which tallies, since most of the sales were at 26/- to 27/- per cwt).

The total cost of the iron, plus carriage, was £3078.6.2; the cost of the iron used, therefore, was £2842.11.8 and we can build up a cost schedule as follows for the production of 129 tons of steel:

		Total Cost	Per Ton of Steel
Iron plus Carriage		£2842.11. 8	£22.04
Charcoal		£8. 3. 0	£0.06_3
Coal		£44.17. 6	£0.34_8
Steelmaking:			
Labour	£88.16.0		
Drinking	£3. 2.6		
Sundries	£4. 4.9		
Slitting	£6. 0.0	£102. 3. 3	£0.79_2
Repairs:			
Materials & Sundries	£31. 1.5		
2 New Pots	£15.16.9	£46.18. 2	£0.36_4
Expenses:			
Rent	£35. 8.0		
Taxes & Fees	£ 2. 3.2		
Letters	19.6		
Interest	£72. 7.0	£110.17. 8	£0.85_9
TOTAL COSTS		£3155.11. 3	£24.47
Profit		£212. 6.11	£1.65
SELLING VALUE		£3367.18. 2	£26.12

It is also interesting to try to assess the size of furnace. In the first 15 months of operation there are what appear to be 17 entries for "steel carrying out" (referring presumably to the discharging of the furnace after cementation). Unfortunately the accounts thereafter are less detailed but, since steel sales seem to have been reasonably constant, if we assume this is the usual rate of working, we are led to expect that there would have been a further 20 heats over the next 18 months, making 37 heats in all. There was, however, a furnace repair, necessitating the replacement of the two pots, so that we must assume some loss of production to, say, 35 heats. Since 130 tons of steel was produced, this indicates that the furnace capacity was probably of the order of 3½ to 3¾ tons, a relatively small furnace. Since the accounts mention provision of a "pair of potts" at one time we must assume that this was a two-chest furnace (although single chest furnaces were in operation at this period, as indicated in Gabriel Jars' Voyages Metallurgiques"). Assuming an internal cross section of around 21" x 24", the chests would then be about 6 to 7ft long; this would fit in with the formula derived by Le Play on his survey of Sheffield steelmaking some 80 years later.

GEORGE GREAVES – 1763

Whilst the accounts here are not as detailed as in the previous set, a reasonable assessment of production can be obtained. One significant feature is that the principle of hire conversion occurs in this period, a figure of 50/0d per ton being charged.

We can balance out the amount of iron used and the amount of steel produced to indicate that there was a loss of almost two tons on conversion as follows:

			T c q lb
IRON	Stock taken over		10. 6.3.18
	Purchases:	AOK	3. 0.0.23
		0-0 & Ⓛ	10. 4.3. 5
		0-0	20. 2.3.16
			43.14.3. 6

		T c q lb
	Residual stock: .	
	0-0 & Ⓛ	10. 4.3.15
	0-0	3.12.1. 6
	Loose iron	2.14
	Raw ends	1.2.17
		13.19.1.14
	Iron used	29.15.1.20
STEEL	Stock taken over	1. 4.0.10
	Residual stock	2. 6.3.12
	Excess stock produced	1. 2.3. 2
	Steel sold	26.13.2.12
	Steel produced *(from purchased iron)*	27.16.1.14
	Steel hire converted	6. 7.1. 8
	Total steel production	34. 3.2.22

As far as can be ascertained from the accounts, there were some nine heats produced in this period of eight months; if this were so, the tempo of operations and the furnace charges were both very similar to those in Ibberson's time.

JOSEPH HANCOCK, – 1763-1764

Here the story gets confused. Between August 23rd and November 16th 1763 around 15 tons of steel was sold. The next sale is prefixed "Steel from Darnall" and some 12½ tons of this was sold between April 13th and August 28th 1764. The day book is divided into "Old Steel Furnace" and "New Steel Furnace". In the former there are two entries for "ale paid at drawing" indicating two heats of cementation steel; in the latter, more surprisingly, are references to sieves, blue or "blew" pots, four pairs of cast iron ingots (presumably moulds), steel scraps, "coak" baskets, clay, the digging of a vault, "barrs for casting furnace", clay scuttles, a "trading" trough, two "pott" moulds, four "furnish" covers – in other words, all the accoutrements of a Huntsman type cast steel melting furnace. The implications are therefore that the new furnace was not a cementation furnace, particularly as there are subsequent payments for steel casting. But the new furnace only seems to have been lit on July 6th.

The ledger accounts are not much more helpful, other than in giving a list of stock transferred to Mr Bates:

	c q lb
Steel remaining in the steel furnace at Scotland	68. 1. 4
Ⓛ Steel from Darnall	7. 3. 3
Raw ends	2. 1.27
AOK iron and ditto misconverted	13. 2.24
Ⓛ GL and 0-0 iron from Darnall	118. 3.12
Cast Steel	3. 3. 7
Scraps	5. 0.21

The main ledger account is incomplete.

It seems from this that the original cementation furnace at Scotland Street went out of commission in the latter part of 1763 (incidentally leaving some 68 cwt in it, which confirms the previous assessment of the furnace size), that a cementation furnace at Darnall about which nothing is known supplied steel during 1764 (possibly on a hire working basis, since the Company's stock included some iron at Darnall) and that a crucible furnace was erected during this period.

SAMUEL BATES – 1764-1765

Here is further confusion. Steel scraps are being bought, together with clay, and there is a payment for steel casting. In addition, however, there is a payment for rent on the old furnace, together with repairs to it. Subsequently there would appear to be two heats made in the repaired furnace.

Steel sales amount to a total of 11½ tons in the period and all would appear to have been blister steel, since cast steel would have sold at a higher price. For iron purchases, however, we can only find cost and not weight or quality. If we assume a price of £22 per ton, then iron purchases are also of the order of 11½ tons. A balance of iron against steel then gives us the following picture:

Steel taken into stock	78 cwt
Steel remaining in stock	66 cwt
Steel sold	231 cwt
Steel produced	219 cwt
Iron taken into stock	131 cwt
Iron purchased	230 cwt
Iron remaining in stock	134 cwt
Iron consumed	227 cwt

But, significantly, if this is the consumption on two heats, the repairs to the furnace have increased its size to around 5½ tons capacity. There may, however, have been three heats, in which case the original figure fits.

JOSEPH BOWER – 1765-1766

There is evidence in this period of small scale activity on crucible melting, with purchases of scrap and clay. More significant still, are items in the sales for "Ingots run steel" at 19½ lb each. This is the first time we have any indication of the scale of operations. In the 1764 accounts, however, we find purchase of 4 furnish covers and 4 pairs of cast iron ingot (moulds). From this we can reasonably envisage a four hole furnace with 20 lb pots; Huntsman in 1767 was reported to have a six hole furnace with 13 lb pots by one of his

Swedish visitors, so the Cutlers' Company furnace was not a small one. Even so, it should have been capable of turning out 4 to 5 tons of cast steel per annum even using one melt per day for three days per week in each hole and there is no sign in the accounts of any such activity. Run steel sales in this particular period only amounted to some 12½ cwt at 50/0d per cwt as against 20½ tons of blister steel at 25/0d to 29/0d per cwt. If we exclude the small entries for run steel we can derive the following balance:

Steel taken into stock		66 cwt
Steel remaining in stock		25 cwt
Steel sold		410 cwt
Steel produced		369 cwt
Iron taken into stock		134 cwt
Iron purchased:		
Mr Swallow	£ 18.0.4	26 cwt
Mr Sykes	£448.5.0	406 cwt
Iron remaining in stock		204 cwt
Iron consumed		362 cwt

The iron purchased from Mr Swallow is of interest since it was presumably produced locally from local materials, possibly at Attercliffe Forge. In the computation of its weight it has been assumed that it would probably sell at £14/£15 per ton in such case. This is the first indication of any trials on iron other than Swedish.

During this period, there is evidence for only four cementation heats, in this case giving a furnace capacity of 4½ tons.

WILLIAM BIRKS – 1766-1769

For this period we know the iron purchases in detail, except for one item from Mrs Fell (which we assume to be similar to the Swallow purchase in the last account); the value of this purchase is £18.12.0 and probably again represents around 25-26 cwt.

There are no sales of run steel or cast steel and there are no items relevant to crucible steel melting in the day book, so it may be assumed that activities here have ceased. On the other hand, a major repair job appears to have been carried out on the cementation furnace in the early part of 1768 and the accounts are, in fact, separated at this point. Unfortunately there is no stock list at the end of the period and it does look, in fact, as though the whole was used. On the other hand, if we assume this, we get a very poor balance, there being a discrepancy of some 5 tons:

Steel taken into stock	27 cwt
Steel sold	1001 cwt
Steel produced	974 cwt
Iron taken into stock	204 cwt
Iron purchased	245 cwt
	615 cwt
Fell assumed to be	25 cwt
Iron consumed	1089 cwt

In addition, however, it is to be noted that hire conversion is again being practised, some 380 cwt being converted in this case. There is accordingly a total conversion of around 68 tons in this period. It is quite clear that there were five conversion heats after the repair to the furnace; in all probability there were seven heats before but this figure could be in error. Under the final regime of Beely we shall obtain clear evidence for a furnace charge of around 7½ tons; if the last five charges were of this size, this leaves 30 tons for the earlier operations and if there were 7 heats, this confirms the previous figure of around 4½ tons per heat.

One point of interest to be noted from the ledger is that there were fairly substantial purchases of parcels of blister steel in this period by Huntsman himself.

THOMAS BEELY – 1769-1772

There is no evidence in this time for the production of any cast steel; in fact, in December 1769 "ingot moulds" were sold, and this can be taken to mark the end of this particular episode.

The documentation with regard to the cementation furnace operations is most full, however, and we know quite definitely that 34 heats were run in this period. We also know that sales of steel amounting to 24¾ tons were effected; more importantly, however, almost ten times this amount of steel was produced on a hire converting basis.

There is no evidence of any stock carry over. Purchases of iron amounted to 26⅝ tons, all from Joseph Sykes, as against the production mentioned above.

Hire conversion for general customers is detailed but almost two thirds was for one particular customer, Messrs Watson, Raynor and Turner. The total production was as follows:

	T c q lb
Steel produced for sale	24.15.3.10
Steel for W R & T prior to 2.8.71	83.16.0. 0
Steel for W R & T after 2.8.71	87. 9.0. 0
Steel converted for other customers	64.10.0.24
TOTAL	260.11.0. 6

This clearly gives an average charge per cementation heat of

7.65 tons, which is confirmed by individual heat details for WR & T which vary from 6¾ to 8¾ tons (with one exception at 2½ tons, which may only have been a part charge). The hire conversion charge for WR & T was 30/0d per ton; other customers were asked to pay as much as 40/0d per ton on occasion.

At the same time, the accounts are sufficiently detailed to allow an assessment of the conversion costs to be made; these give a total of 25/6d per ton, so that this was a very reasonable line of business to pursue. It is of interest to compare the rates per ton on this larger furnace with the costs under Ibberson some dozen years or so earlier and also with those quoted by Le Play for a Sheffield 18 ton furnace some 70 years later:

	1759–1762 3½ Ton Furnace	1769–1772 7½ Ton Furnace	1842 18 Ton Furnace
Charcoal	0.063	0.073	0.118
Coal	0.348	0.462	0.322
Labour	0.792	0.298	0.281
Repairs	0.364	0.141	0.119
Expenses	0.859	0.300	0.267
TOTAL	£2.426 per ton	**£1.274 per ton**	**£1.107 per ton**

In retrospect, therefore, these accounts relate to what might be termed a reasonably successful venture as regards the production of blister steel by the cementation process. The original furnace, with a capacity of some 3½ tons, seems to have been enlarged twice, eventually having about double the capabilities of the original. This could have been done without a lot of trouble by enlarging the cross section of the chests and lengthening them somewhat but still containing them within the same cone (if it were the normal type of furnace – there may not have been a superimposed cone but merely two end chimneys, as illustrated by Broling for a Sheffield furnace in 1797, in which case enlargement was even simpler).

A feature which was not previously reported until these accounts were studied in detail was the excursion into crucible steel melting; this does not appear to have been a successful venture, having lasted for only about four years in a very desultory fashion and not producing more than a few tons for sale at the most. Without this exercise, the cementation steel project would probably have shown a very reasonable profit. It could have been that the scale was too large for the times; with an ingot of 19½ lb the cast steel furnace would appear to have been bigger than the Huntsman furnace of the same date.

The close of the venture occurred at a time when the introduction of hire converting on a major scale was proving to be a very sound commercial proposition and it is suggested that the subsequent lease of the furnace to the major customer for hire conversion indicated that the Cutlers' Company felt that the needs of their members were not being best served in this way and that they were best to opt out of such business.

