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Sir William Siemens 1823 - 1883

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Contents

The cover illustration is of **Sir William Siemens** who died one hundred years ago last November, and who made a momentous contribution to both ferrous and non-ferrous metallurgy.

As a tribute in the centenary year, our President, Dr Kenneth Barraclough, wrote the article which appears opposite, for the British Steel Corporation's *Sheffield Laboratories Newsletter*. It is reprinted with the kind permission of BSC.

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Sir William Siemens 1823-1883

K C Barraclough

Sir William Siemens died on 19th November 1883. The intervening hundred years has been a period of ever accelerating change in technology but, as far as steel-making has been concerned, it is really only in the past twenty years that the Open Hearth furnace, which owed its origin to this remarkable man, has been superseded as the major source of the world's steel. It seems appropriate, then, to mark the centenary of his death with a re-appraisal of his contribution to the steel industry.

He was born as Karl Wilhelm Siemens, near Hanover in 1823 the seventh of fourteen children, born to a German farmer. His oldest brother, Werner, was destined to found the firm of Siemens and Halske in Berlin and it was he who arranged for Karl Wilhelm to be trained in science at the University of Gorringen prior to becoming an engineering apprentice at the works. At the age of twenty he came to England to sell an electroplating process which his brother had invented; the process was in fact purchased by Elkingtons of Birmingham and this was to be largely responsible for the demise of the so-called Sheffield plate.

The following year he came back to England; as it turned out, he was to stay here for the rest of his life. By 1845 he was in Manchester and was learning the new science of thermodynamics from Joule. Two years later his younger brother, Frederick, joined him here and together they applied their energies to making improvements in furnace efficiency. By 1856, William Siemens as he was now known had become a British citizen and was working as an engineering consultant in London, making a serious study of the regenerative principle for combustion in furnaces. This method of preheating the combustion air followed naturally from Nielson's application of hot blast in the coke fired blast furnace. The idea of passing the combustion gases through a chamber containing firebrick chequerwork to absorb their heat and then reversing the air flow so that it became pre-heated prior to combustion of the fuel, the spent gases then passing through the second regenerator so that on further reversal the process could be repeated at the other end of the furnace chamber was patented by Frederick Siemens in 1857. Using solid fuel, however the ash carried in the flue gas deposited in the chequer work and choked the flow; this was difficult to clean out and so the efficiency, originally much improved with hotter combustion flame, soon fell. By inventing the gas producer (Fig 1) it was possible to convert the coal into a relatively dust-free gaseous fuel. Now the regenerative furnace would work effectively, particularly if two sets of chequer work were provided at each end, one to preheat the air and the other, a smaller one, to preheat the gas, both fitted with reversing valves. Such an arrangement was patented by the two brothers in 1861.

In the interim, regenerative furnaces had been introduced for the reheating of billets for rerolling, in the iron trade at the Wednesbury works of Lloyd and Foster and at the steel-works of Marriott and Atkinson in Sheffield. Siemens was, however, already looking at more ambitious projects – at the iron puddling process and at the actual steelmaking operation.

Using his gas-fired furnace, and Siemens pointed out that this allowed the cheapest of coal slack to be used as fuel – it was possible to provide a reliable installation capable of maintaining temperatures of the order of 1650°C, earlier problems with firebrick refractories having been overcome by the use of the newly available Dinas silica brick. The first commercial unit was destined to be installed as a glass-melting furnace at Chance Brothers' works in Birmingham. Here it was that Siemens met Michael Faraday, who was sufficiently impressed with what he saw to invite Siemens to give a lecture at the Royal Institution. This was in 1862. Siemens reported on the current use of regenerative furnaces in the glass industry, and in the metal working trades as applied to the reheating of billets and ingots for rolling. He also drew attention to modifications to puddling furnaces at the works of Gibbs Brothers at Deepfields, and of Richard Smith at the Round Oak; these had been installed under the supervision of his brother and were showing promise – in retrospect, it would seem, this promise was not fulfilled. He had to confess that another important application of the regenerative furnace – in steel-making – was in course of application at the Brades Works near Birmingham but had so far failed to succeed in Sheffield where it had been tried previously. His drawing of a proposed steel furnace, Figure 2, showed a regeneratively fired chamber with a flat hearth carrying some twenty steel-making crucibles; the chamber was covered by a number of removable lids to allow crucibles to be placed and with-drawn.

This type of equipment was, however, soon to succeed and came into increasing use in Sheffield, the home of the Huntsman type coke fired furnace which it partially replaced – but only partially, since there was considerable prejudice in favour of the old established way of doing things as well as considerable capital tied up in existing plant. It eventually found more favour in America, particularly in the Pittsburgh area where Sheffield type establishments sprang up in the years following the Civil War, largely run by Sheffield born personnel in the first instance but willing to accept new developments more readily than where the tradition had been born.

It is interesting to note that the River Don Works built as the largest single crucible steel-works in the world in 1863, was originally designed to have 384 double crucible holes of the old Huntsman type. By 1867, however, some half of this capacity was gas fired using furnaces of the Siemens type. The changes in technique which occurred over this period are intriguing. The original crucible process as developed by Benjamin Huntsman in the 1740s melted blister steel bar, produced from Swedish bar iron by the cementation process. Its function was, indeed, to refine the only steel then available. This technique was to be used for a hundred years. By 1860, however, it had become quite usual to employ charges made up from suitable mixtures of Swedish white cast iron, the proportions being adjusted to give the desired carbon content in the melt, without recourse to the time consuming and productivity inhibiting cementation process. It had been suggested as early as 1800 that all that was needed was to mix charcoal with the bar iron in the crucible and melt the two together to give the desired steel. At this time, however, there were difficulties of a practical nature. The bar iron did not melt until a temperature of over 1500°C was reached; if this was achieved, the charcoal would then be taken into solution, but the wear and tear on the furnace due to the extra heat required and the longer time taken for the melts could not be endured. So the original course of re-

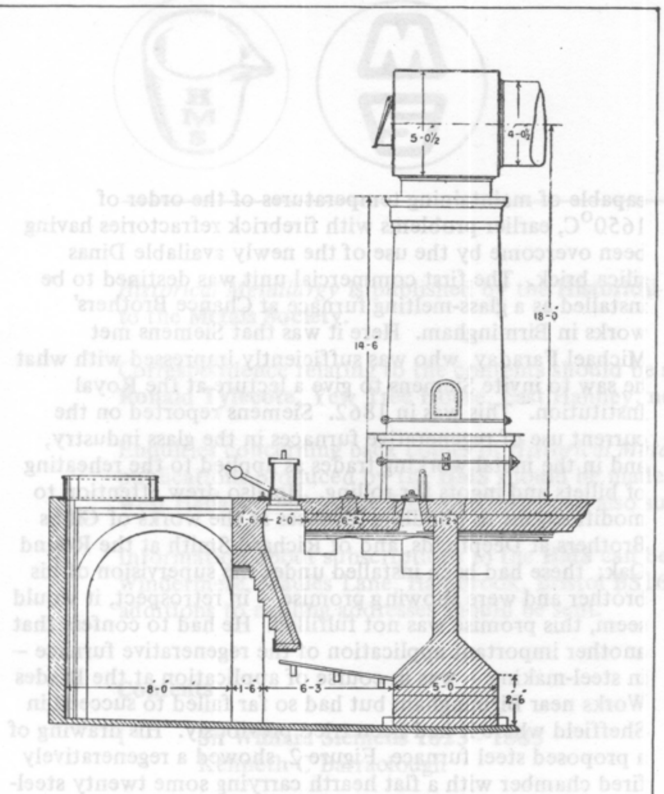

Fig 1 Siemens Gas Producer c1860

melting the blister steel, which by reason of its inherent carbon content had a melting point some 50 - 100°C lower than that of the bar iron from which it was made, was resumed. Following the release of the Swedish cast iron to the Sheffield market in 1855, it was realised that charges containing this material would start to melt at 1200°C and that as the temperature rose the bar iron added with it to the crucible would progressively melt into it; this was a very practical solution to the problem. With the advent of the gas fired furnace, however, coupled with the use of the more heat resisting Dinas brick, higher temperatures could be achieved and withstood by the furnace lining; in their gas fired furnaces, Vickers at River Don Works made their steel from bar iron and charcoal; their only concession was to use crucibles which had a proportion of graphite incorporated into the more normal clay mixture. Such crucibles would withstand the more onerous conditions in the gas fired furnace better than the conventional 'white pot' used in the coke fired furnaces. One further point is worth making in connection with the type of charge put into the crucibles at this period – the incorporation of a proportion of good quality scrap, generally from crucible steel production, with the main charge was becoming more and more standard practice, whichever process was being used.

Such, then, was the situation as regards crucible steel melting, originally the only method available for producing liquid steel. Since about 1860, however, the Bessemer process had been finding increasing application. It did not function as a replacement for crucible steel, which in any case was too expensive for general purposes, but as a new development, producing a cheaper general purpose material,

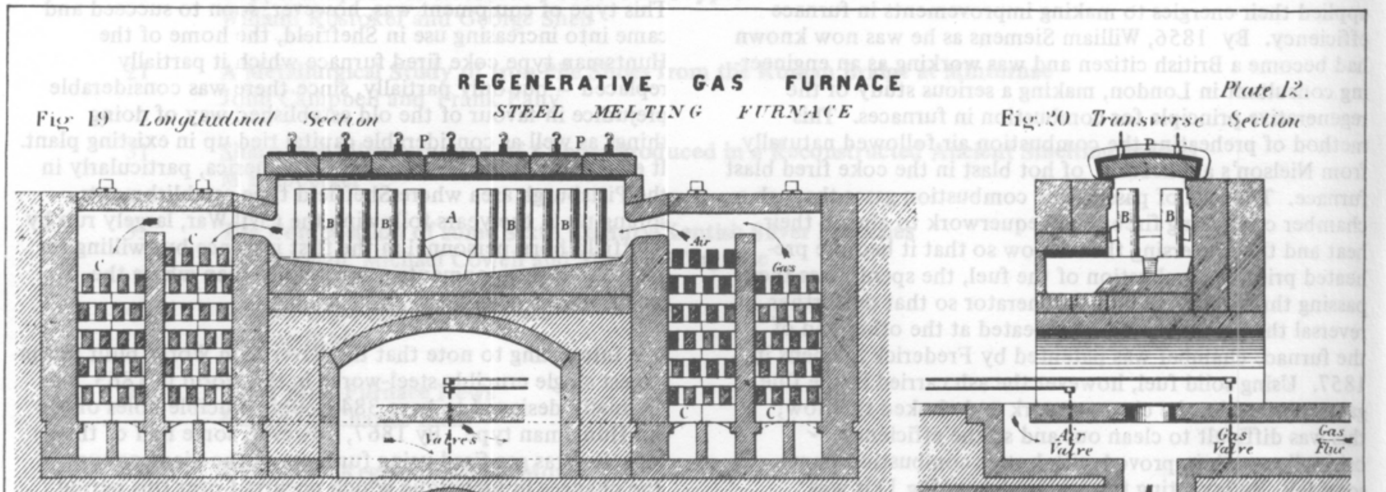

Fig 2. Regenerative Gas Furnace for Steel Melting – 1862

used more as a replacement for wrought iron and particularly where a stronger material had advantages. A good example was the production of rails for the expanding railway networks all over the world. Here the old Sheffield crucible steel-makers – such as John Brown and Charles Cammell – found a new market and, for about a dozen years in the 1860s and early 1870s, something like 50% of the total world output of rails, previously made from wrought iron, came from Bessemer converters and rolling mills specially erected in the Sheffield area for this purpose.

There was obviously a need for steel of this type and it was this market that William Siemens had his eye on. His thinking, clearly, was that, since the raw materials could be melted in crucibles on his regeneratively heated hearth, could they not be melted in bulk on the hearth itself? His first partial success came with his collaboration with Charles Attwood at Tow Law in County Durham in 1862. Here cast iron and wrought iron, from the Weardale ores, were melted together on the open hearth of a fixed furnace with roof and walls made from silica brick and a hearth made from fritted white silica sand on a foundation of high quality firebrick. The proportion of cast iron was varied according to the final desired carbon – just as in the modified crucible process – and 'cullet', or broken glass, was added to give a protective cover or slag above the molten metal. A proportion of steel scrap, when available, was also added. When molten, the metal was run out into a ladle by breaking open a tap hole leading from the lowest part of the hearth. The metal was then poured into ingot moulds or run into sand moulds to provide steel castings. Whilst basically this is the process which was to continue almost unchanged for many years, the operations at Tow Law only ran for a short period; it must be presumed that there were difficulties in this early experimentation.

The process was also taken up in France, by the two brothers Emile and Pierre Martin at Seraing. Here the original process was to melt cast iron on to the open hearth, then to melt in scrap iron, steel scrap, or preferably, puddled balls; these additions were often pre-heated to ease their solution in the metal bath. An important part of the process was the use of a fluid slag cover, made up by adding blast furnace slag to the cast iron in the furnace. When all the metal was molten, half of it was run off and cast; more cast iron, scrap and puddled balls would then be added and the process repeated. In this way the furnace could be kept going continuously for a week or more.

Eventually, however, the product of such a process proved too variable and a batch process was evolved. A description of this has survived, using a Siemens type furnace with a

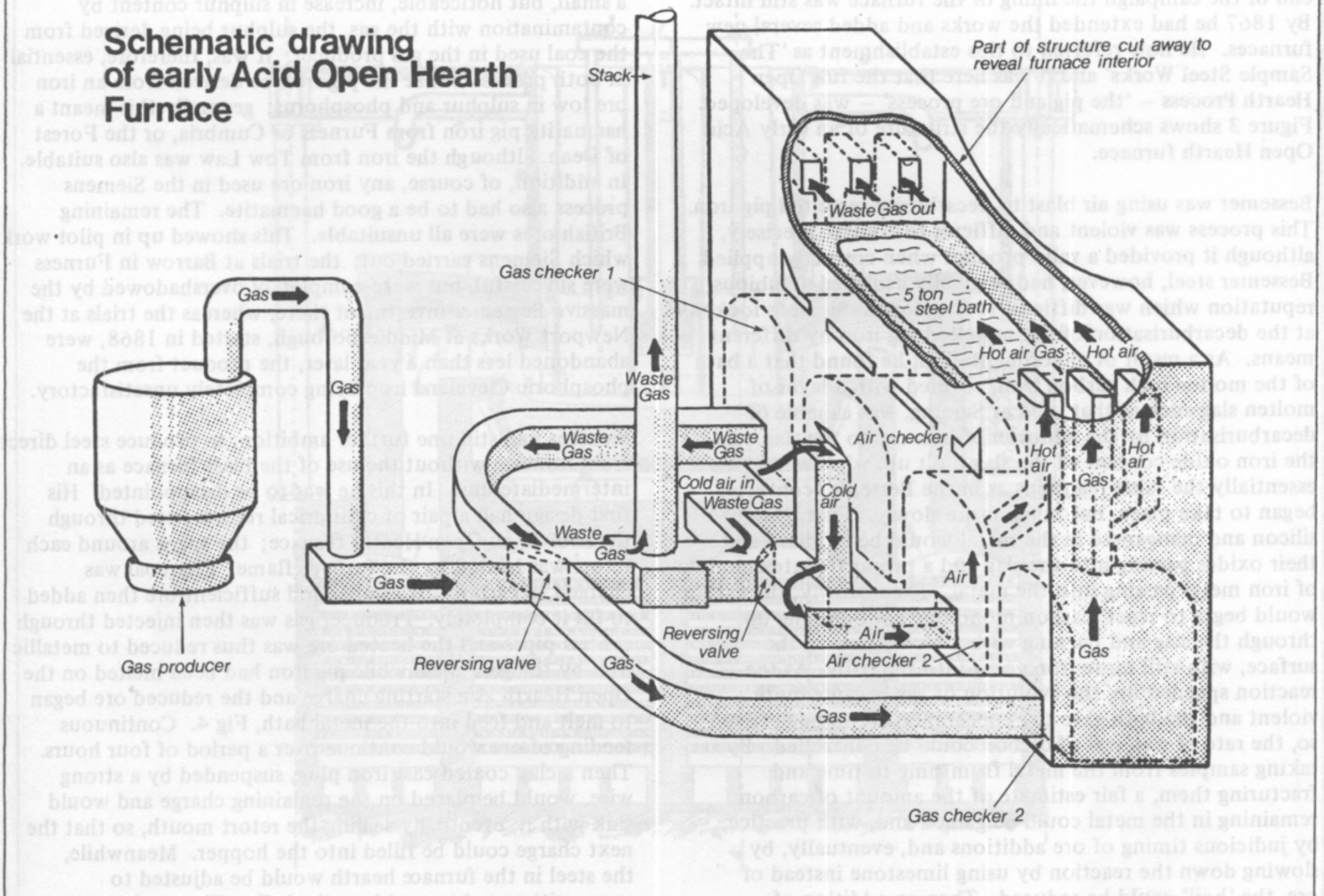

Fig 3. Early Open Hearth Furnace
(Iron & Steel Special Issue 1969)

capacity of 4000 lb. The initial charge was 700 lb of cast iron to which, when molten, successive batches of around 200 lb of puddled steel or iron were added, these having been pre-heated. After the second of such additions, the black oxide scum which had formed was raked off and a cover provided by adding sufficient blast furnace slag (specified as having been derived from a charcoal fired furnace) mixed with its own weight of pure sand. The addition of further batches of 200 lb or so of steel scrap or puddled balls continued until the furnace was full. Then, after testing the 'temper' of the metal (that is, judging the carbon content by examining the fracture of a sample taken from the furnace), a suitable addition of cast iron was made to bring up the carbon to the desired level and the metal run out into the ladle and cast into ingots. It was reported that twenty-four 'fusions' (the Sheffielder called them 'heats') could be made per week, but that it was necessary to have two furnaces since repairs were needed after every 10 or 12 fusions. The metal loss was of the order of 10-12%. This, then, was really the first commercially successful process for steel-making using the regenerative furnace and it came in 1864. It was to become known as the Siemens Martin process or the 'pig and scrap process' as applied to Open Hearth steel-making.

Meanwhile, Siemens had been considering further ideas on steelmaking and, in order to investigate their feasibility he took over a small works in Birmingham in 1865. From a small furnace he built there, he soon reported a five week campaign, making soft steel for wire, at a cost less than Bessemer's and with a superior quality. Moreover, at the end of the campaign the lining of the furnace was still intact. By 1867 he had extended the works and added several new furnaces. He now referred to this establishment as 'The Sample Steel Works' and it was here that the full Open Hearth Process – 'the pig and ore process' – was developed. Figure 3 shows schematically the structure of an early Acid Open Hearth furnace.

Bessemer was using air blast to decarburise remelted pig iron. This process was violent and difficult to control precisely, although it provided a valid product when correctly applied. Bessemer steel, however, had originally acquired a dubious reputation which was difficult to live down. Siemens looked at the decarburisation of the remelted pig iron by different means. As a result of experimentation, he found that a bath of the molten high carbon iron, covered with a layer of molten slag such as that used at Seraing, was capable of decarburisation by the addition of iron ore to the slag. As the iron oxide content of the slag built up, what were essentially the same reactions as in the Bessemer converter began to take place, but much more slowly. First, the silicon and manganese in the metal would be oxidised and their oxides passing into the slag and a proportionate amount of iron metal passing into the metal. Then, slowly, the carbon would begin to react, carbon monoxide gas bubbling up through the slag and burning with a blue flame on the surface, with still more iron going into the bath. As the reaction speeded up, the evolution of gas became quite violent and the bath gave the appearance of 'boiling'. Even so, the rate of removal of carbon could be controlled. By taking samples from the metal from time to time and fracturing them, a fair estimate of the amount of carbon remaining in the metal could be gained and, with practice, by judicious timing of ore additions and, eventually, by slowing down the reaction by using limestone instead of ore, the 'boil' could be reduced. Then an addition of 'spiegeleisen' – a manganese rich cast iron – could stop the boil completely. Using a final sample, the amount of pig iron which was needed to bring the carbon back to the desired level in the final metal could be calculated and, after melting this in, the metal could be run out of the furnace into the ladle. Alternatively, instead of using the final addition of pig iron, the metal could be run out and charcoal or anthracite could be thrown into the stream as the metal entered the ladle.

This was a much more controllable process than the Bessemer method, where everything was burned out and the situation then rapidly corrected by strong deoxidation and recarburisation. It had in it the basis of quality steel-making. Moreover, as against the 10% loss in metal weight in the Bessemer process, Siemens recovered iron from the iron ore and showed an overall gain in yield over the weight of the pig iron charged. At this stage, Siemens felt the need for larger premises and in 1868 he moved to Landore in the Lower Swansea Valley. By mid-1869, he was producing 75 tons of steel per week there and it is clear from his later papers that it was 'the pig and ore process' which he was using.

One point should be made clear at this stage. The furnaces used by both Bessemer and Siemens were constructed using siliceous (or 'acid') linings, since firebrick, silica brick, silica sand and ganister were virtually the only materials available to them. This meant that the slag had to be compatible with the lining; it had to be rich in silica (an 'acid' slag). It meant further that the two most detrimental elements as far as the steelmaker is concerned – sulphur and phosphorus – could not be removed during the steelmaking process; indeed, in the Bessemer process their level tended to increase by concentration since a certain proportion of the metal was lost by oxidation, whereas in the Siemens process there was a small, but noticeable, increase in sulphur content by contamination with the gas, the sulphur being derived from the coal used in the gas producer. It was, therefore, essential in both processes that the pig iron be derived from an iron ore low in sulphur and phosphorus; generally this meant a haematite pig iron from Furness or Cumbria, or the Forest of Dean, although the iron from Tow Law was also suitable. In addition, of course, any iron ore used in the Siemens process also had to be a good haematite. The remaining British ores were all unsuitable. This showed up in pilot work which Siemens carried out; the trials at Barrow in Furness were successful, but were completely overshadowed by the massive Bessemer investment there, whereas the trials at the Newport Works at Middlesborough, started in 1868, were abandoned less than a year later, the product from the phosphoric Cleveland iron being completely unsatisfactory.

Siemens had still one further ambition: to produce steel direct from iron ore without the use of the blast furnace as an intermediate unit. In this he was to be disappointed. His first design had a pair of cylindrical retorts fitted through the roof of an Open Hearth furnace; the space around each retort was heated by the furnace flame. Charcoal was charged to each retort hopper and sufficient ore then added to fill it completely. Producer gas was then injected through central pipes and the heated ore was thus reduced to metallic iron by the gas. Meanwhile pig iron had been melted on the Open Hearth as a starting charge and the reduced ore began to melt and feed into the metal bath, Fig 4. Continuous feeding of ore would continue over a period of four hours. Then a clay coated cast iron plug, suspended by a strong wire, would be placed on the remaining charge and would sink with it, eventually sealing the retort mouth, so that the next charge could be filled into the hopper. Meanwhile, the steel in the furnace hearth would be adjusted to composition and tapped into the ladle. The results were not particularly encouraging. Nevertheless Siemens persisted. The following year he patented a rotating reduction furnace Fig 5, in which ore and carbonaceous matter were mixed and heated with producer gas, the product being allowed to discharge into the Open Hearth furnace below, which again contained a small bath of remelted pig iron. This process was in fact tried out on a semi-commercial scale in a plant erected at Towcester and gave some usable material, but the product was erratic and the costs were high.

Anyone studying these patents, and particularly the detailed drawings attached to them, will be in no doubt of the genius of the inventor. Their bearing on the direct reduction processes of the last thirty years cannot be gainsaid. As it so came about, contemporary improvements in blast furnace efficiency, the utilisation of scrap which became more and more plentiful and the eventual deployment of liquid metal straight from the blast furnace brought about economies which made the more complex processes suggested by Siemens unnecessary. This in no way, however, detracts from his firm grasp of principle and his mastery of engineering, even though he was too ambitious given the state of technology of his time.

The first full scale commercial application of Siemens' Open Hearth steelmaking process in these islands arose as a result of investigations with rather a different intention.

Charles Tennant, the chemical manufacturer at the St. Rollox Works in Glasgow, had for years been using pyrites as a raw material in the production of sulphuric acid. The sulphur was removed by roasting and it was good economics to extract the residue to recover the copper contained in it. The waste product, known as 'Blue Billy', was mainly iron oxide and, by 1870, there were thousands of tons of this dumped near the St. Rollox works. Tennant enquired of Siemens whether this could be used in steelmaking. After some preliminary experiments Siemens considered he was on the road to success with the project and it was agreed therefore, for a full scale steelworks to be built and, previous to the full process being developed to use the Blue Billy, to make steel by the conventional process. Siemens' subsequent experiments were inconclusive but the plant was so successful with the pig and scrap process that Blue Billy was eventually forgotten. In this way, the Steel Company of Scotland set up the Hallside works, starting with four 6-ton Siemens furnaces in 1873. Within a year, there were eight furnaces, producing at the rate of 18,000 tons per annum.

By now the quality of Open Hearth steel was beginning to be appreciated. In 1875 the Chief Naval Architect of the Royal Navy challenged the steelmakers to produce a thoroughly reliable material that 'could be worked up without fear or trembling'. Siemens, from his Landore Works, took up the challenge; his general manager, James Riley read a paper to the Institute of Naval Architects the following year

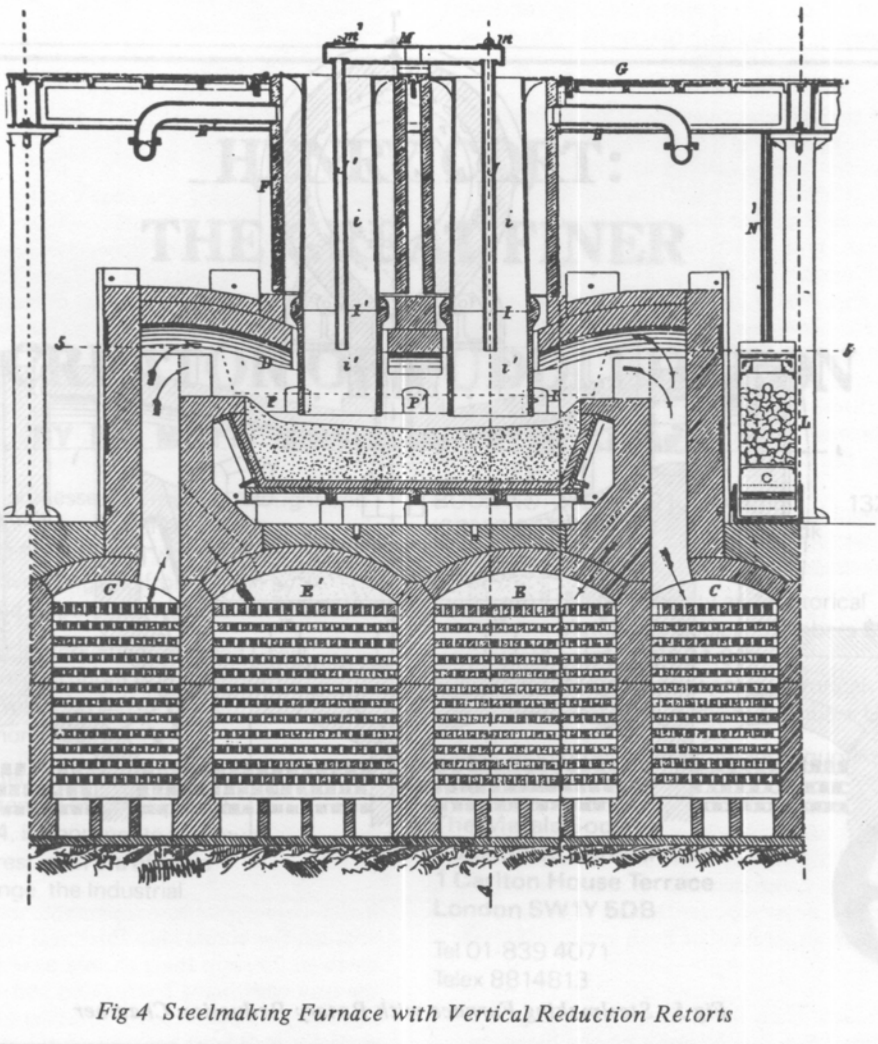

Fig 4 Steelmaking Furnace with Vertical Reduction Retorts

proving the quality of Open Hearth steel and indicating its production capabilities, should the demand arise. In 1877, Lloyds agreed to a reduction in weight of 20% for steel plate as against wrought iron plate. The use of steel in shipbuilding in the years that followed gave a real boost to Siemens Open Hearth production.

Up to this time, the Sheffield steelmakers had used crucible steel for any particularly important ingot for forging – heavy ordnance items, for instance. This might seem surprising, since the weight of metal per crucible was limited to some 60 or 70 lb. But there had been evolved a multiple pouring technique, whereby the contents of several hundreds of crucibles, all made ready at one time, were poured in rapid succession into a tundish situated over an ingot mould set below floor level, the whole operation being programmed so that a constant stream of metal issued from the tundish nozzle into the mould. Ingots of up to 25 tons in weight were fairly frequently made in this way, one at River Don works requiring 672 crucible melts poured within half an hour. This obviously, was a process crying out for simplification, but since only crucible steel was considered good enough, there was no alternative. With growing confidence in the Open Hearth process, however, there was a gradual move away from crucible steel. So it was that John Brown installed Open Hearth furnaces to make forging ingots in 1879. Firths, Cammells and Jessops followed his lead over the next few years and the use of the Siemens Open Hearth process, the pig and scrap process, operated in acid lined furnaces, just as Siemens had originally perfected back in the 1860s, became the basis of the Sheffield heavy forging industry and was to remain so for the first sixty years of the twentieth century.

In 1879, by which time the Siemens process had been adopted by some 28 British steelmaking concerns, with a joint output of the order of 200,000 tons per annum – as against about four times this amount from the Bessemer converters – there came an invention which was to change the whole picture of steel production. This was the development of what came to be known as 'basic steel-making' by S G Thomas which was to make the phosphoric ores available for steel. Originally applied to the Bessemer process, which spread rapidly both in America and in Europe (where, incidentally, it became known as the Thomas process), it was equally applicable to the Open Hearth process. From a slow start in the 1880s, Basic Open Hearth steelmaking was destined to overtake the Bessemer production and to become the major source of the world's steel until the advent of the basic oxygen processes from 1960 onwards.

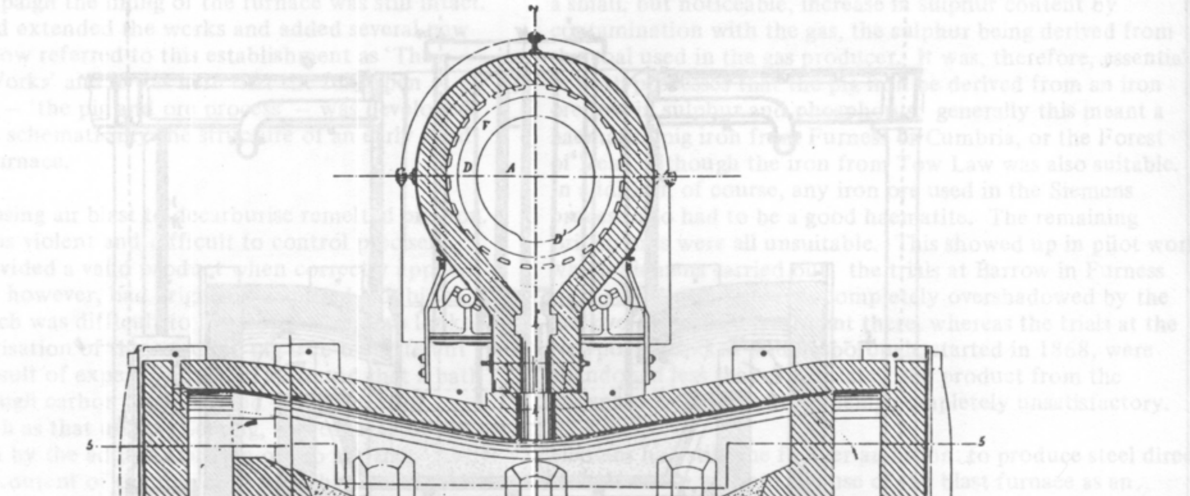

Fig 5. Steelmaking Furnace with Rotary Reduction Chamber

The genius of William Siemens was recognised during his lifetime and it must have been most gratifying to him to receive the Bessemer Gold Medal from the Iron and Steel Institute in 1875. Two years later he became President of that Institute. He was knighted in 1883. In view of this, the officials and workmen at Landore prepared an illuminated address, enclosed in a model of an Open Hearth furnace, with the brickwork in ivory and the remainder in Siemens steel. Alas, he was not to receive this expression of their affection, since the new knight died suddenly just prior to the date planned for the banquet. His widow – he had married Anne, sister of Professor Gordon of Edinburgh, in 1859 – received the testimonial. She commented that he would have valued it more highly than the honour it was intended to mark.

One hundred years ago, then, ended the career of a most remarkable man whose legacy to the engineering world was a steelmaking technique so versatile that it could provide ingots for forging to guns, ship propeller shafts or boiler drums, for rolling into ship plate, beams and girders – or into sheet for galvanising or billet for drawing into wire; it could make mild steel, or high carbon steel for file manufacture or alloy steel for highly stressed components; it could operate in small 5-ton units for providing the metal for castings, in 50 to 100 ton furnaces for making forging ingots or in huge 350 ton tilting furnaces for the bulk production of cheap but serviceable steel; it could operate on carefully selected materials with acid linings to produce high quality steel or in basic lined furnaces give the bulk steel needed for the expanding economies around the world. Twenty-five years ago these furnaces were a practical testimonial to Charles William Siemens, the farmer's son from Germany who made our country his home and whose genius ensured him a place alongside that of Bessemer; between them they made the expansion of engineering technology possible by making steel, that remarkable metal, available in the quantity in which it was required at a price at which it could be afforded. Bessemer was an inspired inventor; Brearley commented that 'Bessemer conceived an idea which would never have entered a steel-maker's head – the idea worked, but it was an amazing piece of indiscretion to assume that it would lead to anything but failure'. Siemens, on the other hand, was a trained engineer; in the end he overtook Bessemer. At this late date, however, both processes have been superseded and neither of them can be seen in action in this country. Indeed, there is a Bessemer converter erected as a museum exhibit at the Kelham Island Museum in Sheffield but efforts to preserve a Siemens furnace have, more is the pity, failed. Now, therefore, there is no tangible legacy to the outstanding figure in the steelmaking world in Victorian times. Perhaps he would like it to be remembered that one obituary referred to his home as 'the rendezvous of all that was great in science, art and literature'.

Further examination of cutting tip from cannon-boring tool

E M Trent and E F Smart

A paper by D S Butler and C F Tebbutt in 1975[1] describes a 17th century cannon-boring bar from a water-powered iron-working site in Sussex. Attached is a report from Dr R F Tylecote on a metallurgical examination of one of the cutting bits from this bar. Because of its importance in the historical record of metal cutting tools Dr Tylecote kindly lent the polished section of the cutting bit for further metallurgical examination. The details are given here but it is worthwhile to consider first the mode of action of the tool and the operation performed.

Fig 2, from the paper by Butler and Tebbutt, is a sketch of the boring tool. The wrought iron bar, octagonal in section, is approximately 65 mm across and 3.53 m long. The cutting head, is integral with the bar and approx 105 mm dia. In the head four radial slots were formed at right angles in which the cutting bits or teeth were wedged using shims. The maximum diameter across the teeth would have generated a hole about 135 mm dia. It is not possible to be more accurate about these dimensions because of corrosion. Although the cutter was 'in surprisingly good condition' considering its nearly 300 years buried in soil, it had to be cleaned of corrosion product by electrolytic treatment for two months. Because of the rust and the cleaning treatment some caution is necessary in defining the precise shape and size of the cutter.

The cutter is similar in character to some of those described by Biringuccio in 'Pirotechnia'[2] (Fig 1). He says 'if one wishes to make a steel borer for boring cannon or double cannon, it would be difficult to make it so that it would keep an exactly square shape, be stable at the end of an iron shaft and have good corners. It would be difficult to make it and to heat, temper or sharpen it on the wheel because it is too large a mass. To do this one makes a round block of bronze a little smaller than the diameter of the ball'. (The cannon ball). 'In this are put four or at most six grooves that are shaped at the bottom like a swallow's tail. The four well-tempered sharpened steel knives are fitted in these'. He then describes how this bronze tooling head is bolted to a wooden or iron shaft to form the boring bar.

The use of an iron head integral with the shaft is a modification but otherwise the tool is similar to the description and illustration in 'Pirotechnia' the first edition of which was in 1540. Butler and Tebbutt suggest that the Sussex bar was made and in use about 1650 to 1664. Biringuccio refers to the boring of bronze cannon but it was cast iron cannon which were bored by the Sussex bar. The methods of operation were probably similar and Biringuccio has useful information about this also. Having described the mould manufacture, extraction of the gun from the mould and drilling of the hole for 'introducing fire' into the gun, he writes ' . . . the guns can be called finished if the hollow inside where the ball is to pass has been perfectly cleaned of bronze or clay. But for greater caution, for beauty and safety of the gun, and to make sure that it achieves its purpose of shooting with perfect accuracy, gentlemen – soldiers or master gunners – began to desire that both small and large ones should be bored . . .'.

Biringuccio makes it clear that, in his day, the boring of cannon was an 'optional extra' – to clean up the barrel and not to remove a large amount of material. Sometimes he repeated the boring two or three times, increasing the diameter by 'a thread if not more'. The thickness of the layer removed in boring was thus very small. This method, as far as is known, continued to be used in the 17th century. It was not until the 18th century that the superior accuracy of cannon bored from the solid brought this method into use.

Biringuccio's drawings show the boring tool directly driven by a wheel (a tread mill, a horse driven mill or a water mill).

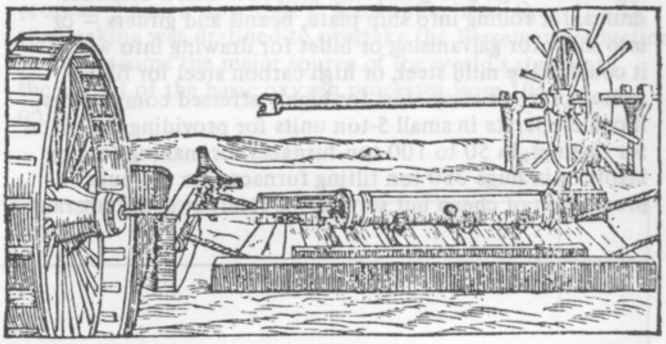

Figure 1. Drawing from Biringuccio captioned: Machines for boring guns

The cutting speed was directly related to the speed of the mill wheel and the diameter of the cutter. With the water mills the speed could have been about 10 rpm giving a cutter speed of just over 2m/min. The gun is shown strapped to a sort of sledge which was drawn onto the boring bar by a windlass operated by one or several men. The feed was regulated by the pressure exerted by the windlass, and this suggests that the feed was very low.

The shape of the boring bar head and the profile of the cutting bits are shown in the sketch (Fig 2) and in the photograph given by Butler and Tebbutt[1]. There is a considerable taper from the leading edge to the rear of the cutting bits such that the diameter at the rear of the cutter was about 6 to 8 mm larger than at the leading edge. It is very likely that the layer removed during boring was no thicker than 3 to 4 mm and, therefore, that the cutting was done entirely by the side cutting edges of the bits, the front edges not being involved in cutting and not necessarily being shaped to act as cutters. Because the tool shape has been altered by corrosion and the cleaning treatment, it is not certain that the taper of the cutters was the original shape but this seems very likely and it is proposed that cutting took place as shown diagrammatically in Fig 3. This is in fact a reaming rather than a boring process since there is a multi-toothed tool taking a light cut to improve the accuracy of the hole.

If this is accepted as a reasonable model of the boring process, the actual chip thickness was very small and, at the speed of 2m/min there should have been little problem with the tool edge being overheated and softened as long as it was sharp. Tool wear by abrasion of entrapped sand particles may have been more of a problem, particularly with such a small feed and depth of cut.

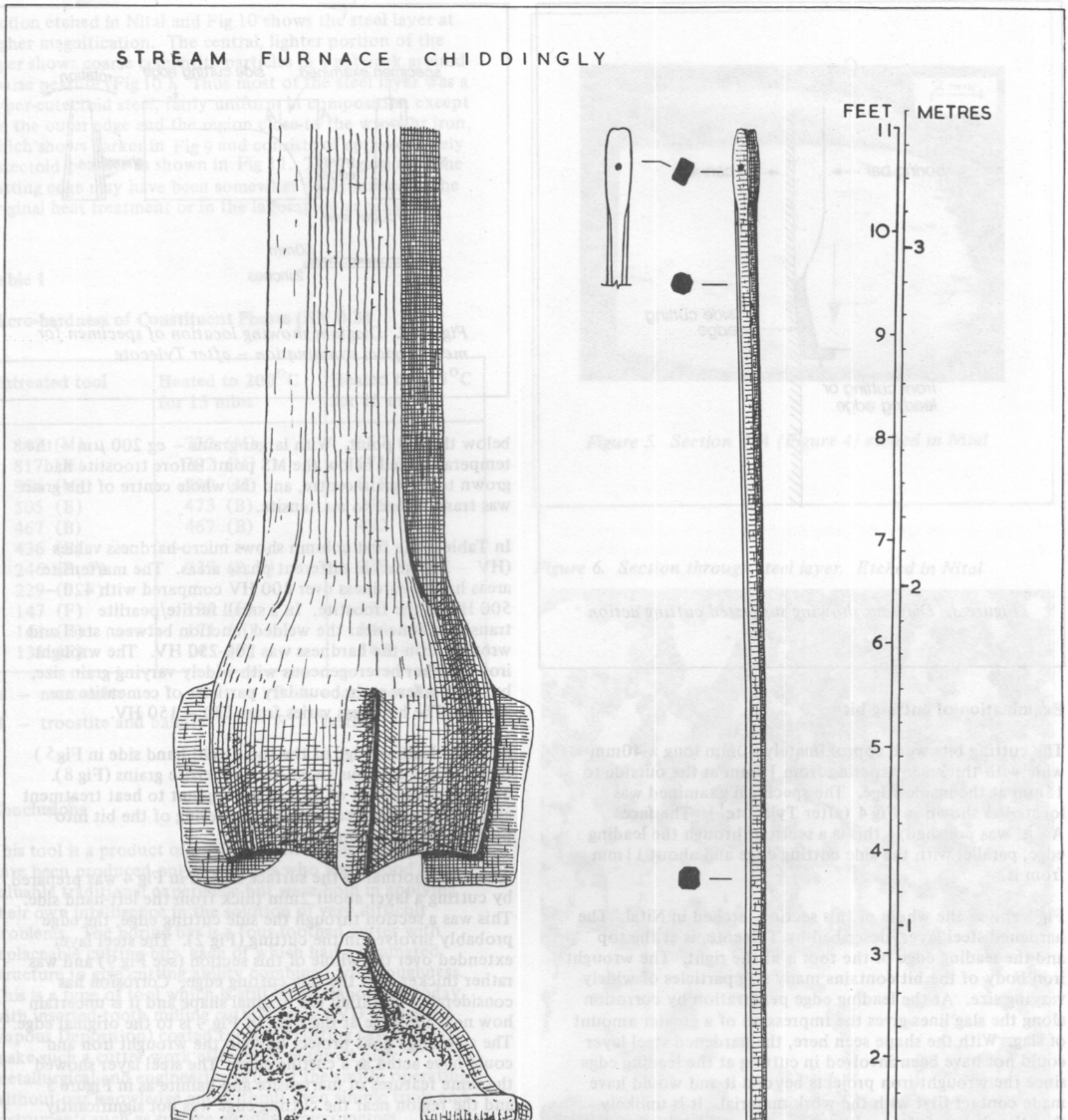
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Figure 2

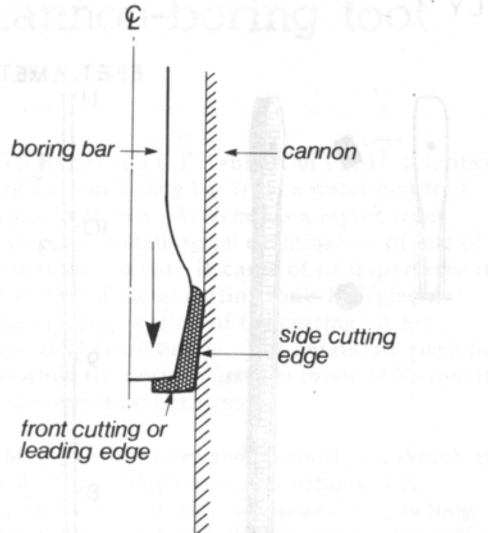

Figure 3. Diagram showing suggested cutting action

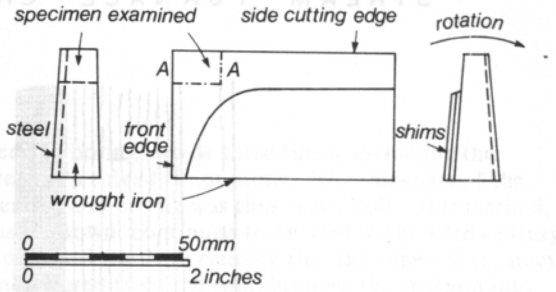

Figure 4. Diagram showing location of specimen for metallurgical examination – after Tylecote

Examination of cutting bit

The cutting bits were approximately 70mm long x 40mm wide with thickness tapering from 10mm at the outside to 15mm at the inside edge. The specimen examined was located as shown in Fig 4 (after Tylecote[1]). The face A - A' was polished – this is a section through the leading edge, parallel with the side cutting edge and about 11mm from it.

Fig 5 shows the whole of this section, etched in Nital. The hardened steel layer, described by Tylecote, is at the top and the leading edge of the tool is at the right. The wrought iron body of the bit contains many slag particles of widely varying size. At the leading edge penetration by corrosion along the slag lines gives the impression of a greater amount of slag. With the shape seen here, the hardened steel layer could not have been involved in cutting at the leading edge since the wrought iron projects beyond it and would have made contact first with the work material. It is unlikely that the shape of the tool has been so completely altered by corrosion.

In the carburised steel layer the white parts are martensite and wide variations in structure are obvious in Fig 5 and in Fig 6 at higher magnification. The slag inclusions show the origin of the steel as carburised wrought iron. Martensite is present as isolated patches up to 200 μm across, the darker areas being troostite (fine pearlite) and bainite. Fig 7 shows the martensite areas with troostite (fine pearlite) and bainite nucleated at grain boundaries and growing out from these. The reason for the patchy structure is that the austenitic grain size varied greatly in different parts of the steel layer. The quenching rate had not been high enough to prevent nucleation at grain boundaries, and where grain size was small, eg 40 μm, the whole grain was transformed to troostite with some bainite before the temperature fell below the MS point. With larger grains – eg 200 μm – the temperature fell below the MS point before troostite had grown to the grain centre, and the whole centre of the grain was transformed to martensite.

In Table 1 the first column shows micro-hardness values (HV – 300 gms) in different phase areas. The martensite areas have a hardness over 800 HV compared with 420 – 500 HV in the troostite. In a small ferrite/pearlite transition zone near the welded junction between steel and wrought iron the hardness was 200-250 HV. The wrought iron is rather heterogeneous with widely varying grain size, but only a few grain boundary particles of cementite are visible. The hardness varies from 130 – 150 HV.

Near the leading edge of the tool (right-hand side in Fig 5) there were numerous twins in large ferrite grains (Fig 8). These are the result of impact subsequent to heat treatment and were probably caused by hammering of the bit into position in the boring head.

A section normal to the surface shown in Fig 4 was prepared by cutting a layer about 2mm thick from the left-hand side. This was a section through the side cutting edge, the edge probably involved in the cutting (Fig 2). The steel layer extended over the whole of this section (see Fig 9) and was rather thicker near the side cutting edge. Corrosion has considerably modified the original shape and it is uncertain how near the edge at the right of Fig 9 is to the original edge. The steel edge does project beyond the wrought iron and could have acted as a cutting edge. The steel layer showed the same features of martensite and bainite as in Figure 5 and the region near the cutting edge was not significantly different from the rest of the steel layer.

This section of the tool was heat treated with the object of finding more about the composition and heat treatment of the steel layer. It was first heated in a salt bath for 15 minutes at 200°C and then to 275°C. The results of micro-hardness tests after each heating are shown in columns two and three of Table 1. After the 200°C temper, the hardness of the martensite areas was reduced to just under 800 HV and, after a 275°C temper, to just below 650 HV. The hardness of other structural areas was not significantly affected. This demonstrates that, in the original heat treatment, the tool had been quenched but not tempered.

The section was then sealed in an evacuated silica tube, heated in a furnace to 850°C for 5 minutes and furnace cooled to room temperature. Fig 9 shows the annealed section etched in Nital and Fig 10 shows the steel layer at higher magnification. The central, lighter portion of the layer shows coarse cementite particles in a network around coarse pearlite (Fig 10). Thus most of the steel layer was a hyper-eutectoid steel, fairly uniform in composition except for the outer edge and the region close to the wrought iron, which shows darker in Fig 9 and consists of approximately eutectoid pearlite as shown in Fig 11. The region near the cutting edge may have been somewhat decarburised in the original heat treatment or in the laboratory annealing.

Table 1

Micro-hardness of Constituent Phases (HV 0.3)

Untreated tool	Heated to 200°C for 15 mins	Heated to 275°C for 15 mins
842 (M)	730 (M)	657 (M)
817 (M)	792 (M)	671 (M)
836 (M)	780 (M)	618 (M)
505 (B)	473 (B)	446 (B)
467 (B)	467 (B)	422 (B)
436 (B)		
246 (P, F)	227 (P, F)	238 (P, F)
229 (P, F)		
147 (F)	139 (F)	133 (F)
161 (F)	171 (F)	144 (F)
131 (F)	145 (F)	163 (F)

M – martensite P – coarse pearlite
B – troostite and bainite F – ferrite

Conclusions

This tool is a product of great sophistication which could have been produced only by smiths who made good use of valuable traditional experience but were bold in applying their own intelligence in the solution of very difficult problems. The boring bar is a four-toothed cutter with replaceable cutting bits, each of which had a laminated structure to give cutting ability combined with toughness. This is a type of tool which is still being elaborated today with inserted-tooth milling cutters using CVD (Chemical Vapour Deposition) coated tools for cutting cast iron. To make such a cutter work efficiently required high metallurgical and engineering skills of the smith, operating without our knowledge and without even simple tools and instruments such as surface grinders, micrometers, temperature measuring instruments and hardness measurement.

For the boring head to work efficiently great accuracy was required in shaping and aligning the tapered teeth in the slots so that each tooth was removing the same thickness of metal along all or most of its cutting edge. Without the aid of a surface grinder and accurate measuring instruments it was a daunting task to position the teeth with the necessary accuracy by hammering them into slots in the head. The teeth had to be so firmly in position that they would not become dislodged during the machining oepration. To ensure this, the teeth had to be formed with precision and the forming of accurate slots in the wrought iron head required great skill and ingenuity.

The use of laminated tools with steel cutting edges backed

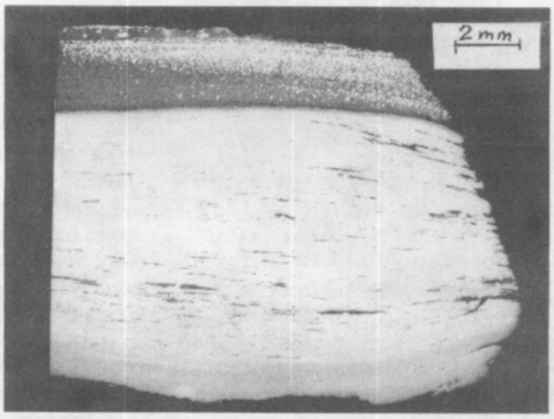

Figure 5. Section A-A (Figure 4) etched in Nital

Figure 6. Section through steel layer. Etched in Nital

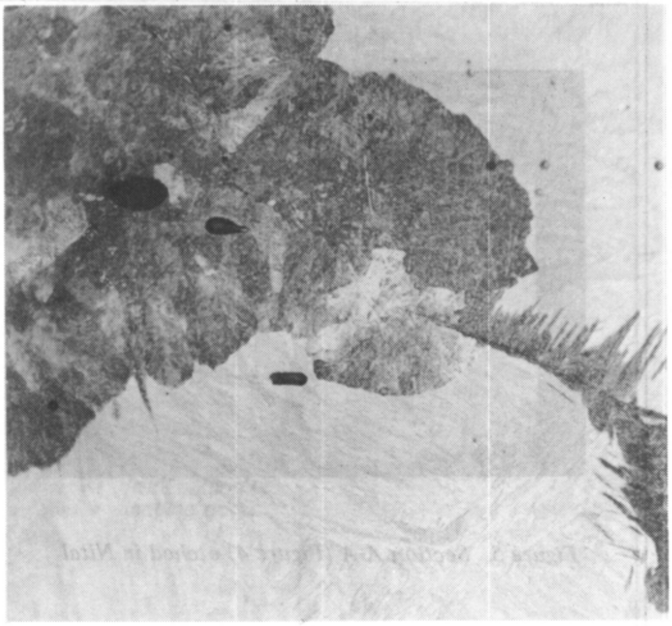

Figure 7. Detail of Figure 6

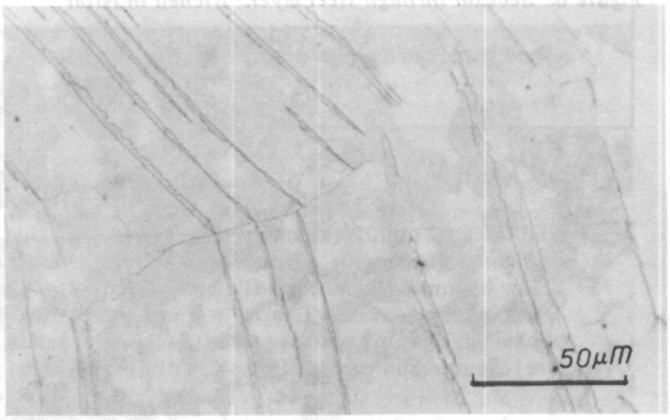

Figure 8. Twins in large ferrite grains near leading edge of tool.

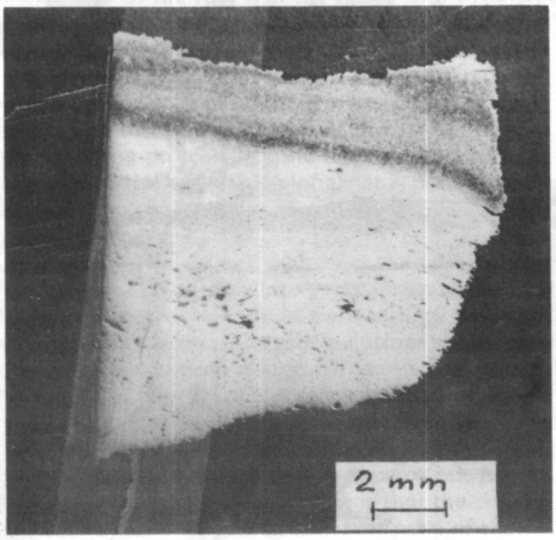

Figure 9. Section through side cutting edge. Normal to section in Figure 5 after annealing

Figure 10. Detail of Figure 9. Structure of light central part of steel layer – annealed

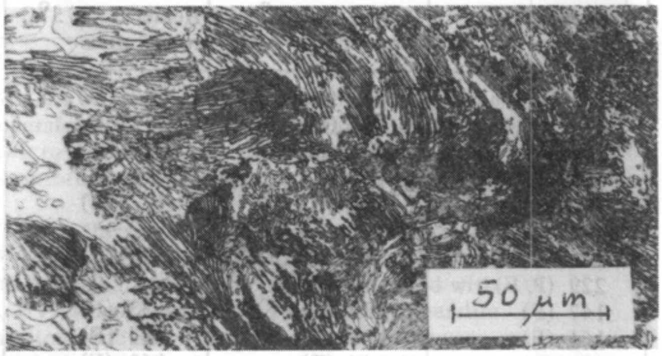

Figure 11. Detail of Figure 9. Structure of dark part of steel layer – annealed

by wrought iron was traditional smiths' craftsmanship, going back at least to Roman times[3]. Biringuccio does not mention a laminated structure in relation to the teeth for boring heads, but it may have been an advantage because it was necessary to hammer the teeth into the slots. The heat treatment seems to have been quenching without subsequent tempering. A straight water quench of a small tool bit in a hyper-eutectoid steel should have produced a completely martensitic steel layer. A reduced rate of quenching must have been used, perhaps to reduce the incidence of brittle failures. The patchy martensite/troostite structure resulting from this treatment cannot have been ideal. Tools of inconsistent properties must have resulted with the hardness at the edge varying from 500 to 850 HV.

The main reason for this inhomogeneity was the greatly varying austenite grain size. This must have been a common feature of steel made by carburising wrought iron and forging or rolling layers of this together, unless extreme measures were used to ensure uniformity as with the manufacture of Japanese swords. Uniformity of grain size and, as a consequence, of response to hardening, must have been a major advantage of the crucible steel making process when introduced after 1740.

References

1 **D S Butler and C F Tebbutt,** Post Medieval Archaeology Vol 9, 1975, p38.

2 **V Biringuccio,** Pirotechnia – English translation, MIT Press, 1966.

3 **R F Tylecote,** A history of metallurgy, The Metals Society, pp 57-59.

Copper sulphate as an ancient source of copper

William Rostoker and George Shen***

Abstract

Water-soluble copper sulfate and related salts can be recovered from ground water seepage in caverns and mines. Weathered copper sulfide minerals evolve to sulfates which are dispersed in ore near the earth's surface. Mined sulfide ore can weather slowly above ground to sulfate. Heap leaching, heap roasting/leaching are large scale activities to recover copper by a solubilization route. Copper can be recovered from water solutions by displacement using iron. The produce is a metal which can be of high purity. Copper sulfate can also be used directly in carbon reduction smelting operations. Experimental results show that iron in the forms of steel and various cast irons can serve in the displacement reactions although the rates of metal recovery and the character of the copper deposits vary.

Introduction

Copper sulfate has some unusual attributes which make copper extraction possible with or without a pyrometallurgical process. Three water-soluble minerals are commonly dispersed in the oxidized, upper strata of large chalcopyrite deposits. These include: chalcanthite – $CuSO_4.5H_2O$; broncantite – $Cu_4SO_4(OH)_6$; and atacamite – $Cu_2Cl(OH)_3$. Under weathering conditions, sulfide ores convert slowly to the water-soluble sulfates. The same outcome can be achieved more rapidly by low temperature roasting.

Metallic iron immersed in a copper sulfate solution will precipitate metallic copper (cementation) in an exchange reaction that leaves the reacted iron as soluble ferrous sulfate ($FeSO_4$). With protracted immersion almost all of the soluble copper can be converted to metal. The metal when dried, melted and refined is a high purity product. Alternatively, if the copper sulfate is crystallized out of aqueous solution, the crystals can be smelted to metallic copper by the same technology applicable to oxide minerals such as malachite – $Cu_2CO_3(OH)_2$. Hydrated crystals upon heating discharge their water of crystallization by 150°C and the anhydrous form dissociates to CuO above about 700°C with the discharge of SO_2. Malachite progressively dissociates above 200°C with the same ultimate residual solid product, CuO. CuO is readily reducible by carbon and CO gas at temperatures well below those necessary to smelt to liquid slag and liquid metal.

Copper sulfate has a long history as a useful or interesting chemical and pharmaceutical. Hoover and Hoover[1] in an extended footnote (translation of Agricola's De Re Metallica) refer to the names 'chalcanthon' used in ancient Greece and 'vitriol' ascribed to Albertus Magnus (circa 1280 AD). The term vitriol was used broadly to identify three hydrated sulfates of $CuSO_4$, $FeSO_4$ and $ZnSO_4$. They were distinguished by an adjective describing their color.

Thus hydrated copper sulfate was called 'blue vitriol'. The ancient Chinese literature refers to the bitter water from certain springs from which, by heating, blue crystals (hydrated copper sulfate) emerge. The crystals themselves were called 'bile crystals)[2,3]. Two other names: 'gall vitriol' and 'stone gall' were introduced by Sun and Sun[4] in their translation of T'ien-Kung K'ai-Wu (17th century AD). The English language versions of the names are choices by the translators often using terms like vitriol which are already familiar to the specialized readership. The 1st century AD Greek writer Dioscorides[1] described vitriol of all species as solidified liquids formed as they trickle down drop by drop and congeal in certain mines and caverns. He also observed that water collecting in caves might congeal to form crystals in the water and that this could be encouraged or hastened by boiling and cooling.

The extraction of copper metal using iron displacement should be distinguished from the use of copper solutions to produce a decorative copper finish on iron objects. Smith[5] recounts some of these practices. Alchemists used displacement of metals by other metals from solutions as evidence of the potential for transmutations. However, while the decorative finish practices may have preceded the development of extractive processes, this should not be construed as an inevitable sequitur.

Perhaps the earliest clear description of the extraction of copper metal on an industrial basis is provided by the 12th century AD. The Chinese history, Sung Shih[2] reads as follows:

'The method of producing steeped copper is to make thin plates of cast iron and immerse them by rows in troughs of blue vitriol solution. After some days a layer of red powder * is formed by the copper sulfate over the surface of the iron; this is collected by scraping and after three purifications in the furnace gives a good copper. Broadly speaking, for every pound of copper, 2 lbs 4 oz of iron is needed. The Hsing-li Factory at Jao-Chou and the Chhien-shan Factory at Hsin-Chao produced a definite amount of this vitriol copper each year.' Note again the use of terms chosen by the translators to improve clarity for the European and American readers.

In his analyses of cast iron production during the Northern Sung period (960-1126 AD), Hartwell[6] makes the point that cast iron output was an essential factor in copper production. In one year (1114 AD) he cites records that 1870 tons of iron were used for the purpose of extracting copper from solutions. The productivity figures given by Sha[3] are similar: 1218 tons of copper production in 1162 AD by the copper cementation process which was said to represent 27% of the total copper production. This is equivalent to 1811 tons of iron using the Sung Shih conversion or 1486 tons of iron by more modern estimates[7]. Also, Tegengren[8] cites that in 1090 AD iron smelters were established in Kwangtung province to supply copper works for copper recovery by the cementation process. One such copper

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* 'Powder' is an interpretation; the literal translation is 'reddish coal'.

works is reported to have produced about 400 tons of metal in one year. These impressive production figures may have dropped off radically during the Jurchen and Mongol occupations and not recovered because the T'ien-Kung K'ai-Wu[4] makes no mention of the copper cementation process in its Chapter 14 on Metal Extraction and Processing. There is, however, a quotation in Chapter 11 on Calcination of Stones to the effect that a heated iron article quenched in an aqueous solution of gall vitriol becomes the color of copper.

In other parts of the world, cement copper was produced by iron displacement on a commercial scale from mine waters in what is now Czechoslovakia from the 16th century AD[8]. Note that water percolating through rock fissures collects at low points in tunnels and particularly at the bottom of a mine shaft (sump). When the copper salt-laden water drips very slowly through cavern roofs or tunnel walls, the water may evaporate at the same rate resulting in natural crystal growths of hydrated copper sulfate (also other sulfates). These natural deposits probably were the first discoveries of these chemicals called vitriols. Despite the existence of copper workings at Rio Tinto and Tharsis regions since pre-history, there seems no basis for interpreting that the cementation process was used earlier than the 18th century. At Tharsis, the earliest recorded use of the process dates only from the 19th century AD.[9]

Industrial Solubilizing of Copper Minerals

Hayward[10] records (without reference) that heap leaching for copper metal recovery has been used continuously since 1752 at Rio Tinto in Spain. Heap leaching is a procedure whereby mined and crushed sulfide ores containing copper are brought to a convenient flat surface area; piled on the ground exposed to air, sun heating and rain; the rain water, rich in soluble copper, is collected by drainage systems; and the metal is extracted. Since this procedure has persisted into modern times, details of the method are available.[10]

Ore sized from 7.6 cm down are piled in heaps that permit simple drainage. The heap can be conical in geometry but more likely, when very large volumes of ore are involved, in the form of a raised plateau. Ventilating flues are arranged to promote oxidation of the sulfides to sulfates. The oxidation of copper sulfides directly is possible; also, by reaction with air and ferric sulfates formed by air oxidation. Considerable heat is developed during the early stages of oxidation and unless the admission of air is regulated by the ore fragment packing, the heap may ignite. In modern times water is sprayed over the heap on a regular basis. The water is recycled from the copper extraction tanks (spent liquor). Several years may be involved in the recovery of soluble copper. In ancient times, rainy seasons would be the times for soluble copper leaching and during long, dry, hot summers the solutions would concentrate by evaporation. Obviously, wherever this process was conducted on a large scale, catch basins and ponds should be apparent.

The manufacture of vitriols for other purposes than metal recovery is described by Agricola[1] as follows:

'The fourth method of making vitriol is from vitriolous earth or stones. Such ore is at first carried and heaped up, and then is left for five or six months exposed to the rain of spring and autumn, to the heat of the summer and to the rime and frost of the winter. It must be turned over several times with shovels, so that the part at the bottom may be brought to the top, and it is thus ventilated and cooled; by this means the earth crumbles up and loosens, and the stone changes from hard to soft. Then the ore is covered with a roof, or else it is taken away and placed under a roof, and remains in that place six, seven or eight months. Afterward as large a portion as is required is thrown into a vat, which is half filled with water; this vat is 30 m long, 7 m wide, 2.7 m deep. It has an opening at the bottom so that when it is opened the dregs of the ore from which the vitriol comes may be drawn off, and it has at the height of one foot from the bottom, three or four holes so that when closed the water may be retained, and when open the solution flows out'. This is clearly heap leaching although the ultimate product is not for metal production.

A variant of heap leaching is leaching ore in place. In modern times this has been applied to mines from which the high grade ore has already been extracted. The tunnels and shafts provide conduits for ground waters laden with soluble copper to drain to low points such as the sump of the main shaft. The collected water can be pumped out or the sump can serve as the precipitation tank. All of these methods provide a recurring crop of copper with very little labor involved.

In recent years the solubilizing of sulfide copper has been shown to be accelerated by certain micro-organisms (see reviews by Tuovinen and Kelly[14], Habashi[12] and Brierley[13]. Laboratory experiments have demonstrated that copper solubilization of chalcopyrite develops concentrations five times higher with micro-organism activity than without, ie 2.75 g/l vs. 0.5 g/l in 160 hours. Since the micro-organism species is apparently indigenous to regions with large copper sulfide ore deposits it would seem that the accelerated solubilization would be implicit in a heap leaching operation conducted with comminuted ore above ground.

In a few cases of known ore deposits in the world, weathering over geological periods in the ore levels near the surface of the main chalcopyrite deposit has converted material sufficiently high in the water-soluble minerals that heap leaching does not require much further weathering to provide a rich harvest of copper sulfate solution. At the enormous deposits of this kind at Chuquicamata (Chile) ore heaps can be leached out in 96 hours using recirculating sprays of solution. These reach copper concentrations of 42 g/l[10] The structure of the geologically weathered overlay above a major copper sulfide (or chalcopyrite) deposit is described by Koucky and Steinberg[14].