The later history of the furnace is known only in outline; twelve years later it was sold to Peter Cadman. Some eighteen years later, he was reputed to be using 150 tons of Swedish iron per year; was he still using the same furnace? If so, he would have to have increased its size yet again to something of the order of 10–11 tons capacity, which is improbable without a rebuild.

The Author wishes to thank the Master Cutler, Mr Arnold Carr, for his kind permission to publish these findings and the extracts from the Minutes; he wishes to record his appreciation of the interest shown and the facilities provided by both Mr W G Ibberson and Mr R T Doncaster. He also acknowledges the interest and assistance of his wife in the examination of the records and of Miss Lynda Glover in the preparation of the manuscript.

APPENDIX I

EXTRACT FROM "HISTORY OF THE CUTLER'S COMPANY"

(R E Leader, 1905, Vol. I, pp 174–175)

At the beginning of the eighteenth century, Sheffield men were turning their attention to the possibility of making their own steel, instead of being dependent upon an outside supply; and encouraged by the success of Mr Samuel Shore and others, the Cutlers' Company seems to have contemplated embarking in this enterprise on its own account:–

1730 Oct 5	*Spent at a meeting at Horsfield's to consult about making steel – –*	*8 . 6*
Oct 17	*About the same affair with Wardens and others – – – – – –*	*2 . 6*
Nov 2	*Spent at Horsfields about the Steel Affair – – – – – –*	*6 . 6*
Nov 10	*At Watsons with Mr Wilson Mr Fell, and Mr Speight – – – – – –*	*4 . 0*
Nov 12	*At Horsfields with Wardens & Searchers about the Steel affair – –*	*4 . 6*
	At several other times about the Steel affair, spent – – – – –	*4 .10*
Jan 8	*At Watsons with Mr Fell, Mr Speight & Thomas Wilson – – – – –*	*6 .10*

There had previously been intimate association between the Company and the iron-forges, involving the desirability of keeping on good terms with the forgemen, as is shown by the annual entries of Christmas boxes paid to the workmen at Mr Fell's, Mr Shore's and Mr Speight's. And at a later date there is an interesting note, as to which one would gladly have further knowledge, bringing the Company into touch with that cast-steel invention of Huntsman's which was destined to have so vital an effect upon Sheffield's trade: "1750. By expenses at Jacob Roberts's about Huntsman's, the steel founder's, request, 4s."

It was not, however, until 1759 that the Company, undeterred by the luckless trading experiences already described, plunged into a steel-making adventure. The beginning was in the year of office of Thomas Ibberson. The capital consisted of £100, advanced by the Company, and £580 of borrowed money of which, however, £130 was shortly repaid. A furnace was taken in Scotland Street,* and the iron needed was obtained, partly from Mr Samuel Wordsworth, of London, but chiefly from Mr Joseph Sykes, of Hull. The best brands seem to have been preferred, for only one transaction in local iron is recorded – the purchase of a few tons from Mrs Fell, of Attercliffe Forge, in 1767.† The management was left in the hands of Mr Ibberson, from the "first heat" in November, 1759, to the beginning of 1762, the profits for the three-and-a-quarter years being, £212. 6s. 11d. Then the control was entrusted to a committee, consisting of the Master and Wardens for the time being, and four elected members. They began by laying down very precise regulations, the chief interest in which, now, consists in the declaration that the object was to supply steel at a price "if possible something below the common market, and yet to bring in a gain to the Company something more than equal to answer the expense of the trust, and the interest of the capital stock or fund." It was, in fact, a co-operative movement. Every "drawing" was to be exposed to sale equally and impartially to all persons willing to buy, no secret preference of picking or choice being given. Ready money was to be paid before removal of the steel, and the Master Cutler was to render an annual account.

It was a counsel of perfection impossible of attainment. The ready money plan, piously observed at first, was soon relaxed, and the attempt to change the management annually, with the Masters, was found unworkable. Mr George Greaves, the first of these, contrived, indeed, to make a profit of £71. 8s. 1¼d. in the eight months during which the furnace was under his control; but his successor, Joseph Hancock, showed a loss of £38. 4s. 1¼d., while, if Samuel Bates and Joseph Bower did not lose, they did not gain. The next Master, William Birks, had £160 additional capital placed at his disposal, and he kept the control for two-and-a-half years. Then Thomas Beely tried his hand for three years, and adopted the plan of delegating the conversion of steel to the firm of Watson, Raynor and Turner. But it was of no use. In August, 1772, the Company resolved to give up the steel furnace. It was accordingly let to the firm just named, at an annual rental of £20, and the Company found itself with this and some £365 remaining of the capital invested. Mr Samuel Bates had taken £10 as salary for his trouble; the succeeding Masters paid themselves £15 a year. We take final leave of the steel furnace in 1784, when the Company assigned it, for £200, to Mr Peter Cadman and Mr James Camm.

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* *In 1764 a new furnace was erected on land leased to the Company by Matthew Lambert for 800 years, at a ground rent of £1. 2s. 0½d. The locality is probably indicated by the name "Furnace Hill" and "Lambert Croft." The cost of liquor at the stone laying was £1 16s. 0d.*

† *Mr Hunter was of opinion that the Attercliffe forges, on whose site the works of Sanderson Brothers were afterwards erected, were the oldest in the neighbourhood – perhaps in the kingdom. They were established by the feudal lords of Hallamshire, at a time when no private persons could be found with sufficient capital for such an undertaking, and the neighbouring woods afforded ample supply of "cord wood," for charcoal burning and smelting.*

APPENDIX II

At a meeting of the Master Warden and Searchers and Assistants of the Company of Cutlers in Hallamshire at the Cutlers Hall in Sheffield the 26th day of February 1763.

FOR the most convenient Management of the Trade of making or converting of Iron into Steel in order to supply the Members of Company at as low and reasonable a price as may be, the following rules and orders were this day resolved and agreed upon.

THAT the Master Cutler and Wardens for the time being and four others to be annually elected by the Company at some public meeting shall be a Committee to direct, superintend and manage the said Steel Trade as well as in the buying in fit sorts of Iron for the purpose and keeping a regular supply thereof as for taking care that the conversion thereof done by some skillful and carefull Workman.

THAT the Committee for the present year shall be Mr George Greaves the Master and Mr Joseph Hancock, Mr John Patton the Wardens of the said Company and Mr William Webster the younger, Mr Samuel Bates, Mr John Turner and Mr William Birks.

THAT a skillfull and careful Agent or Workman shall from time to time as occasion shall require be appointed by the Committee or the major part of them to manage the furnace and the conversion of Iron into Steel and the same person or some proper person to assist him shall keep a book wherein

he or they shall enter the weight and quantity of Iron from time to time put into the furnace to be converted and the weight or quantity drawn out when the heat is over.

THAT the said Agent or Workman shall give notice to the said Committee of the time when he intends to draw the Steel out of the furnace.

THAT the steel upon every drawing shall be exposed to Sale equally and impartially to all persons that shall be willing to buy the same at such rates and prices as shall be from time to time directed under the hands of the Committee or the major part of them in which Sale no secret preference of picking or choice shall be given to any person whatsoever.

THAT the Steel shall be disposed of amongst the Members of the Corporation equally and impartially at the rate or price directed which rate or price shall if possible be something below the Common Market and yet to bring in a Gain to the Company something more than equal to answer the expenses of the Trust and the Interest of the Capital Stock or Fund appropriated or set apart to that end.

THAT the quantity to be sold to any person between Heat and Heat shall be limited and confined within such weight as shall be resolved on and directed by the major part of the said Committee and no more than such quantity. And for the quantity so taken no Credit shall be given but ready money shall be paid for it before it be taken away unless to a person who shall bring with him a note of consent in writing under the hands of four of the Committee at least to take away his quantity of steel on Credit for no more than one month and in such case the buyer before it is delivered by the Agent shall sign a promissory note in the form or to the effect following:

One month after date I promise to pay Mr A B Master of the Company of Cutlers or Order the Sum of .... for value received in .... of Steel sold and delivered to me this day Witness my hand the ....day of ....

provided nevertheless that no Credit shall be given to anyone for a second parcel until such time as he shall have paid all that stood on former Credit.

THAT the Master Cutler for the time being shall be Treasurer of this Fund to whom the Agent shall account as often as required so to do and pay over the money in his hands to such Treasurer and deliver to him all such notes as he shall from time to time have taken.

THAT the Master Cutler shall lay the books of Accounts of the said Trade and Fund every meeting day to be inspected by the rest of his Brothers of the Company and at the close of his year shall fairly make his annual account to the Company and pay over the balance in his hands to the succeeding Treasurer.

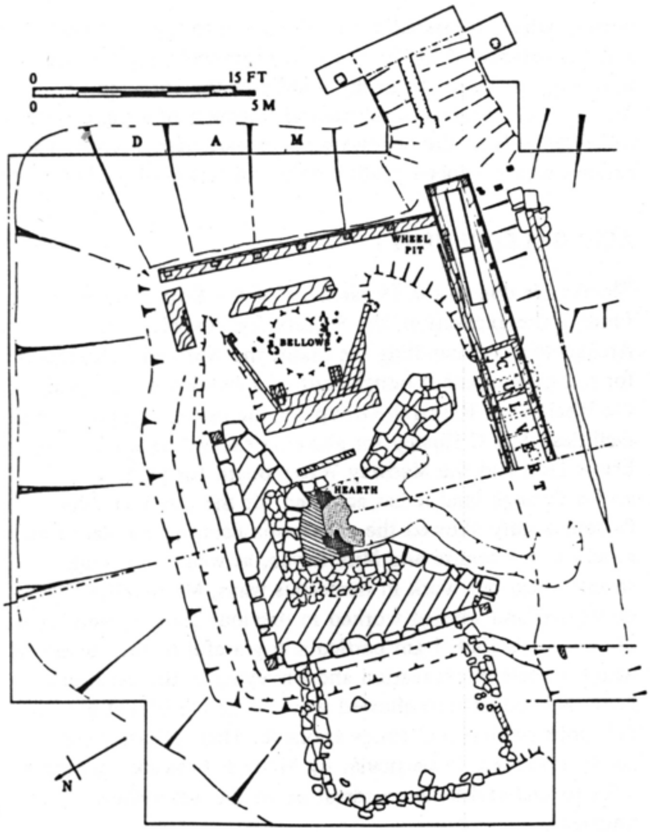
Excavations at Chingley Furnace *July–August 1972*

D W Crossley

The furnace, sited at (NGR) TQ/684327 is known from documentary references to have been in operation in 1565 and 1574, and to have been derelict in 1588. It is doubtful whether it was subsequently rebuilt. It smelted iron ore from the adjacent Furnace Pit Shaw with charcoal from local woodlands.

This year's excavation completed work begun in 1969-70, and the site will be flooded when the Bewl Dam is built.

The furnace complex formed a compact unit on the north-east side of the valley of the Bewl. A comparatively short dam had been built across the valley, and immediately downstream a platform had been cut into the sandstone of the valley side. On this was built the stone tower of the furnace, the bellows structure and, during the life of the site, a store building. A wheelpit and tailrace had been cut into the edge of the platform on its stream side. *(Plate 1 and Plan)*



The furnace was a stone tower, surviving near its centre to 4–5 ft above the platform. Its lowest course was well built with ashlar facings and a heavy rubble core, although the pillar between the bellows and casting arches was of poorer quality at this level. Although the footing course may in any case have been of better build than the stonework above, it was clear from the stratification of the north-west foundation trenches that all the upper surviving stone work of the furnace was a replacement.It was of poorer material, bulging in places, and with clay rather than rubble core.

The hearth had been rebuilt on several occasions, as is to be expected, and the substantial fragment which remained in place in the central square of the tower was built over a cavity or sump which was itself cut into the natural sandstone of the platform. A worthwhile section of the hearth lining was obtained. The sump was connected to drainage channels, one of which led to the porous filling above the tailrace, but the other was apparently incomplete. The furnace tower had been braced with timbers, and fragments of vertical posts were in place at three of the corners.

The bellows area was of great interest, giving as complete an indication of its equipment as has yet been seen in this country. The bellows were probably within a building between the dam and the south-east of the furnace: a substantial sleeper beam was in place along the south-east edge of the excavated platform, marking the fringe of the dam, and the latter was revetted by horizontal edge-set planks set behind vertical timbers which could support a roof spanning over to the furnace, above the blowing arch. Within this area were the base-frame and pivots for two sets of bellows, whose boards were apparently raised by cams on the wheel shaft; these presumably fell under their own weight, no doubt assisted by weights at their extreme ends. A substantial fragment of the shaft was approximately in place, where it had dropped after having its extremities, with their bearing surfaces, chopped off. The cam holes were intact, although the cams themselves had been removed: each set of bellows would operate 3 times per revolution of the shaft, thus giving a draught six times per turn of the waterwheel. The massive wooden bearing block for the north-east end of the shaft survived, although its bearing had been removed.

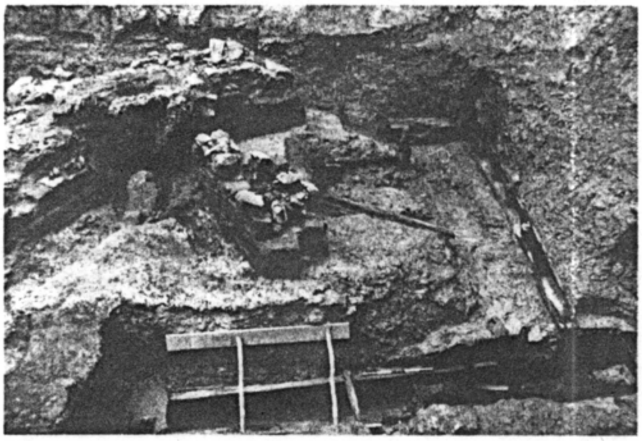


Plate 1

At the south-west end of the shaft lay a substantial fragment

(Plate 1) of an over-shot waterwheel in a timber wheel pit, and, beyond it, stonework on which a shaft bearing would have stood. The wheel, exactly eleven feet in diameter, was twelve inches wide between 1-1½ inch thick sideboards, with well shaped curved bucket boards nailed to the sides and strengthened by dowels against their backs. This was not the first wheel to be used, as fragments of straight bucket-boards lay in the lower silt of the wheelpit. The wheelpit had a plank floor, pegged to cross-sleepers, and the frame of the pit was built using mortice-and-tenon joints. Several of its uprights had continued above the level of the upper rails of the pit, to support the penstock. The latter had been fed through a trench cut in the top of the dam, which was sectioned to show the beam slot on which a wooden shoot or flash must have been built. The clean material in this trench suggested deliberate filling, probably for a higher penstock.

The tailrace was also of timber, culverted with planks. This was notable for being set close to the casting arch of the furnace, running beneath the casting floor, whose sand lay on a thick deposit of slag which had been tipped over the culvert. This layout allowed a compact platform, as well as permitting a shorter wheel shaft than would have been necessary had water channels been taken, open, well clear of the casting floor. The south-west side of the tailrace timber was set into the original alluvium of the valley.

The original unit had been completed by the excavation of a neatly cut drain trench along the north-east and north-west sides. This had tapped springs along the foot of the scarped hillside, taking water to the point in the tailrace where culvert boarding ended. It seemed that a good deal of the water collected must also have seeped across the bellows area to the wheelpit, particularly as the drain, although filled with a porous ash and covered by boards, seems to have been forgotten and covered by uneven material, including clay, associated with the rebuilding of the furnace walls. A later addition was a poorly-built structure, perhaps a storehouse, against the north-west side of the furnace, its walls standing over the foundation trench associated with the poor-quality rebuilding of the main structure.

Thus the elements of a charcoal-period furnace were present; indeed the only feature missing was the charging bridge, which need have been no more than planks from a shelf at the top of the dug-out scarp to the furnace top.

The finds confirmed the documentary dating. There was no pottery which suggested use of the site into the 17th century, and the balance of the local earthenware and imported stoneware suggested activity in the middle of the 16th century. Among other objects, a substantial fragment of a pig of iron and fragments of the bellows were of particular interest. The bellows area produced prolific nails and scraps of leather.

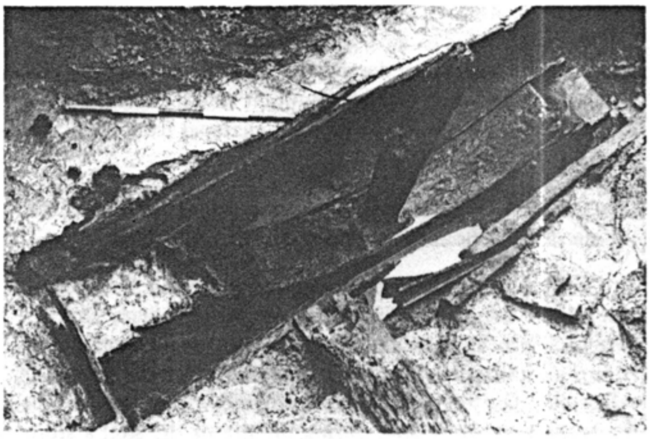


Plate 2

ACKNOWLEDGEMENTS

Thanks are due to the Department of the Environment for funding the excavation, the Society for Post-Medieval Archaeology for handling the grant, the Nuffield Foundation for use of equipment bought out of a fieldwork grant and the Weald Iron Research Group for the use of equipment and facilities; Mrs C Hussey for allowing excavation on Scotney Estate land and the Medway Water Board for permitting access through land it has acquired for the reservoir. Mrs Parsons kindly allowed the excavation camp to be placed on a field in her tenure and Miss Bevan, as well as allowing access, aided our work in numerous ways, Mr and Mrs Veitch on whose land we had worked in previous seasons, were again of great assistance. I am particularly grateful to the volunteers whose efforts in excavation and surveying in the usual unfavourable conditions allowed work to be completed within the limits of time and funds available. Their efforts were amply rewarded, in particular by Mr W F Beswick's generous offer to undertake the conservation of the waterwheel fragment.

8th Annual Conference, 15|17 September 1972, CARDIFF

The eighth annual Historical Metallurgy Group autumn conference took place over the weekend of 15/17th September 1972 at Cardiff. Almost seventy members and their guests took part and were accommodated in Aberdare Hall where both lectures and meals were arranged.

After dinner on the Friday evening **Dr Norman Swindells** and **Dr R F Tylecote**, chairman and president respectively, welcomed those taking part and paid tribute to the inspiration, work and nevertobe forgotten memory of the man to whom the HMG owes so much, **Reg Morton**.

Then steel-worker, **Tom Grey-Davies** talked of the River Wye, in general and its historical and metallurgical associations. He was followed by **Professor Gordon Tucker**, professionally an electrical engineer and a man with a deep regard and respect for all aspects of industrial history who dealt in some depth with the wire drawing activities which flourished on the banks of the Angidy River tributary and at Tintern for about three and a half centuries from 1566.

On a very autumnal Saturday with fitful sunshine, occasional drizzle and an end-of-the-summer chill, two coaches took conference members away from the rush and bustle of weekend Cardiff into the erstwhile industrial valleys of east Wales and the lower reaches of the Wye. The route followed and some idea of the sites visited, can best be gauged from the accompanying description written for the HMG Bulletin by the chief organiser of the conference, **D Morgan Rees** from the Department of Industry, National Museum of Wales, but it should be placed on record that as always the organisation was immaculate and Aberdare Hall was reached again after a thoroughly satisfying if fatiguing day.

Members were taken in two coaches under the guidance of T G Grey-Davies and Martin Headworth, and Richard Keen and D Morgan Rees respectively.

The coaches travelled north from Aberdare Hall for a short distance to Eastern Avenue and then eastwards until they joined M4 at Forge Lane, a name derived from the Bassaleg Forge which was operative during the 17th-18th centuries. The coaches left M4 at the Risca intersection and then travelled northwards along the valley of the Ebbw River.

During the first part of the journey after leaving Rogerstone, where there was an iron forge during the 18th century, and its modern aluminium works, the route on the way to Risca ran close to the lower reaches of the Monmouthshire Canal, still recognisable as such. To the immediate south of Risca and to the west of the road stood the site of the former Pontymister Steelworks, which is now occupied by a firm of scrap merchants.

The valley of the Ebbw from Risca to Crumlin and to its head was one of the 'eastern' coal-mining valleys of Monmouthshire and the members were taken through typical South Wales valleys' mining towns such as Cross Keys, Cwmcarn and Newbridge. The town of Abercarn has an interesting industrial history. In 1783 a local forge was taking an appreciable amount of pig iron from Hirwaun Ironworks. The forge is mentioned in Archdeacon William Coxe's **Tour through Monmouthshire**, 1801. In 1845 a tinplate works was erected and in 1893 the plant comprised 8 mills; it was acquired by Richard Thomas & Co Ltd., in 1914.

The mining town of Crumlin became famous for the Viaduct which was built to span the valley and to connect the Newport, Abergavenny and Hereford Railway with the Taff Vale Railway Extension and thereby open up new mining areas and provide communication with Swansea and Merthyr. The viaduct was opened in 1856 and dismantled during June and July 1966.

The coaches travelled eastwards from Crumlin, passing the colliery near Hafod-yr-Ynys on the way to the Trosnant Furnace site in Cwm-y-Glyn. This was one of the furnaces in which Richard Hanbury was interested towards the end of the 16th century. The site appears to have had a long association with ironmaking because it was the subject of a lease drawn up in 1812, between Capel Hanbury Leigh, the original owner, and Watkin George, a partner in the Ynysfach Ironworks, Merthyr Tydfil owned by the Crawshays. A number of coloured drawings attached to the lease show the Trosnant location, its watercourse and the position of the waterwheel, the Blaendare Furnaces, immediately to the south of Trsonant, and the sites of the four forges and plating mill in Pontypool. Members listened to a short talk on the history of this site and had an opportunity of examining the furnace remains and of looking at the old buildings nearby.

During the journey along the valley of Afon Lwyd the coaches went through Pontnewynydd where the company of Partridge Jones and John Paton Ltd operated a steel sheet works for a fairly long period. Above the valley to the west there were 19th century ironworks at Abersychan and Varteg *(Y Farteg)*. At the head of the valley members visited the site of the Blaenavon Ironworks, established in 1789, and in production until 1860. After a short talk on the history of the works, and on its future as an Industrial Monument under the guardianship of the Department of the Environment, the site was explored thoroughly.

There followed a visit to Forgeside where the Blaenavon Works was further developed. This site is now occupied by Doncaster Blaenavon Ltd. The local management was kind enough to offer welcome hospitality and to arrange for the Works to be visited. It was also possible to see the obelisk erected by the Newport Metallurgical Society and unveiled in 1962, to commemorate the achievement of Sidney Gilchrist Thomas.

The journey from Blaenavon to Abergavenny was broken at Garnddyris *(bramble cairn)* the location of a forge established in 1818, one which was worked in conjunction with Blaenavon Ironworks. A short talk was given by a member of the industrial archaeology group, of the Abergavenny Steam Society, which is excavating on the forge site. A number of interesting features were looked at, but no one succeeded in interpreting any of them fully, possibly because the work of excavation was incomplete. In remembering this particular visit it is pleasing to be able to say that the young men concerned have come across documentary evidence which has assisted them considerably in placing the various features which made up the forge. During the descent towards Abergavenny the coaches passed the point where the tramroad from Garnddyris dropped down to the warehouse on the Brecon and Abergavenny Canal at Llanfoist.

From Abergavenny the coaches travelled to Monmouth and thence down the Wye Valley, passing the site of the Coed Ithel furnace the subject of a talk by Dr Tylecote, to Tintern. From Tintern they ran westwards up the valley of Angidy River to Pont y Saeson *(Englishmen's Bridge)*. During the outward journey and the return journey to Tintern Professor Tucker, by changing coaches, was able to point out the various features of this old, ironmaking, iron forging and wire drawing valley. Under his guidance the ponds which supplied water power, were visited and some time was spent on the sites of the original Upper Forge and the Upper Wireworks, due note being taken of the leat which served this wireworks. During the period subsequently spent at Tintern there was an opportunity to see the Lower Pond and the present-day building on the site of the original Abbey or Lower Forge.

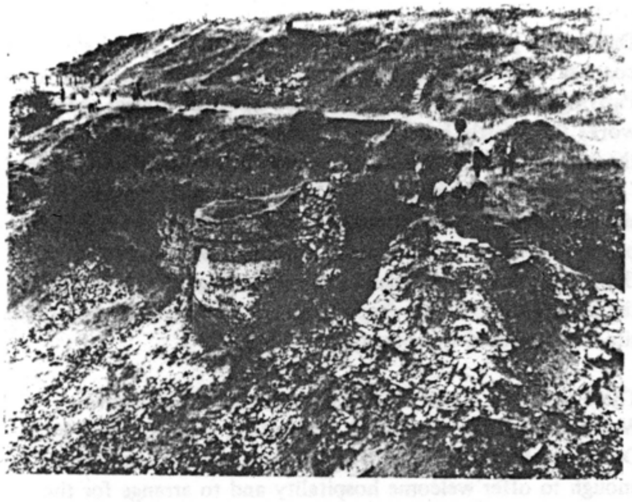


Plate 1 – The remains (to be taken into guardianship by the Department of the Environment) of furnaces at the Blaenavon Ironworks.

By permission of the management of Llanwern Steel Works (arranged by Martin Headworth) the coaches travelled through the Spencer Works on their return to Cardiff.

After Dinner Dr Tylecote spoke about the history of and subsequent excavations at the Coed Ithel furnace on the bank of the Wye a few miles above Tintern which had revealed so much about 16th/17th century charcoal iron making in the area.