The extraordinary tonnage of cement copper production in 12th century China represents something of a mystery. While Sha, et al[3] identify the water-soluble minerals of copper as would any good book on geology, there is only the implication that such deposits were the source of copper-rich water solutions. Remarks in 12th century writings about bitter water and its ability to deposit copper on an iron pan do not constitute any solid evidence of adequate natural supplies of copper-rich water. Read[15] in his review of copper resources of China makes no mention of such deposits as existing or having existed. A People's Republic of China brochure on the great Tongluchan copper mine, one of China's oldest, makes no mention of such deposits[16].

Despite the absence of evidence, one must consider heap leaching as a probable source of copper-rich aqueous solutions of sufficient magnitude to support the industrial scale of cement copper production. This is suggested in the translation of a book (Chou Hui, 1193 AD) referring to earth-containing vitriol[2].

Another option for the production of water-soluble copper salts is sulfate roasting. Chalcopyrite roasted in the temperature range of $500^{o} - 600^{o}C$ converts efficiently to anhydrous copper sulfate and hematite – Fe_2O_3 (Habashi, 1978). There is very little sulfating of the iron sulfides. Above ~700°C the oxidation is directly to cupric oxide and a copper-rich magnetite – $(Cu,Fe)_3O_4$. The sulfates formed by a lower temperature roast transform to the same products above this temperature with the evolution of SO_3. The sulfating roast is a very efficient solubilizer of copper sulfide ores. In simple laboratory experiments, chalcopyrite concentrates roasted at 500°C produced a water-soluble component which represented more than 90% of the analyzed copper[17]. Descriptions of the physical systems for crushing, heaping, roasting and leaching in more recent times are to be found in most extractive metallurgy texts of the first half of the 20th century (see, for example references 10, 18, 19 and 20).

Heap roasting and subsequent leaching were probably first done on a large scale at Rio Tinto starting some time in the 1830s and certainly by 1849[9]. Checkland refers to 'earlier developments of this sort in the treatment of cupreous pyrites in Germany and Italy, especially at the mine of Agordo in the Venetian States'. The mined ore was burned in the open air in long heaps each of some 1000 tons. Ignition was by small wood but once started they burned with some control of air supply for as long as six months. When cold, the heaps were broken up, transported and dumped into tanks of water. When the solution reached some high concentration of copper salts (saturation?) it was run off into deep channels (launders) where the copper was precipitated on lumps of pig iron. The cement copper was refined in melting furnaces, presumably to oxidize out the alloyed iron and then de-oxidized with charcoal.

The use of iron displacement as the recovery procedure for extracting copper from aqueous solutions is only one of the feasible methods appropriate to early technologies. The other is to crystallize out the hydrated copper sulfate and smelt to metal. On crystallizing blue vitriol, the writer Shen Kuo (1030-1094 AD) recorded that when bitter water was heated it yielded copper sulfate crystals[2]. Agricola[1] provides the most detailed description of the ancient processing:

'The vitriol water is collected into pools, and if it cannot be drained into them, it must be drawn up and carried to them in buckets by a workman. In hot regions or in summer, it is poured into out-of-doors pits which have been dug to a certain depth, or else it is extracted from shafts by pumps and poured into launders, through which it flows into pits, where it is condensed by the heat of the sun. In cold regions and in winter these vitriol waters are boiled down with equal parts of fresh water in rectangular leaden cauldrons; then, when cold, the mixture is poured into vats or into tanks, which Pliny calls wooden fish tanks. In these tanks light cross beams are fixed to the upper part, so that they may be stationary, and from them hand ropes stretched with little stones; to these the contents of the thickened solutions congeal and adhere in transparent cubes or seeds of vitriol, like bunches of grapes.'

Copper sulfate may be charged directly into a shaft or bowl furnace. The water of crystallization is driven off by 150°C and the sulfate dissociates to oxide at above about 700°C. The products of the sulfating roast of chalcopyrite yield both the cupric oxide and the copper-iron spinel oxide. Under relatively simple conditions of smelting the copper can be reduced to molten metal and the iron oxides kept in the molten slag[17].

An extensive discussion of the recovery of copper by solubilizing, crystallization and smelting has been presented in the specific context of possible copper recovery processing in Ancient Cyprus by Koucky and Steinberg[14].

Iron Used in the Cementation of Copper

Both Tegengren[8] and Hartwell[6] speak of the large iron production necessary to support the copper cementation industry in Sung China. The implication is that the iron is really cast iron since bloom iron production does not ever seem to have been an important activity, and fining or puddling was reserved for military hardware. Certainly the cost of iron refined from cast iron would have been as high as the copper metal itself and there was little scrap to turn to use. The Sung Shih in the previously cited quotation is specific that plates of cast iron were immersed in blue vitriol solution. The use of cast iron is consistent with outputs during that period of great growth in production. Hartwell (1966) cites estimates of cast iron production increasing from 13,500 to 125,000 tons per year over the period 806 to 1078 AD. Curiously the estimates for the same period by scholars of the People's Republic of China are only about 5000 tons per annum[21]. Hartwell[6] cites consumption of iron for cementation of copper of 1400 tons per annum and Tegengren[8] cites 960 tons of iron in this period for the same purpose. These consumptions would have been a major fraction of the lower total iron production figure and perhaps inconsistent with other very large uses of cast iron for farm implements, road, quarry, mining and construction tools, cooking pots and salt pans, and weapons.

The use of cast iron for cementation of copper has little precedent elsewhere (Rio Tinto) and no parallel in modern times. Cast iron is a family of quite different materials so that it is a matter of some interest as to which cast iron was put to use. During the Han period and before, cast iron was the white iron variety, ie eutectic of austenite (transformed) and iron carbide. However, the combination of decarburization to ferrite and malleabilizing to ferrite and graphite had been developed in that period[22]. By the Tang and Sung periods both white and gray cast irons were being produced. Still later in the Ming period, the high sulfur levels presumably associated with the use of coal as the smelting fuel led back to white iron production (based on unpublished microstructure studies of artifacts in the Field Museum, Chicago, by the authors). There are therefore three cast iron materials that could have served the copper cementation industry: (a) white iron; (b) malleabilized iron (with or without decarburization); (c) gray iron. Since there is no published work on the efficacy of these materials for this application, some laboratory experiments were performed.

Experimental Objectives

The intent of these experiments was to verify the feasibility of any of the three cast irons of antiquity to be useful in the recovery of copper from sulfate solutions. The physical character of the copper deposit, its iron content, ease of stripping, indications of progressive retardation of copper deposition are exemplary of factors involved in feasibility. In addition, some unanticipated observations were made and recorded. Efficiencies of copper-iron exchange were not studied because the idea itself is a more modern viewpoint and such determinations are relatively meaningless on less than a pilot plant scale.

(a) Effects of Concentration of Soluble Copper

Mine waters are frequently referred to both in the ancient and modern contexts. Shinano[23] gives copper (metal ion) concentrations for a contemporary mine of 0.11-0.17 grams per liter (g/l) of solution. The mine water collected in a sump at a rate of 0.41 m^3 per minute which represents at least 63.4 kg of copper per day or 23 metric tons per year. At the other extremity, heap leach liquors concentrated by evaporation could, depending on temperature and time, reach 800 - 400 g/l. These numbers reflect the saturation values of $CuSO_4.5H_2O$ in cold and hot water as given by the Handbook of Chemistry and Physics (60th ed, CRC Press, 1979).

(b) Effect of Temperature

Simple concepts of diffusion suggest that the rate of cementation could be enhanced by heating and this was certainly recognized by the Chinese industrialists. According to Sha, et al[3] the effectiveness of heating the solution was recognized but regarded as uneconomical. The cost of copper per catty* produced from boiling solution was estimated to be 80 cash * as compared with 50 cash by the cold immersion method; ie the hot process overall was more than half again as expensive as the cold process.

(c) Effect of Agitation

At least in modern times the efficacy of solution flow rate, agitation or stirring is recognized[7] Although there is no such mention in the ancient literature, it represents a simple empirical discovery. There is no published data of the effect on copper deposition rate.

Experimental Procedures

The following iron materials were used for copper cementation studies:

Steel – common, commercial, mild steel (nominally 0.2% C) in the form of 3 cm diameter round bar from which 0.4 cm thick slices were cut.

White Cast Iron – eutectic composition (circa 4.3%C) in the form of 3 cm diameter round bars from which 0.4 cm thick slices were cut.

Malleable Iron – produced from the white cast iron by annealing at 1000°- 1100°C.

Gray Cast Iron – Cut into rectangular slices of approximate dimensions: 3.5 cm x 2.5 cm x 0.4 cm. The cast iron was of commercial origin with probably about 1.5% Si and 3% C.

A 'chemical-purity', hydrated copper sulfate ($CuSO_4$. $5H_2O$) was used. It was in fine crystalline form and readily dissolved in cold water. A one liter volume of solution was used in each experiment. The steel, white iron and malleable iron specimens were held in a plastic hose clamp device and suspended, immersed in the solution. The grey iron specimens were drilled to form a hole for suspension purposes.

After a given time of immersion, the iron specimen was removed and the copper removed. If the copper was in mud-like form or as nodules, it could be brushed off or washed off with a spray of water. On occasions the copper could be stripped off as a single piece. The solution was filtered and the copper particles washed and added to the strippings. The copper recovered was air dried and then oven dried before weighing. The dried metal melted and agglomerated into a bead readily with little loss in weight.

Solutions were heated on an electrical hot plate with an aluminium foil cover so that condensate would be largely recirculated. Agitation was provided by an electro-magnetic stirrer in common use in chemical laboratories.

Experimental Results

The weights of copper metal recovered have been converted to cementation rates expressed as grams per unit time, $g/cm^2/hr$. Table I shows the effect of solution concentration, using steel, to be an increase in cementation rate approximated by a linear relation: cementation rate, $g/cm^2/hr = 0.005$ x solution concentration (g/l of Cu). Similar accelerations are indicated by white iron and gray iron. Another comparison in Table II shows that substantial differences develop over longer periods of immersion. Under comparable conditions the cementation rate on steel is nearly three times faster than on gray or malleable iron and nearly ten times more rapid than on white iron.

These differences can be related to some direct observations. In the cases of gray and malleable iron a black mud separates the copper deposit from the iron. The black mud is presumably graphite which is an insoluble component of the iron and must become a barrier to penetration of copper ions to the iron surface*. The comparatively low rate of cementation on white iron is clearly related to the density of the copper deposit. It could be stripped from the iron substrate only with great difficulty and came off in two unbroken sheets, representing the two faces of the iron specimen. The coherent deposit simply reduced ion transport to the exchange reaction site.

Both increased temperature and the imposition of steady stirring action produce large increases in the rates of cementation as might be expected (Tables III and IV). The increase in temperature from 20° to 80°C appeared to double the cementation rate.

The burden of the cement copper itself exercises a damping effect on the cementation rate no matter what is the physical character of the deposit. This may be seen in the data given in Table V. The nature of the deposit is highly variable with conditions of cementation. At the low copper ion concentrations the deposit is mud-like and much of it falls off the specimen collecting at the bottom of the solution container. Above about 2.5 g/l of soluble copper the deposit is more coherent and nodules of copper develop as part of the deposit. However, the deposit can be easily scraped off the surface of the iron. In two instances the deposit achieved a high measure of integrity.

At a solution concentration of 25.5 g/l of soluble copper, the deposit on white iron was dense and well bonded

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* Through Chinese history the metric conversion of the catty ranges from 222.73 to 596.82 grams[4]. The term 'Cash' is a monetary unit and cannot be sensibly converted to modern equivalents. In a footnote, Hartwell[24] cites the cost of a US standard bushel of rice in 1075 AD at North China markets as 425 cash.

* The term 'reddish coal' in the Sung Shih[2] makes some sense as a mixture of black graphite and red copper powder scrapped off cast iron.

Table I

Effect of Solution Concentration on Copper Cementation Rates *

Solution Concentration g/l (salt)	g/l (Cu)	Cu Cementation Rate	Rate Multiplier	Conditions
1	0.26	0.5	--	eutectic white cast iron
5	1.28	1.4	2.8	20^{o}C, 48 hr
10	2.55	3.4	6.8	
1	0.26	0.3	--	steel, 20^{o}C,
10	2.55	1.5	5	95 hr
30	7.65	6.4	21	
100	25.50	20.0	66	
1	0.26	0.4	--	gray cast iron,
100	25.50	20.0	80	20^{o}C, 24 hr

* As with this and following tables, conditions of experiment involve one liter of solution and about 10/15 cm^2 of specimen surface area.

Table II

Comparison of Iron Materials on Copper Cementation Rates

Solution Concentration g/l (salt)	g/l. (Cu)	Metal	Cu Cementation Rate $g/cm^2/hr \times 10^{-3}$	Conditions
1	0.26	steel	1.2	20^{o}C, 24 hr
1	0.26	white iron	.0	
1	0.26	gray iron	0.4	
30	7.65	steel	6.4	20^{o}C, 96 hr
30	7.65	gray iron	4.5	
30	7.65	malleable iron	5.6	
100	25.5	steel	20.0	20^{o}C, 95 hr
100	25.5	gray iron	7.4	
100	25.5	white iron	2.1	
100	25.5	malleable iron	6.7	

Table III

Effect of Temperature on Copper Cementation Rate

Solution Concentration g/l. (salt)	g/l (Cu)	Temperature ^{o}C	Cu Cementation Rate $g/cm^2/hr \times 10^{-3}$	Conditions
1	0.26	20	1.1	white iron,
1	0.26	56	1.3	24 hr
1	0.26	80	2.2	
1	0.26	20	1.2	steel,
1	0.26	81	2.0	24 hr
1	0.26	20	0.4	gray iron,
1	0.26	82	0.9	24 hr

Table IV

Effect of Stirring on Copper Cementation Rate

Solution Concentration g/l (salt)	g/l (Cu)	Stirred	Cu Cementation Rate $g/cm^2/hr \times 10^{-3}$	Conditions
1	0.26	no	1.0	white iron,
1	0.26	yes	1.8	20°C, 24 hr
5	1.28	no	2.0	white iron,
5	1.28	yes	6.0	20°C, 24 hr

Table V

Effect of Time on Copper Cementation Rate

Solution Concentration g/l (salt)	g/l (Cu)	Time hrs	Cu/Cementation Rate $g/cm^2/hr \times 10^{-3}$	Conditions
1	0.26	21	1.0	white iron,
1	0.26	48	0.5	20°C
	0.26	24	1.2	steel,
1	026	95	0.3	20°C
100	25.5	21.3	18.0	gray iron,
100	25.5	48	12.0	20°C
100	25.5	95	7.4	
100	25.5	46	30.0	steel,
100	25.5	95	20.0	20°C

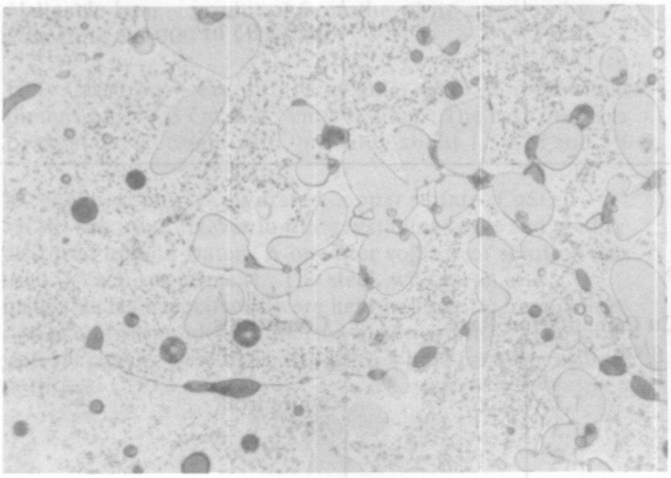

Figure 1 *Microstructure of a cement copper sample which was magnetic both in the form of the dried, metal powder deposit and as a fused bead. The structure shows globular primary crystallization of iron in a matrix of copper from which additional iron has precipitated from solid solution. This is the top of the bead. The high volume percentage of iron dendrites reflects gravity segregation before freezing occurred. Magnification: x400.*

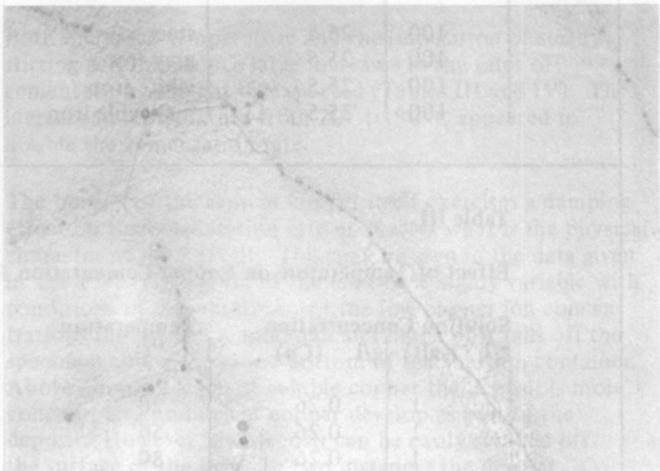

Figure 2 *Microstructure of a cement copper sample which showed no magnetic response. There are no indications of the primary crystallization of iron and accordingly the solidification of the copper led to the growth of very large dendritic crystals during freezing. There is an intergranular segregation which is probably Cu-Cu_2O eutectic. There is also precipitation in the Cy crystals which is probably iron. Magnification: x200.*

to the iron substrate. In another experiment the influence of the $FeSO_4$ build up in the solution was examined. A fresh specimen of steel was immersed in a fresh solution of copper sulfate at a concentration of 25.5 g/l of soluble copper. The deposit was bright, nodular and easily scraped off. A second addition of 25.5 g/l of soluble copper was added to the filtered solution and a second fresh specimen of steel was immersed. The second deposit was much less in amount but very much more dense and was pried intact off the steel surfaces with some difficulty. The deposition rates were correspondingly indicative: 20×10^{-3} g/cm^2/hr in the second run. This effect of density of copper deposit as a factor in deposition rate was noted by Monniger[7]. Tenacious copper deposits were correlated with solution concentrations of higher than 20 g/l of soluble copper. The recommended practice was to dilute such leach solutions to 14 g/l

The nature of the iron dissolution and the copper deposition process was illustrated by an experiment in the production of a dense, deposit of copper on white cast iron. The solution was a reconstituted copper sulfate strength of 20 g/l with residual ferrous sulfate from previous deposition runs. The new deposit was quite dense because when pried off it came off in one piece. The deposit left integral with the white iron substrate was mounted and polished for metallographic examination. The resultant photomicrographs are shown in Figures 3(a) and 3 (b). The low magnification shows a gap between the copper deposit and the substrate metal. This gap is filled with a black soot which is probably carbon or graphite. The dimensions of the gap are exaggerated by the specimen mounting process. The higher magnification view shows that the dissolution process attacks the pearlitic zones between eutectic carbide preferentially.

Many of the mud-like deposits when dried were strongly magnetic indicating entrapped or occluded iron. The nodular deposits were uniformly non-magnetic. Correlated in a different way, dilute solutions were more likely to produce a magnetic cement copper whereas stronger solutions did not. Specimens of the magnetic copper and non-magnetic copper were melted in carbon crucibles. Both types yielded copper-appearing beads with little loss of weight occasioned by the fusion. The magnetic bead had limited deformation capacity as judged by cold hammering. Cracks appeared on the curved surfaces not in contact with the hammer. The non-magnetic beads were exceedingly deformable, showing no edge or peripheral cracking despite heavy deformation. The microstructures of these two copper cement products are shown in Figs 1 and 2. The magnetic copper is clearly populated with iron dendrites. The micrograph creates an illusion of higher iron content because the iron floats to the top of the melt during freezing. The micrograph in Fig 1 reflects the segregation at the top of the bead. In Fig 2 the non-magnetic copper shows little but interdentritic eutectic significant of a high level of alloyed oxygen. There are no evidences of primary crystallization of iron.

Summary

Under appropriate conditions of a solution concentration in excess of about 3 g/l of soluble copper, a high quality metal can be recovered by the cementation process. In more dilute solutions there is a risk of appreciable iron occlusion and alloying during fusion. If unrefined, this copper would have poor deformation properties and poor casting fluidity. However, refining (or 'purification' as termed by the Sung Shih) is possible because iron will oxidize in preference to copper and be carried off in a slag or flux during a molten copper exposure to air.

Cast irons of all types can be used for copper cementation although under specific conditions the rates of cementation can be very different and in general lower than with the use of low carbon steel. However, this is not a process where cementation rates influence the ultimate cost of the product very much. The ancient 'metallurgists' used the iron materials at hand. Indeed the availability of steel scrap in large quantities is a very recent development in history.

There are a number of sources of soluble copper some of which require higher orders of technological development. Nevertheless, heap leaching of either weathered ores or deeper chalcopyrite ores represent rich resources of soluble copper capable of tonnage annual outputs. In identifying such activities at an ancient site there are two features that offer supporting evidence. The ore heaps stripped of soluble copper should still be evident although they may well have acquired an overburden. It is likely that leach liquor was concentrated by evaporation in open, shallow pools which did not leak. These should be evident, again, after removal of the overburden. Unfortunately they would look just like sea salt evaporation pans.

The existence of residual heaps without the evaporation pans might indicate a boiling tank alternative. However, this would be demanding of thermal energy, expensive and therefore more likely to reflect use as a chemical agent as for dyes or as a pharmaceutical product. There were other uses than to produce metal to which copper salts were put.

Considering the output of mine waters at the Kosaka mine[23] at a level of about 23 tons per year, the Chinese national outputs in the 12th century AD of more than 1000 tons per year probably could not be derivative from naturally occurring solutions forming in mines, caverns and mountain streams. Heap leaching seems the only approach to achieving such levels of output. Whether the ores contained soluble copper by geological changes or by open weathering of chalcopyrite ores cannot be resolved with existing published information.

The possibility of crystallized copper sulfate as the input to a copper smelting cannot unfortunately be verified very easily since the copper metal product and the slag effluent would demonstrate features indistinguishable from a malachite reduction operation. Such a process would be an intelligent use of limited charcoal resources because the copper input material is free of the extraneous rock (gangue) associated with ores. Note that even a modern ore flotation concentrate still contains about 50% extraneous rock particles.

Acknowledgement

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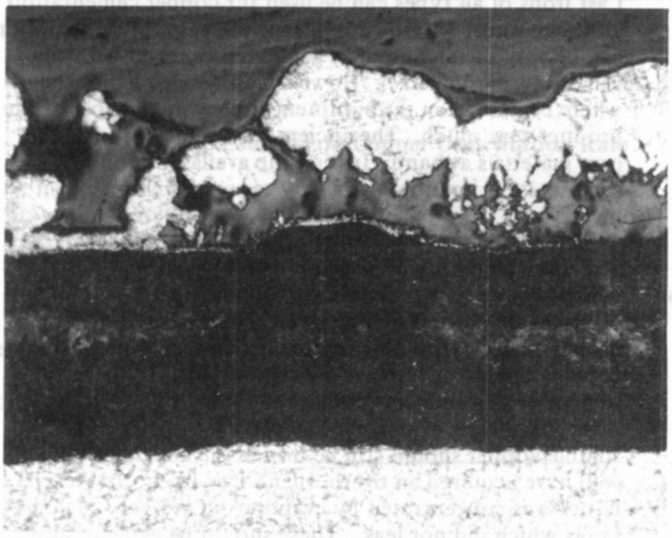
References

1 H C Hoover and L H Hoover, **Georgius Agricola - De Re Metallica (1556), Translation and Footnotes,** originally published 1912, republished Dover Publ, 1950.

2 J Needham, P Y Ho, G P Lu and N Sivin, **Science and Civilization in China, Vol 5, Pt IV, Chemistry and Chemical Technology,** Cambridge University Press, 1980.



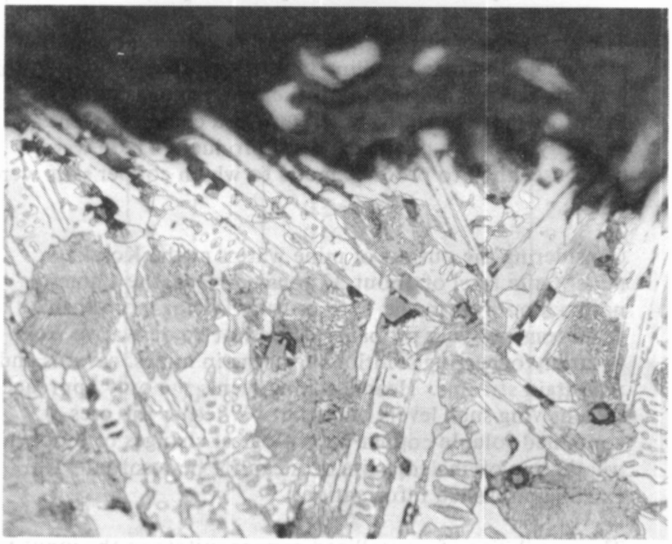


Figure 3 *(a) A view of the copper deposit separated from the white cast iron substrate by a black, soot-like residue. The gap width is exaggerated somewhat by the mounting process. Magnification: x50.*

(b) The substrate surface shows that the dissolution process preferentially attacks the pearlite zones between the eutectic carbide. Magnification: x400.

3 T Y Sha, C G Li and G Y Huan, **History of the Development of Mining in Ancient China,** Geology Publication Society, People's Republic of China, July 1980.

4 E Z Sun and S C Sun, **T'ien-Kung K'ai-Wu by Sung Ying Hsing (1637 AD), Translation and Notes,** Pennsylvania State University Press, 1966.

5 C S Smith, 'Beginnings of Industrial Electrochemistry' in **Proc of Symposium on Selected Topics in the History of Electrochemistry,** The Electrochemical Soc, 360-397, 1978.

6 R Hartwell, 'A Revolution in the Chinese Iron and Coal Industries During the Northern Sung, 960-1126 AD', J Asian Studies, 1962, **21**, 153-162.

7 F M Monninger, 'Precipitation of Copper on Iron', Mining Congress Journal, Oct 1963, **49**, 48-51.

8 F R Tegengren, 'The Iron Ores and Iron Industry of China, Pt II', Memoirs of the Geological Survey of China, Ser A, No 2, Dec 1923.

9 S G Checkland, **The Mines of Tharsis,** Allen and Unwin (London), 1967.

10 C R Hayward, **Outline of Metallurgical Practice,** Van Nostrand, 1940.

11 O H Tuovinen and D P Kelly, 'Use of Micro Organisms for the Recovery of Metals', International Metallurgical Reviews, March 1974, **19**, 21-31.

12 F Habashi, **Chalcopyrite,** McGraw-Hill, 1978.

13 C L Brierley, 'Microbiological Mining', Scientific American, 1982, **247**, No 2, 44-53.

14 F L Koucky and A Steinberg, 'Ancient Mining and Mineral Dressing on Cyprus'. Paper given at the Seminar on Early Pyrotechnology sponsored by the Smithsonian Institution and the National Bureau of Standards, April 1979.

15 T T Read, 'Mineral Production and Resources of China', Trans American Inst of Mining Engineers, 1913, **43**, 1-53.

16 **Tongluchan – A Pearl Among Ancient Mines,** ed Huangshi Museum, Chinese Soc Metals, Archeomet Gp Beijing University of Iron and Steel, Cultural Relics Publishing House, Beijing, People's Republic of China, 1980.

17 W Rostoker and M Sadowski, 'The Carbon Reduction of Fully Oxidized Chalcopyrite (Copper) Ores', J Historical Metallurgy Soc, 1980, **14**, (1), 38-42.

18 J L Bray, **Non-Ferrous Production Metallurgy,** John Wiley, 1941.

19 H O Hofman, **Metallurgy of Copper,** McGraw-Hill, 1924.

20 W Gowland, **Metallurgy of the Non-Ferrous Metals,** Charles Griffin, 1918.

21 Y T Liu, 'The Evolution of the Furnace in Ancient China' Wen Wu, 1978, No 2, 18-26.

22 **Metallurgy of Ancient China,** authored by the archeometallurgy staff at the Beijing University of Iron and Steel, Cultural Publishing House, People's Republic of China, 1978.

23 F Shinano, 'The Copper Ore Deposit of the Kosaka Mines: Properties of the Deposit Related to the Recovery of Cement Copper', Chisitou Chosajo Geppo, Vol 1, 125-130, 1950.

24 R Hartwell, 'Markets, Technology and the Structure of Enterprise in the Development of the Eleventh Century Chinese Iron and Steel Industry', J Economic History, 1966, **26**, 29-58.

A metallurgical study of iron pile shoes from the Roman bridge at Minturnae

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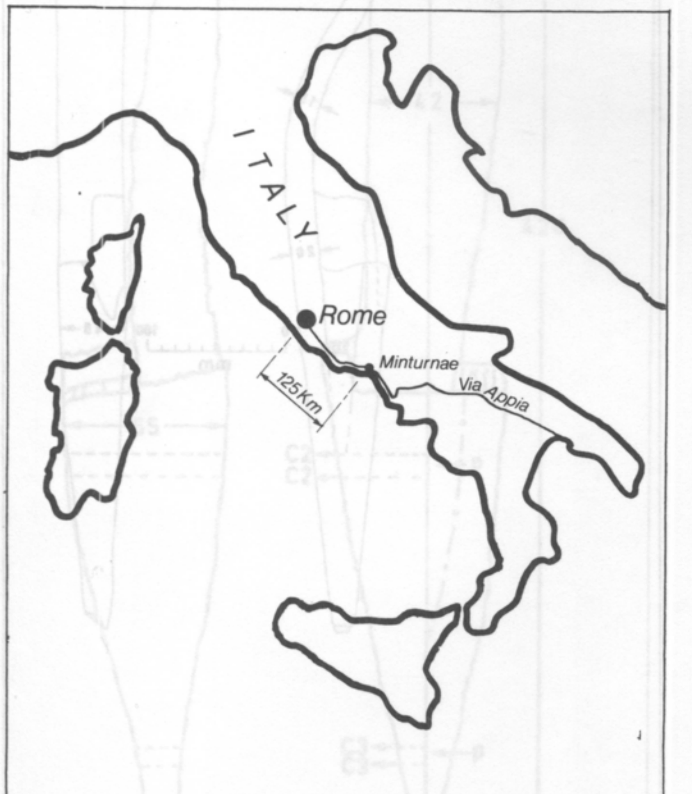
The Site

In 312 BC the Via Appia reached Minturnae on the banks of the Liris (present day Garigliano). In 44 BC Cicero in a letter to Atticus[1] recorded that he 'reached at dawn the Pons Tirenus at Minturnae' thus giving the only known contemporary reference to a bridge across the Garigliano at Minturnae.



Map showing site of Minturnae

This bridge site was located during underwater surveys of the port region of Minturnae which have been carried out over several seasons under the archaeological direction of Brother S Dominic Ruegg of St Mary's College, California.

At the bridge site the Garigliano is 6 metres deep and 50 metres wide. The river bottom is of shingle and flat except for the slope up to the west bank which consists of a tumble of rocks interspersed with Roman material. The high iron concentration from Roman and second world war junk on the bottom has caused the formation of a hard concretion over much of the site. The bridge site is on the slope up to the west bank and consists of an area 7 metres by 8 metres containing at least 150 piles, in places so close together that they are touching. The piles are of Italian oak and have rotted flush with the river bottom, the parts below the surface being remarkedly well preserved. The piles are predominantly of square cross-section with a few round ones (whole trees), a few a quarter of a circle (a quarter of a tree) and a very few rectangular. The largest pile (EF) was 45 cm x 46 cm although most were less than 30 cm x 30 cm with 18 cm x 16 cm as the smallest.

The high area density of piles together with tree ring analysis and radiocarbon dating indicates that the bridge was maintained over some centuries. There are probably more piles under the heavily concreted area to the south and possibly under the shingle crossing the river although it is likely the site consists of just one pier of the bridge.

We were able to excavate around a few piles to a depth of two metres but could not raise a complete pile. Six iron shoes for pile tips were recovered for metallurgical study but all of these came from close to the surface of the river bottom and therefore possibly belong to misdriven, discarded or later period piles. They may not form a representative sample of shoes from well driven piles over the full lifetime of the bridge.

The Shoes

Shoe A (Figure 1)

This was the largest shoe recovered from the site, the mass of iron remaining being 10.5 kg. It was located 50 cm on the west bank side of pile DU. The ends of both arms are badly corroded away as they protruded above the river bottom. It appears that the shoe only had two arms with two shorter pieces helping to form the tip. It is possible, but unlikely, that the two shorter pieces are parts of longer arms that have broken off rather cleanly.

The tip was manufactured by forge welding four flat strips of metal each 65 mm wide and 20 mm thick with the long arms elongated and thinned out to 80 mm wide and 8 mm thick. It is always possible that the long arms are part of a single piece bent back on itself. The shoe could not be sectioned to study this detail as it is required whole for a museum display.

The long arm has three eroded nail holes, one of which holds the remnants of a nail. This arm is bent at its weak point, the lower nailhole. If this bend is deliberate the shoe would fit a pile about 20 cm across; about half the size of the largest pile uncovered. However, the bend appears to be accidental as the remaining part of the short arm shows no such bending at the lower nailhole. If so, this shoe would fit a pile up to 45 cm across which is consistent with the largest piles recorded on the site.

Shoe A has been conserved for display.

Shoe B (Figure 2)

The tip of this shoe shows sign of contact with a hard object and one or three arms have broken off, the residual mass of iron being 5.5 kg. It was recovered near pile GW and has a trace of wood associated with it. The long arm has three rectangular nail holes and the remains of two nail heads are still corroded in position. It would appear that this shoe broke away from its associated pile when it struck a hard object and went off course.