He was followed by a series of mini-lectures, usually illustrated, as indeed all those throughout the weekend were, by colour slides, including contributions by **Harry Paar** (additional documentary evidence on iron making activities in the Wye Valley during the 17th century) **Ian Standing** (Forest of Dean iron mines), **Dr H G Bachmann** (from Frankfort) who spoke about copper slags, **B M Allen** (the History of the Soldering Iron) and **Bernard Hardman** (Evidence of Early Iron Making Sites).

The evening ended with a memorable showing of a film on the traditional Japanese Tatara iron making process.

On Sunday morning **George Boon** (Department of Archaeology, National Museum of Wales) and **D Morgan Rees**, spoke about non-ferrous metal mining of the Roman era in Britain in general, and Wales in particular, and the remains of the iron industry in south east Wales.

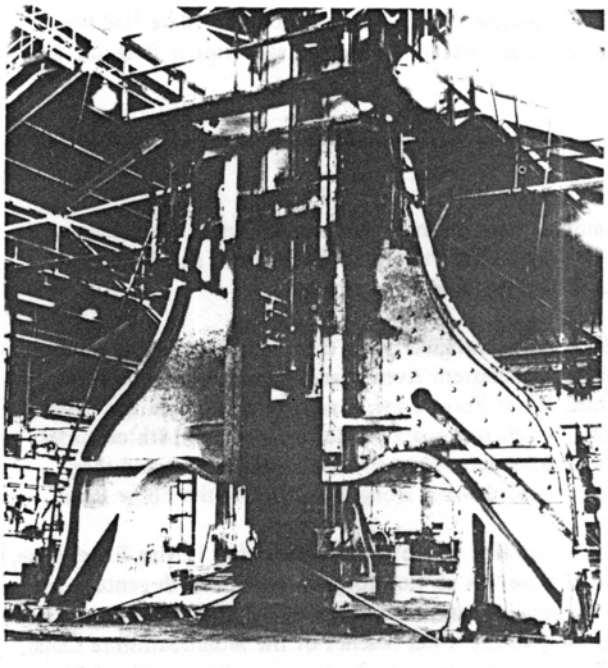


Plate 2 – The seven ton steam forging hammer at Doncaster Blaenavon Limited.

Book review and Abstracts

Arthur Raistrick: Industrial Archaeology. 15 cm x 23.5 cm. *London: Eyre Methuen.* 1972. pp xiii + 314, 51 plates, 21 drawings and diagrams, £5.50.

Dr Raistrick has used this book to express his concern for the reputation and future direction of his topic. It becomes clear from several passages that he is unhappy about aspects which have worried others in or on the fringes of the field, this reviewer included. He doubts the wisdom of setting Industrial Archaeology apart from archaeology as a whole. Why, he wonders, should fieldwork as a method in industrial history differ in the Industrial Revolution period from any other, prehistoric, Roman or medieval? Disciplined observation and recording are universally applicable, and if the archaeologist involved with medieval industry is expected to employ the range of skills seen in work on habitation or military sites of the period, why, when time moves on to the mid-18th century and beyond, should standards relax? It is not enough to say that the more recent sites involve different skills, often taken to mean a balance away from excavation, towards field recording. In the first place many of the later sites are stratified, require excavation, and do not receive it; conversely, it is one of the most frequently expressed and dangerous fallacies that the archaeology of the earlier periods is synonymous with excavation. Here fieldwork and observation are of the essence, and form the basis without which excavation is frequently premature. A second basic point at which the author hints but to which he should have given more attention is the tendency of those who are blinkered enough to call themselves Industrial Archaeologists, as if they practised some subject in its own right, to pay little heed to the context of the sites they explore. The material remains must be seen as complementing the written record, elucidating and amplifying such accounts or correspondence as fall short of giving a full picture. How often do regional studies, and journal articles on industrial sites fail to show how their subjects fit in. What respect can their authors' views achieve until they do?

Dr Raistrick is right to air these problems, uncomfortable reading though some may find them. The question really is whether the format of the book fits the intention. For it is a compromise between a review of work done in the last twenty years and the direction in which it appears to be going, and a general survey of industrial history on the ground. The first should more appropriately be published as cheaply as possible, as a paperback polemic. The present problems could and one hopes will disappear in a decade, and much of the need for this book with them. A hard-back volume costing £5.50 is certainly not their place, particularly as, in addition, it contains ephemera out of date even when published, particularly in Part 3 of the book, 'The Place of Museums in Industrial Archaeology'. In the second apparent intention, the volume definitely falls short. Some sections are woefully inadequate: can railways and canals be covered in three and a half pages, or railways in two and a half, to any purpose? And there is a remarkable tendency to split consideration of topics between two parts of the book, the first entitled "The Materials and Field Evidence of Industrial Archaeology", the second 'A view of Industrial Archaeology in Britain'.

Apart from these basic problems, there are too many small errors. Several topics of which this reviewer has some experience have examples of names mis-spelt or facts confused. Some may be the result of hasty proof-reading, but there are doubts about the author's original references.

All in all, this is a necessary book, but in its published form, an unsatisfactory one, and cannot be recommended at this price, which is quite unrealistic in the light of its largely, and, hopefully, temporary purpose.

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Abstracts

GENERAL

Anon. ***Tracing trade routes by analyzing ancient artifacts of copper. Chemistry,*** **41, No.8, 8-9 (1968).**

Describes analyses of native copper mixed in various parts of the world undertaken by Paul Fields and Arnold Friedman of the Argonne National Laboratory, and Eiler L Hendrickson and Richard W Ramette of Carelton College, in the hope of defining geographic differences.

Copper from each region should contain impurities of different trace metals in different amounts. Then by applying analytical techniques to copper artifacts, perhaps location where the copper was mined could be determined. Such information is useful to archaeologists and anthropologists because trade routes used by ancient peoples can be traced.

Copper from our hemisphere seems to contain more silver than mercury. European copper is the reverse. Further, in the Americas, the amount of impurities decreases as mining locations are increasingly southerly.

Both neutron activation analysis and spark source mass spectrometry are used.

Damascus steel in the light of metallographic examination.
J Piaskowski Wiadomosci Hutnicze, 1967, 22 (7-8), 225-230. (In Pol.). A summary of metallographic examinations of Damascus steel made by Pearson (1795), Mushet (1804), Faraday (1819), Breant (1823), Karsten (1827), Henry (1852), Ilimov (1841), de Luynes (1844), Bouis (1861), Belaiew (1911), Joly (1914), Zschokke (1924), Maryon (1960) and Panseri (1962). The author concludes that there were two kinds of Damascus steel: low carbon steel (0.5% C) and high carbon steel (1.5% C).

Early Damascus steel from the point of view of modern metallography. J Piaskowski. Kwart. Historii Nauki i Techniki, 1966, **11**, (3), 241-247. (In Pol). The production and properties of both kinds of Damascus steel are explained on the basis of the Fe-C diagram.

The characteristics of the composition and the technology of iron objects as criteria of culture and chronology. J Piaskowski. Wiadomosci Archeol. 1969, **34**, (3-4), 332-354. (In Pol.). Composition and technology could be criteria of "archaeological culture". Frequency distributions show that they are generally characteristic of particular archaeological cultures on the territory of Poland. The problem of the amount of data is discussed.

O Werner. On the occurrence of zinc and brass in prehistoric and medieval times. Erzmetall, 1970, **23** (6), 259-308. (In Ger.). After reviewing the information on zinc and brass the author notes that before zinc was known as such in the 16th century in the Far East, the zinc content of brasses was rarely above 30%. He concludes that this is the limit of zinc obtainable by the calamine process and supports this conclusion by three experiments made at 1000°C. The first of these showed the heating of a boat containing metallic zinc together with one containing copper, in a graphite tube closed with a quartz fibre bung at one end, converted the copper to a brass containing 40-65% Zn. The second experiment showed that the reduction of zinc oxide with charcoal in contact with a boat containing metallic copper could not raise the zinc content of the copper above 28%. In the third experiment he placed a boat containing a 42% Zn brass in contact with the ZnO and charcoal mixture and found that after 2 hours the zinc content of the brass was reduced to 28%.

From these experiments he concludes that the equilibrium between copper and zinc vapour formed by the reduction of ZnO is such under these conditions that a brass of more than 28% Zn cannot be obtained. Only when the zinc vapour pressure is of such a level as that of molten zinc can brasses of higher zinc content be formed. Thus, he concludes that all brasses containing more than about 30% Zn alleged to belong to a period before the 16th century are fakes. No doubt some are, but there are isolated cases of zinc contents above this such as in some well-stratified examples in Roman Britain, and of course there are one or two cases of zinc metal being found in a classical context such as in the Athenian Agora in Roman times. One wonders whether the experiments should have been taken to a higher temperature when the equilibrium might have moved in favour of higher zinc contents. Furthermore, it is quite possible for the calamine process to have produced some metallic zinc at the cool end of the crucible or retort in the presence of excessive carbon,and this could have been put back into the brass to enhance the zinc content.

Admittedly the bulk of the evidence is very much in favour of his conclusion but one would think that the isolated case of a zinc content greater than 28% could be explained just as well be a slight variation from his experimental conditions as by fraud.

BRITISH ISLES

T G Grey-Davies, Why Tintern? *Foundry Trad J.*, 1971, **131**, (2871/72), 843-844. Shortage of wire for making wool-cards led Elizabeth I to establish the Society of the Mineral and Battery Works. William Humphery, Assay Master of the Royal Mint was entrusted with the task of setting up suitable works. Building commenced at 1566 at Tintern, six water wheels being installed to provide power. Christopher Schutz, a native of Annaberg, Saxony, was engaged to supervise operations, but he knew nothing about iron production and the works was soon in trouble. Another German, Barnes Keysar, was appointed supervisor, and while awaiting his arrival, and the delivery of new machinery, Schutz smelted copper and zinc, and so established the modern brass foundry industry. Before iron wire was successfully produced, yet another German, Corslett Tinkhaus had to be employed. While searching with Tinkhaus for low phosphorus iron ore, Schutz discovered a deposit of galena, the source of several thousands of pounds worth of silver used for British coinage.

W H Manning, An iron level padlock from Caerleon, Monmouthshire. *Bull. Board Celtic Stud*, **22**, 410-16, pls, figs, refs, (1968).

X-ray photography has permitted the tentative reconstruction of internal details of a rare type of padlock found in the Croft Barrack excavations (Mrs Murray-Threipland, 1966), in a deposit of first half of 2nd cent. AD. The X-rays could only be interpreted by reference to padlocks from Saalburg and Lullingstone, although the Caerleon lock is subtler than either. It was designed to hold fast a link of chain by means of a bolt operated by a complex sequence of springs (probably of steel). The present position of the bolt and the condition of the casing suggest that the lock had been forced. Some details of the bit of the key can also be suggested.

H H Coghlan and I Mac Phail: An examination of two Bronze Age flat axes from Ireland. *Archeol. austr.*, **41**, 48-65 (1967).

Redeposited copper, only once previously reported in connection with prehistoric and early metals, was found in the course of metallographic analysis of two bronze axes in the Newbury Museum. The first axe, although conventionally "flat" was probably produced in a bivalve mould, and had been hot and cold forged in the process of raising the flanges and hardening the cutting edge (hardness figures: 187 and 156 at cutting edge, 103-115 elsewhere).

EUROPE

Karl Lohberg: Report on a lead pipe from Zugmantel-Kastell. *Saalburg-Jahrbuch*, **24**, 75-6 (1967).

The lead pipe was made by shaping a tube from a cast sheet of lead of 2-4 mm thick. The edges were joined together by another cast. The lead of the cast joint is somewhat higher in tin and copper than the metal of the tube. The same observation was made frequently on similar objects from elsewhere. The proportion of tin to copper was found to be 8.5 : 10, and in the cast joint 10 : 1. Silver is 0.01% (Tylecote, *Metallurgy in Archaeology*, 1962, 96ff, states a percentage 0.002-0.006 for Roman lead pipe). Antimony was also present.

Karl Lohberg: Examination of lead pipe from Magdalensberg (Karnten). *Kartner Museumsschr*, **40**, 18-34 (1966).

A section of lead pipe was examined by metallographical, radiographical, and chemical methods. The pipe was manufactured from a cast sheet containing 0.2-0.4% of tin and 0.03-0.05% of copper. The cast joint showed 0.4-0.68% of tin and 0.05-0.075% of copper. By spectrochemical analysis also Bi, Ag, Sb, Cd, As were determined. A damaged section was "repaired" with an alloy of 70.2% Pb and 28.6% Sn, possibly by "smearing".

Karl Lohberg: Examination of a lead pipe from the Roman bath at Badenweiler, district of Mullheim. *Badische Fundber*, **23**, 199-203 (1967).

The lead pipe of the Roman bath at Badenweiler consists of tin- and copper-containing lead. For the manufacture of the pipes bands of unknown lengths and a thickness of 10mm were joined by a lead cast slightly higher in tin. The joint bands were then shaped into the final pipe and the joint again obtained by a cast. The described technique was certainly not of general use in the Roman Empire, since Tylecote came to other conclusions when he examined lead pipes from Great Britain *(Metallurgy in Archaeology*, London, 1962, 94ff). The tube metal has 0.33-0.38% of tin, 0.07-0.1% of copper, whereas for the cast joint the respective figures are 0.40-0.48% and 0.06-0.1%. Silver was approximately 0.005% and antimony 0.05-0.06% for the tube, and 0.006-0.007% silver, 0.01-0.03% antimony for the joint.

Friedrich Karl Neumann: The history of iron in the Alpine regions. 3. Investigations of ancient finds from excavations at Magdalensberg, Carinthia. *Arch. Eisenhuttenwes.*, **35**, 495-502 (1964).

Technical information on the composition and structure of iron objects and ores found at Magdalensberg.

C Panseri and M Leoni: Research on an iron spearhead from the Etruscan sanctuary of Fanum Voltumnae, fourth to third centuries. BC. *Archeological Chemistry*, papers presented at a symposium sponsored by the Division of the History of Chemistry, American Chemical Society, Atlantic City, NJ, September 1962, edited by Levey, M. 205-29 (1967).

After corrosion removal, the laurel leaf specimen measured 105 x 40 x 8 mm and weighed 60 g. It was composed of a number of layers, produced by forge-welding a lump of 0.4-0.5%-C Fe between 2 lumps composed of sheets of lower-C Fe, with two thin sheets of Ni-Fe steel interposed. The whole was forged, honed, and shaped with the hard pearlite centre layer forming the cutting edge. No signs of subsequent heat treatment are present. Vickers Microhardness numbers were obtained as follows: center pearlite layers 200-215, mainly ferrite layers 135-145, ferrite-pearlite layers 170-180, and steel layers 240-250 kg/mm^2. Analysis of the steel layers indicate it could have been obtained from siderite of meteoric origin, possible included for mystic as well as physical properties. This spearhead indicates that the Etruscans were skilled in the "welded Damascus" metalworking techniques, in contrast to some other concurrent cultures where it was not introduced or deteriorated, eg the Gallic tribes.

L Cambi: Chemical-metallurgical researches on the Picenian bronzes preserved in the Archeological Museum of Ancona. *Studi Etruschi*, **30**, 247-55 (1962).

Chemical composition of bronze ornaments, tools, and weapons, of the Picenian period is reported in detail. Analytical data, obtained by chemical and spectrographic means, include lead, iron, silver, nickel, cobalt, zinc, arsenic, antimony, bismuth and gold. Presence of bismuth (0.04 to 0.21%) points to possible imports of copper from northern areas; reference is made to bronzes from the upper Danube area containing impurities of bismuth, arsenic, antimony, silver, nickel and cobalt.

H Drescher: Review of bronze pots from 12th to 18th century and of the ancient foundry marks of Northern Germany. *Fond. ital.*, No.8, 309-14 (1967).

A technological history of three-legged bronze pots in Germany.

Gerhard Becker and Walther Dick: Iron coining stamp from the Roman age found at Trier. Timbre a frapper le fer de l'ere romaine trouve a Trier. *Arch. Eisenhuettenwes.*, **38**, No. 5, 351-4 (1967).

An old Roman iron stamp die used in the 4th century AD for producing coins was found during excavation work near the German town of Trier. A few chips (1g) taken from the broken handle and a section of the surface layer of the crown were examined microscopically. The handle and crown were of bloomery puddle iron and the surface layer had been hardened by a carburizing heat treatment.

Richard Reece: Analyses of some Roman Imperial denarii of the Second and early Third centuries. *Num. Chron.*, **5**, 175-6 (1965).

A series of eleven denarii from AD 130 to 235 were chemically analysed. The silver content was found to fall from 81% to around 40%. The main changes occurred between coins of Commodus (190) with 74% silver, Septimius Severus (207) 48%, and Maximinus (235) 42%).

Edvard Grunau: Composition of antique bronze coins. *Giesserei,* **54**,No.26, 693-4 (1967).

The chemical structure and hardness of three Greek and one Carthaginian coin, all coined approximately 400 BC, was determined. All four coins are lead-containing tin-bronze but, whereas the Carthaginian coin has nearly pure tin, the Greek coins are heavily contaminated with lead. The Greek coins contained 10.7, 7.8, and 11.8% lead as compared to 0.07% lead in the Carthaginian coin. All of the coins were practically zinc free.

Emil Kraume and Vera Hatz: Silver analyses of German coins of the tenth century. *Hamburger Beitr. z. Numism.,* **7**, No.21, 35-8 (1967).

A chemical analysis of several 10th century German coins (Magdeburg, Cologne, Mainz, Regensburg, Goslar). The origin of the silver of these coins is discussed and analysis of the Otto Adelheid pfennige is included.

A C Bouquet and M Waring: *European Brasses.* Book. Brederick A Praeger, New York, NY, USA, 1968, 78 pp, $28.50.

Basically a picture book which includes a text giving the basic facts regarding medieval funerary brasses: how medieval brass or latten was made; its chemical composition; the rise and decline of the art from the 12th to 16th centures; and the possibilities of its origins either in stone engraving or enamel work.

This book has been reviewed by Mellow, J. R., *The New York Times, Book Review,* 7 (February 8, 1968).

G Somigli: The bronzes from Pirzeus. *Fond. ital.,* No. 9, 305-7 (1966).

Three large bronze statues are described and the casting technique by the lost wax procedure is discussed. Due to favorable conditions of conservation in permeable ground sands no dangerous corrosion had developed and, therefore, restoration was limited to mechanical treatment.

Joachim Emmerling: Technological examinations on a sword from Horrweiler. *Forsch. Ber. Berlin,* **8**, 120-3 (1967).

From a 7th century spatha, owned by the Staaliche Museum at Berlin, a section was sawed out, polished, and etched for metallographical examination. The blade was found to consist of a core and the damascening applied on it. The edges are attached. Carbon content beyond the range of possible hardening and microscopic structure showed that the sword was not hardened.

Hans-Jurgen Hundt: A late Hallstatt sword from the Hagenauer Forest. *Rom German. Zentralmuseums Mainz, Jb,* **10**, 171-81 (1963).

Describes the technical construction of an iron Hallstatt sword by the use of radiographs.

Hans-Jurgen Hundt: Technical investigation of a Hallstatt dagger from Estavayer-le-Lac. *Rom. German. Zentralmuseums Mainz, Jb.,* **10**, 182-9 (1963).

The construction and production of an iron Hallstatt dagger were investigated by radiographs.

Edvard Grunau: The composition of ancient bronze coins. *Giesserei,* **24**, 693-694 (1967).

Chemical and metallurgic analyses of four bronze coins (of Macedonia, Gela, Metapontum, Zeugitana), bought in south Italy, are discussed. The difference in alloy of the three Greek coins from that of the coin of Zeugitana is illustrated, with an outline of the chemical composition of each. The corrosion of the four coins and the chemical influence of the soil is discussed.

S Kolkowna: On the tools used for the manufacture of precious metal objects in northern Pontide. *Kwartal. Hist. Kult. mater., Polska,* **15**, No.4, 729-32 (1967). Resume in French.

Enumeration of the tools used in the manufacture of objects found in the "Point-Euxin."

Armin Wyttenbach: Activation analysis investigation on Bernese coins of the 15th and 16th centuries. *Schweiz. Muenzbl.,* **17**, 15-24 (1967), in German. From *Nucl. Sci. Abstr.,* **22**, No.15, 30449 (1968).

Activation analysis was carried out on some Bernese coins: the Plappart, minted in 1421 and 1490, the Funfer of 1466 and 1492, and the Rollbatzen of 1492 and 1528. The coins were exposed to neutron irradn. The Au contents of these coins were detd. and tabulated. The low Ag content of the Rollbatzen is attributed to a better refining technique for the Au. The Ag content of the coins was detd. and compared.

Emil Kraume and Vera Hatz: Analysis of German silver coins from the 10th century. *Hamburger Beitrage fur Numismatik,* 35-38.

The results of spectrochemical analysis from 27 coins (listed in an appendix) lead to the conclusion that the coin silver obviously was from remelted foreign coins.

Erik Olsson: Lime-kilns in Gotland. *Meddelelser om Konserverung,* 1, No.7, 15-18 (1969). In Swedish with German summary.

In the isle of Gotland, Sweden, there were many lime-kilns in the Middle Ages and the island exported quicklime to many countries. Until the 18th century, there were more than 300 kilns working. With a subsidy from the Swedish government in 1967 the last of the kilns which is still working after the old traditions was preserved. The quicklime from this kiln is sold at the cost of production for conservation of buildings by the museum in Visby (Lansmuseet, Mellangatan 19, 62100 Visby, Sweden). Technical information about the lime by Mr Ingmar Holstrom. Statens Byggnadsforskning, Fack, 27163, 10252, Stockholm 27.

Axel Hartmann: On the spectralanalysis of some Bronze Age Gold Finds from the Danube region. *Bericht der Romisch-Germanischen Kommission Mainz,* 46-47, 63-73 (1965-66).

The analytical data have shown that three "Materialgruppen" can be discerned. The origin of the raw gold from the "Siebenburgischen Erzgebirge" seems at least probable.

Hans-Jurgen Hundt: An Iron Chest-lock and Textile Remainders from a Chamber Tomb from Haithabu. *Jahrbuch des Romisch-Germanishchen Zentralmuseums Maniz,* No. 13, 304-11 (1966).

From excellent radiographs of a thoroughly corroded iron lock it was possible to recognize its mechanism. Both construction and function are explained by a series of drawings.

H Zurn: Furnaces in the prehistorical settlement at Erenstein in the Ulm Region (Danube). Les fours dans l'etablissement prehistorique d'Erenstein dans la region d'Ulm (Danube). *Brot Geback,* 20, No.2, 30-2 (1966).

An account of prehistoric iron manufacture in Germany.

W Kimmig and E Gersbach: The excavations at the Heuneburg 1966-69, *Germania,* 49, (1971) 1-2 p21-91. (In German).

Description of the results of the Heuneburg Grabungen in the years 1966-69 with a separate chapter on metallic specimens found. Besides arrowheads, structure and composition of a spindle-shaped bloom of Heuneburg I date are discussed.

S von Schnurben: A lead bar of the 19th Legion from the main camp at Haltern. *Germania,* 49, (1971) 1-2, p132. (In German).

Description of a newly found lead bar at Haltern. The bar is cast in the dimensions 62.5:10.0:11.5 and weighs about 64 kg. It is very readably stamped CCIII L (egio) XIX.

The problem is whether this first archeological evidence between Rhein and Elbe of one of the three legions lost in the battle of the Saltus teuto burgensis gives a clue for stationing the XIX Legion at Haltern, or if it was only produced by the XIX Legion in some other part of Europe eg. the Eifel. The author states that a metallurgical examination is intended.

Sigrid Dusek: Iron Melting Furnaces of a German Settlement near Gera-Tinz. *Alt-Thuringen,* 9, 95-183 (1967).

An exhaustive description of the excavation and construction of iron melting-furnaces with a numerous analytical data on the composition of slag remainders. 120 references; drawings.

Kumahiko Hasegawa: Ancient direct iron-smelting processes in Europe. *Tetsu To Hague,* 54, No.11, 1177-92 (1968) in Japanese.

Reconstruction and operational expts. in Germany, the USSR and England with ancient direct iron-smelting furnaces actually used in the LaTene age (500 BC), the Roman era, and the Middle Ages are summarized. These furnaces produced slag-mixed sponge iron at very low temp.; this was converted to useful iron in a secondary process. The fundamental technologies for temp. control, furnace construction, and slag sepn. were very similar to those of recent years.

Achille G Lefebvre: Belgian iron and steel industry: its history, characteristics, and trends. *Symp. Belg. Sci. Ind.,* 181-94 (1966).

This is a bilingual history (Japanese-English) of the fundamental processes of steel production (Bessemer, Thomas, Linz Donawitz, and LD-AC) in Belgium. Charts of Belgian producers' output, comparison of outputs by various methods, and comparisons with other countries and their relative applicability to particular ores and uses are given. The geographical proximity of Fe ore to other raw materials for steel production in Belgium, wages, and trends in investments are also discussed in detail.

M F Laranjeira and M E Fronteira E Silva: Isotopic analyses of Roman lead from Conimbriga and of galenas from neighbouring mines. *Rev. Port. Quim,* 10, No.1, 55-6 (1968). Three samples of Roman Pb pipes from Conimbriga and samples of galena from the neighbouring mines of Bracal, Malhada, and Coval da Mo were analysed by mass spectrometry. A comparison of the measured $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios with previous results showed that the Pb used in Conimbriga was from different origins.