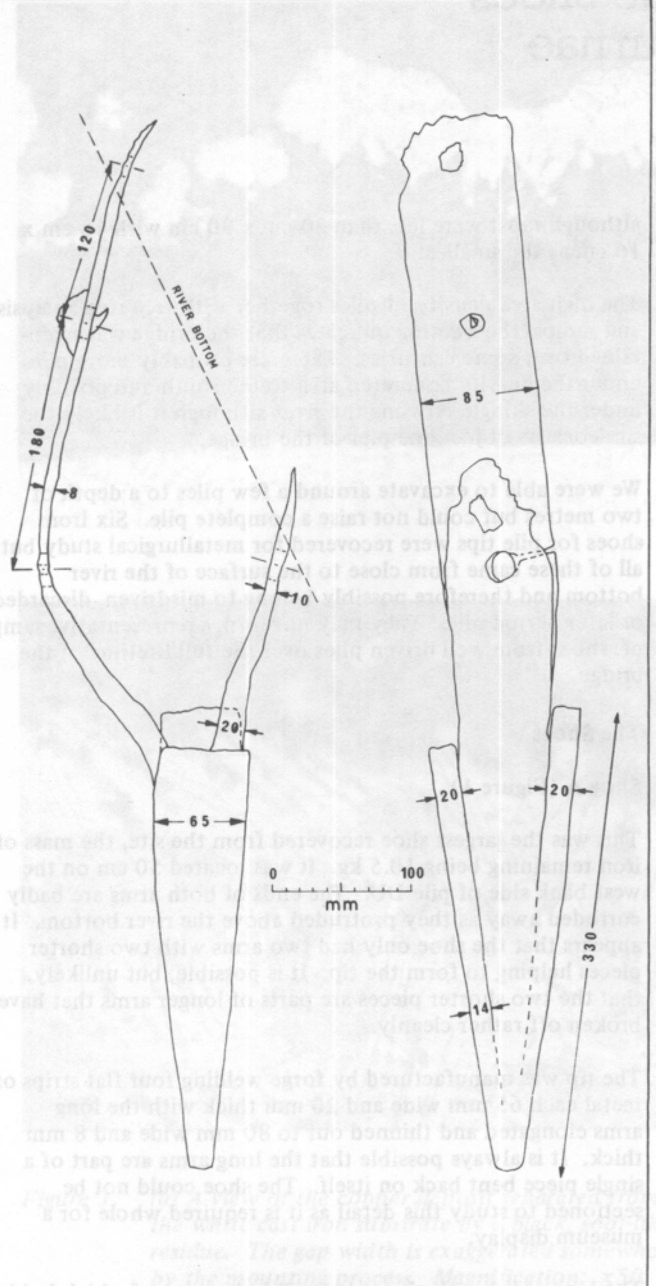


Figure 1. Shoe A. The largest shoe recovered from the site to date, it is consistent with the largest size pile recorded on the site.

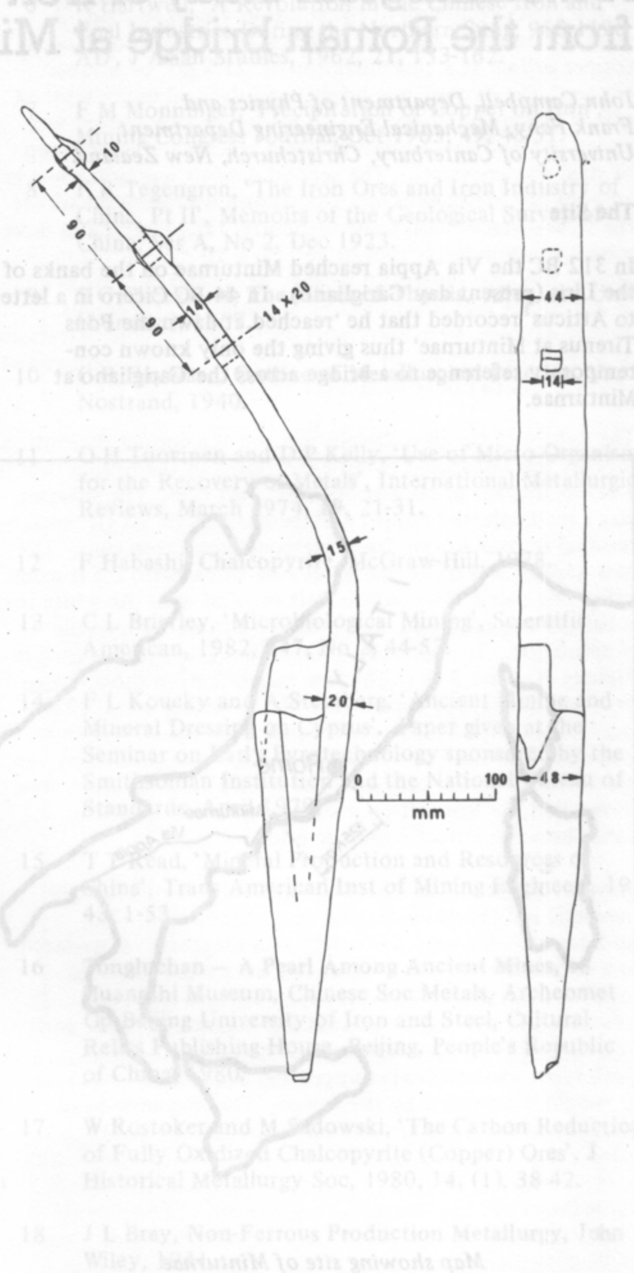


Figure 2 Shoe B. The remaining arm is unusually long when compared with those on Shoe E. It has three nail holes for securing it to a pile.

Shoe B was constructed by forge welding four flat strips of iron 48 mm wide and 20 mm thick with the long arm elongated and thinned. It is not as substantial as shoe A but is considerably longer than shoes E and F.

Shoe C (Figure 3)

This shoe was excavated in general debris near the surface of the river bottom and was very badly corroded, its residual mass being 2.5 kg. Only one arm remains and the structure above the tip is unclear. The shoe was sectioned longitudinally (C1-C1) and one piece prepared for macroexamination by etching with 2% Nital. The inhomogeneous nature of the metal is clearly evident (Figure 4).

The longitudinal macrosection implies that the surviving part of this shoe is a single piece of metal that has been folded back on itself. The external surfaces of this piece have had the surface erosion enhanced by the etching process showing lamellar striations. The pattern of the striations indicates that a plate (arm?) over 15 mm thick had been welded onto the back side as shown by the dot-dash line in figure 3. In the longitudinal section this join corresponds to the curve in the macro-structure shown by the two arrows (J-J) in figure 4. This erosion pattern may have been fortuitous as no such pattern shows on the other half of the shoe nor in the two transverse sections cut through it. Thus the construction of this poorly preserved piece of shoe is in doubt but there are the above indications that it is of similar construction to the well preserved shoes A and E with good

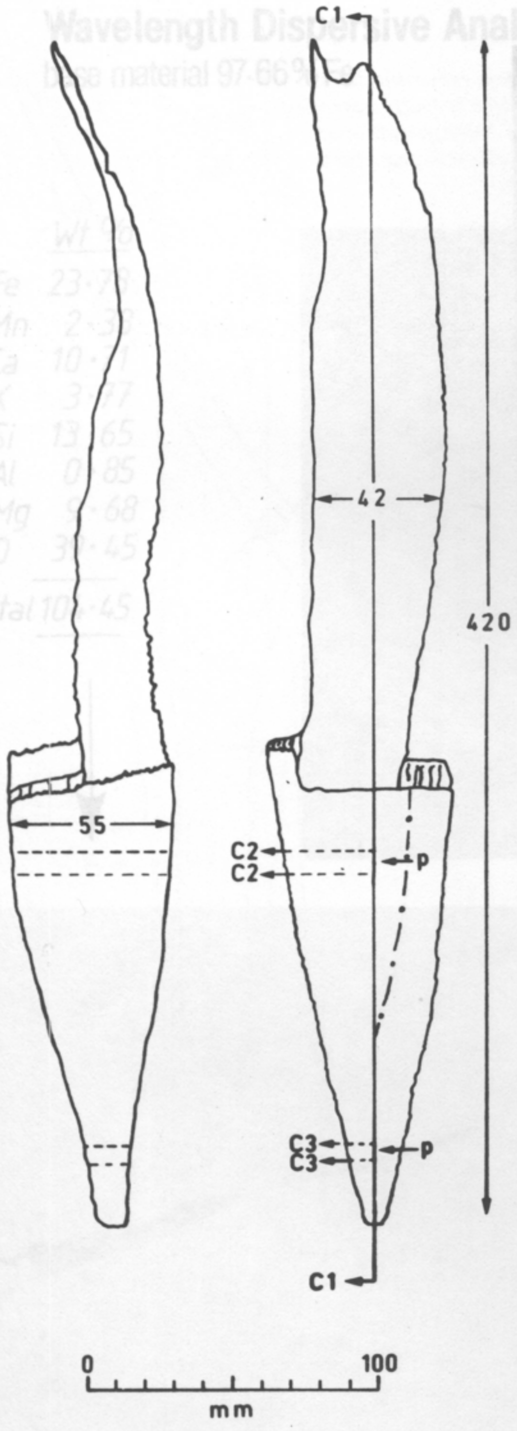


Figure 3. *Shoe C. This shoe has so little remaining and is externally so corroded that its original shape cannot be determined with certainty. The shoe was sectioned longitudinally (C1-C1) and the right-hand half etched for macroexamination of the cut and polished face. Surface striations on the etched external surfaces of this half indicated a weld as shown by the line*

evidence in this case that one pair of opposite arms of the shoe are formed from one length of iron folded over on itself with the folded end worked to form the basic tip shape then two other arms or side plates added.

Two transverse sections (C2-C2, C3-C3) were cut from the discarded half of the shoe and prepared for micro examination (Figure 4). The polished and etched surfaces are marked p in figure 3. Section C3-C3 was chosen as the most interesting area of inhomogeneity. The structures range from those associated with lower carbon steels (predominantly ferritic) to those of high carbon steel (predominantly pearlitic). There is also a large variation in grain size and grain shape ranging from the directionality associated with cold working to the Widmanstatten type associated with high temperature.

In general, the non-metallic inclusions indicate directionality imparted by working either above or below the recrystallisation temperature (hot or cold working). This directionality remains despite subsequent heating and thus provides a very important method in assessing methods of manufacture. The bulk of these non-metallic inclusions, that is, the smaller ones, were of a single phase and an investigation into their composition was determined in the scanning electron microscope using wavelength dispersive analysis (Figure 5).

Shoe D (Figure 6)

This shoe was excavated amongst debris around pile DU. It is badly corroded, concreted and twisted out of shape so that the method of construction is unclear. The arm seems to be fairly central to the wide end of the tip but this could be accidental due to the distorted nature of the shoe. This shoe seems to have been damaged when being driven (it has a nail corroded into the nail hole) and hence was discarded near the surface.

A section DD was cut off the tip for microanalysis which showed that the microstructure was ferritic (iron containing less than 0.025% carbon) with elongated non-metallic inclusions. Some of these massive inclusions consisted of a duplex structure and wavelength dispersive X-ray analysis showed that the lighter phase had doubled the iron content of the darker phase.

Shoe E (Figure 7)

This is the best preserved of all the shoes. It is constructed from four flat-strips 50 mm wide and 10 mm thick, the width reduced where the arms are forge welded together to increase the thickness to 15 mm. Part of one arm has corroded away leaving 4.5 kg of residual iron. Each arm had two nail holes and three bent nails were in position in the top hole of each arm. (As one was shifted before its orientation was recorded it is not shown in the drawing – Figure 7). The bending of the nails and the damage to the tip indicate that the pile struck an obstacle whilst being driven and went off course, causing it to be abandoned near the surface. A 40 cm length of a 22 cm diameter pile (CK) was recovered with this shoe.

Section EE was cut out and macroetched with 2% Nital in order to allow a study of the cross section of the welds. Vickers Pyramid Hardness test traverses were made across the section with the results shown in Figure 8. The hardness values ranged from 90 to 242 HV30. The former corresponds to ferritic iron and the latter with high carbon steel. The inhomogeneity of the metal can be clearly seen as can the forge welded method of construction.

Shoe E has been conserved for display.

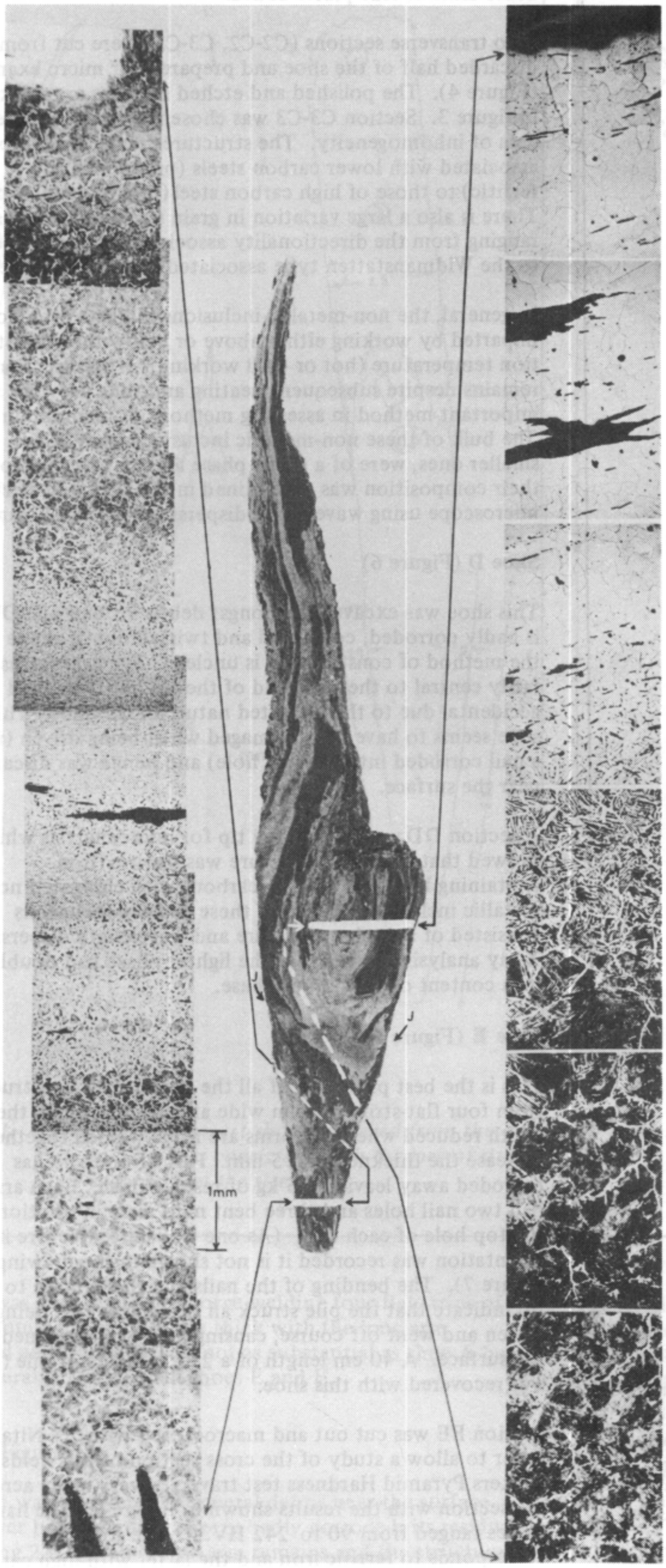


Figure 4.

Macrostructure of the longitudinal section of shoe C and the microstructure of two traverses across the etched face adjacent to the areas marked in white (faces p on sections C2-C2 and C3-C3 of figure 3). The etchant used was 2% Nital. The curved line of the join of a suspected arm or plate welded onto the back surface is shown by the two arrows j-j.

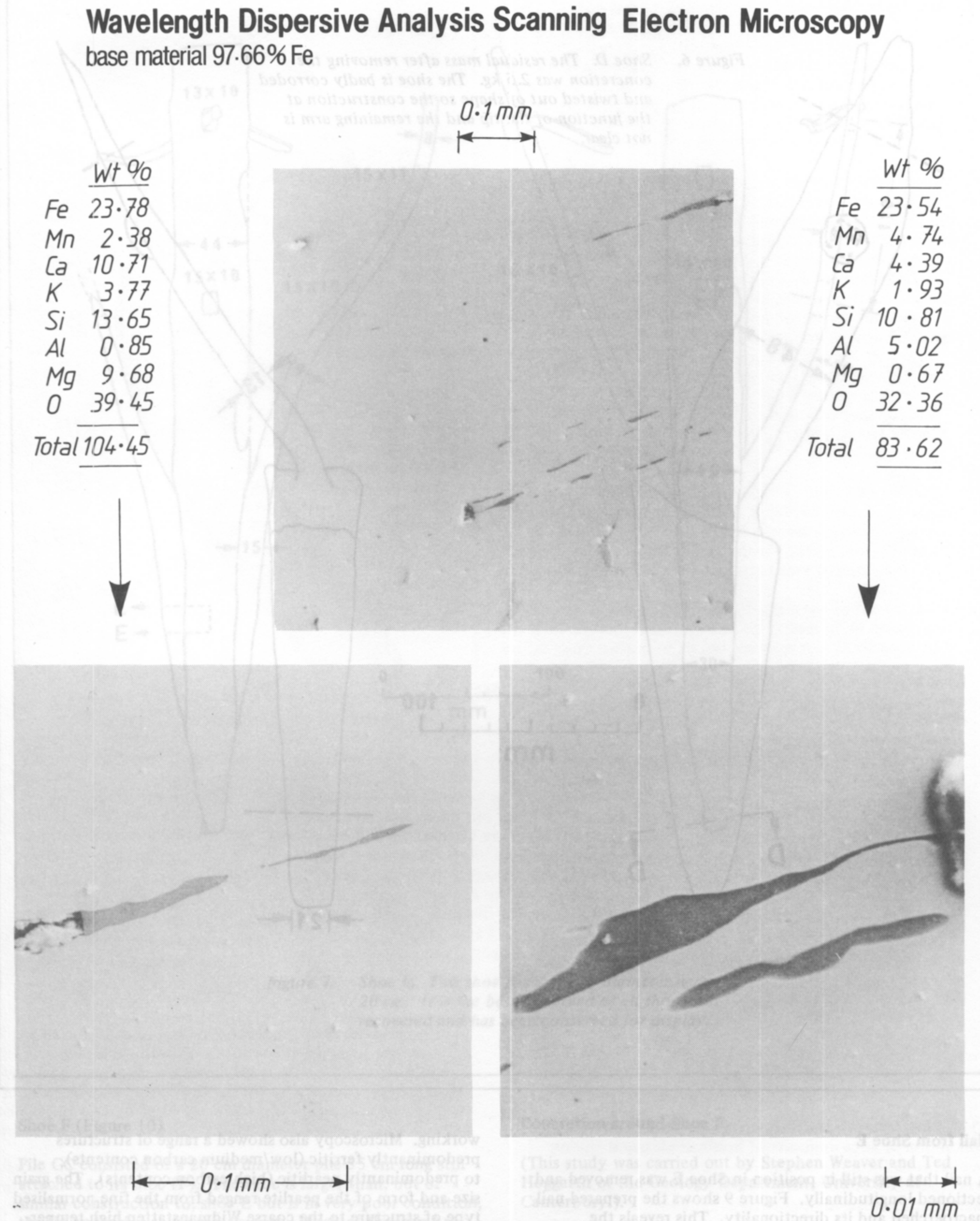


Figure 5. *Non-metallic inclusions in Shoe C showing the elongation imparted when working the metal into a pile shoe and the analysis of two of the inclusions.*

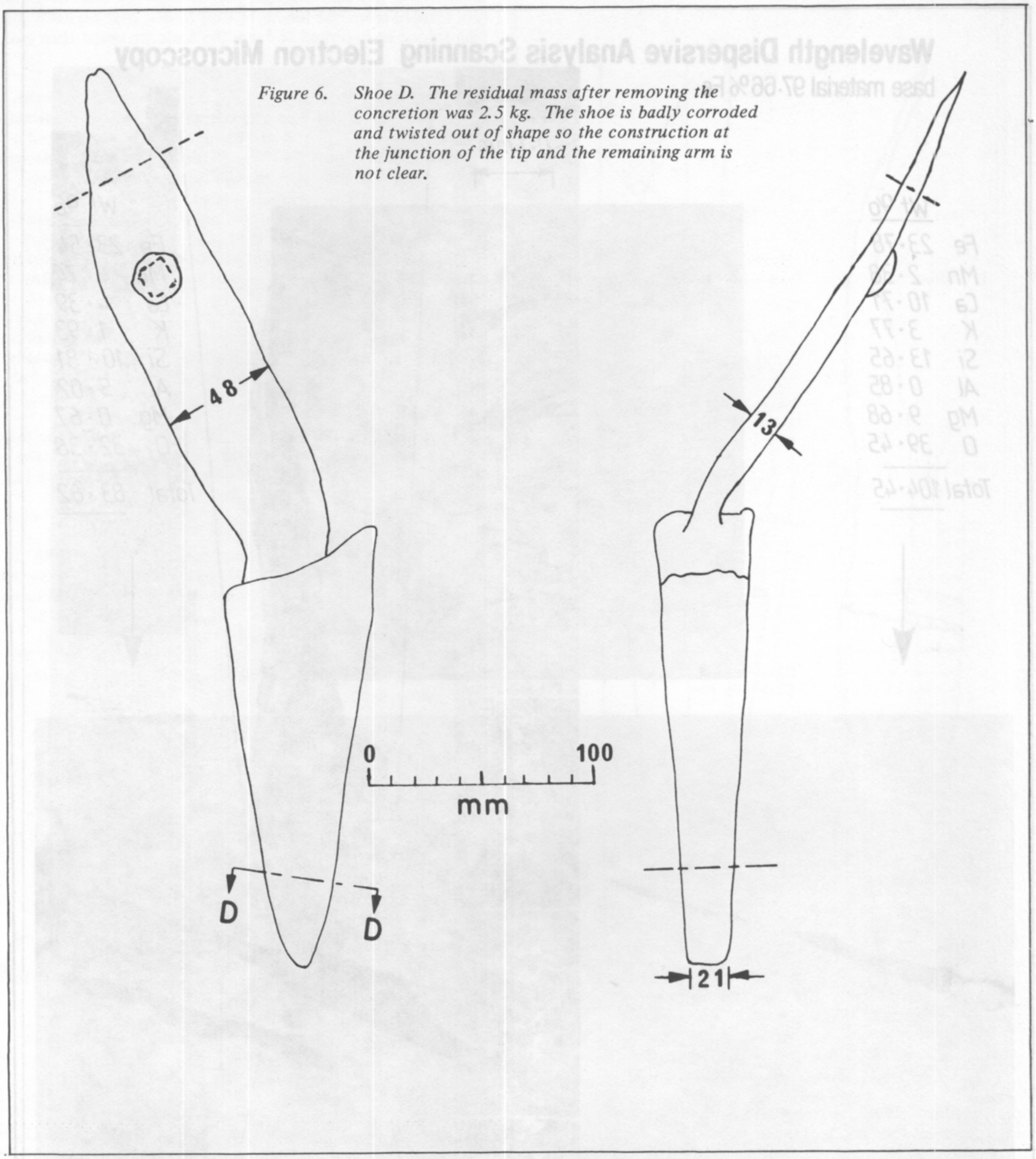


Figure 6. Shoe D. The residual mass after removing the concretion was 2.5 kg. The shoe is badly corroded and twisted out of shape so the construction at the junction of the tip and the remaining arm is not clear.

Nail from Shoe E

A nail that was still in position in Shoe E was removed and sectioned longitudinally. Figure 9 shows the prepared nail macroetched and its directionality. This reveals the conventional flow of the metal with the 'upset' flow line pattern of the head showing that it had been forged to shape. This method is still selected to give maximum strength. The flow lines are a striation, fibre-like condition caused by local differences in composition and the presence of inclusions which are drawn out in the direction of working. Microscopy also showed a range of structures predominantly ferritic (low/medium carbon contents) to predominantly pearlitic (high carbon contents). The grain size and form of the pearlite ranged from the fine normalised type of structure to the coarse Widmanstatten high temperature type.

A sulphur print, a method of detecting sulphur segregation, was made and although the flow lines previously observed were again shown up, the nail proved to be singularly free of sulphur (sulphur pick up is one of the difficulties in producing high grade steels).

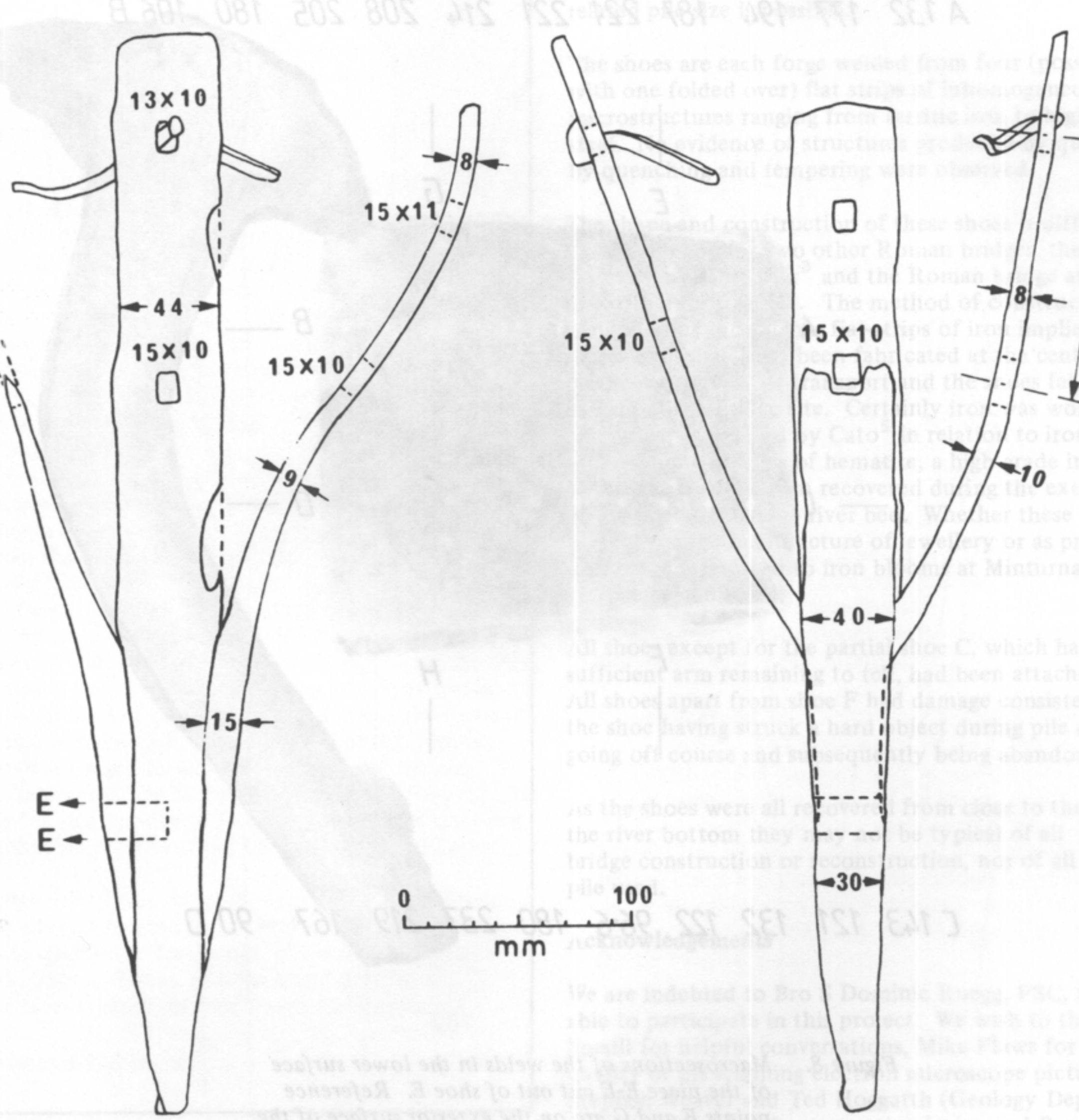


Figure 7. Shoe E. This shoe fits a pile of diameter near 20 cm. It is the best preserved of all shoes recovered and has been conserved for display.

Shoe F (Figure 10)

Pile GC consisted of a 20 cm diameter pile 55 cm long still attached to its shoe (F). The shoe is larger than, but of similar construction to, shoe E but is in very poor condition, the tip appearing to be mostly rust. Much of the iron has diffused outwards to form a 20 mm thick concretion layer around the shoe. All shoes had some concretion but none approached the thickness on shoe F.

Concretion around Shoe F

(This study was carried out by Stephen Weaver and Ted Hoggarth of the Geology Department, University of Canterbury.).

A cross-section of the concretion was cut for X-ray diffraction (XRD) analysis of the crystalline components of the concretion. Four concentric layers and an outer skin were visible to the naked eye. The layers were gradational and marked by different shades of brown or orange-brown.

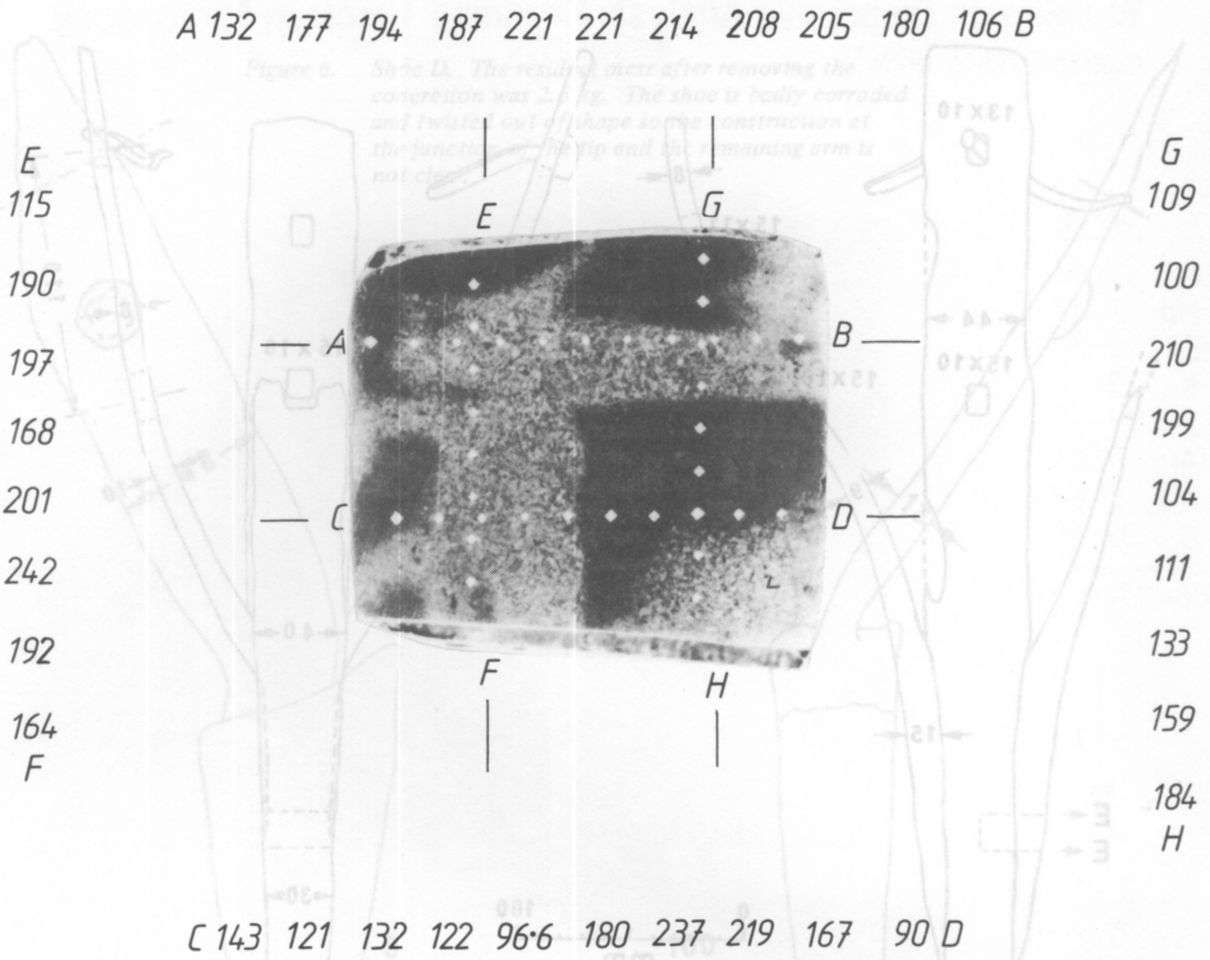


Figure 8. Macrosections of the welds in the lower surface of the piece E-E cut out of shoe E. Reference points E and G are on the exterior surface of the side arm of the shoe, the weld between the side arm and the tip is roughly along the line A-B and the weld between the two central arms of the tip is roughly along the line E-F. The numbers shown are the value of the Vickers Pyramid Hardness Numbers HV30 obtained along the lines of the traverses.

There was often no clear boundary between metal and concretion as large amounts of iron had clearly diffused outwards to form the concretion. Much of the concretion was composed of amorphous iron oxides. Crystalline material identified by XRD was as follows:-

Layer 1 (metal shoe): Goethite (αFeO (OH))+ Akaganeite (βFeO (OH)) + quartz. The first two may be loosely termed limonite (a mixture of iron oxhydroxides).

Layer 2 : Plagioclase Feldspar + quartz.

Layer 3 : Plagioclase Feldspar + kaolinite + illite + quartz.

Layer 4 : Plagioclase Feldspar + quartz.

Skin : Plagioclase Feldspar + calcite + kaolinite + quartz.