Emil Kraume and Vera Hatz: The "Otto-Adelheid-Pfennige" and their recoining. *Hamburger Beitrage fur Numismatik,* **13-23 (1961).**

Nature and origin of the coin silver are discussed. With tables containing 133 spectrochemical analytical data.

S P Pachova: A metallurgical centre of the Zarubinian civilisation near the village of Lyuteh. *Sov. Arch.* 1970 (1), 140-151.

A settlement in the Kiev region of the Lower Dnieper dated to the early part of the 1st millenium AD. It was situated in a low and marshy heavily forested area with bog iron ore. It contained the remains of 15 bloomery hearths and over 3 tonnes of slag together with some pieces of bloomery iron. The tip of a Scythian type arrow showed the existence of an earlier settlement datable to the 7-6th centuries BC. The bloomery hearths were similar to those found in the Czech site of Lodenice with shafts of 0.40–0.45 m outside diameter and walls 6-7 cm thick. These had slag tapping pits in front and similar types exist in the Holy Cross mountains of Poland. But the majority of hearths found did not have slag tapping facilities and were therefore of a more primitive type. It was estimated that these had been used at least 10 times and not once only like some of the other Northern European examples. No tuyeres were found and it is assumed that air was blown in through holes in the furnace wall. Charcoal was made on the site.

As a result of experimental work it was concluded that one cubic metre of wood was required for each smelt which produced 3 kg of iron with a yield of 20-30% of the dressed ore charged. It is estimated that 148 persons were employed producing a total output of 90 kg per season (year). Some crucibles and copper-base fibulas were also found but there were hardly any traces of iron smithing. It is concluded therefore that the site was primarily a raw iron producing unit of the first few centuries AD.

G Becker and W Dick: The iron-shod piles of the Roman bridge at Treves. *Arch. Eisenh.* 1971, Mar. **42, 223-227. (In** German).

The pile shoes had a high corrosion resistance and consisted of welded wrought iron containing 0.213-0.218% P and 0.12-0.16% Ni. Metallurgical examinatioin included the determination of impact strength and transition temperature perhaps the first time such a property has been determined for a Roman bloomery iron. The corrosion resistance was tested in a modern industrial atmosphere and was presumably even better in the organic environment of a river bed.

J Piaskowski: Metallographic examinations of iron objects from Wegra, district of Przasnysz. *Mat. Archaeologiczne.* 1969, **10,** 73-82. (In Pol.).

Gives the results of quantitative and qualitative chemical analysis, metallographic structure and grain-size, microhardness and Vickers hardness testing of 2 spear heads and 5 rivets of the 3rd-4th centuries. All the objects are made of low phosphorus irregularly carburized iron identified by the author as being from the Holy Cross Mountains.

M Picon, J Condamin and S Boucher: Technical research on bronzes from Roman Gaul, II. *Gallia,* **25,** No.1, 153-68 (1967).

Describes "alexandrin", Gallo-Roman, and Gallic bronzes from Gaul. Alexandrin designates a category of objects differentiated from Greek and Roman objects by their exotic or caricatural inspiration and the presence of a small proportion of zinc. The Gallo-Roman bronzes are related to the Celtic religion by their *Dispater* subject and should be attached to Roman art by esthetic principles. These too possess zinc in low concentrations and, for certain examples,

Hans Malzacher and H Vetters: Contributions to the history of iron in the Alpine district. 1 and 2. *Stahl u. Eisen,* **84,** 674-80 (1964).

Describes Roman ironmaking as related to Magdalensberg and present archeological work in Magdalensberg.

See also **7-634** for Part 3.

Otto Schaaber: Metallurgical examination of ancient Bloomery steel objects from Magdalensberg. *Arch. Eisenhuttenwes.,* **35,** 502-6 (1964).

Investigations have demonstrated that ancient iron workers could produce high-carbon steel, could differentiate between hard and soft steel, and knew how to utilize their different properties. Probable methods of production are discussed.

Kolbjorn Skaare and Eiliv Steinnes: Coins: Neutron activation analysis of Norwegian medieval coins. *Nordisk Numismatisk Unions Medlemsblad.* 81-9 (May 1966).

Neutron-activation analysis of one Anglo-Saxon and 11 medieval Norwegian coins (together with three modern Norwegian specimens for comparison). Percentages of silver, copper and gold are given.

Clemens Bohne: On the working of copper ores in the Bronze

Age, melting experiments with copper pyrites. *Archeologica Austriaca,* No.44, 49-60 (1968).

The melting experiments with Mittelberg copper pyrites have proven that it is possible to produce a copper metal using a very primitive furnace. The metal thus obtained was quite close to Bronze Age copper. 20 references, illus.

B Bearzi: Bronze in antiquity. *Fond. Ital.,* **15,** No. 2, 65-7 (1966).

Examination of antique bronze statues in Italy shows that the materials used can be divided, according to the period, into three groups: (1) Graeco-Etruscan (6th-3rd century BC) containing Cu 83-91, Sn 7-12, and Pb 1-6%; (2) Roman (1st century BC-3rd century AD) containing Cu 64-79, Sn 5-11, and Pb 10-27%; and (3) Tuscan Renaissance (13th-17th century AD) containing Cu 85-92, Sn 6-13, and Pb 1-2%. A number of bronzes cast during the Renaissance period fall outside this classification, however, some contain up to 17% Zn.

B Bearzi: The lion and griffin of Perugia. *Fond. ital.,* **15,** No. 5, 157-63 (1966).

A consideration of the methods of casting and joining used to produce two mediaeval Italian bronze statues is presented.

Hans-Eugen Buhler and Cristian Strassburger: Metallographic examination of two Frankish swords dating from the ninth century. *Arch. Eisenhuttenwes.,* **37,** No.8 613-19 (1966).

Examination revealed the method of manufacture of two swords. One had a carburized cutting edge produced by stepwise cementation and quenching. The other had a Damascus blade; the pattern is based on two initial materials, a high-phosphorus low-carbon ferrite and a low-phosphorus, high-carbon ferrite-pearlite structure. Microprobe analysis suggests that high phosphorus contents (up to 0.7%) raise the solubility of carbon in ferrite.

C Panseri and M Leoni: On the Etruscan technique for making iron arms: examination of a sword tip of the fourth century BC from Montefiascone. *Metal. ital.,* **58,** No.10, 381-9 (1966).

A series of metallographic analyses show that the sword had been made according to the Damascene technique.

M Picon and G Chapotat: Research on the origin of bronzes found at Mont Beuvray. *Soc. Eduenne, Mem.,* **51,** No. 2, 85-95 (1967).

Describes hammered and cast Roman bronzes and in particular various bronzes and brass fragments from Mount Beauvray in the collection of the Musee Rolin. Autun. Italian and Celtic provenances are suggested.

Martin Levey: Medieval Arabic minting of gold and silver coins. *Chymia,* **12,** 3-14 (1967).

The operations of the medieval Egyptian mint are described from a manuscript by Ibn Ba'ra.

Axel Hartmann: Spectrum analyses of BA gold finds from the Danube region. *Germania,* **46,** 19-27 (1968), figs., refs.

A preliminary report on the analysis of 1417 gold objects dating from Eneolithic to La Tene times. Most of the gold is of alluvial origin, very little having been mined. The 3 most important gold-groups are described. Group B, dating to the Copper Age and EBA, was probably mined and imported from the East Mediterranean. Objects of Group A3 date predominantly to the MBA and are concentrated in Transylvania, where the gold probably came from alluvial deposits. Objects of Group N/NC, an alluvial gold, date to the LBA and are widely distributed. In Ireland this gold is always alloyed with up to 10% copper, whereas in Central Europe objects with no copper are also found. The alloying of gold with copper was probably initiated in Ireland. The origin of this gold has not yet been determined. These analyses will be fully treated in a future volume of *Studien zu den Anfangen der Metallurgie.MGS*

Richard D Buck, Anne F Clapp, Delbert Spurlock and Ruth Spitler: Domenichino's copper plate. *ICA Newsletter,* **6,** No.2, 4 (1968).

A small painting by Domenichino on copper has been examined at the Intermuseum Laboratory, Oberlin, Ohio. An x-radiograph was made partly as a trial because equipment capable of penetrating metal had not been available previously. The developed film showed traces of the painting masked by the density of the copper support. The copper confirmed an estimate that the plate had been rolled not hammered. Varying densities in the x-radiograph caused by uneven thickness of copper fell into roughly parallel patterns suggesting the defects to be expected from a primitive rolling mill.

Second, the x-radiograph was covered with a random pattern of light toned marks of scratching. A similar but different system of scratches is visible on the back of the copper, but these logically should record as dark not light lines. The painted side was re-examined under the binocular microscope. In tiny lacunae of the paint what seemed to be a white metallic surface was found. At one edge the matter became clear. There is a coating of white metal over the copper on the front side of the plate. A test indicated the presence of lead. It is assumed that the plate was scratched, then heated and coated thinly with lead or a lead alloy, perhaps to establish a better bond between the metal and the paint, a problem that was noted by contemporary writers. No ground is present in the usual sense. However, there seems to be an organic pellicle, now rather yellowed, between the metal and the paint. The lead alloy coating may be unique.

J Piaskowski: Metallographic examinations of ancient iron objects and slag from Upper Silesia and the Czestochowa region. *Sprawozd. Archeologiczne,* 1969, **20,** 425-444. (In Pol.)

A chemical and metallographic examination of 13 prehistoric and 8 medieval iron objects. Three objects were made of high phosphorus iron, the others – mostly carburized – contain less than 0.2% P.

ASIA

Vera Bird and Henry Hodges: A metallurgical examination of two early iron swords from Luristan. *Stud. Cons.*, **13,** 215-223 (1968).

Two iron swords from Luristan were examined by X-rays and using metallographic sections. The first sword was shown to have a hilt made of five pieces of metal joined by four rivets, while the pommel was secured by a dowel on the end of the tang. Hilt and blade were sectioned for metallographic study. This showed that while the core of each part was pearlite, decarburization had taken place at the surfaces to give ferritic structures. The second sword was shown to have been made of seven pieces. The pommel was secured as in the first sword, but all other pieces were joined by fitting into prepared slots, the edges of which were burred. A section was cut from the hilt at a point where a decorative band had been applied. This showed large-grained ferrite at the surface and fine-grained ferrite with cementite at the boundaries in the core. It is argued that work previously carried out by other metallographers was inconsistent due to inadequate sampling, and that swords of this type were essentially of wrought iron, the presence of pearlite being accidental rather than intentional.

K T M Hedge: Source of the metal in the lead coins of the Kshatrapa period. *Curr. Sci.*, **37,** No. 18, 518-20 (1968).

Spectrometric studies of Pb coins of the Kshatrapa period which were recovered at Nagara, India indicated that almost the same metallic impurities are present in the coins as in galena ore from the Aravalli region: thus, the ore for the coins was probably mined at the Aravalli region. The Indian Pb metallurgical industry was thus shown to be at least 16 centuries old. Quant. chem. anal. of the coins indicated that the Pb was not alloyed with other metals to increase hardness.

Kumahiko Hasegawa and Seiichi Wajima: Slags from Tatara ruins in Japan. *Shigen Kagaku Kenkyusho Iho,* No. 68, 95-113 (1967) in Japanese.

The 22 ruins of old Tatara in Japan are described. The slags contained Fe 21.22-62.89, metallic Fe 0.14-11.39, FeO 5.82-59.05, SiO_2 6.90-36.30, and TiO_2 0.07-15.53%. Magnetite, wustite, fayalite, goethite, limonite, and other gangues were observed. The most ancient slags did not contain magnetite, but in the modern slags the magnetite crystals were well-developed. The smelting temp. of Tatara was inferred as 1200-400°. The wustite and fayalite in slags proved the smelting of the ores.

Tadahiko Katori: Bell of Hoko-ji temple. *Museum,* No.208, 22-23 (July, 1968) in Japanese.

The bell, the biggest in Japan, dates back to 1614. In this article the condition of its casting is cited from old documents. The total amount of metal used exceeded 60 tons; 136 treadle bellows capable of working from 225 to 1000 kg were used; and about 3200 persons joined in the attempt.

A K Lahiri; T Banerjee; B R Nijhawan: Some observations on ancient iron. *Nat. Met. Lab. Tech. J.,* **9,** No.2, 32-3 (1967).

The Sun Temple of Konarak in India is situated on the sea coast and is believed to have been built about 1000 years ago. The heavy Fe beams, the largest weighing about 9,000lb, were originally used as supports under lintels. Microexamination shows the beams have a cast structure, with varying amounts of ferrite and pearlite, and good amount of slag inclusions. Besides those, Fe beams have also been used as lintels in the Jagannath Temple of Puri situated on the sea coast about 25 miles from Konarak. In addition to the Delhi Iron Pillar, the other important ancient Fe monument in India is the Fe pillar at Dhar in Central India. To explain the excellent state of preservation of these ancient structures, the authors suggest that in ancient Fe, a good amount of slag inclusions is dispersed in 3-dimensional network in the mass of the metal. This type of intermixed dispersion of slag and metal is directly connected with the manufacturing process adopted where the reduced ore and the slag obtained were spongey puddled masses which were subsequently forge-welded together; the slag thus formed envelopes around the latter, affording adequate corrosion resistance to the exposed metal by drastically reducing the number of breakdown areas where corrosion could be initiated. This theory is the only one which can explain the high corrosion resistance of ancient Fe, still existing under varying climatic conditions. 11 references.