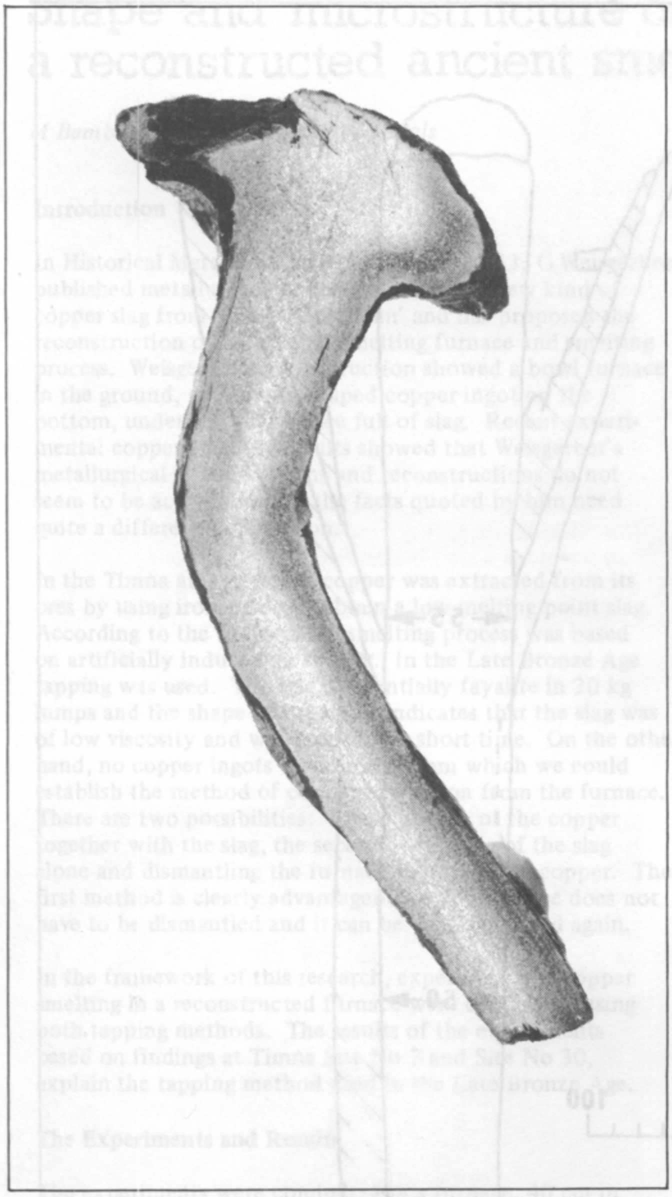


Figure 9. Macrosection of a nail from Shoe E showing its method of fabrication in order to produce high strength. The residual length of the broken nail is 65 mm whilst another from this shoe was 90 mm long.

The Akaganeite is an interesting mineral as it needs small but definite quantities of chlorine ions to stabilize its structure.[2] Its occurrence is therefore indicative of sea water showing that the port area of Minturnae was at least tidal when the concretion started to form. The other layers may be indicative of environmental changes on the river bottom.

The layered structure of the concretion did not show up well on the microprobe traverse. The boundary between layer 2 and the metal (layer 1) was gradational over a distance of 800 $>\mu$m with a higher concentration of Fe and S and lower concentrations of Ti, Si, Na and Ca in the latter.

Conclusions

The largest shoe (A) has an arm spread consistent with the diameter of the largest pile located whilst shoes E and F were associated with a common smaller pile size. Shoes B, C and D each have only one arm remaining so no estimate of related pile size is possible.

The shoes are each forge welded from four (possibly three with one folded over) flat strips of inhomogeneous iron with microstructures ranging from ferritic iron to high carbon steel. No evidence of structures produced by quenching or by quenching and tempering were observed.

The shape and construction of these shoes is different to those reported for two other Roman bridges, the first Roman bridge at Trier[3] and the Roman bridge at Aldwincle in Northamptonshire[4]. The method of construction of the Pons Tiernus shoes from flat strips of iron implies that these strips may have been fabricated at the central bloomery for ease of transport and the shoes fabricated as needed at the bridge site. Certainly iron was worked at Minturnae as implied by Cato[5] in relation to iron farming tools. Single crystals of hematite, a high grade iron ore (reference 6) have been recovered during the excavations of the port area of the river bed. Whether these were present for the manufacture of jewellery or as proof that iron ore was reduced to iron blooms at Minturnae has not yet been established.

All shoes except for the partial shoe C, which had insufficient arm remaining to tell, had been attached to piles. All shoes apart from shoe F had damage consistent with the shoe having struck a hard object during pile driving, going off course and subsequently being abandoned.

As the shoes were all recovered from close to the surface of the river bottom they may not be typical of all periods of bridge construction or reconstruction, nor of all sizes of pile used.

Acknowledgements

We are indebted to Bro S Dominic Ruegg, FSC, for being able to participate in this project. We wish to thank John Smaill for helpful conversations, Mike Flaws for the quality of his scanning electron microscope pictures and Stephen Weaver and Ted Hoggarth (Geology Department) for the analysis of the concretion layer, and Bro Dominic and the unknown referee for their helpful comments on this paper.

References

1 **Cicero.** Letters to Atticus XVI 13, 10 Nov 44BC.

2 **J W Murray.** 'Iron Oxides' Ch in Marine Minerals (Ed R G Burns) 1979. Mineralogical Society of America Short Course Notes Vol 6.

3 **H Cuppers.** Die Trierer Romebrucken Band V 1969 Philipp von Zabern, West Germany.

4 **D A Jackson and T M Ambrose.** A Roman Timber Bridge at Aldwincle, Northamptonshire. Britannia 1976, 7, 39-72.

5 **Cato.** De agri cultura 135 1.

6 **R F Tylecote.** A History of Metallurgy, 1976, London. The Metals Society.

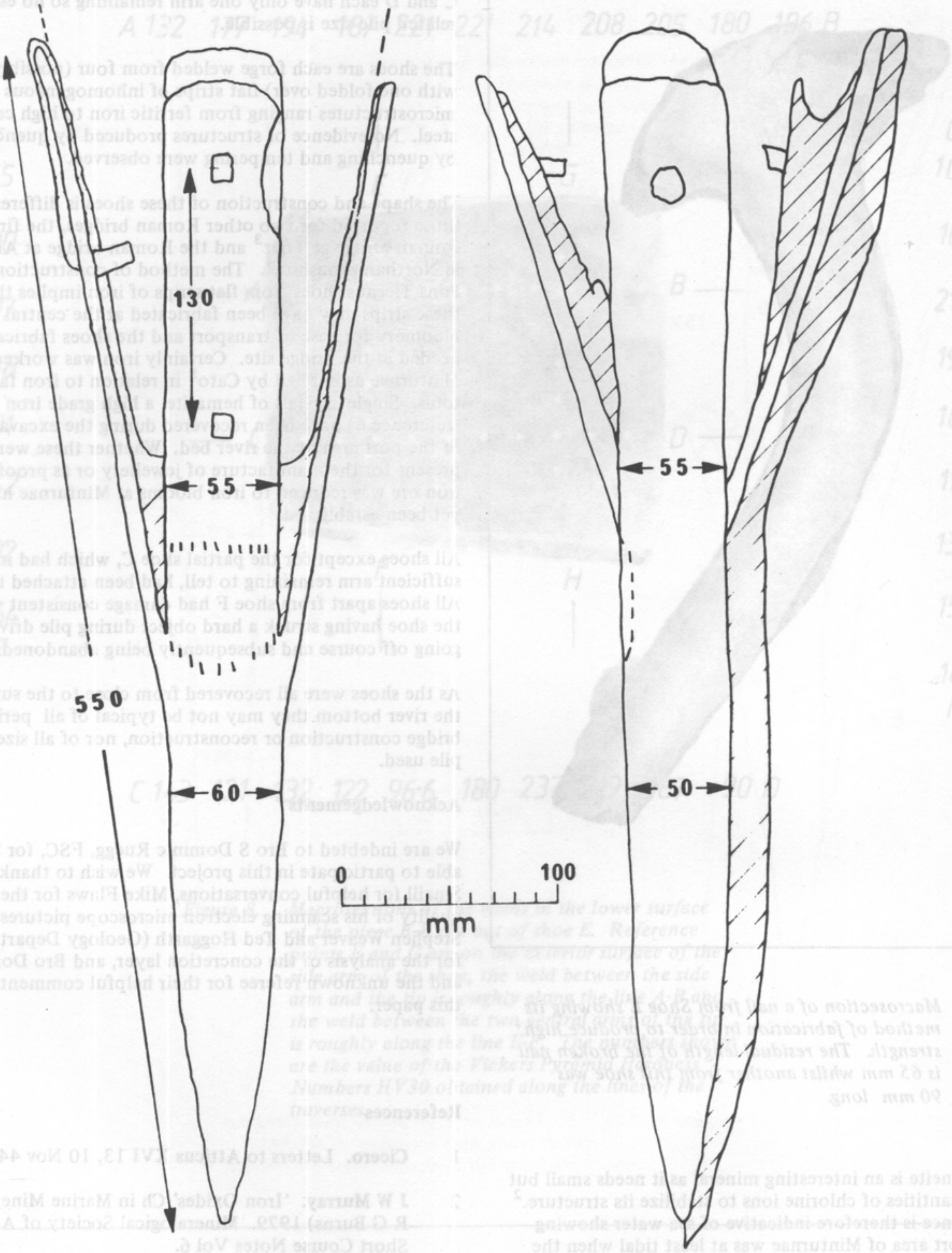


Figure 10. Shoe F. This shoe was still attached to its pile (GC) and was surrounded by a layer of concretion (hatched area) 20 mm thick in places. Parts of this layer were removed to determine the shape of the shoe. For much of the tip there was no clear boundary between the metal and the concretion. The nails and nailholes were indistinct.

Shape and microstructure of copper produced in a reconstructed ancient smelting process

M Bamberger, Israel Institute of Metals

Introduction

In Historical Metallurgy Vol 12 (1978) p40-43, G Weisgerber published metallurgical conclusions from 'a new kind of copper slag from Tawi Aarja Oman' and has proposed the reconstruction of the related smelting furnace and smelting process. Weisgerber's reconstruction showed a bowl furnace in the ground, with a bun-shaped copper ingot on the bottom, underneath a furnace full of slag. Recent experimental copper smelting results showed that Weisgerber's metallurgical interpretations and reconstructions do not seem to be acceptable and the facts quoted by him need quite a different explanation.

In the Timna area in Israel, copper was extracted from its ores by using iron oxide to obtain a low melting point slag. According to the findings the smelting process was based on artificially induced air supply. In the Late Bronze Age tapping was used. The slag is essentially fayalite in 20 kg lumps and the shape of the latter indicates that the slag was of low viscosity and was tapped in a short time. On the other hand, no copper ingots were found from which we could establish the method of copper extraction from the furnace. There are two possibilities: First, tapping of the copper together with the slag, the second – tapping of the slag alone and dismantling the furnace to obtain the copper. The first method is clearly advantageous as the furnace does not have to be dismantled and it can be used again and again.

In the framework of this research, experiments of copper smelting in a reconstructed furnace were conducted using both tapping methods. The results of the experiments based on findings at Timna Site No 2 and Site No 30, explain the tapping method used in the Late Bronze Age.

The Experiments and Results

The experiments were conducted in a furnace, 40 cm in diameter, in which six tuyeres, 12.5 mm in diameter, were installed to supply air. The distance of the tuyeres from the furnace bottom was 15 cm and they were installed at an angle pointing towards the centre of the furnace bottom (Fig 1). This design ensured an even air distribution across the whole cross-section of the furnace, including its bottom. This enabled sufficient heat to be generated at the furnace bottom to ensure that the slag remain liquid.

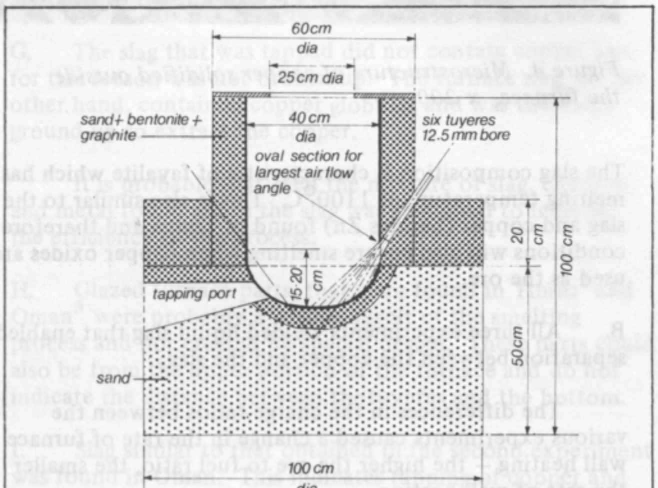


Figure 1. Schematic representation of the furnace

The furnace was built from a mixture of silica sand, bentonite and charcoal powder. The air was supplied by bellows and gauged by flowmeters when each pair of tuyeres had its separate flow meter. The charge included silica, hematite, brass swarf as a copper source and charcoal. The air supply was at a rate of 250 l/min per tuyere. The Fe_2O_3/silica ratio in the ore was kept at 2.3 and copper concentration was 25%.

Experimental stages: pre-heat for 1.5 hours, using charcoal alone, loading of ore and charcoal for 1.5 hours and heating for an additional 15 minutes until slag was formed and then tapping. In all experiments temperatures below the furnace and in the walls were monitored.

Experiment No 1: 15 kg of hematite containing 70% Fe_2O_3 and 10% SiO_2. 3 kg silica and 10 kg of 60:40 brass as swarf. Charge ratio ore/fuel = 2/3. The tapped slag was very liquid. After dismantling, a lump of copper-base alloy was found on the bottom, underneath a slag layer (Fig 2). The furnace bottom lost its shape due to reaction with the slag. The copper lump was not found in the centre of the furnace, which was the lowest point in the furnace, but rather concentrated randomly in a place formed by the erosion of the furnace bottom.

The slag was coated by another layer, 2 cm thick formed by reaction between the furnace wall and the slag. Slag was found adhering to the furnace wall even above the tuyeres and seemed as if it was sintered.

A mixture of slag, metal (copper + iron) and charcoal was found above the slag layer.

The rate of heating of the furnace wall was 162°C/hr, and the temperature 1 cm below its bottom reached 950°C.

Experiment No 2: A similar charge was used as in the previous experiment, but the charge ratio was ore/fuel = 1/1. A pit, 22 cm in diameter and 10 cm deep, was prepared in the sand outside the furnace. The slag and copper were tapped into this pit. The slag remained liquid for about 15 min. This enabled the copper to sink below the slag (Fig 3) to form a copper slab 9 cm in diameter and 1 cm thick weighing 2 kg.

The slag lump had a rough surface and a thin layer (0.1 cm) of sand clung to it. The upper surface contained gas bubbles and some charcoal which came out of the furnace during tapping and floated on the slag.

The metallographic structure of the copper, revealed by etching with ammonia and H_2O_2 at a magnification of x200 is shown in Fig 4. Cored, copper-rich solid solution can be seen. An iron-rich phase can be seen as specks scattered across the section.

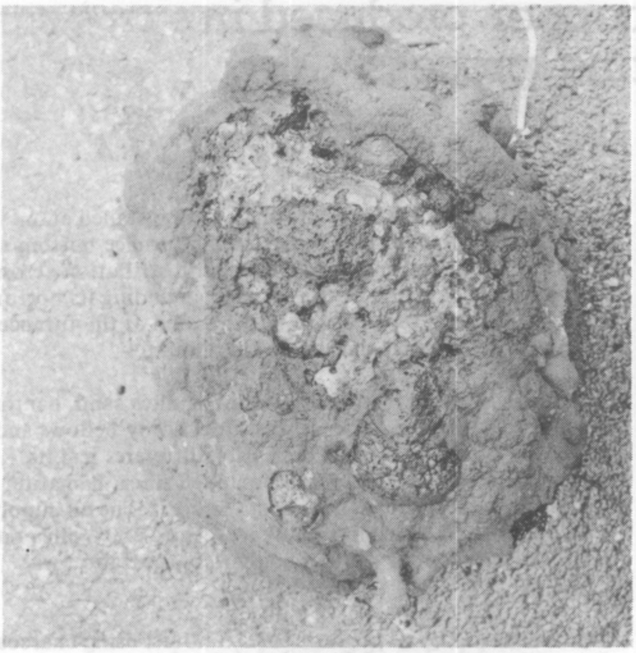


Figure 2. Lump of copper and slag found on furnace bottom. (Maximum width = 40 cm)

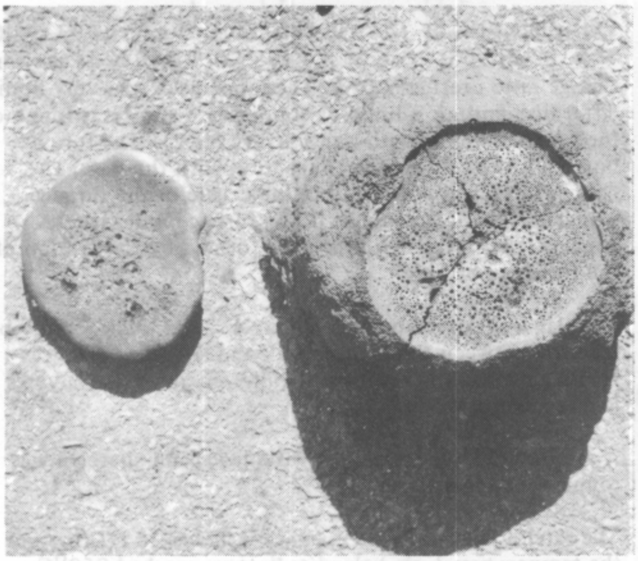


Figure 3. Copper and slag solidified outside the furnace. (Cu ingot = 9 cm diameter)

The furnace yielded a mixture of slag, metal and charcoal, and slag was found on the furnace walls as well. The rate of furnace wall heating was 109°C/hr and the temperature 1 cm below the bottom was 950°C maximum.

Experiment No 3: The total quantity of the ore was double that of the previous experiments, but the composition was similar. The charge ratio was ore/fuel = 2/1. The tapped slag was very liquid. When the furnace was dismantled, a copper layer 30 cm in diameter and 1.5 cm thick was found below a slag layer 4 cm thick (Fig 5). The quantity of copper was large enough to cover the entire bottom of the furnace and therefore copper was distributed across the whole cross-section. The copper lump and the slag did not attain the shape of the original furnace bottom because of its erosion during smelting.

The copper slag yielded metallographic structure with a much larger grain size than that seen in Fig 4 – see Fig 6 at 200X magnification etched with ammonia and H_2O_2. The difference in microstructure stems from differences in the cooling rate. The slower the cooling rate, the coarser the grains. Cooling in hot sand (experiment No 3) is slower than in cold sand (experiment No 2). Therefore the grain size in experiment No 3 is larger than in experiment No 2.

A mixture of slag, metal and charcoal was found above the slag layer. Slag was also found on the furnace walls. The heating rate of the furnace wall was 88°C/hr and the temperature 1 cm below the bottom reached 1000°C.

Conclusions

The following conclusions can be drawn:

A. The experiments are reconstructions of copper extraction from oxides. Despite the fact that brass swarf rather than copper oxides were used, the following slag and metal compositions were obtained:

Slag:-	Fe_2O_3	SiO_2	CaO	Cu
	~45%	36-37%	~7%	0.2-0.9%
Metal:-	Cu	Fe	Zn	
	~91%	4-6%	~2%	

Figure 4. Microstructure of copper solidified outside the furnace. x 200

The slag composition is characteristic of fayalite which has a melting temperature of 1100°C. This is also similar to the slag and copper (besides Zn) found in Timna and therefore the conditions will also ensure smelting when copper oxides are used as the ore.

B. All three experiments yielded liquid slag that enabled separation between the copper and the slag.

The differences in the charge ratios between the various experiments caused a change in the rate of furnace wall heating – the higher the ore to fuel ratio, the smaller the rate of wall heating.

C. The slag is very reactive with the silica lining. In the furnace the slag was therefore coated with a hard layer, 2 cm

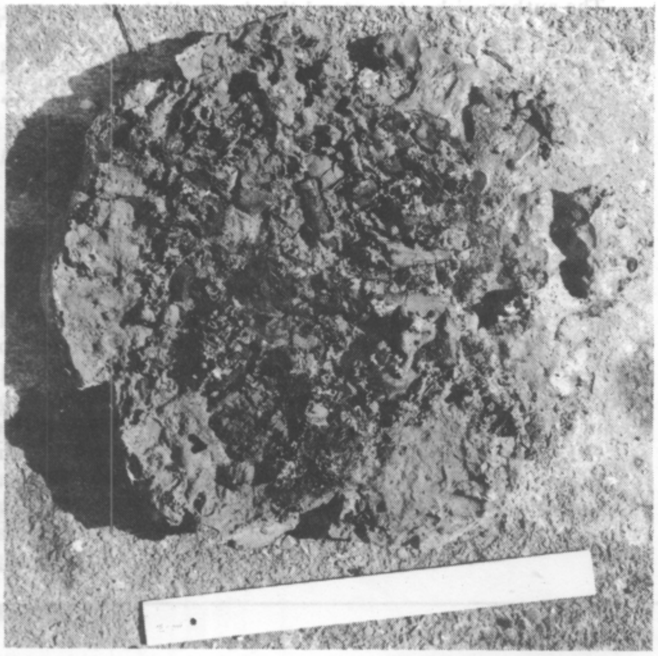


Figure 5. Slag and copper spread over whole furnace cross section. Scale = 30 cm.

thick. When the slag solidified outside the furnace, only a thin layer developed.

D. High temperature in the furnace caused the melting of the inner furnace wall and formed a glazed lining in areas above the tuyeres.

E. The above phenomena – slag reactivity and high temperature – causes the furnace to lose its original shape and the copper produced in it will not accumulate at the centre of its bottom. On the other hand, tapping the copper and slag into a pit outside the furnace, ensures the concentration of the copper in the middle of the pit. Therefore even the plano-convex ingots described by Tylecote[1] may be solidified outside the furnace.

F. The furnace slag was always covered with a mixture of charcoal, slag and metal; such coating was not found on the tapped slag. The latter had a blistered surface and charcoal attached to the surface.

G. The slag that was tapped did not contain copper and for this reason was not broken up. The furnace slag, on the other hand, contained copper globules and was therefore ground up to extract the copper.

It is probable that even the mixture of slag, charcoal and metal found above the slag was re-melted to increase the efficiency of the process.

H. Glazed furnace parts, that were found in Timna[2] and Oman[3] were probably a natural result of the smelting process and not created by special design. These parts could also be from the upper portion of the furnace and do not indicate the distance between the tuyeres and the bottom.

I. Slag similar to that obtained in the second experiment was found in Oman. This indicates tapping of copper and slag which is a better process than dismantling the furnace to extract the copper. This also explains the fact that the copper was found in the middle of the slag 'cake' bottom, the presence of a thin reaction layer on the slag, also the shape of the upper surface of the slag and the absence of a lump of slag, charcoal and metal mixture characteristic of furnace slag. However, this conclusion should be qualified as we do not know the chemical composition of the charge, slag or the furnace wall in Oman.

J. Microstructure analysis of samples from Experiment 2 and 3: The Cu-Zn phase diagram shows the β phase only above 38% Zn, therefore it cannot appear in our samples. On the other hand copper-iron solid solutions do exist and may exist in our samples which contain 3.4-4% Fe.

A later experiment was carried out under the same conditions, but using Timna ore instead of brass swarf. In this experiment the chemical composition of slag and metal in this case with Zinc at 0.2% and the structure were the same as those of the experiments presented above. It ensures again that the structure is a Cu-Fe alloy rather than β brass.

The cooling rate even outside the furnace is slow because the metal was tapped with very much slag (weight ratio 1:3). The structure is always equiaxed and differs only in grain size.

cooling outside the furnace – 65 μm

cooling inside the furnace – 100 μm

Figure 6. Microstructure of copper solidified on furnace bottom. x 200

The columnar growth from bottom and top found in an ingot cast into a sand pit[1] is due to the absence of a thick slag layer above the metal, as it is in the case of slag + metal tapped from one smelting furnace

The high percentage of iron causes the samples to be magnetic as in the case of those from Timna[1], and causes a higher liquidus temperature (~1250°C) which means a higher air and charcoal supply than needed for iron-free copper smelting.

K. The smelting process described by Agricola (9th book) shows the tapping of metal and slag into a pit outside the furnace as in experiment 2.

I. There is a substantial difference in the microstructure of the copper solidifying in the furnace as compared with that solidifying outside the furnace – the latter has a much finer microstructure. This indicates that by examining the microstructure it can be determined if the copper was tapped with the slag or if it solidified in the furnace.

It is advisable to perform this examination on copper samples to determine the extraction method.

Acknowledgements

The research was sponsored by the Volkswagen Foundation and was conducted with the participation of Prof H G Bachmann, Prof B Rothenberg and Prof P Wincierz.

Chemical analysis was performed by the 'Degussa' Company, Hanau.

The author wishes to extend thanks to all the above-mentioned people and special thanks to A Amram from the Israel Institute of Metal, for his invaluable part in conducting the experiments.

References

1 R F Tylecote, Properties of Copper Ingots of Late Bronze Age Type. Festschrift fur Richard Pittioni. Archaeologia Austriaca, Beiheft 14, 1976, Vol 2 pp 157-172.

2 B Rothenberg, **Timna,** Valley of the Biblical Copper Mines, Thames and Hudson, 1972.

3 G Weisgerber, A New Kind of Copper Slag from Tawi Aarja, Oman, **Historical Metallurgy,** 1978, **12** (1), 40-43.

4 G Agricola, **De Re Metallica,** 1556, Translated by H C Hoover and L H Hoover, New York; Dover Publications, 1950.

Letter to the Editor: Seeking information on cast iron pigs

Dear Sir,

This seems an ideal opportunity to ask for some advice from your society. During the Phase I excavation a large iron pig was found on the edge of the site bearing the name **'Duddon'** cast in relief in the centre. This pig measures 131 cm long, 13 cms wide, 6.5 cm high and weighs 55 kg! In Phase 2 excavation a cast iron bar was found in the headrace with the name **'Lorn'** cast in relief at one end. This bar measures 138 cm long, 5 cm wide, 3.5 cm high and weighs about 15 kg. This one poses problems as to its origin, as you know that the Bonawe Furnace in Scotland was the **'Lorn'** furnace operated by the Newland Company, but also the Charcoal Iron Company at Backbarrow used the name **'Lorn'** as a trademark in the early 20th century. Both pieces of cast iron have recently been given conservation treatment by the Abbot Hall Museum, Kendal, and are due to go on display at the Kendal Museum.

I am at present gathering information on casting pig iron to make up a display for the museum. I should be interested to know if such pieces of cast iron were of a typical size and weight. Other pigs found during the excavations at Duddon were much smaller, without any inscriptions, is 30 cm long, 9 cm wide, 5 cm high, weighing 7 kg.

On the question of dating these two bars, my suggestions are that the 'Duddon' pig may have been cast in the late 18th century or early 19th century when operated by the Duddon Company. Harrison, Ainslie and Company took over Duddon in 1828 and as they already operated Bonawe furnace perhaps the name of the Scottish furnace was adopted as a trade mark. Thus the 'Lorn' pig may relate to the last period of working prior to its closure in 1867.

I notice in Reg Morton's article that there are pigs from Duddon with the inscriptions D1762, D1772 and D1781. In another article by a Newcomen Society member, Mr J A Smythe, the D1772 pig's dimensions are 42" long, 4" wide, 3.5" high and weighing 70 lb.

I hope you can help me out with information on the size and weight of cast pig iron in the 18th and 19th centuries and if you require further information on Duddon please get in touch.

Yours sincerely,

Andrew Lowe
Lake District Special Planning Board

The composition of some sixth century Kentish silver brooches

David Leigh, Michael Cowell and Stephen Turgoose

Abstract

Twenty-five sixth century silver square-headed brooches have been analysed by XRF. They come from the cemeteries of Howletts in Kent and Chessel Down on the Isle of Wight. The effect of a greater degree of corrosion on the latter group's analyses is explained and its significance assessed. The results support the theory that the metal source might have been scrap Roman silver and brass, as well as melted down Germanic metalwork. Comparison between paired brooches points to the casting of some pairs from a single batch of metal. The results justify a broader programme.

Introduction

This pilot study of twenty-five square-headed brooches explores the potential contribution and limitations of analysis to the archaeological understanding of Dark Age jewellery. These brooches have rectangular headplates covering the pin attachment, a curved bow to accommodate the cloth, and a trapezoidal or cruciform footplate hiding the pin-catch (Fig 1). Most of the Anglo-Saxon brooches are made of copper alloy, are found singly and are somewhat larger than the Kentish brooches which were usually worn in pairs. The silver versions are found almost exclusively in Kent or in cemeteries where the other burial evidence suggests a strong Kentish cultural connection. They were mostly produced in the first half of the sixth century A.D.

The brooches in question comprise ten from the cemetery of Howletts, near Littlebourne, Kent[1] and fifteen from the Kentish cemetery of Chessel Down, on the Isle of Wight[2]. They are all held in the collection of the Department of Medieval and Later Antiquities in the British Museum.

Analysis

All the brooches were analysed by X-ray fluorescence (XRF) on a scraped and polished surface. The equipment consists of a Link Systems model 290 spectrometer using a molybdenum targetted x-ray tube operating at 25 kV. The incident beam is collimated so that it interacts with the specimen over an area approximately 2mm in diameter. All measurements were made in air.

Five elements were quantified: silver ($L\alpha$ peak), copper ($K\alpha$ peak), zinc ($K\alpha$ peak), gold ($L\alpha$ peak) and lead ($L\alpha$ peak). In most of the brooches small amounts of tin were detectable by emission spectroscopy. However, the tin concentrations could not be accurately quantified by this particular XRF technique because of spectral line interference between the secondary silver peaks and the tin $L\alpha$ peak used for measurement. Nevertheless it was estimated (by a subtraction procedure) that the tin concentrations ranged up to about 2%. Calculation of composition from nett peak integrals was determined by a fundamental parameters type of matrix correction programme[3].

A major factor governing the accuracy which can be obtained with x-ray fluorescence analysis is the condition of the surface of the specimen examined. Ideally, for the best results, this should be a plane surface free of irregularities and corrosion representative of the bulk of the metal. Unfortunately, whereas the examined areas on most of the Chessel Down brooches largely fulfilled these criteria, those from Howletts did not. Most of the Howletts brooches are more or less internally corroded and other elements, such as chlorine and bromine, particularly associated with corroded silver were detected. When the surface to be examined was scraped to remove deposits and surface enrichment, the metal came away as a powder rather than in the form of shavings and further scraping deeper into the body failed to find sound metal. Those objects showing evidence of internal corrosion are marked as such in Table I. In these cases the analytical data should be regarded with caution and are only intended to give a general indication of composition.

The calculation procedure is such that the results always total 100 per cent irrespective of whether the specimen is corroded or whether other elements are present which have not been quantified. The precision of the analyses of uncorroded metal is difficult to determine in practice because it depends on the homogeneity of the object. However it is probably in the range ±0.5 - 1.0 per cent absolute for the silver and for other components at greater than 2 per cent concentration and is up to ±50 per cent relative for components at less than 2 per cent concentration. As a result of an unknown but small amount of tin being present in the brooches the silver content in most cases may be 1 - 2 per cent higher than the true figure, the effect the presence of tin has on the concentration of minor components of the alloy being negligible.

Results (Table I)

The majority of brooches from both sites consist of silver-copper alloys containing, in some cases, appreciable amounts of zinc, gold and lead. The results suggest that the source of metal for many of the brooches was a moderately pure silver, alloyed with a copper-based alloy (containing zinc, tin and lead) similar to modern 'gunmetal'.

This conclusion is based on the close relationship between the zinc and copper contents. In the absence of zinc metal, copper zinc alloys of up to 28 per cent zinc (2:6:1 of copper:zinc) were manufactured using the zinc ore calamine by the cementation process[4]. If a given amount of copper is present in the alloy this sets a limit on the maximum amount of zinc to be expected if its source was a brass or gunmetal. In Figure 2 the line drawn through the origin represents the theoretical maximum ratio of zinc to copper which could be the result of using a mixture of copper and gunmetal/brass for alloying or, more likely, a copper-based zinc alloy containing less than 28 per cent zinc. Points below the line are richer in zinc than the theoretical maximum and apparently could not be the result of using brass for alloying.

One feature common to all of the brooches which are rich in zinc is that they are to some degree corroded. It seems possible that corrosion or treatment has caused loss of some or all of the copper, without seriously affecting the zinc content. Dezincification of a brass is a common phenomenon as also is decuprification of a silver alloy, but for an explana-

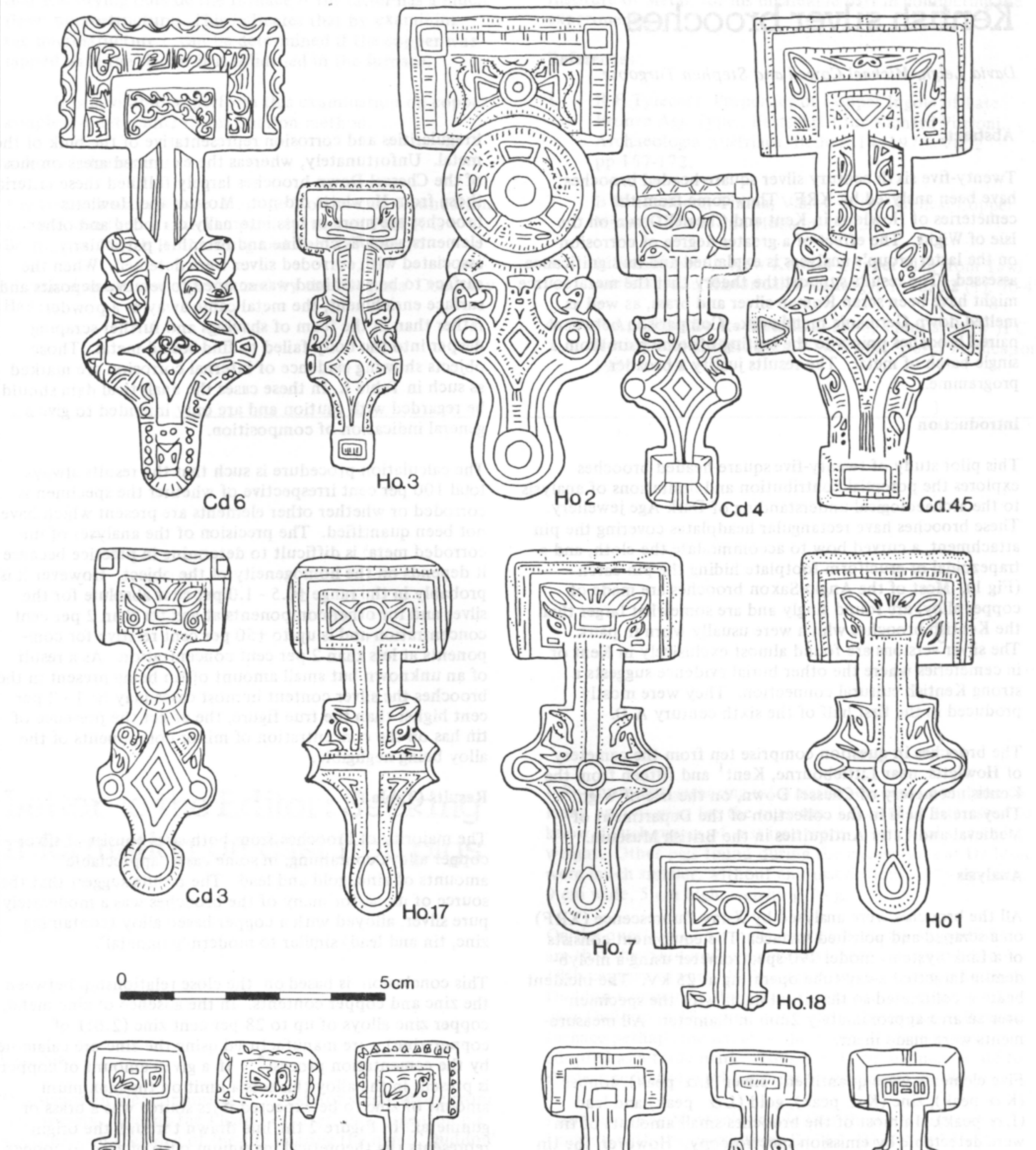


Figure 1 The silver brooches analysed. Only one brooch is illustrated in the case of pairs or trios, see Table I

tion of decuprification in this more complex situation we must consider the probable structure and corrosion mechanisms in more detail.

Corrosion

The question which first arises is whether the low Cu:Zn ratios are the cause of the brooches corroding, a result of corrosion, or coincidental. An understanding of the corrosion behaviour of these alloys requires a knowledge of their structure.

Silver-copper alloys

Silver and copper form a classical binary eutectic system with the eutectic point at 28.1 per cent Cu, 779°C[5]. The maximum solubility of copper in silver is 8.8 wt%, at the eutectic temperature, so alloys with more copper than this (but <28%) will always be two phase systems, consisting of a primary silver-rich phase and eutectic mixture. The solubility of copper in silver decreases rapidly with temperature (5.8% at 700°C, 1.8% at 500°C, 0.7% at 400°C), so even alloys with low copper contents may contain two

BM Number	Brooch	% Silver	% Copper	% Zinc	% Gold	% Lead	Corrosion ?
67, 7-29, 10	Cd.3	92.0	6.0	<0.2	0.6	1.4	
" 11	Cd.4	89.6	5.0	0.8	2.9	1.6	
" 6	Cd.6	69.6	27.1	0.4	0.5	2.1	
" 18	Cd.7	78.5	16.5	0.9	1.3	2.7	
" 13	Cd.5 i	85.7	5.6	2.9	0.9	4.9	γs
" 23	ii	64.6	28.2	3.6	0.6	3.0	
" 21	Cd.10 i	88.6	9.2	0.1	1.1	1.0	
" 19	ii	84.2	13.4	0.1	1.2	1.1	
" 20	Cd.40 i	88.6	8.3	1.1	0.8	1.1	
" 24	ii	89.6	6.0	2.1	0.8	1.5	
" 22	Cd.55 i	91.5	4.6	1.6	1.3	0.9	
" 12	ii	91.7	4.4	1.1	1.1	1.6	
" 8	Cd.45 i	92.0	5.9	0.8	0.6	0.7	
" 7	ii	91.4	5.7	1.0	0.6	1.3	
" 9	iii	91.0	7.0	0.8	0.6	0.6	
96, 11-26, 1	Ho 1	89.6	7.7	0.2	1.7	0.8	
1918, 7-11, 1	Ho 2	92.7	2.4	2.0	1.8	1.1	γs
96, 11-26, 2	Ho 3	89.9	5.3	1.6	1.2	1.9	
1936, 5-11, 61	Ho 17	91.6	1.8	2.1	3.5	0.7	γ
" 28	Ho 7 i	95.7	0.5	1.9	1.4	0.5	γ
" 27	ii	95.4	1.3	1.7	1.1	0.4	γs
1935, 10-29, 7	Ho 12 i	97.0	0.4	1.0	1.5	0.1	γ
" 8	ii	96.3	0.7	1.1	1.8	0.2	γ
1936, 5-11, 64	Ho 18 i	93.1	2.1	2.3	1.5	0.9	γ
" 63	ii	96.0	0.5	1.4	1.9	0.2	γ

Table I — γs slight corrosion — γ severe internal corrosion

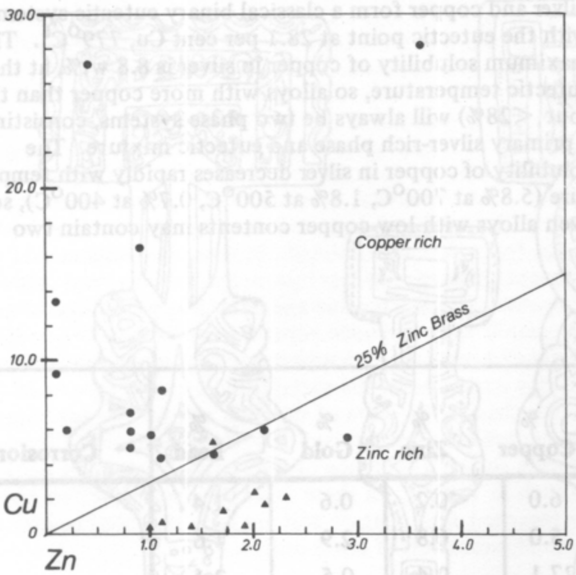


Figure 2 **Copper and Zinc distribution**

phases. The extent to which copper will separate out of solid solution depends on factors such as working temperature and cooling rate.

The corrosion of these two phase alloys can lead to the selective dissolution of the copper-rich phase, as would be expected from the standard electrode potentials of the two metals ($E^oAG^+/Ag = 0.8v$, $E^oCu^{2+}/Cu = 0.34v$), which explains the lower copper contents of the corroded brooches.

Silver-copper-zinc alloys

The phase diagrams for this ternary system have been determined[6] and show that with less than 20% Zn only two solid phases exist, the same as in the Ag-Cu system. The presence of zinc decreases the eutectic temperature and slightly increases the ratio of silver to copper in the eutectic, but does not greatly influence the solubility of copper in silver, or vice versa. The zinc will be in solution in both the copper-rich and silver-rich phases, the ratio of the concentrations in the two being about 3:2. We can thus calculate the composition of each phase, and the amounts of them present in an alloy of a given temperature. For example, a 92:6:2 (Ag:Cu:Zn) alloy (wt %) annealed or treated at 400°C (solubility of Ag in Cu 0.5%) will contain:

94.5% of Ag phase of composition

97.4% Ag, 0.7% Cu and 1.95% Zn

and 5.5% of Cu phase of composition

96.2% Cu, 0.5% Ag and 2.9% Zn.

Or, in terms of distribution of the components by weight in 100g of alloy.

(g)	Ag	Cu	Zn	Total
Ag phase	91.97	0.65	1.84	94.5
Cu phase	0.03	5.35	0.16	5.5
Total	92	6	2	100

Thus in this alloy 92 per cent of the zinc present will be in solid solution in the silver, compared to only 11 per cent of the total copper.

This alloy is in the range analysed in the uncorroded brooches, and is consistent with the use of a cementation brass as the source of copper and zinc. Corrosion will be expected to occur as before, with selective dissolution of the most active, ie the copper-rich, phase but not necessarily the most active metal. By analogy to brass, where dezincification does not occur with less than 15 per cent Zn, we would not expect selective dissolution of the zinc out of the silver-rich phase. Also the mechanism often proposed for brass – dissolution of the whole surface followed by deposition of copper – would not seem applicable to silver base alloys.

The result of this corrosion of the copper phase in the alloy above, if carried to completion, would be to leave a porous metal of composition 97.4 per cent Ag, 0.7 per cent Cu, 2 per cent Zn, quite similar to those determined. The exact composition of the corroded alloy will obviously depend on the initial composition, heat treatment and extent of corrosion, but it is clear that the analysis of the corroded brooches are quite consistent with the supposition that the primary source of zinc was a copper alloy with a zinc content of less than 28 per cent (cementation brass).

The usefulness of the analyses of the corroded brooches for source studies is clearly somewhat limited by corrosion effects, but these can to some extent be allowed for. Where pairs of brooches are found together in the same grave in similar burial environments their analyses should be affected to the same degree.

Discussion

Metal Sources

The kingdom of Kent was a centre of wealth and trade in the sixth century. Its possessions and the quality and sumptiousness of its craftwork as evidenced by the buried jewellery in particular, are eloquent proof of this. So also is the fact that much of the best jewellery, in the earlier part of the century at least, was of silver rather than the otherwise ubiquitous copper alloy. Where did the silver come from?

It seems unlikely that silver was extracted in Anglo-Saxon England until a much later date. Copper silver ores from which it might have been extracted are found in workable quantities in Devon and Cornwall[7], areas not involved with the economy of Anglo-Saxon England, let alone Kent, at this time. Nor is there any material or literary evidence that the mining of argentiferous lead ores pursued by the Romans was again taken up until the ninth century[8,9]. Nor was there at this time any demand for coinage silver.

If silver was being extracted on the Continent then it is possible that it was being imported to Kent, just like other precious goods (garnets, amethysts, glassware etc). But the use of gold rather than silver for continental coinage at this stage[10] seems to preclude this possibility.

The silver probably derived from a secondary source. At the middle of the fifth century there must still have been available scrap silver in the form of a) late Roman silver coinage; b) Roman silver plate and other objects; and, as time progressed, c) an increasing quantity of Germanic silver (itself made from re-melted Roman scrap).

An important clue is provided by a hoard of scrap silver found at Hostentorp in Denmark[11,12]. It contains silver ingots, rods, wires, rings, fragments of Roman sheet silver vessels and fragmentary Germanic silverwork, the latest items dating the hoard to the early years of the sixth century. Most of the objects are cut up or rolled into bundles. They give every appearance of being a stock of raw material awaiting use, the cut ingots suggesting the remains of partially used silver stock already re-melted. Here is tangible evidence that scrap metal from all the above sources was used and that remelted Germanic jewellery probably provided a not inconsiderable proportion of the metal required for its continued production. There are sound archaeological grounds for equating metal-working practices in Denmark with those in Kent in the early sixth century[13,14], so we may place good reliance on this parallel. It is possible that other scrap hoards from Scandinavia, Europe and the British Isles point in the same direction.

The practice of re-melting earlier metalwork to make new is well-attested. In many societies 'the smith . . . only contributes his skill to production whilst the customer supplies the raw material and/or fuel and/or labour'[15]. There are apparently 'widespread ethnographic references to provision of broken or worn out implements by the customer to a smith in part or whole exchange for new implements' (idem). Such an explanation would fit well with the suspiciously small proportion of silver brooches surviving in graves, compared with the much larger number which, on typological grounds, we may expect to have been manufactured originally[16]. It would also tally with the remarkable disparity between the large numbers of moulds found at the metalworking site of Helgo in Sweden and the very small numbers of surviving metal brooches produced from such moulds[17].

Ultimately the source of silver, even from any remelted Germanic jewellery, must have been Roman. Officially stamped silver ingots and silver plate were distributed widely in the later Empire as gifts to soldiers and officials. It may be no coincidence that six of the eleven such ingots from Roman Britain, each weighing about one Roman pound, have been found in Kent[18,19]. Silver coinage was in plentiful supply until about 420 and had disappeared from circulation by 430[20], though not, evidently, into the ground.

Analysis of two of the ingots[21], of later silver coin[22] and of silver plate[23,24] all indicate a much purer silver alloy than is found in these Kentish brooches so we may look also to a source of Roman scrap copper alloy for the other component apparent from our analyses. The contribution of copper from the silver alloy (up to 3 or 4 per cent), would imply a lower copper to zinc ratio for the added metal than is suggested by a direct comparison of the figures in these analyses.

On the other hand, if we assume that one addition of a copper alloy provided all the zinc and copper, we can calculate the zinc content of the alloys used from the composition of the uncorroded brooches. These are:

Zn content of Cu alloy	No of brooches
0 - 4%	4
4 - 8	1
8 - 12	4
12 - 16	2
16 - 20	0
20 - 24	1
24 - 28	2

which shows similarity to the results of Craddock[4] in the analysis of Roman copper alloys with more than 1 per cent zinc. His graph of number of artefacts against zinc content showed three maxima:

1 Less than 4% (fortuitous use of scrap brass)

2 Around 13% (equal mixtures of cementation brass and other copper alloys) and

3 22% (cementation brass).

If there were more analyses available here it would be tempting to suggest that the copper alloys added to the silver for the brooches reflect this general distribution, and that the exact composition of the copper was of no interest to the manufacturer.

Although the tin content of the brooches was not accurately quantified the indications are that its concentration is approximately half that of the zinc in some cases. This suggests that appreciable amounts of bronze may have been included bearing in mind that there is usually less tin in a bronze than zinc in brass.

The gold content is generally a little high compared with that found in late Roman silver (eg the Mildenhall dish, 0.6% - 0.8%[25], but could be accounted for by the accumulation of gold from re-melting gilded objects. The zinc component must have come almost entirely from the copper alloy, since zinc was almost absent from late Roman silver.

Copper-based alloy would have been readily available in the form of scrap Roman brass objects, brass being the characteristic later copper alloy used for objects, but is unlikely to have come from coin which, by the fourth century, contained very little zinc at all[4].

A comparative analysis of a silver bow brooch from Denmark[25] has a similar composition; while some work on East Gothic brooches, also by Riederer, implies more heterogeneous sources[26].

What emerges from this study is the value of a larger programme of analyses to a higher standard of accuracy and to embrace a wider range of elements, including trace elements such as bismuth[27]. Even though the usefulness of these for characterising metal sources in alloys of such mixed origins might be limited, they would improve recognition of brooches from the same batch of metal. Atomic absorption (AAS) would be well suited to this task and although samples would be required these need only be about 20 mg in weight[28]. Any future XRF work along these lines should enable tin to be quantified in addition to the metals determined in this study. It would also be helpful to have analyses of contemporary copper alloy objects, if only to establish the degree of control exercised in the choice of scrap metal. The Romans seem to have controlled the low levels of copper added to their silver for making plate [24]; and analysis of fifth/sixth century Scandinavian gold bracteates suggests a parallel practice, late Roman/Byzantine gold solidi having been alloyed with silver and copper to a consistent gold standard [29]. The composition of contemporary copper alloy brooches from the same workshop will be particularly relevant, for we should expect to find them made of the kinds of alloys added to the silver brooches. While the results may be said to support the suggestion that late Roman scrap silver and brass were combined to produce a metal of the desired visual and physical properties, they cannot yet be said to prove this. In general, the analyses of the uncorroded brooches present a remarkably uniform picture, especially of silver content.

Internal Comparisons

Comments must still be largely restricted to results from uncorroded samples, but notice is now taken of those Howletts pairs of brooches which come from the same grave and probably suffered corrosion to the same degree.

With a few exceptions all the brooches from the two sites may be taken as the products of a single Kentish workshop [30], so, corrosion aside, there is no reason to expect any significant variations between the two sets of results.

Taking first the pairs of brooches:

Cd.55 i & ii — These are extremely similar in composition, the differences being well within the range of experimental error.

Ho.12 i & ii — These are also extremely close in composition.

Ho.7 i & ii — These are extremely close in silver contents, and the slight differences in copper, zinc and gold contents could be accounted for by their recorded difference in corrosion conditions.

Cd.10 i & ii — Moderately close compositions, though marked difference in copper content. Yet both have unusually low zinc contents.

Cd.40 i & ii — Moderately close compositions, but showing a small but significant analytical difference in copper and zinc contents.

Ho.18 i & ii — These show significantly different compositions, although the exceptionally low copper content of Ho.18.ii might be due to its greater corrosion than i.

Cd.5 i & ii — The markedly different copper contents at first suggest a significant difference in original composition. However calculation shows that extensive corrosion of an alloy like Cd.5 (i) could result in measurements similar to that obtained for Cd.5(ii).

Unless there was an exceptional degree of metal control it seems more than likely that the two brooches of the pair Cd.55 were cast from the same batch of metal; and at least possible that the members of Ho.12 and Ho.7 were also. The case is more doubtful for Cd.10, Cd.40 and Cd.5.

Most of these brooches are small enough for sufficient metal to have been melted for a pair in one crucible [31] thus permitting a single casting operation. If scrap was being used then it could have been melted in that crucible or have been prepared prior to casting in ingot form.

The Chessel Down trio results present difficulties of interpretation. Close inspection of the brooches themselves shows that Cd.45.ii (BM 67, 7-29, 7) is different in several details from i and iii which form an almost identical pair. Yet the analyses, although close, show a small but significant analytical difference in the copper content of iii from the other two. On the other hand, the gold contents of all three are identical and lead contents of i and iii are the same, and different from ii. The conclusion is by no means clear. All we can say is that the three brooches were made with slightly different batches of metal, fortuitously or deliberately of very similar composition.

Of the single brooches, although Ho.3 and Cd.4 are by no means a pair, they have sufficient stylistic similarities to suggest their being contemporary products. The extreme closeness of their compositions is therefore reassuring.

Apart from one brooch of the Cd.5 pair, the only other brooch to have an unusually low silver content is Cd.6. It also has an exceptionally high copper:zinc ratio. Here the analytical results provide confirmation of the stylistic judgment that this brooch is possibly not a product of the Kentish workshop [32].

Considered for the internal evidence they provide, these analyses demonstrate considerable potential for a larger programme extending to other classes of silver jewellery, from Kent and from elsewhere, on the basis of which it should be possible to advance from this brooch-by-brooch comparison to some statistically significant conclusions. The analysis of heavily corroded brooches, although of more limited value for accurate comparisons, is still clearly worthwhile.

Acknowledgements

We should like to thank Mrs Leslie Webster and the Keeper of the Department of Medieval and Later Antiquities in the British Museum for permitting the brooches to be analysed; and Dr M S Tite for helpful discussions in the preparation of this paper.

References

1 A Meaney, **A Gazetteer of Early Anglo-Saxon Burial Sites,** 1964, London, p 125.

2 C J Arnold, **The Anglo-Saxon Cemeteries of the Isle of Wight,** 1982, London, British Museum.

3 M Cowell, 'Energy dispersive X-ray fluorescence analysis of ancient gold alloys', in **P A C T** Vol I, 1977, X-ray Microfluorescence Analysis applied to Archaeology.

4 P T Craddock, 'The composition of the copper alloys used by the Greek, Etruscan and Roman civilisation 3', **Jnl Arch Science,** 1978, 5, 1-16.

5 M Hansen, **'Constitution of binary alloys'** 2nd ed, 1958, McGraw-Hill.

6 G H Sistare, in **Metals Handbook** 8th ed, 1973, vol 8, pp 130-1.

7 R F Tylecote, **Metallurgy in Archaeology**, 1962, London, Arnold, p 79.

8 C R Hart, **The Early Charters of Northern England and the North Midlands**, 1975, Leicester, p 102 Charter No 99, AD 835.

9 H P R Finberg (ed), **The Agrarian History of England and Wales**, Volume I, Part II, 1972, Cambridge, p 422.

10 D M Metcalf, J M Merrick, L K Hamblin, **Studies in the Composition of Early Medieval Coinage**, 1968, Newcastle upon Tyne p 8.

11 O Voss, 'The Hostentorp silver hoard' **Acta Archaeologica**, 1954, 25, 171f.

12 E Munksgaard, 'Late-antique silver scrap found in Denmark' **Acta Archaeologica**, 1955, 26.

13 E Bakka, 'On the beginnings of Salin's Style I in England' Universiteter I Bergen, Årbok, Historisk-Antikvarisk Rekke Nr 3.

14 G Haseloff, 'Salin's Style I', **Med Arch**, 1974, 17, 1-15.

15 M J Rowlands, 'The archaeological interpretation of prehistoric metalworking' **World Arch**, 1971, 3, 211.

16 D Leigh, **Square-headed brooches of sixth century Kent**, unpublished Ph D, Thesis, 1980, University College, Cardiff, pp 10-18.

17 W Holmqvist et al, **Excavations at Helgo IV, The Workshop – Part I**, 1972, Stockholm, p 137.

18 K S Painter, 'A late-Roman silver ingot from Kent', **Ant Jnl**, 1972, 52, 84-92.

19 K S Painter, 'Two Roman silver ingots from Kent', **Arch Cant**, 1981, 97, 201-7.

20 J P C Kent, 'From Roman to Saxon England' in R H W Dolley (Ed) **'Anglo Saxon Coins'** 1961, London p 5 ff.

21 As Painter 1981, op cit, pp 201, 204.

22 L E Cope, 'The metallurgical analysis of Roman Imperial silver and Aes coinage' in E T Hall and D M Metcalf (Eds). **Methods of Chemical and Metallurgical Investigation of Ancient Coinage**, 1972, London, p 42, nos 24, 25.

23 K S Painter, **The Mildenhall Treasure**, 1977, London, British Museum, p 36.

24 M J Hughes and J A Hall, 'X-ray fluorescence analysis of late Roman and Sassanian silver plate', **Jnl Arch Science**, 1979, 6, 321-344.

25 J Riederer, unpublished, kindly reported by Elizabeth Munksgaard.

26 J Riederer, 'Metallurgische Untersuchung Ostgotischen Trachtzubehörs' in V Bierbrauer, **Die ostgotischen Grab-und-Schatzfunde in Italian**, 1975, Spoleto.

27 H McKerrell and R B K Stevenson, 'Some analysis of Anglo-Saxon and associated Oriental silver coinage' in E T Hall and D Metcalf 1972, op cit.

28 M J Hughes, M Cowell and P T Craddock, 'Atomic absorption techniques in archaeology', **Archaeometry**, 1976, 18, 19-37.

29 S Chadwick Hawkes and M Pollard, 'The gold bracteates from sixth-century Anglo-Saxon graves in Kent', **Frühmittelalterliche Studien**, 1981, 15, 341.

30 D Leigh 1980, op cit.

31 H Roth, 'Beobachtungen an merowingerzeitlichen Gusstiegeln' **Frühmittelalterliche Studien**, 1977, 11, 85-91.

32 D Leigh 1980 op cit, p 125.

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Roman brass-making in Britain

Justine Bayley, Ancient Monuments Laboratory, London

By the time of Christ brass was an established alloy, widely used in the Roman Empire. It appears in quantity in late Iron Age Britain in the decade or so before the Conquest and continues in use in Roman Britain, being found most frequently in first century contexts[1].

Evidence for brass working has come from a number of sites which have produced dribbles of molten metal, crucibles containing traces of brass (eg Cirencester, Baldock and Colchester) and unfinished objects of the metal (eg Stead[2]). However, there has been no evidence to suggest how or where this brass was made. Craddock[3] reviewed the knowledge derived from both Roman authors and material remains but concluded that '. . . not much is known of the actual techniques of Roman brass production'. Despite this lack of information it is generally accepted that the Romans made brass by the cementation process[3,4]. This involved heating copper metal, calamine (zinc oxide) and charcoal together in a sealed crucible at a temperature of 900-1000°C. The calamine was reduced to zinc vapour which diffused into the finely divided copper and formed brass. Finally the metal in the crucible would have been melted to homogenise it.

Recent excavations in Colchester have produced crucible fragments from Roman levels on several sites. Most are metal melting crucibles containing traces of copper alloys but some, from the Culver Street site, are quite different from the rest. These, it is suggested, are brass-making crucibles, material evidence for the cementation process outlined above. Visually these brass-making crucibles are quite unlike any metal-melting crucibles of any period as both fabric and form (in so far as it can be reconstructed) appear unique. X-ray fluorescence (XRF) analysis shows the presence of a similar suite of elements to those found on copper alloy melting crucibles but in quite novel proportions.

The fabric is somewhat variable but generally contains only a small amount of mineral temper together with considerable quantities of vegetable matter. It is dark grey except near the outer surface where it is vitrified, vesicular and paler in colour. It does not appear very refractory and the vitrification penetrates deeply enough to suggest it would have had little strength when hot. This would have made manipulation or movement of the crucibles difficult. Unlike ordinary crucibles none of these sherds have red (copper coloured) patches in their vitrified surfaces and there are no visible droplets of metal trapped in either the vitrified surface or in cracks in the thickness of the walls. The sherds are now very porous and friable and most of the pieces show fresh fractures that have occurred since excavation. This fragility means that no complete or even substantially complete crucibles were found so the reconstruction is tentative; it may be that there is more than one shape of vessel represented among the surviving fragments.

The crucibles were hand made. There are no extra outer layers as are often found on Roman metal-melting crucibles and although some rim pieces have a pseudo-two-layer structure (see Fig 1) there is no difference in the fabric and the extra clay seems most likely to have been the remains of the luting for a lid as has been noted in other cases, eg Bachmann[5]. The sherds are 8-10mm thick and two fragments have projecting knobs which may have acted as props or handles

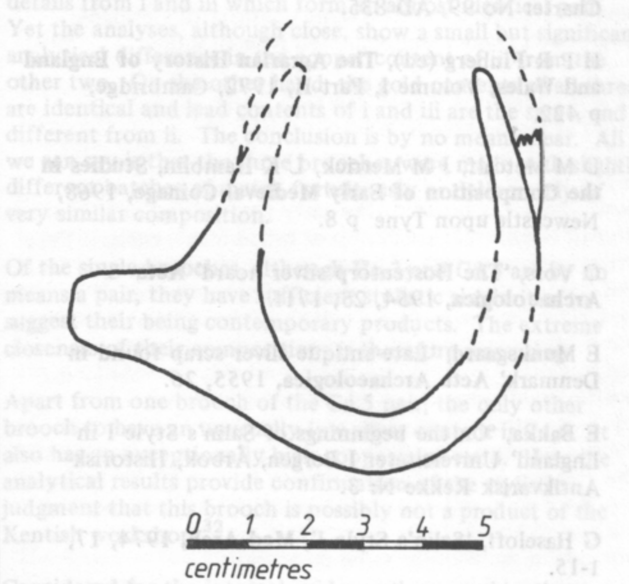

Fig 1. Reconstruction of brass-making crucible from two surviving fragments. Scale 1:1

(see Fig 1). The few larger fragments suggest a pear-shaped body with a narrow mouth at the top which was sealed before the crucible was used. Maximum internal diameters were of the order of 4-6 cm.

The description so far does not contain anything to support the thesis that these crucibles were used for brass-making; the XRF analyses, though, supply strong positive evidence. All two dozen sherds were analysed and it was found that the outer surfaces contained almost no detectable metals while the inner surfaces gave very high readings for zinc together with weak signals for copper and occasionally lead. Zinc has a high vapour pressure (ie when zinc or a zinc-containing alloy is heated a lot of zinc vapour is given off) so all refractories that have been used to melt brass contain considerable amounts of zinc as the vapour goes into the pores of the fabric and may even get trapped in a vitreous slag phase. The levels of zinc detected here, however, are far higher than is found even in crucibles used to melt brass (XRF peak heights up to an order of magnitude larger, measured relative to iron which is present at an approximately constant level in clays). This suggests that these crucibles have been subjected to high zinc vapour pressures for a considerable length of time, exactly the conditions that must prevail in brass-making crucibles.

The archaeological context adds greatly to the intrinsic interest of these crucibles. The earliest are associated with a series of rectangular features about 50 by 100 cm much disturbed but with flat, burnt bottoms dug down perhaps 30 cm from the contemporary ground surface. They were regularly arranged within a room of a large post-built building on the **praetentura** side of the **via principalis** of the fortress built some time after AD 43/44. They were used early in the building's life as they were all sealed by the occupation layer that had built up by AD 48/55 when the building was demolished as part of the work associated with the conversion of the fortress into a **colonia**. Most of the rest of the brass-making crucibles are from late first to mid second century contexts but these are almost certainly

Fig 2 Plan view of crucible

residual, redeposited from the earlier military phase though some do seem to be stratified in second century 'industrial' levels.

As a postscript it should be noted that many small fragments of what appear to be similar crucibles have been found recently in Belgic (ie late Iron Age, c AD 20-60) pits in Canterbury. Only a minority have the very high zinc levels notes in the examples from Colchester so their interpretation cannot be as positive.

A second site in Canterbury has produced one complete crucible of the same sort of fabric as the others (see Fig 3). It is made in two parts, top and bottom, and has high levels of zinc detectable on its inner surface and a droplet of corroded brass trapped in the thickness of the wall. It was found inside a timber building which is thought to be contemporary with a second century metalled road.

Acknowledgements

I should like to thank Nick Smith and Philip Crummy of Colchester Archaeological Trust for permission to publish these finds in advance of their publication. The finds from Canterbury came from excavations carried out by Canterbury Archaeological Trust under the direction of Tim Tatton-Brown on the 77-9 Castle Street (CB/R.I) site, excavated in 1976. and at 7 Palace Street, excavated in 1983.

References

1 J Bayley and S A Butcher, Variations in alloy composition of Roman brooches. **Revue d'Archeometrie,** 1981, supplement 29.

2 I Stead. A Roman . . . brooch-blank from Baldock, Herts. **Antiq J** 1975,**55** (2), 397. (Analysis has shown the blank is brass rather than bronze as stated).

3 P T Craddock. The origins and early use of brass. **J Arch Sci,** 1978, **5** (1), 1-16.

4 R F Tylecote, **Metallurgy in Archaeology**, London, 1962, p 53.

5 H G Bachmann. Crucibles from a Roman settlement in Germany. **Hist Metall,** 1976, **10** (1), 34-35.

Fig 3 Brass-making crucible from Palace St, Canterbury. Scale 1:1

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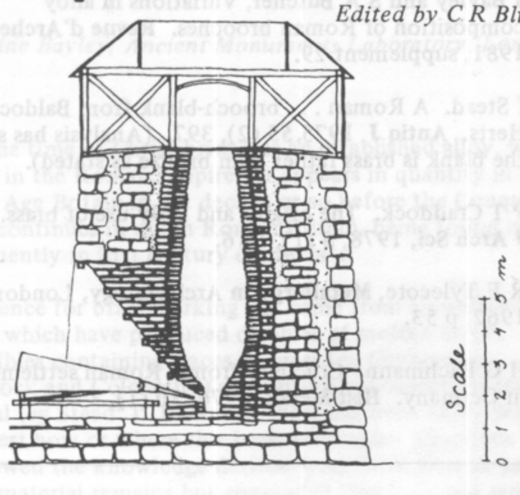
She studied physics at Sussex University and then archaeology at the Institute of Archaeology in London. Since 1973 she has worked for the Ancient Monuments Laboratory in the Dept of the Environment, mainly on technological finds from archaeological excavations in England. Her particular interests are non-ferrous metal and glass working in the Roman and early medieval periods.

Early Blast Furnace News

Edited by C R Blick



Excavation at Furnace Farm, Melbourne, South Derbyshire SK 379240

The existence of a C17/C18 charcoal blast furnace, somewhere in the valley of the new Brook at Melbourne was known for some time but the imminent flooding of the site by the Staunton Harold reservoir stimulated W H Bailey and Edgar Brook to locate it and then excavate it, mainly on their own, over 1957 to 1963, for about 40 weekends each year. Both are now deceased but we are all most fortunate that Anne Lardeur, Bailey's schoolgirl (then) daughter, worked with them and has put together the story of the excavation from her father's copious notes. This was presented at the 18th Annual Conference at Loughborough by her as a lecture copiously illustrated with pictures taken over the whole period.

The furnace had been deliberately demolished and, before excavation took place, nothing was visible above ground and in fact the exposure of the first piece of dressed stone was very fortuitous. By the time the site had to be evacuated because of the rising waters of the reservoir, the furnace area had been cleared, revealing the bottom 2m of the furnace pillar, the wheel pit and ancillary buildings. This exposed the lower level of the bosh, taphole and pigbed, tuyere and bellows area.

The early history of the furnace is unknown. There is a rough map which suggests that a furnace, or possibly earlier bloomery, was already in operation in 1625. Two purchases in 1657 and 1659 refer to 'Hammermen from Melbourne'. Then the furnace is clearly marked on an estate map of 1735. Operations ceased in 1772 and, in 1773, the furnace was advertised for sale, apparently unsuccessfully. The site then appears to have been converted to a pottery and an attempt possibly made to work the furnace as a kiln.

Mrs Lardeur is writing this up for publication in a future issue of the journal.

Pippingford blast furnace, Sussex. TQ 450316

Two gun casting furnaces on this site (c 1700-1720 to C1720 - 1730) were excavated in 1974 by D W Crossley and fully published.