Karunakar Hegde: An analytical examination of a metal image from Samalaji. *Orient. Inst., J.,* **12,**No.2, 177-80 (1962).

An early 14th century statuette was discovered at Nagadhara in 1961 while digging a foundation trench. Its chemical composition was found to be: tin: 1.76; lead: 4.25; copper 74.92; iron: 2.78; zinc: 15.35; nickel, arsenic and bismuth were found in traces. The metal used was evidently brass. The image was cast solid.

Karunakar Hegde: Examination of a bronze axe from Somnath. ***Orient. Inst., J.*****, 12, No.4, 266-369 (1963).**

The axe was excavated from the stratified chalcolithic levels belonging to the latter half of the second millenium BC,at Somnath. Its chemical composition was: copper: 8.186; tin: 12.82; iron: 2.57; lead: 1.21; cobalt, arsenic and bismuth were present in traces. Traces of cobalt and absence of silver indicate that the copper was taken from the ancient copper ore at Babai, where copper is found associated with cobalt.

G K Ogale: Development of metallurgy in India. ***Freiberg. Forschungsh., Reithe B*****, 127, 77-8 (1966).**

Ancient methods of producing steel and iron alloys go back to the third century, but its methods and procedures have been lost over the centuries. Composition Brinell hardness of such steels are compared with present day standards. It is quite certain that charcoal was the principal fuel used for cast iron alloys since the earliest times.

John D Cooney: On the meaning of "black bronze". ***Agypt. Sprache Altertumsk.*****, 93, Nos. 1-2, 43-7 (1966).**

The term "black bronze" must be interpreted as meaning a bronze specially darkened by a sulphide to receive inlays of other metals like gold and electrum. It is conjectured that the source of the sulphide was yolk of egg. The process was introduced probably from Syria very early in Dynasty XVIII and continued at least until Dynasty XXX.

G B Avalishvili: Ancient metallurgical refining furnace in Kvemo-Kartli. ***Soobshch. Akad. Nauk Gruz. SSR*****, 50, No.2, 505-9 (1968) in Georgian.**

Stone molds for casting bronze objects, some foundry tools, and some axes and hatchets of Oriental-Armenian and Oriental-Caucasian workmanship were dated back to the VIII–IX century BC and permitted the establishment of the existence of large metallurgical furnaces in the foothills near Gantiadi of the Caucasic region.

Anon: Prehistoric arsenicated copper. ***Sci. Progr., Nat., Fr.*** **No. 3383, 97 (1967).**

Objects of mesopotamian influence dating from 2500 BC. The content of arsenic was about 10%. Explanation of the effect of the quantity.

J K Mukherjee: A K Lahiri; T Banerjee: Structural properties of rust from ancient iron. ***Nat. Mat. Lab. Tech. J.*****, 10, No. 1, 25-9 (1968).**

Phys. and chem. tests conducted on rust collected from ancient iron beams of the 1000-year-old Sun Temple at Konarak situated on the Bay of Bengal, 20 miles from Puri in Orissa State, India, indicate that the rust consists mainly of Fe_3O_4, γ-Fe_2O_3, and alpha- and gamma-$Fe_2O_3 \cdot H_2O$. Further work is under way to establish the structure of the oxides and to determine the possible structural changes that occur in rust exposed under various conditions for different periods.

Hohn D Milliman; Frank T Manheim: Submarine encrustation of a Byzantine nail. ***J. Sediment. Petrology*****, 38, No. 3, 950-3 (1968).**

Virtually all the Fe objects recovered from a 7th century Byzantine shipwreck off the coast of Turkey were encrusted with a carbonate-rich layer. Mineralogical and chemical examination revealed limonite, siderite, and aragonite as dominant authigenic phases. The encrustations are explained by oxidation (corrosion) of the metal in seawater. The inner half of an encrustation is dominated by a ground mass of an opaque mineral, probably limonite. Goethite was not detected by x-ray diffraction, but its amorphous equivalent was assumed from microscopic examination and chemical analysis. The principal cryst. minerals in the inner and middle layers were calcite (with appreciable quantities of smaller ions in solid soln.), siderite, and magnetite. The outer layer was a cohesive but porous aragonite matrix enclosing carbonate skeletal debris.

S K Bhowhik: The conservation and technique of silver bangles discovered at Rojdi, India. ***Studies in Conservation,;*** **13, 150-5 (1968). Fr., Ger., Ital., Span. summaries.**

The treatment of two silver bangles found at Rojdi and dated c. 2000 BC is described. The bangles were separated by removing the hard incrustations with a 20% sodium hexametaphosphate solution of 0-88 ammonia and a 20% aqueous solution of ammonium thio-sulphate.

O Werner: Spectro-chemical analysis of ancient and modern Indian bronzes. ***Materialprufung*****, 7, No.12, 463-470 (1965).**

Since the appearance of the first technical instruction about metallurgy and casting in the Gupta-period (about 400 AD) the manufacturing of bronze objects in India has undergone almost no change. This makes detection of fakes difficult. Main constituents of the analyzed Indian bronzes were: tin, from 5 to 12% by weight; zinc, from 13 to 20% by weight (and correspondingly very low tin content) especially in bronzes from Northern India, while new Indian bronzes were actually brass containing zinc from 20 to 50% by weight; lead, from 10 to 15% by weight, when found, was a good evidence for the antiquity of the object as the lead content of new alloys is very low, 0.2 to 3% by weight. However, some Indian bronzes lacking lead can also be antique. Small quantities of arsenic and antimony showed relationship with lead content, whereas traces of cadmium appeared to have a similar relationship with the zinc content. Such associations refer to ore composition and can be used to locate mining centres as well as metallurgical or casting sites. The detection of a comparatively high gold content, from 0.1 to 0.7% by weight, in statues or figurines of deities as compared with ordinary objects (gold content about 0.005% by weight) were considered to be an intentional addition expressing ritual tendencies. The author quotes evidence of consecration performed in this way discovered in the composition of medieval European and Chinese (3rd century AD) figures.

Hans-Gunter Buchholz: Analysis of prehistoric metal objects from Cyprus and the surrounding countries. *Berliner Jahrbuch fur Vor- und Fruhgeschichte,* 7, 189-256 (1967).

Some 472 analyses are listed. The main subjects discussed on this basis are: The characteristics of the copper produced on the island during the early period – correlation between composition of the metal and the ore deposit. Ores from the Tamassos region are characterised by the combination of antimony-zinc and the absence of lead and silver. Those from Skouriotissa contain lead, silver, gold, arsenic, antimony and bismuth, they are very low in nickel and cobalt. The combination of gold and silver seems to be significant, together with a higher percentage of zinc. All ores from the island are free of tin. Thus it can be concluded with some certainty that copper objects with gold and silver when free of tin but high in zinc do originate in Cyprus.

Masaki Nakano: Bronze mirrors of the Narra period: the Todai-ji chukyo yodo bunan (drafts for documents concerning mirrors for the Todai-ji Temple) among the archives of the Shoso-in (II). *Museum (Japan),* 192, 2-13 (March 1967). In Japanese.

Describes the inventory of materials used in a bronze casting made during the Nara Period, including polishing materials and fuel. On the basis of specifications the author believes that the resulting mirrors were of inferior colouring, because they contain too much copper, and also that the total amount of the materials used is excessive for the casting project.

B S Ridgway: The lady from the sea: a Greek bronze in Turkey. *AJA,* 71, No.4, 329-34 (1967).

A description of a Greek bronze from the Izmi Museum included in the travelling exhibit *Art Treasures of Turkey* circulated by the Smithsonian Institution, 1966-1968, includes the casting technique. The sculpture seems to have been made out of a great number of separate pieces, cast independently and then joined by soldering.

I A Gselichvili: Ancient iron metallurgy at Madneouli. *Akad. Nauk. Gruz. SSR, Soobshch.,* 39, No.2, 307-12 (1965). In Georgian.

A technical discussion of iron metallurgy in Georgia during the 12-13th centuries.

William Samolin and Isabella M Drew: Eurasian animal style plaques. I. *Mon. Serica,* 24, 170-83 (1965).

The study is devoted solely to the composition of the alloy and trace element patterns. Analysis of 50 plaques of wide geographic origin, but dated stylistically from Chan-kuo to Han (403 BC-AD 220), are tabulated. Pb, Ag, Sn, Zn and Cu were determined colorimetrically or complexometrically. Trace elements, Al, As, Au, Bi, Ca, Co, Cr, Fe, Mg, Mn, Ni, Sb, Si, Ti were done spectrometrically with DC arc. Operating procedures are described in detail. Errors and limits of detection are discussed. All objects analysed are illustrated. No conclusions are drawn because this is obviously only the beginning of an extended study.

F E Treloar: Examination of archaeological remains from Kedah, Malaya. *At. Energy Aust.,* 10, No.3, 20-6 (1967).

Archaeological remains of Kedah, Malaya, were analysed using x-ray fluorescence, neutron activation, and spark spectrography. The compositions of copper and silver artifacts are reported.

I F Bouriakov: The ancient silver mine of Lachkerek. Mine ancienne d'argent Lachkerek. *Sov. Arkheol.,* No. 1, 282-9 (1965). In Russian.

The mine was located in the Angren River basin in Tadjikistan. Ceramics discovered in the miners' houses dated from the ninth century AD. Slag was distinguishable by its red colour and by its composition of up to 40% lead. The mining was interrupted at the end of the tenth century by the war between the Samanides and Karakhanides.

G B Avalishvili: The tomb of a master founder from a burial ground near the village of Gantiadi in South Georgia, USSR. *Sov. Arch.* 1970 4, 183-189.

A number of stone moulds were found one of which was an open mould for flat axes with a matrix for a chisel-shaped bar on the opposite side. Others were two two-part stone moulds for lunate axes of East Transcaucasian type; one of these had been broken and fastened with iron clamps and another with copper clamps. A fragment of another mould was also found. The crucibles were of hemispherical type with lips. The rest of the metal finds were part of the founder's personal weapons and apparel and consisted of a knife, iron spearheads and bronze ornaments.

The flat axes are datable to the 9-8th centuries BC and some of the other bronze artifacts can be dated to this period. This is clearly a period of transition and the author discusses the social issues involved.

V I Siderov and P N Starostin: The remains of Early Medieval foundry workshops in the settlement of Scherbet. *Sov. Arch.* 1970 4, 233-237 (In Russian).

A pre-Bulgar site of the 4-7th century AD in the Kuibyshev area of the Tatar ASSR. The settlement produced tools, weapons and costume accessories. Two foundry workshops were found in the central area yielding slag, triangular copper-base bar ingots 18.5cm long, and parts of 12 conical crucibles. The chemical composition of 5 of the bars was 30% Zn, 0.8-2.0% Sn, 4-5% Pb, remainder Cu. Thus these were leaded brasses. Of the others, 2 of the bars were 15% Zn brasses and one was an impure copper. A buckle was found to contain 20% Sn, 8% Pb, and 2% Zn. The slag was a silicate containing iron and copper and a crucible deposit was impure copper. No ore was found.

A D Vinogradov and E E Kouzmina: Foundry moulds from Lyavlyaka. *Sov. Arch.* 1970 2, 125-135. (In Russian).

This site is in Inner Kyzylkum, part of the steppe zone of Central Asia and south-east of the Aral Sea. It produced two sets of three-part stone moulds for socketed axe-hammers and adze-axes of a type found in Iran and dated to the end of the 3rd to the beginning of the second millennium BC. This is the first time that such moulds have been found. The parting line of the mould proper was vertical, and the two pieces forming this part of the mould formed a "print" to contain the core that formed the socket. This mould was closed at the top by a cover stone (the third part of the set) which contained a gate for pouring at one end.

The moulds were made from a coarse-grained brown-grey sandstone. Slag and ore were found on the site; the nearest deposit of ore was about 20 km away and has a copper content of 0.53-1.38%.

J W Barnes; M P Nackowski and E H Bailey: Geology and ore deposits in the Sizma-Ladik mercury district, Turkey. *CENTO report on the mining district studied during the 4th CENTO training programme.* July-September 1969 (Ed. Mary M Lawrence).

J W Barnes and E H Bailey: Geologists discover ancient retort — evidence points to world's oldest underground mine. *World Mining (US Edition)* 1972, April, p 49-55.