The remains of the west furnace were only lightly covered and were uncovered in 1979 for the visit of HMS members at the Annual Conference at Brighton. It is now hoped to consolidate these masonry remains and the necessary organisation is being set up.

Dovey Blast Furnace, Eglwysfach, Dyfi, Dyfed. (1755 to post 1796). SN 685952

This furnace was visited by members attending the 1977 Annual Conference, when Douglas Hague explained its history, the occupancy of the site and later developments when the furnace hearth and bosh were removed to permit its change of use to a root store. The DoE were then commencing restoration of the buildings.

Now, five years later, much has been achieved and we are indebted to Dr Sian E Rees – Inspector of Ancient Monuments, S W Wales – Mr John R Cole and Dr C B Phillips for the following information.

During 1977/78, a ground plan and detailed structural survey were carried out. This revealed the poor state of the roof timbers. Now all the rotten woodwork had been replaced and the roof reslated. The unusual decision to rebuild the stack, to indicate discreetly how it had appeared, was taken. The early C20 water wheel was retained and the water supply – leats and dam – was cleared and restored, and the masonry repointed.

The lining and blocking – installed when this part was converted into a root store – was removed from the furnace proper and the hearth area and, externally, the casting floor area were excavated. The hearth stone was located, intact, with slag still adherent. This will be further examined during this year's projected excavation as will the casting floor. Not all the detritus, from the period after the furnace had fallen out of use until its conversion to a sawmill early this century, has yet been removed. Heavy flagstones have to be lifted when it is hoped to find the foundations at least of the cast house.

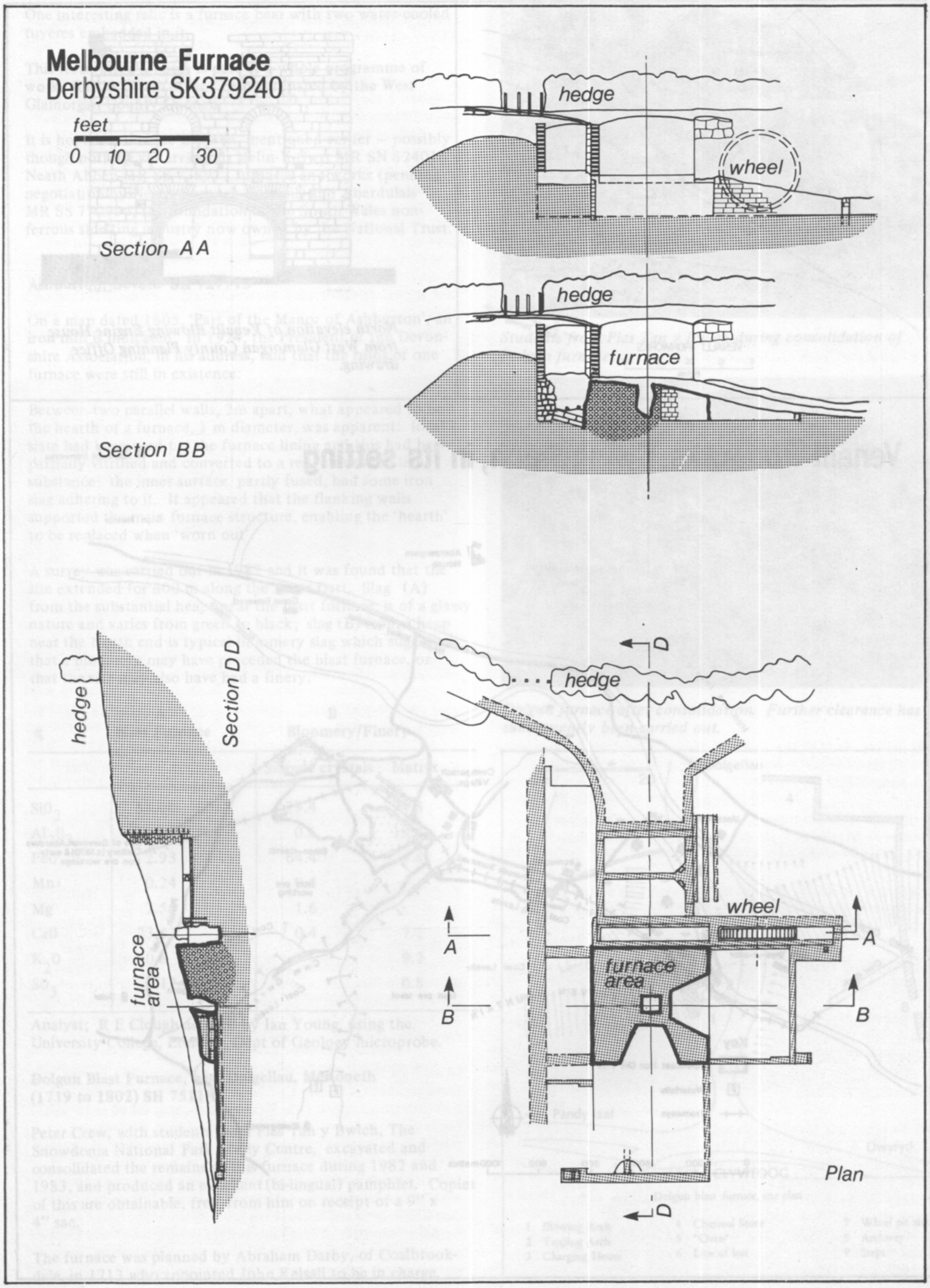
Venallt Blast Furnaces, Cwmgwrach, Neath Valley. SN 864050

Two blast furnaces were operated at this ironworks from 1842 using locally obtained anthracite and the hot blast process, steam engine blown, developed, as reported earlier at Ynyscedwyn ironworks Ystradgynlais. There was probably an ironworks on the site before this.

The works was closed by the 1860s like many other ironworks on the heads of the South Wales valleys.

The remaining wall of the two furnaces, the roofless engine house and the base of the chimney survive. The engine house has always been regarded as a good example of very few now remaining and, two years ago, was in very poor conditions – the southern wall being on the point of collapse.

Demolition was threatened. Then the West Glamorgan County Council, in liaison with the HMS, the Neath and Tennant Canal Society, the Prince of Wales Committee and the Forestry Commission as landowners, sponsored a scheme under the Community Enterprise programme to restore the structures. Since work commenced in January 1982, the chimney base has been cleared, the cast house wall has been restored, a buttress constructed to safeguard the furnace platform, and the south wall of the blowing engine house reconstructed.


Melbourne Furnace
Derbyshire SK379240
feet
0 10 20 30
hedge
wheel
Section A A
hedge
furnace
Section B B
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Section D D
furnace area
D
hedge
A
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wheel
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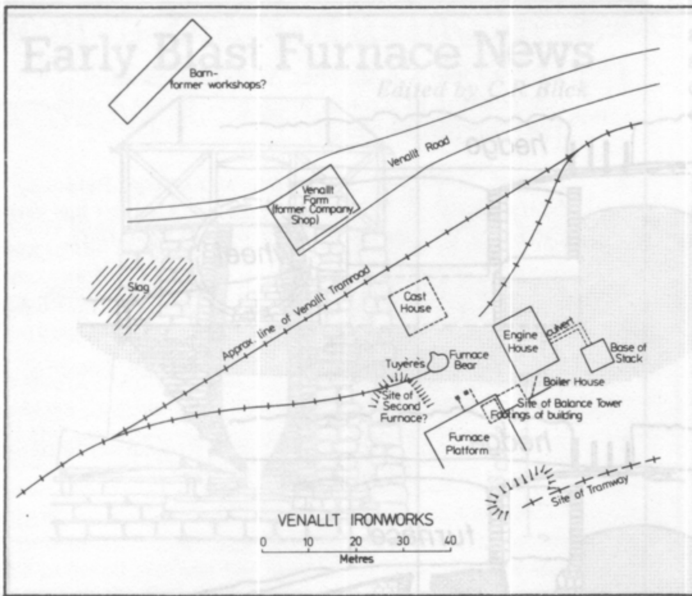
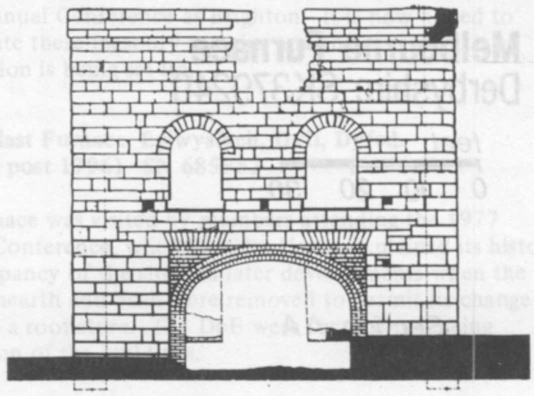
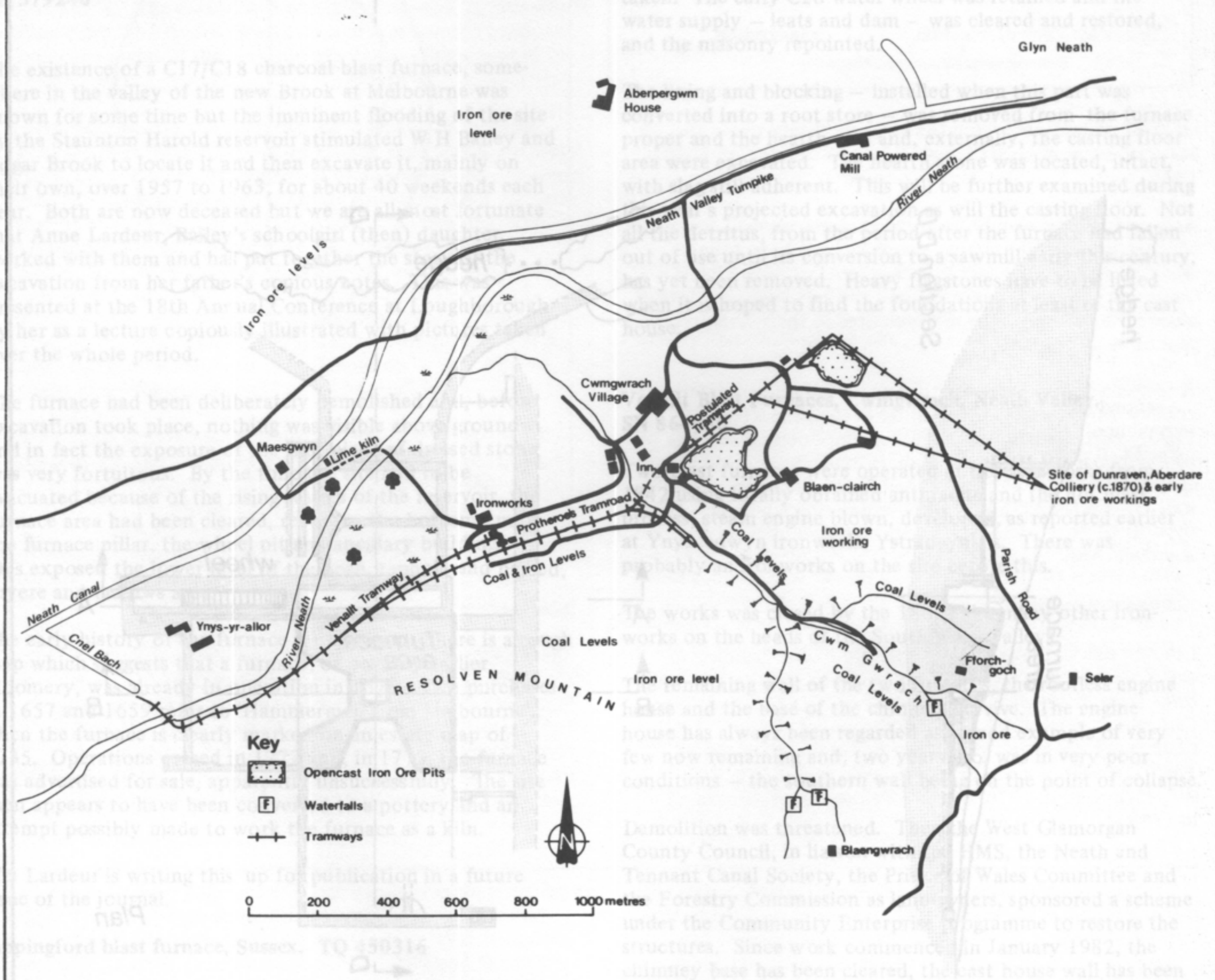
D
Plan





North elevation of Venallt Blowing Engine House from West Glamorgan County Planning Office drawing.

Venallt Ironworks, Cwmgwrach, in its setting



One interesting relic is a furnace bear with two water-cooled tuyeres embedded in it.

This restoration scheme is part of a whole programme of works for the Neath Valley being prepared by the West Glamorgan County Council.

It is hoped to include Banwen, mentioned earlier – possibly though nothing yet arranged, Melin-Y-Cwrt MR SN 824018 – Neath Abbey MR SS 738977 furnaces and works (pending negotiation by Neath Borough Council) and Aberdulais MR SS 772994, the foundation of the South Wales non-ferrous smelting industry now owned by the National Trust.

Ashburton, Devon. SX 727713

On a map dated 1605, 'Part of the Manor of Ashburton', an **iron mill** is indicated. In 1924, the President of the Devonshire Association, in his address, said that the ruins of one furnace were still in existence:

Between two parallel walls, 2m apart, what appeared to be the hearth of a furnace, 1 m diameter, was apparent: local slate had been used for the furnace lining and this had been partially vitrified and converted to a red, stoneware like substance; the inner surface, partly fused, had some iron slag adhering to it. It appeared that the flanking walls supported the main furnace structure, enabling the 'hearth' to be replaced when 'worn out'.

A survey was carried out in 1982 and it was found that the site extended for 600 m along the River Dart. Slag (A) from the substantial heaps near the blast furnace, is of a glassy nature and varies from green to black; slag (B) from a heap near the North end is typical bloomery slag which suggests that a bloomery may have preceded the blast furnace, or that the site may also have had a finery.

%	A Blast Furnace	B Bloomery/Finery	
		Silicate crystals	Matrix
SiO_2	58.00	29.4	34.8
Al_2O_3	12.00	0.6	19.4
FeO	2.93	64.4	24.8
MnO	0.24	0.4	-
Mg	2.56	1.6	1.4
CaO	23.42	0.4	7.2
K_2O	0.8	-	9.2
SO_3	0.12	-	0.8

Analyst; R E Clough assisted by Ian Young, using the University College, London, Dept of Geology microprobe.

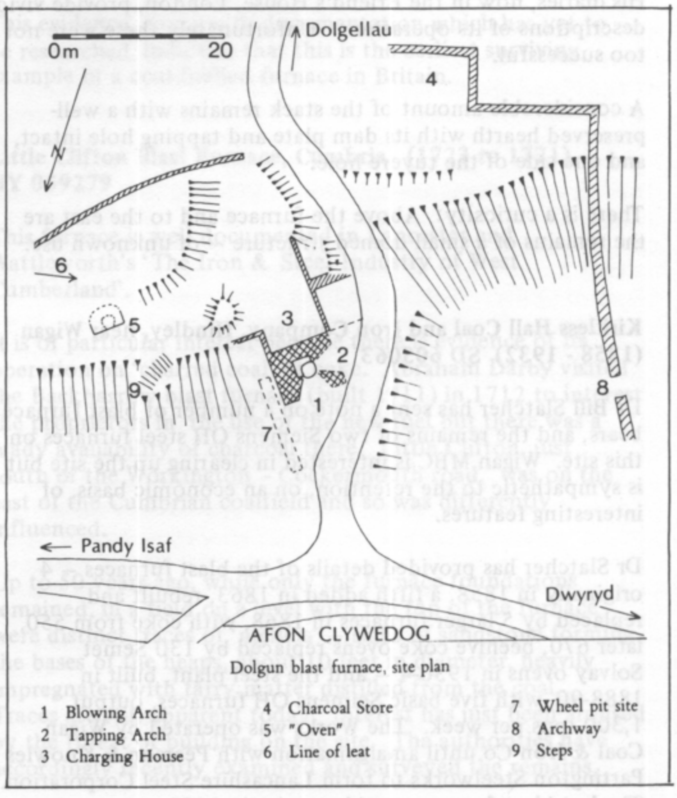
Dolgun Blast Furnace, near Dolgellau, Merioneth (1719 to 1802) SH 751187

Peter Crew, with students from Plas Tan y Bwlch, The Snowdonia National Park Study Centre, excavated and consolidated the remains of this furnace during 1982 and 1983, and produced an excellent (bi-lingual) pamphlet. Copies of this are obtainable, free, from him on receipt of a 9" x 4" sae.

The furnace was planned by Abraham Darby, of Coalbrookdale, in 1713 who appointed John Kelsall to be in charge.

Students from Plas Tan y Bwlch during consolidation of Dolgun furnace

Dolgun furnace after consolidation. Further clearance has subsequently been carried out.



Dolgun blast furnace, site plan

this would be necessary to control the air inlet and manage problems with slag entering the tuyere. So an air inlet was unlikely but not impossible.

For (b) when wishing to produce heavy castings the hearth would have to be filled with iron leaving little room for slag accumulation. There was no provision for a 'slag notch' in those early days. So it would have been necessary to tap off slag continuously. In Sweden, from late C19, blast furnaces normally had a separate slag tapping arch opposite the iron tapping arch. Initially there was a cast iron tymp in the furnace lining but later a water cooled outlet was provided, that is, a forerunner of the present 'slag notch'.

The question posed by Bjorkenstam is – could there have been a lintel, or cast iron ring, in the shaft lining, with a runner extending therefrom lined with firebrick?

The hearth and bosh of the furnace are missing and so it will be difficult to calculate the capacity of hearth, up to a safe distance from the tuyere. On the other hand, the dimensions of the well preserved circular casting pit indicate that, according to Crossley, cannon of typical late C18 proportions could be cast – or farm rollers, or sugar crushers – which might have been a feature of the later phase of furnace operation after the Spencer period. A scatter of coke in the demolition debris supports this theory.

Or – is this aperture indicative of an early form of bosh tuyere? The lines of a blast furnace are dictated by the physical, as well as chemical changes in the burden as it descends and is smelted. Rich ore practice is different to lean ore practice, the latter being predominant in Britain. Provision must first be made for the even descent of the ore and limestone and coke. There is a drying out, a release of Co_2 – a deposition of carbon which calls for a slight 'batter' that is a widening, or expansion, of the shaft. About two thirds down the stack, the temperature has risen, coke has been burnt and reduction of the burden to metal and slag has taken place, and is being finalised, resulting in a contraction, and requirement for less volume – hence the 'bosh' and a tapering inwards to the crucible, or hearth, of the furnace where the liquid iron and slag collect beneath the tuyere line.

Early blast furnaces tended to have considerable 'outward batters' and steep, inward tapering boshes, or 'flat' boshes. As outputs were increased both these tapers were moderated and every plant appeared to have its own ideas about the location in height of the bosh. The burden was completely unprepared – lumps to dust, and the breeze went in with the coke. Slags tended to be very limy, with a high $Ca0/Si0_2$ ratio of 1.5 and over, and very viscous. With high, flat boshes, driving a furnace would be very arduous.

In North Lincolnshire, bosh tuyeres were introduced in the early years of the C19, fed from the supply of air to the main tuyeres. These burnt coke higher up and helped to reduce the large lumps of ore, which caused excessive metallurgical load on the hearth, and to keep the bosh and lower stack free from accretions which impeded steady descent.

There is evidence (JISI 1873 (i)) that the Ditton Brook blast furnace, Warrington, had gunmetal tuyeres located 2½ metres (sic) above the main tuyeres. The Old Furnace, at Coalbrookdale, has an aperture, high up the bosh, which the late Reg Morton thought might be a bosh tuyere. There certainly appeared to be a period of 50/60 years when this secondary source of combustion was of great assistance in keeping burden descent reasonably consistent.

Since the 1930s the ore burden has been progressively prepared, first of all in sizing then in sintering – and coke has been sized and screened from breeze – so making the physical, and metallurgical load more equable. Modern furnaces tend to have slight batters, parallel portions above the boshes, short and steep boshes – much more like cylinders, slightly expanded at the lower 'midriffs'.

Bosh tuyeres have not been used in North Lincolnshire since the 1940s, but were located at 3 to 3½ metres above the main tuyere level, with hearth diameters of 3½ to 5 metres. So it appears to be unlikely that the Rockley aperture, from visual indication, led to a bosh tuyere – the height above the main tuyere not being sufficient.

Does this indicate that a slag tapping arch – a slag notch – was its function?

Cleator Blast Furnace, Cumbria (1694-1705). NY 014131

Fieldwork by Peter J Brown (briefly reported in Post Medieval Archaeology 16 (1982) p 226) has shown that the tymp arch of a blast furnace survives within a former mill near to the spade forge.

In amplification, Brown quotes from documentary evidence that a company was established in 1692 - 1693 to smelt iron ore with coal. Besides the Cleator furnace, another may have been constructed at Whitehaven in 1698. But the venture proved unsuccessful although coal, charcoal, and coal and charcoal mixed here tried as fuels. The furnace did achieve some success with charcoal alone though.

The furnace is identified in the mill complex (now in use as a dwelling) near to the spade forge. Two arches survived into the late C19 but now only the casting arch survives (as the background to a handsome firebasket) the other unfortunately suffering due to extensive structural alteration, in ignorance of identification, only a short time ago.

This evidence, along with documentation which has yet to be researched, indicates that this is the earliest surviving example of a coal-fuelled furnace in Britain.

Little Clifton Blast Furnace, Cumbria. (1723 to 1771) NY 059279

This furnace is well documented in Lancaster and Wattleworth's 'The Iron & Steel Industry of West Cumberland'.

It is of particular interest because there is evidence of its operation on 'charred coal' or coke. Abraham Darby visited the Backbarrow blast furnace (built 1711) in 1712 to interest the proprietors in the use of the new fuel but there was a ready availability of charcoal there. Little Clifton, just south of the Workington - Cockermouth road, was on the east of the Cumbrian coalfield and so was differently influenced.

Up to 50 years ago, while only the furnace foundations remained, in a field on a level with the top of the furnace were distinct traces of 'meilers' – slabs of sandstone forming the bases of the heaps, about 10 feet in diameter, heavily impregnated with tarry matter distilled from the coal. Traces are still apparent today. Interest has just been aroused by the threat of building on the site. The authorities have accordingly recently examined and surveyed the remains, this would be necessary to control the air inlet and manage problems with slag entering the tuyere. So an air inlet was unlikely but not impossible.

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Stepaside Blast Furnaces, Kilgetty, S Pembrokeshire, Dyfed (1849 to 1877) SN 142073

Following the request for technical assistance reported in JHMS, Volume 17/2 members Peter Greenough and Peter Hutchinson inspected the site early in 1983 and examined related documents and literature. They produced a useful report for the Dyfed County Museum.

Apparently the Kilgetty Ironworks were set up in 1849 to smelt local ore with anthracite coal. Even with hot blast this was unsuccessful and the installation of Coppee coke ovens (for carbonising a mixture of anthracite, duff and bituminous coal slack) – and the use of imported hematite ore – could not ameliorate the position, and iron production ceased in 1874.

A plan of the works site (1887) and dimensions of one furnace (1863) were available, and Greenough and Hutchinson interpreted the present position therefrom. The low level had been bulldozed flat so that 2-3 feet of cinders covered the original working levels. The walls of the cast house, the masonry of one corner of one furnace and the engine house survive to varying extents. The high line support wall is intact and the ore kilns are quite recognisable.

The owner of the site is interested in some form of conservation.

Obituary

R A Mott, DSc, C Chem, FRSC, died on 10 October, aged 84.

Reggie Mott (as he was known to his great circle of colleagues and friends) had a world-wide reputation as one of the foremost solid fuel scientists of this century and as a notable historian of the coking, iron and steel industries. That reputation is securely founded on a massive record of some 200 publications, the range of activity revealed thereby being matched by no other worker in his field.

In his scientific contributions he touched upon virtually every aspect of the production and utilization of coke oven coke. Necessarily, this led him into studies of the raw material, coal, and of coke-burning appliances, from the blast furnace to the domestic boiler and stove.

In his student days (he graduated in 1922), Reggie was a champion mile runner and he was credited with the first performance of a celebrated Rag prank, causing much hilarity in the centre of Leeds and calling for considerable physical agility. Walking (and, for many years, climbing) remained his favourite recreation into temporal old age. In his life, however, recreation was strictly rationed, as an aid to and refreshment for his work.

Whilst in professional employment, his leisure hours were devoted to his historical researches, and retirement (of course, he never really retired and he never grew mentally old) enabled him to pursue them with even greater vigour.

The earliest fruits of his labours in industrial history were a 'History of coke-making', which remains the most reliable guide up to the mid-1930s, and the total demolishment of works which for long years had continued to accept Dud Dudley's spurious claims to have smelted iron with coal as the carbonaceous raw material. This latter led him inevitably to Abraham Darby I, who it was known, had used coke. Mott's painstaking examination and collation of the surviving records of the Coalbrookdale Co. enabled the early history of the company to be told in much more detail and with far greater authenticity than hitherto. In particular, he proved that the first successful use of coke in the blast furnace had been achieved in 1709, rather than the somewhat later dates which other writers had quoted. Mott's proof justified the quarter-millenary celebrations (in 1959) to which he was the leading contributor.

As with his scientific essays, his other numerous historical papers range widely, from very specific topics, such as the implications of the 'Sheffield thwitel' (Chaucer), and the quantification of the Newcastle 'chaldron' to broad issues including Wealden iron, the effect of the Norman Conquest on ironmaking in the North, and the development of iron wagonways. In his last years he gave much effort to aspects of industrial history of the area of Sheffield (where he lived for 60 years), to the Spencer partnerships and Yorkshire iron, and to the rehabilitation of Henry Cort. It was a source of great satisfaction to him that he lived to see the bicentenary of Cort's first patent marked by the publication of a book based upon his researches and writings*.

Reggie was a man of indomitable spirit. He met and overcame frustration in his career, tragedy in his private life, and the late debilitation of strokes. None of these did more than halt his work very temporarily and none in any way affected his concern for family, friends and colleagues.

To give a rounded picture of the man, it is necessary to add that Reggie Mott enjoyed (and probably really did enjoy) a reputation for iconoclasm and controversy. That may help to explain why, sadly and deplorably, no great honours came his way, but his iconoclasm was always well directed and in controversy he remained unfailingly courteous, a man totally without malice. It was more than sufficient for him to have achieved what he did and to have earned the affection of his colleagues and the respect of generations of solid-fuel scientists and industrial historians.

* 'Henry Cort: the great finer', by R A Mott, edited by Peter Singer, 1983. The Metals Society.

This appreciation was written for the Metals Society World by Dr J E Barker a consultant on coal, coke and coke making and appeared in the December 1983 edition. We are grateful for the co-operation of Mary Chim (MSW Editor) for giving permission for it to be used here.

Book reviews

Early Pyrotechnology; the Evolution of the First Fire-Using Industries. *Edited by Theodore A Wertime and Steven F Wertime, Smithsonian Institution Press, Washington DC 1982, A4 format, soft covers, pp 249. Obtainable from the Superintendent of Documents, US Government Printing Office, Washington DC 20402.*

The collection of all the early fire-using industries under the heading of Pyrotechnology was the idea of Ted Wertime who managed to finish the editing of this volume with his son's help before his untimely death in 1982. This volume is naturally dedicated to its originator and editor.

This volume comprises the papers given at the seminar held at the Smithsonian Institution and the National Bureau of Standards in April 1979. This was one of the important and most useful Smithsonian Institution and National Bureau of Standards Seminars on the Application of Materials and Measurement Sciences to Archaeology and Museum Conservation, organized by Alan D Franklin and Jacqueline S Olin. Another of these was on Archaeological Ceramics on which a review will follow later.

Ted Wertime organised several expeditions across Asiatic and Near Eastern deserts in one of which I had the instructive and pleasurable experience of taking part. These were intended to build up an overall picture of the early technologies of the region, some of which were still in being and most of which had left their remains on the desert floor for all who understood them to learn from them.

After an extensive preface and introduction by the editors, the work opens with a paper on chert working in North America by Barbara Purdy. Quarrying was done by fire-setting but care had to be used to avoid the necessary quenching damaging the chert itself. But careful and controlled heating can be used to improve flaking quality and produce an implement with a sharper edge. This has been known for 35,000 years. Of greater interest to the archaeometallurgist is the paper by Purdy and David Clark on Early Metallurgy in North America which concentrates on the working and properties of native copper. Again, North American examples of the early use of such material go back to 3000 BC and this paper presents new and most useful material on the subject. Auger spectroscopy was used to show the high purity of the copper, compared to man-made copper which might have been imported and used by the Early Indian peoples. Expected increases in hardness were obtained by cold work and useful data is given. The presence of the Cu_2O-Cu eutectic is a good way of distinguishing unmelted from melted native copper but it is possible for severe subsurface oxidation to occur during annealing.

Indications are that the Indian cultures were familiar with the processes of annealing but not melting and casting. They had reached 'Stage 2' of copper technology.

Ceramics and glass come next and these involve the working temperature of refractories such as furnace linings and crucibles determined by the classical processes of pyrometry and temperature diffusivity. Examples were taken from Greece and Palestine and examined by workers in the British Museum. Soda-lime glasses from mid-second millennium Iraq are reported by Pamela Vandiver of MIT, and Mesopotamian faience by Bob Hedges of the Oxford Laboratory.

Section 3 on Plasters and cements starts with a mention of lime plasters dating back to 3200 - 2800 BC from Anshan (Iran) but of course we now know that these went back to 7000 - 6500 BC at Lipenski Vir and no doubt many other places. It seems that such early people had no difficulty in calcining large amounts of limestone at around 900^{o}C for use on floors etc. Conophagos introduces the most interesting example of water-resistant plaster containing 30% PbO for lining cisterns in the Laurion area of Greece. This material was bound with slaked lime and applied very thinly.

Hydraulic cements are next dealt with in a masterly paper by Joan Mishara. These include the puzzolanic cements in which there is a hydration process involving, for the first time, calcium-silicates calcined at 1000^{o}C. Due emphasis is given to the need for fine-grinding in the case of cements and it would appear that fineness and large surface area is the most important property of the volcanic ash found around Vesuvius. This paper discusses the views of Pliny and Vitruvius and is one of the best on the early history and structure of cements.

We return to metallurgy in Len Salkield's paper on Rio Tinto and Tharsis mines in S. Spain. Salkield was one of the first to put forward the now generally accepted theory that most of the Rio Tinto slags are derived from silver and not copper smelting. Koucky and Steinberg deal with Cyprus, its sulphide ores and slags, and the possibility of copper recovery by hydrometallurgical means. Here, again, the argument is supported by the classical writers such as Galen and Aristotle. The case is well-argued and very plausible, and the problem of the copius amounts of slag overcome by suggesting that hydrometallurgy was used only as a concentrating process and was followed by the smelting of the resulting impure sulphates.

In a second paper in this seminar Conophagos gives his views on the techniques used at Laurion for the smelting of lead and the recovery of silver based upon his and other excavations in the area. His reconstruction of the smelting furnaces is more than 4 m high and perhaps much higher than is necessary or justified by the remains on the ground. There is still need to check this by experiment. He gives a useful table of slag analyses showing that they contain up to 25% Pb. But we lack data on the output from the washeries and therefore the feed to the smelters which he claims was mainly oxidised ores.

The next paper by Ericson, Pandolfi and Patterson dealt with copper extraction and suggests the use of sulphur isotope ratios for telling whether oxide or matte smelting has been used. As for lead, the lead content of human bones can be used as a monitor for production rate and changes in technique. Donald Avery makes the only contribution on man-made iron — the African Bloomery Process — which used bellows-blown bowl furnaces 110 cm across and 60 cm deep. Experiments were carried out and temperatures measured (which reached 1800^{o}C under reducing conditions). The product was a mixture of iron with 0 to more than 0.8% C and a low-wustite slag. During smithing the wustite content of the slag was increased and the carbon content of the metal reduced.

Pigott and his colleagues have been examining the finds from Tepe Hissar made by Dyson in 1976 (some of the material in Philadelphia that needs examining goes back at least 50 years before this). At Hissar, copper smelting (or melting?) started early, for copper slag was incorporated into pottery dated to 3300-3000 BC. There is a useful discussion of kilns found on the site.

As in the case of Sialk there was an extensive scatter of slag over the mound. Analyses show high lead, moderate copper and low iron (in most cases) which suggests that the slags are more likely to be crucible slags, like Petrie's slag from Serabit in Sinai, than smelting slags. Two impure copper ingots were also analyzed and one gave 0.79% Ni and the other 2.3% Zn. Both carried appreciable lead and are possibly the sort of copper that gave rise to the slags.

Finally, to complete the series, Piaskowski introduces the thorny question of early iron with high Ni laminations and the question of meteoric origin. I certainly no longer agree with the latter possibility (which will please the author!) and believe that, after the work of Tholander, it is due to oxidation enrichment or the use of pieces of high nickel iron smelted from the type of garnierite ore found in Greece and being studied by Varoufakis.

Surface segregation of Cu and Ni in steel is a modern problem, but a similar phenomenon in wrought iron was pointed out by Chilton and Evans in 1955. Recent work has shown that this, like arsenic enrichment, is far more common than was previously thought and with the advent of the electron probe it is far easier to detect.

It is difficult to do this marvellous volume justice in the scope of a short review. But it is a most stimulating introduction to the unity of materials science and the pyrotechnological aspects in particular. It should be a lesson to those who may start as specialists that they may end up finding that the straight and narrow path is not the key to the solution of most problems.