As far as the historical side is concerned these two papers cover the same ground. In the course of a survey in the modern mercury mining area of Turkey they found evidence of prehistoric mining and Greco-Roman smelting of the red mercury ore cinnebar (HgS). The mining site is only about 65 KM from the Neolithic site of Catal Huyuk where cinnebar-painted skulls were found dated to about 6000 BC.

Near the modern Cirakman mine, 2 km south of Ladik, was found what is believed to be a smelting place cut into a solid platform of limestone. A 50 cm diameter depression is supposed to have held a clay retort inside which the mercury ore was heated with charcoal by excess air admitted through vents underneath. The SO_2 was allowed to escape with the Hg vapour up a long sloping chimney made of pottery tubes. Some of the Hg would collect in the retort and was allowed to drain into a trough and collecting basin cut into the floor. The rest would have collected as droplets in the clay tube and could have been recovered by gentle tapping after the fire had burnt out.

Evidence for two archaeological finds of metallic mercury is quoted; a small vessel of Hg in a grave at Kurna dated to 1500 BC and a Chinese mausoleum dated to 200 BC which contained a model depicting two rivers of mercury flowing into a pool. Dioscorides and Pliny (1st century AD) both refer to Hg distillation and it is claimed that the Phoenicians and Cartharginians knew about the metal as early as 700 BC. The principal uses of the metal in these early periods must have been for gilding or the recovery of gold by amalgamation.

AMERICA

Anon: The beginnings of metallurgy in the new world. *Archeologia. Fr.*, No. 13, 52-5 (1966) ill.

The Great Lakes region and copper mining in 2000 BC; Hopewell civilization in northern Mexico and Ohio in 200 AD; Peruvian gold of the Chavin period, 600 BC; the mosaics and inlays of 200-700 AD. Use of "huairas": Platine, Peru, "umbaga" (alloy of native argentinian gold and copper). Columbian casting techniques. Discovery of Br·at the arrival of the Spaniards, iron unknown.

Phil C Weigand: The mines and mining techniques of the Chalchihuites culture. *American Antiquity*, **33**, No.1, 45-61 (1968).

Mines in western Zacatecas, Mexico had their greatest development from 350 AD to c. 700 AD by colonists from classic Teotihuacan. The article describes the shafts, tunnels and rooms. They were dug in gravel beds covered by an unbroken caliche top. The tunnels had occasional retaining walls of blocks. The tunnels and rooms were dug with the principle of arched support clearly in mind. When rooms became enlarged, pillars of the mineral-bearing strata were left to provide roof support. Splints for lighting, stone scrapers, mauls and axes were found in the mines.

Wilhelm P Bauer and Kurt Rossmanith: On the spectroscopic and technological indentification of the "mise en couleur" decoration technique on Tumbaga objects from the Chiriqui region. *Archiv Volkerkunde*, **19**, 1-10 (1964-65).

The gold-copper alloy was fused from pure gold, which was free from platinum, and pure copper. The objects were then formed from this metal. All objects but one which was not further worked up, had coatings of approximately 0.1 mm from the "mise en couleur" gilding technique.

AFRICA

E R Caley and L W Shank: Composition of two Manillas. *Num. Chron.*, **6**, 331-5 (1966).

Complete chemical analyses are given. One manilla was at least two hundred years old; the other more recent. Both were found to be composed of complex copper alloys. It is doubtful that this kind of ring money was ever made of unalloyed copper.

J Piaskowski: Metallographic examinations of iron objects from Niani and Baladougon (Guinea). *Materiay Zachodniopomorskie* 1967, **13**, 575-581. (In Polish)

Gives the results of quantitative and qualitative chemical analysis, metallographic structure and grain-size, and micro-hardness and Vickers hardness of 3 early and one modern object. The former were made of low phosphorus bloomery iron.

AUSTRALIA

C Pearson: Cannon survive 200 years under the sea. *Foundry Trade J.*, 1972, **132**, (2882), 307-310.

In 1770, James Cook was forced to jettison six cast-iron cannon off the Great Barrier Reef. These guns were recovered in 1969 and the article describes the removal of coral encrustation, the cleaning and preservation of the guns by an electrolytic method. Their chemical analysis is given. Indications are that the guns were cast in the mid 18th century.

TECHNIQUES

A Mutz: Technical skills of the Romans – metal turning. *Antike Welt 2* (Nr 4) 1971, p 28 (In German).

An article concerning the metal turning at roman times, which is based on studies in over 40 museums. The author describes the different techniques and tries to reconstruct the machines used.

Arthur Steinberg: Techniques of Working bronze. *Exhibition Catalogue. Master Bronzes from the Classical World, City Art Museum, St. Louis, Mo., The Fogg Art Museum, Cambridge, Mass., and the Los Angeles Country Museum of Art, Los Angeles, Cal., USA.*, 9-15 (1967).

A review which covers casting, joining, surface decoration, cold working, and patina. Bivalve molds for casting weapons, and molds for piece mold casting and lost wax casting are illustrated with diagrams. Methods for using chaplets and spacers to separate cores from molds in producing hollow castings are shown. Inability to vent the mold and cracks caused by too rapid prebaking of molds resulted in defective castings. Joins were made both mechanically (rivets, force fittings, etc). and metallurgically; also by hard soldering. Surface decoration was done by tracing, punching, and engraving; also by inlaying with silver, gold, and niello. Revetting or overlaying involved pressing or gluing a thin sheet of metal, usually gold, to the surfaceof the bronze. Still more effective was fire gilding with an amalgam of gold and mercury.

Bronze, to a limited extent, could be cold worked from ingots into vessels with frequent annealing; also by raising from a bronze sheet by hammering over a stake, or by sinking into a depression. Cold worked bronzes were decorated by hammering a design up from the back by a process called repousse or by embossing. Hammering the metal down from the front was called chasing. Punching and stamping were also employed. The final decor effect, patina, was a product of time and environment quite beyond the control of the original maker.

Clemens Bohne: On the problem of hardening copper weapons and tools. *Technische Beitrage zur Archaologie II*, **II**, 126-130 (1965).

The process of hardening native copper, arsenic bronze and tin bronze was investigated; the results are described in diagrams.

Rene Wyn: Bronze Age casting techniques. *Book. Verlag Paul Haupt, Bern, Switzerland*, 1967, 12 pp., Sfrs. 4.40.

Rene Wyn: Bronze Age Metal Craft Work. *Book. Verlag Paul Haupt, Bern. Switzerland*, 1967, 14 pp., ill., Sfrs. 4.70.

K C Barraclough: Puddled steel: a forgotten chapter in the history of steelmaking. *JISI,* 1971, **209,** 785-789.

The modification of the puddling process to produce metal of medium and high carbon content (0.5-0.9%). It used plant available to increase the output of material needed in increasing quantities before the completed development of the Bessemer and Siemens-Martin processes. Describes what is known of operations in Liverpool, Sheffield, Low Moor, and in South Wales. The main users of the process seem to have been in France and Germany.

K C Barraclough: Puddled steel: the technology. *JISI,* 1971, **209,** 952-957.

Gives details of the technique, as used at works in Liege in 1861 1861 and at another works in Germany somewhat later. The latter includes details of the furnace used. The descriptions are supported by metal and slag analyses from German sources. It seems that this process was still in its development stage at the time of the arrival of bulk steelmaking processes, although it was responsible for a considerable tonnage of steel, some of which was used as melting stock for crucible steelmaking. It clearly required skilled operators, more so perhaps than the original wrought iron puddling process. The reason for its failure to arrive and become a more widely used technique lay in the same defects as puddling generally, ie. arduous toil and small batches.

SCIENTIFIC EXAMINATION

Olof Arrhenius: Ore, iron, artifacts and corrosion. *Sveriges Geol. Unders., Ser. C,* **61,** No. 11, 39 pp (1967).

An investigation of ancient Fe artifacts and of the alloying elements in them may give a clue to the origin of the metal. Samples of lake and bog Fe ore, speciemens of Fe ore from bedrock, and artifacts supplied by several museums were examined spectrochemical for As, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sn, V, Zn, and Ag and chemically for P, Mn and Fe. Limonite ores are partially formed by the action of plants a and plant debris and are rich in Mn, Co, Ni, Mo, and P. It appears probable that old Swedish Fe manufacture was founded on both rock and limonite ores. The presence of P in Fe retards corrosion, as does a few percent of Ni and Mn. C content in most of the artifacts investigated is low, indicating that the ore was reduced below 1000 degrees.

Hans-Jurgen Hundt: Investigations of the historical production of a Bronze Age sword castings. *Jahrbh. Rom-German. Zentralmus.,* **12,** 41-58 (1965).

Through the interpretation of radiographs of numerous bronze age swords a system of core casting was detected which was simplified with time.

Andew L Maverick and Rudolf Fichter: The investigation of diffusion processes at soldered joints with an electron microprobe. *Schweiz. Archiv Angew. Wiss. Tech.,* **33,** No. 1, 22-34 (1967).

The diffusion processes which occur in joints made with brazing materials and solders were studied with an electron microprobe. Nine brazing filler materials and solders were joined with base materials of steel, copper and brass, and 24 metal systems were studied. An iron phosphide layer (Fe_2P) was formed between steel and a copper-phosphorous filler material and a 50- µ wide brittle diffusion band was formed between β -brass and steel. The coefficients of diffusion are tabulated for 7 of the systems.

O Yu Krug: Determination of the technological characteristics of the bloomery process from the examination of the slags found. *Sov. Arch.* 1970 **1,** 268-273 (In Russian).

An attempt is made to solve the problem of reconstructing the smelting techniques (hearth design, use of flux etc) by a mathematical treatment of petrographic data (phase analysis) of slags obtained as a result of carefully planned experiments. The results were compared with slags from the excavations at Novgorod from which it was concluded that no flux was used and that tapping of slag occurred three times late in the process.

G F Carter: Ancient coins as records of the past. *Chemistry,* **39,** No.11, 14-19 (1966).

X-ray fluorescence analysis is described simply. Since certain elements are preferentially removed from the surface by the environment, it is necessary to remove surface oxides before obtaining accurate analyses by x-ray fluorescence.

U Zwicker; D Hedrich; E Kalsch and B Stahl: Examinations on the Plating of Ancient Coins by Metallography, Spectral Analysis and x-ray Microfluorescence Analysis. *Der Munzen- und Medaillensammler (Berichte),* **8,** No. 43, 371-80 (1968).

Evidence is given that for the plating of coins from the 4th to the 1st century before Christ no solders were used. The connection between the plating and the coin obviously was effected by alloying due to overheating.

Sassanidian coins (6th to 7th century AD) have been plated by the use of copper rich solder.

Wilhelm P Bauer: Unusual cases of corrosion of gold-copper-silver alloys – examination and intepretation. *Osterreich. Zeitschrift fur Kunst und Denkmalpflege,* pp 115-123.

Microscopical and chemical examination of "Tumbaga" objects combined with a study of the ethnographic sources lead to an interpretation of this unusual corrosion phenomenon due mainly to a particular technique of decoration.

Adrienne R Weill: Critical analysis of the service of ancient metals to history. *Archaeological Chemistry, papers presented at a symposium sponsored by the Division of the History of Chemistry, American Chemical Society, Atlantic City, NJ,* September 1962, edited by Levey, M., 313-46 (1967).

Nondestructive analysis of ancient coins was performed by using x-ray radiography, x-ray fluorescence spectroscopy, and x-ray diffraction analysis. Cu based bronzes and Ag based alloys can be easily distinguished. Dimensions of the unit cell helped to distinguish between the alloys of Ag-Cu-Sn. Minor constituents, eg. Fe, Ni, Zn, Sn, Sb, and Pb, were determined semiquantatively and the results were correlated to the art of making the alloys in ancient times.

BIOGRAPHY

Harry Brearley, 1871-1971. *Stainless Steel,* 1970-71, 17, 2; and 1971, 19, 18).

A very short account on the centenary of the birth of one of the discoverers and commercial exploiters of stainless steel. The second account repeats some biographical detail in what is mainly a note about an exhibition in commemoration of his work.

Founder of the stainless steel industry. *Steel Times,* 1971, **199**, (4), 367-368 .

Another short account of the life of Harry Brearley.

E Elliott: Harry Brearley, born 1871. *Metallurgia,* 1971, **83**, (499), 145-147.

Brief biography of the man responsible for the first successful commercial exploitation of stainless steel.

MISCELLANEOUS

C J Evans: Bronze cannon. *Foundry Trade J.,* 1971, **131**, (2861), 467-470.

The development of cast bronze guns is outlined, using exhibits in the museum of the Royal Regiment of Artillery at Woolwich as examples. From the 15th to the 18th centuries in Europe, guns were cast muzzle upwards, metal being poured into an open mould with feeder head on top. The alloy used was generally 90% Cu, 10% Sn, and a clay core, stiffened with an iron bar, formed the bore. In 1739 vertical boring was introduced in Germany.

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