R F Tylecote

C W Roberts, 'A Legacy from Victorian Enterprise', The Briton Ferry Ironworks and the daughter companies, *produced by Alan Sutton Publishing Limited, Gloucester. 1983, price £5.95. A hard back edition will be available later at about £7.80.*

This is a very acceptable and very comprehensive story of a small Welsh iron and steel works, and its derived companies, produced in unique circumstances.

The author – a member of The Historical Metallurgy Society – is the second son of a director of The Briton Ferry Works Ltd and was born in Briton Ferry. After metallurgical training, he started work at the laboratories of the Albion Steelworks at Briton Ferry, and then moved on to a wider metallurgical career. He has always maintained a strong interest in the profession.

The impetus for the writing of this book came from the acquisition, by the author, of a substantial quantity of original records dating from the period 1845 to 1930 and relating to the establishment at Briton Ferry of a number of companies which built and developed five substantial metallurgical works in the town. These records contained much detailed technological, commercial and financial information which enabled this historic narrative to be written but the text includes a substantial amount of criticism, comparison and comment which correlates the developments at Briton Ferry with corresponding activities in other areas of South Wales, and with the evolution of the British iron and steel industry in general.

Before dealing with Briton Ferry the author presents chapters on 'The outline of the early history of iron and steel': 'the establishment of the ironworks of North Glamorgan and Monmouth': 'the development of the technology of ironmaking': 'the evolution of the Bessemer steelmaking process', and concludes, after detailed histories of the plants, with appendices on technical terms, description of processes, conversion tables and a bibliography – hence the comment on the comprehensive nature of the book. It is well produced and printed on gloss paper, 277 pages, 8 plates, 48 drawings and many tables of production details, and costs of plant and operations.

Briton Ferry was born in 1846 and remained in operation until the 1950s – from iron ore to tinplate or galvanised sheet – when within a few years all production ceased except for some steel at Albion Works until November 1978.

The author concludes with the thought that **'in a century or so, a group of enthusiasts will form an organisation'** for building a similar blast furnace, and production line for tin plate/galvanised sheet by the 'hot dip' methods – **'merely for interest and to reacquire long forgotten skills'**.

What an excellent idea this would be for South Wales– cementing the work already underway, and on similar lines, at The Ironbridge Gorge Museum.

All we would then need would be a similar drive 'in the North'.

Charles Roberts' book would certainly be the blue print for such an effort in South Wales, and is recommended reading for 'historical metallurgists'.

Charles Blick

Masuda Tsuna, Kodo Zuroku – 'Illustrated Book on the Smelting of Copper', *English Translation by Zenryu Shirakawa, edited by Cyril Stanley Smith. Preface, Introduction, text, Appendix. A4 format. Paperback. Burndy Library, Norwalk, Connecticut, 1983, 96 pages + plates.*

This delightful and sumptuous book will be a valuable addition to any archaeologist's or archaeological library. Its main theme, sympathetically directed by the editorship of Cyril Stanley Smith, is a translation of the book by the Japanese, Masuda Tsuna, originally published about 1801, mainly on the smelting and refining of copper in Japan during the eighteenth century. The methods of mining the ore, desilverisation by liquation and associated cupellation are also examined. This is interesting enough in itself, but the accompanying coloured wood block prints in Niwa Motokuni Tokei – 'Tokei' – add a stunning technical and artistic enlightenment to the descriptions, and include one on lead smelting. In these we are at one with the smelters: their expressions, attitudes and demeanour will strike familiar and romantic chords in anyone who has had any experience of similar processes anywhere else in the world before the coming of the Organisation Man. The plates of the tools used add a wealth of detail.

The book is particularly interesting because it gives a detailed record of techniques which are similar or identical to many which were once used in the West but not recorded. Evidence of such work only appears with archaeological research.

Rather after the fashion of Hoover's 1912 translation of

Agricola's 'De re Metallica' Cyril Smith has increased the value of the original treatise with an Introduction that includes selected illustrations – some in colour – taken from other Japanese as well as European works with a commentary to emphasise various points. The colour wood block illustration of the workings of Besshi mine in 1769 showing part of the one hundred and thirty hand operated piston pumps used to shammel water out of the mine is one example.

A few of the Kodo Zuroku illustrations have been reprinted in the past, as well as translations: notably W Gowlands' contribution to **Archaeologia**[1] which also has some Japanese illustrations in a similar style of other processes, such as tin smelting and the reduction of iron ore. We can only hope that we have more to look forward to in the future.

In this edition after a Preface by Bern Dibner and the Introduction, the first part consists of the fourteen colour prints. Their explanatory notes in Japanese written in Chinese characters are translated, along with footnotes by the editor, on the facing page. Following this are the thirteen black and white prints of tools, with footnote translations. The second part of the book, twelve pages of Chinese in Chinese characters describing the operations, is reproduced in full with facing translation and notes. The translator, Zenryu Shirakawa, has obviously taken much care in conveying the shades of meaning in the original.

Alas, it now seems that a reviewer is expected to produce some adverse criticism. With this it is indeed hard to find fault. Perhaps the comment in the Introduction – page 17 – that the double acting box bellows shown give a much more steady blast than the single-acting bellows of the West would have caused surprise to the old West of England tin blowers. Their furnaces were not too many stages of evolution removed from the Japanese types and although single acting bellows were used they were in pairs and the waterwheel driving shaft had its cams arranged to work the bellows in sequence; thus the furnace experienced a blast virtually identical to that from the box bellows[2] as was also common with contemporary iron blast furnaces. The size of the original book does not appear to be quoted, presumably the reproductions are the same size.

Great care has been taken to do full justice to the original. The paper used has the same tint and general surface finish as that for Japanese block prints and the colours are virtually indistinguishable when placed side by side with such prints. The reproduction and typography are first class. Bookbinders will soon be busy casing the book in a more durable cover.

Bryan Earl

1 W Gowland: **Archaeologia** Vol LVI, pp 267-322.

2 R J Law: 18th century drawings of Cornish tin blowing 'castle' in a German 18th century contribution on West of England mining equipment, In Litt Trevithick Society. A similar but much more complicated arrangement is shown and described for German furnaces in **De re Metallica**.

Nicole Echard (Editor), Métallurgies Africaines; nouvelles contributions. *Memoires de la Societe des Africanistes, 9, 1983. Musee de l'Homme, Place du Trocadero, 75116 Paris. About 160 FF. 400 pages.*

This volume contains the papers on iron and copper metallurgy that were presented and discussed during the annual meetings of RCP 322 of the CNRS (National Scientific Research Center) in the Seminar of 1982. Their approach is interdisciplinary and all of the research presented is either recent or still in progress. Most of the papers deal with the different aspects of metal production.

Tylecote, Ronald Frank

This paper describes the techniques of examination now being used on archaeometallurgical materials and discusses the information that can be obtained from them. It deals with copper-base metals, vitrified materials such as slags, ceramics such as tuyeres, as well as iron artifacts and hammer scales. It tries to show the limitations of the more normal investigational techniques of 'chemical' analysis and emphasises the need for the application of geological, metallographic and ceramicist's techniques to the whole spectrum of archaeometallurgical finds.

Fluzin, Philippe

Basic Notions of Iron Metallurgy

The simplicity of a process often hides the complexity of its design and utilization. This is particularly true with objects made of iron. Our objective is to give the reader an overview of the difficulties inherent to the manufacture of an object as simple as an iron nail. Our purpose is thus to provide a brief summary of basic metallurgy in order to make it easier to understand notions essential to the interpretation of metallurgical phenomena, however old they may be.

Robert-Chaleix, Denise and Sognane, Mamadou

A Medieval Metallurgy Works on the Mauritanian bank of the Senegal river

An archaeological expedition of the Mauritanian Scientific Research Institute working along the Mauritanian bank of the Senegal River valley has discovered a number of major metallurgical sites for iron production from laterite ore. In particular, a substantial metallurgical zone was discovered downstream from Kaedi, where there are at present over 40,000 furnaces. Based on archaeological data and information found in ancient arabic textx, a reasonable estimate can date the oldest of the sites at the High Middle Ages (XVIIth - IXth centuries), and it is likely that the metallurgical activity continued until the XVIIth century.

Lambert, Nicole

A new contribution to the study of the Mauritanian Chalcolithic period

Recent discoveries of copper objects and metallurgical finds in the Akjoujt, Zouerate, Nouakchott and western Akjoujt regions, along with their analysis, have shed new light on the study of the Mauritanian Chalcolithic period.

Some two thousand years old, these metallurgical works were fed by the numerous small copper-base outcrops of the Mauritanian chain, including the mine at Akjoujt.

Vanacker, Claudette

Copper and Copper Metallurgy at Tegdaoust (eastern Mauritania). Discoveries and Problems

This article presents the principal discoveries of copper objects and the proof of the existence of copper metallurgy at the Tegdaoust site (eastern Mauritania): small trans-forming metallurgy, lost-wax foundry, ingot casting. Next the problem of the origin of the copper is examined, and, based on recent archaeological discoveries, the author puts forth the hypothesis that the copper used was mostly of local origin and not imported from Morocco.

Grébénart, Danilo

Copper and iron metallurgy in the Agadez region (Niger) – its origins to the beginning of the Middle Ages. General aspects
The Agadez region today appears to be the oldest center of metal works activities in non-nilotic south-saharan Africa.

When transposed on the saharan neolithic period, the Copper Age is divided into two periods: **Copper I** (approximately 2000 to 800 BC), **pre-metallurgy**, using native copper; **Copper II** (approximately 800 BC to the beginning of the Christian era) production of metals using ores.

The Early Iron Age, or **Iron I**, begins at approximately 500 BC and seems to have had a southern origin. During the second phase, or **Iron II**, covering the first thousand years of the Christian era, iron was manufactured in very small quantities and copper was no longer manufactured. It can be hypothesized, however, that the latter metal was imported and purified at Marandet to eliminate the excess lead it contained.

Gouletquer, Pierre

Territories and Technology: Salt and Iron
Using examples taken from the salt and iron industries, this article demonstrates how ethnology and archaeology can complement one another in at least two areas: the approach to territories and technology. By combining processing stages, technical evolutions and their respective spatial implications within the same approach, it is possible to bring out theoretical notions that neither ethnology nor archaeology alone are able to develop.

Bourhis, Jean-Roger

Results of the analysis of copper, bronze and brass objects and metallurgical residues from Antique Africa
Copper-base metal objects from Morocco, Mauritania, Senegal and Niger were analyzed. With the coppers there was a considerable amount of arsenic found, this seeming to be one of the characteristics of African coppers. Bronze was extremely rare. Brass was more commonly found and generally comes from more recent metallurgical works. Finally, metallurgical finds (ores, slags, furnace fragments, metallurgical residues, etc) dating from the second and the last millenium before Christ were also analysed.

Bernus, Suzanne

Discoveries, hypotheses, reconstitution and proofs: medieval copper from Azelik-Takedda
Archaeological prospection in the Eghazer wan Agadez basin (Niger) have resulted in the discovery of copper processing finds which correspond to the 'copper shows' on geological maps. The nature, volume and distribution of these finds vary, however, depending upon the period considered, and several links in the 'processing stages' are still missing. It is thus as yet possible to only venture a hypothesis as to the existence of a more or less earlier Copper Age.

Only the Azelik site, in particular for the medieval period contained elements that have made it possible with the help of current artisans to make a plausible reconstitution of the technique used, this being a new argument for the identity of Azelik-Takedda.

Poncet, Yveline

Metallurgical Ores and Mining: Geographic Considerations
Diverse observations on protohistoric and past metallurgies that have been made by anthropologists are examined here in the light of geomorphological and pedological observations based on sites where ores have been found and on partial data concerning the origin of these same ores (copper, and in particular iron). Working hypotheses are formulated from this data on the criteria for the selection of raw materials used by protohistoric and contemporary smelters.

For iron ores, for example, those containing alkaline elements seem to be mined since their ores are easily recognized and extracted, but which are not found everywhere.

Echard, Nicole

Slags and Symbols. Remarks on Hausa Iron Metallurgy in Niger
What social practices are attested to by the material traces found by archaeologists? Two types of facts related to this question are presented within the context of a discussion of the reciprocal contributions of archaeology and ethnology: on the one hand are facts that leave material traces with a reference to the social and economic conditions of metal production; on the other are facts which remain unperceived by archaeologists but which nevertheless have technical consequences and which make it possible to formulate different hypotheses as to the interpretation of the material finds.

Levy-Luxereau, Anne

Metallurgy in the Nigerian sahel: Constraints of the eco-system and effects of techniques used. The example of the Maradi region.
In the Maradi region of Niger, the ecological conditions were not particularly favourable to iron metallurgy. The implementation of these techniques played a part in the transformation of a fragile milieu that was also subjected to heavy deforestation due to other production techniques.

Bernus, Edmond

The Place and Role of the blacksmiths in Tuareg Society
Tuareg blacksmiths constituted an endogamous group defined by their technical specialization as well as the fact that they belonged to one of the tribes of the warrior aristocracy. Presented is an outline of a typology along with an examination of the relative importance of the principal types within each large Tuareg group.

Generally accepted notions on the blacksmiths handed down through oral tradition are compared here with their actual role within the society. The blacksmiths possessed specific means of defending themselves against those with whom they maintained client relationships: a secret language, **tenet**, and institutionalized forms of vengeance that allowed them to carry out a subtle and codified relationship with Tuareg society, of which they were an indispensable element.

Izard, Michel

The Yatenga Kingdom and its Blacksmiths: an Investigation of the Population History
The former Mooga (Mossi) kingdom of Yatenga (Upper Volta) served as the basis of a survey of the population history. Presented here are the objectives and methodology used, along with the results pertaining to the blacksmith 'population'. Of the 2198 elements covered by the survey, all of which were

local lineage segments, or 'neighbourhoods', 166 are blacksmith elements (7.5%) from 8 'ethnic' groups. The Yatenga blacksmith population is organized around four major branches. One of the objectives of the survey is to date the foundation of the neighbourhoods once an **ad hoc** chronological context has been established. 54 founding dates out of 166 (32.5%) were able to be situated chronologically. An annex contains the questionnaire used in a detailed survey on blacksmiths and metallurgy — separate from the general survey — the results of which are not contained in the article.

Monino, Yves

Delivering iron. Gbayan metallurgy (Central African Republic)
Gbayan and Manzan metallurgy in the Central African Republic is examined here along two complementary axes. The first part analyzes the extensive data available on the material, social and symbolic conditions related to iron production and seeks to define the causes of an astonishing diversity in techniques in comparison with socially similar societies. The second part, based on the observation of a reduction in iron ore, shows the interrelation between the technical and symbolic work and takes up the problem of finalities within the symbolic work within a context where the smelters do not have a status that separates them from the rest of the society.

Chretien, Jean-Pierre

Iron Production in Burundi before Colonial Control
The iron production capacity of blacksmiths in Burundi has long been ignored. Although this production stopped in the 1930s, the smelters from the large Kangozi deposit had a reputation that spread throughout the southern half of the country. A reconstitution of the iron ore reduction operations was organized in August of 1981 under the sponsorship of the Burundi Civilization Centre. Regional variations in techniques are found that correspond to differences in the quality of the ores and wood available.

Iron smelters were at one time active peddlers and appointed suppliers to the court of the king or to chiefs. They often attribute the origin of their activity to the dynasty's founding king, even though it undoubtedly dates back approximately 2000 years. Present blacksmiths express a certain nostalgia for the prosperity the profession knew in the pre-colonial period.

R F Tylecote

Jerzy Piaskowski; The Technology of Ancient Casting Crafts (Technologia Dawnych Odlewow Artystycznych).
Wydawnictwo Instytutu Odlewnictwa, Krakow, 1981.

This is a new survey of many well-known castings that have come down to us and exist in museums and elsewhere in many parts of the world. The ancient crafts of casting large statues, particularly equestrian, bells and artillery are covered. Moulds and moulding, composition of metals and melting procedures are examined.

The 189 pages, 74 plates and 19 tables include many illustrations from Biringuccio and Diderot and some interesting 18th century drawings of reverberatory furnaces and foundries from Polish textbooks.

C R Blick

A new Bulletin from France

Much interesting work on the history of mining and metallurgy is being done in France . . . but it has always been difficult to remain well informed. No publication similar to 'Historical Metallurgy' exists in France; and most of the material published remains quite obscure — at least to most of us. A new Bulletin, an initiative of the 'Association pour la sauvegarde et l'animation des Forges de Buffon' *[Society for the preservation of the forges of Buffon, Bourgogne]* might well help solve this problem.

Groupe d'histoire des Mines et de la Métallurgie

bulletin n°2 Février 1984

Au stade où en est parvenu notre réseau, il a paru bon de réserver déjà une place de ce numéro à la rencontre des 12 et 13 mai 1984 et d'en fournir un pré-programme.

Ouverte, dans la limite du thème minier et métallurgique, à un large public, reflet de l'ensemble des destinataires du bulletin, elle aura pour but de favoriser des échanges variés mais surtout de préparer l'avenir. C'est ainsi qu'était d'ailleurs déjà définie la fonction d'une telle rencontre dans la déclaration d'intention datée du 21 décembre 1982 : apprécier l'utilité de la création d'un comité de coordination, élargissement de la rédaction du bulletin, programmation de journées d'études, etc.

Il s'agira d'abord de régler les problèmes du futur immédiat. En effet, l'aide apportée par le ministère de la Culture (Direction du Patrimoine et Direction des Musées de France) viendra à échéance dans le courant de 1984 et le réseau devra trouver d'autres subsides. Il est légitime de remercier l'instance qui mit le véhicule sur les rails mais qui, à sa suite, prendra le relais ?

Deux façons s'offrent pour envisager le problème : le réseau et le bulletin. En théorie, pour assurer l'existence du premier, il suffit à un certain nombre de personnes et d'organismes de maintenir entre eux des contacts. Mais il se trouve que le bulletin a fait naître d'autres espoirs et augmenter les exigences du réseau au point de les rendre indissociables l'un de l'autre : l'existence du bulletin scelle la réalité du réseau.

Éditorial

Entraîné par sa propre logique, le bulletin est en outre appelé de lui-même à se développer. Est-il concevable que le réseau perdure sans dépasser le stade d'une feuille d'information ? Ce serait briser la dynamique dont celle-ci émane. Si le bulletin manifeste l'existence du réseau, une forme d'expression plus élaborée est la condition de sa permanence. Jusqu'où devons-nous aller ? Les deux journées de mai devront se montrer attentives à déterminer un éventuel seuil critique.

La revue qui semble appelée d'un vœu unanime comme prolongement du bulletin exige un minimum d'assise institutionnelle et un comité de rédaction représentatif. Il serait dangereux de brûler les étapes. Il paraît préférable, en l'état actuel des choses, de s'en tenir pendant encore un an au moins sinon deux à la formule du bulletin, pour évaluer exactement les contraintes éditoriales d'une publication plus lourde, plutôt que de sombrer rapidement dans d'inextricables difficultés financières et humaines. Là encore, c'est la diversité des participants qui devrait garantir la validité des décisions prises lors de la rencontre.

Comme le prévoyait le contrat avec le ministère de la Culture, un répertoire des personnes et organismes intervenant dans le domaine des mines et de la métallurgie sera publié ultérieurement, sous une forme ouverte. Il constituera un numéro spécial du bulletin réservé aux abonnés. Il est encore temps d'enrichir les références d'un tel répertoire dont le besoin a été partout ressenti.

En plus de ces problèmes généraux de perspectives et d'organisation, à court et moyen terme, la rencontre des 12 et 13 mai prochains doit donner lieu à un échange de fond autour de 3 grands axes, dont chacun pourra être abordé sous l'angle aussi bien culturel, économique, social, historique que scientifique ou technologique :

a) géologie, prospection et extraction minières.

b) élaboration du métal brut et première transformation des métaux (fonderie, forgeage, laminage en termes actuels).

c) les diverses approches du produit fini métallique comme source d'informations.

Nous demandons à tous les destinataires du bulletin, qu'ils comptent ou non participer à la rencontre, d'adresser à la rédaction d'ici au 15 mars 1984 une brève notice (1 page dactylographiée au maximum) résumant leurs activités dans le domaine minier et métallurgique. Les textes parvenus serviront à élaborer, pour chacun des trois thèmes, un document de base faisant le point des différentes expériences à partir duquel pourra se développer le débat, déjà dans le cadre de la rencontre, sur les objectifs du réseau.

Les personnes souhaitant jouer le rôle de rapporteur dans un des trois thèmes peuvent se faire connaître dès maintenant.

Publié avec le concours du ministère de la Culture (Directions du Patrimoine et des Musées de France).

The new Bulletin is published on a three-monthly basis. After a trial issue, the No 1 issue appeared in December 1983. This has 8 pages (A4 size) and offers a wealth of information on the latest news in the study of **mining and metallurgy** in France. The function of the Bulletin is to bring news and to help in exchanging information — not to publish articles. This will be clear from the following listing of its (regular) features:

Colloquia and meetings.

Just an example from this issue: 'La métallurgie urbaine en France au Moyen Age' (Metalworking in Medieval Towns in France), 23 March 1984. Further details can be had from M Denis Cailleux, Centre des Recherches d'Histoire des Sciences, 9 Rue Malher, 75004 Paris).

Courses, seminars and conferences.

Example: 'Les Mines et la Metallurgie en France de l'Antiquité au XVIIIe Siècle, a series of six seminars' covering: Transport in Mines (10 December 1983), Iron Slags (14 January 1984), Non-Ferrous Metals (11 February), Introduction and Diffusion of the Blast Furnace in France (10 March), Mine Ventilation (28 April), Nails (19 May). Each seminar takes place at the above-mentioned address in Paris.

University theses (recently published or under preparation)

Exhibitions (in France)

Publications (recently published or under preparation)

This issue mentions the MS book by Mott & Singer on Cort, but most of the publications listed are French, German or Austrian.

Survey of relevant Journals

Covers (in this issue) eg the German 'Technik Geschichte' (History of Technology) 1983, with interesting contributions:

. . . Die Erfindung des Heisswindblasens in Schotland und seine Einfuhrung in Mitteleuropa (the invention of hot blast and its introduction on the Continent);

. . . Die Ausbreitung des Puddelverfahrens und des Kokshochofens in Belgien, Frankreich und Deutschland (the spread of puddling technology and coke blast furnaces in Belgium, France and Germany).

Notes and News

Survey of new projects assisted by the 'Cellule du Patrimoine Industriel de l'Inventaire General (comparable to the DoE), mainly consisting of regional surveys of iron-working sites.

In the Editorial of the No 1 issue of the Bulletin, attention is drawn to a Weekend Meeting, taking place at the Forges de Buffon, Bourgogne, France, on 12 and 13 May 1984. The Meeting is open to all interested in the history of mining and metallurgy. No formal lectures are envisaged, but a lively exchange of experiences and views is expected. The organizing group (the originators of this Bulletin) will present their preservation project: the Forges de Buffon. Details of the Meeting will be given in the No 2 issue, but subscriptions are invited now. All information can be had from the address mentioned below.

How to subscribe to the Bulletin?

A year's subscription (four issues) costs 50 FF (ie about £4.50). Send a cheque or money order with your subscription to:

Association pour la sauvegarde et l'animation des Forges de Buffon,
Buffon, F-21500 Montbard,
France.
(tel. 16(80)92.40.30).

Alex den Ouden

Abstracts

GENERAL

A M Burnett, P T Craddock and K Preston: New light on the origin of orichalcum. *Proceedings of the 9th International Congress of Numismatics. Berne, September 1979, 263-268.*

Dates the introduction of brass for coinage as being 50 years earlier in the Provinces than in Rome itself.

ECJT

L Horne: Fuel for the metal worker. The role of charcoal and charcoal production in ancient metallurgy. *Expedition, Fall 1982,* **25** *(1), 6-13.*

M J Hughes, J P Northover and B E P Staniaszek: Problems in the analysis of leaded bronze alloys in ancient artefacts. *Oxford J Archaeol, 1982,* **1**, *359-363.*

CBA

G McDonnell: Tap slags and hearth bottoms, or how to identify slags. *Current Archaeology, March 1983,* **8** *(3), 81-83.*

Investigation into the terminology and identification of 9 categories of iron working residues divided into two groups. The first consists of tap slag, hammer scale, furnace lining and fuel ash, described in detail. The difficult categories are cinder, furnace bottoms, hearth bottoms, smelting slag and smithing slag also described.

Author

A Oddy: Assaying in Antiquity. *Gold Bulletin, April 1983,* **16** *(2), 52-59.*

The methods developed in antiquity for the assaying of precious metals, in particular gold, are the ancestors of modern chemical analysis, and the need to determine the composition of a manufactured material is the basis of all quality control. In view of the rapid advances made in the past thirty years it is surprising that the techniques known to the Greeks of 2500 years ago are still in use.

Author

V C Pigott: The innovation of iron; cultural dynamics in technological change. *Expedition, Fall 1982* **25** *(1), 20-25*

E Tholander: How ancient technology could influence the properties of artefacts of iron and steel. *PACT, 1982,* **7**, *477-486.*

Already in antiquity different properties of iron and steel were known. Scandinavian iron making in bowl hearths started independently of European technology, the product being soft ferritic iron, made into steel by cementation. The next stage was the bloomery producing soft iron, natural steel and cast iron. Forge welding, alloying with nickel, pattern welding were practiced.

Author (abridged)

E M Trent: Metallurgy as a creative activity. The Metallurgist and the Material Technologist. *May 1982, 197-199.*

A R Williams: The manufacture of Mail. *Gladius, 1980,* **15**, *105-134.*

P Williams, M Sunderland and G Briggs: Viscosities of synthetic slags in the system CaO-'FeO'-SiO_2-MgO. *Trans Inst Mining and Met Section C, 1983,* **92**, *105-109.*

The widespread use of dolomitic lime in basic oxygen steel-making practice throughout the world and the increasing emphasis of slag-refractory interaction in steelmaking economics has highlighted the absence of basic knowledge on the slag system CaO-'FeO'-SiO_2-MgO. Many physical properties have never been quantified either for the binary and ternary combinations or for the full quartenary system. Viscosity and solidus-liquidus temperatures are probably the characteristics of greatest significance at the moment. The experimental difficulties in obtaining viscosity measurements have been overcome in the present study. The slag systems have been examined in the temperature range 1120-1470°C. Viscosity data have been obtained by a rotary viscometric technique applied in a vertical tube furnace with synthetic slags contained by iron and zirconia crucibles. The experimental technique is presented here as a technique within itself and the viability of the method and the apparatus is proven. The data and measurements are presented for the purpose of record only and for their observation by interested readers. A comparison with the limited existing known data is given. Author

M W Williams: Ferrum — A Poem about Ironmaking. *J Metals, November 1982,* **34** *(II), 60-62.*

Reproduces a shortened version of a poem written in the early 1700s and translated from the Latin into English at the request of Sir Robert Hadfield. APG

BRITISH ISLES

P V Addyman, N Pearson and D Tweddle: The Coppergate (York Anglo-Saxon) helmet. *Antiquity, 1982,* **56**, *189-194; Interim, 1982,* **8** *(4), 8-36; Illus London News, August 1982.* CBA

K H Armitage, J E Pearce and A G Vince: A late medieval 'bronze-buckle' mould from Copthall Avenue, London. *Antiq J, 1981,* **61**, *362-364.*

Stack-type clay mould.

M A Barron: Swords and sequence in the British Bronze Age. *Archaeologia 1982,* **107**, *1-42.*

A study based on the archive of the late J D Cowen at Newcastle upon Tyne. It is mainly typological and excludes Irish material. An appendix contains 57 new and 96 previously published analyses. The MBA-LBA transition period shows 4 groups of bronzes, one with high lead. No metallography. RFT

R A Barron: The Finch Foundry Trust and Sticklepath Museum of Rural Industry. *46pp. Obtainable only from the Finch Foundry Trust, £1.35 in UK, £1.65 overseas, including post and packing.*

The 'Foundry' was operated from 1814 to 1960 by the Finch family, mainly producing edge tools. When the site began to become derelict it was happily saved from demolition and became a museum of rural industrial history. Three water-wheels have been restored and may be seen working a pair of heavy tilt-hammers, drop forge hammers and metal cutting shears, as well as providing air blast to various furnaces and forges and operating grindstones for shaping and polishing. AC

J Bayley: Non-ferrous metal and glass working in Anglo-Scandinavian England: An interim statement. *PACT, 1982,* **7**, *487-496.*

Evidence for non-ferrous metal and glass working in the early Medieval period from sites in the Danelaw are compared with material from Wessex and Scandinavia.

Author (abridged)

D Bick: The Old Copper Mines of Snowdonia. *Published by and obtainable from The Pound House, Newent, Glos 129pp, £3.95.*

Physical remains of mine sites in the areas of Porthmadog, Cwm Pennant, Nantle Vale, Beddgelert, Nant Gwynant, Snowdon, Nant Ffrancon, Conway, Llandudno and Ffestiniog. There are a number of plans of mines both above and below ground described. History of the mining enterprises, and the men who instigated and operated them. There is also an appreciation of D C Davies FGS, mining engineer and geologist, well known a hundred years ago, but remembered today only for his several books on mining and quarrying. Source notes and index add value to the very thorough research that has gone into this volume. AC

H Cleere: The Iron Industry in the Romano-British Countryside. The Romano-British Countryside. *Studies in Rural Settlement and Economy (D Miles ed). BAR British Series 103, 1982, 123-135.*

Illustrates different types of organisation of the Roman iron industry with examples given from the Sussex Weald and Northamptonshire. In addition to the traditional relationship between town and agricultural countryside, consideration should be given to that between towns and rural areas with developed industrial production in making evaluations of the Roman provincial economies. Iron-making centres in the Weald are examples of the latter type; the Forest of Dean may have played a similar role, but there are inadequate archaeological data available to permit analysis. CPSA

D Coggins and C Burgess: The Gilmonby, Co Durham, bronze hoard; a preliminary note. *Northern Arch, 1980,* **I** *(I).*

D Cowman: Bronze Age Copper Mines at Danes Island (Co Waterford-? post-med). *Decies (J Old Waterford Soc), 1982,* **20**, *23-27.* CBA

B Cunliffe: Ictis: is it here? (Mount Batten, Devon and the Iron age tin trade), *Oxford J Archaeol, 1983,* **2**, *123-126.* CBA

C L Curle: Pictish and Norse finds from the Brough of Birsay 1934-74. *Soc Antiq Scot Monogr Ser, 1982,* **I**, *141pp.*

Details of moulds etc. CBA

B Dix: The Romano-British farmstead at Odell and its setting: some reflections on the Roman landscape of the SE Midlands. *Landscape Hist, 1981,* **3**, *17-26.*

Site of ironworking. CBA

L N W Flanagan: Some aspects of the composition of Irish Earlier Bronze Age bronze implements, in Irish antiquity *(ed D O Corrain), 1981, 43-51.* CBA

H S Green, A H V Smith, B R Young and R K Harrison: The Caergwrle Bowl: its composition, geological source and archaeological significance. *Rep Inst Geol Sci, 1980,* **80** *(I), 26-30.*

Detailed description of boat-shaped bowl, probably BA. Decorated with shields, oars and waves, executed in part by gold leaf and in part by the wrapping of gold leaf around a white substance identified as a mixture of romarchite (SnO) and cassiterite (SnO_2), presumably originally metallic tin. The bowl is composed of gel-like kerogen-rich material (? bituminite) resembling oil-rich shale that gave a poor X-ray powder defraction pattern with lines of goethite, quartz, mica and possibly siderite and lepidocrosite. The source of the material is uncertain, but may have been Kimmeridge oil shale.

Authors (abridged)

L C Hayward: Ilchester Mead (Somerset) Roman villa. *St Peter Port (Guernsey), Toucan Press, 1982, 55pp.*

Bases of smithing furnaces. CBA

R Ling and T Courtney: Excavations (of lead-working settlement) at Carsington, 1979-1980. *Derbyshire Archaeol J, 1981,* **101,** *58-87.*

CBA

S M Linsley: Furnace rediscovered: provisional note (Wheelbirks, Northumberland). *Ind Archaeol Rev, Winter, 1981-2,* **6** *(I), 69-72.*

CBA

C McCombe: Two centuries of casting production in Exeter. *Foundry Trade Journal, May 5 1983,* **154** *(3262), 576-590.*

This is largely the history of Bodley Bros and Company Limited, Commercial Road, Exeter, from 1790 until 1967, together with a brief review of four other foundries in the same city.

APG

C Mahany, A Burchard and G Simpson: Excavations (of Saxon to medieval sites) in Stamford, Lincolnshire, 1963-9. *Soc Medieval Archaeol Monogr Ser, 1982,* **9,** *pp 186.*

Geology, iron ores and workings. CBA

W A Oddy: A Roman brass head with pseudo-gilding. *Antiq J, 1981,* **61,** *349-350.* CBA

K S Painter, Two (late) Roman (inscribed) silver ingots from Kent. *Archaeol Cantiana, 1982,* **97,** *201-207.*

CBA

K S Painter, A Roman silver ingot from Reculver, Kent. *Antiq J 1981,* **61,** *340-341.*

CBA

W Price: Iron making at Halton (Lancs, 18th-19th century). *Contrebis, 1982,* **9,** *23-29.* CBA

M R C Price: Industrial Saundersfoot, *Gomer Press, Llandysul, Dyfed, 1982.*

Chapter five covers the Iron Industry. Ironstone was obtained from 'patches' driven into the sea cliffs early in the 19th century, and Kilgetty Ironworks (Stepaside) were set up to use the local ore and anthracite coal as a result of a survey and report of 1845. Early in 1849 two blast furnaces had been completed, and the first iron was to be made soon afterwards. However, the attempt to use anthracite coal with hot blast was as unsuccessful here as elsewhere in South Wales, and there were long periods when no iron was made. Despite the installation of Coppee coke ovens for making coke from a mixture of anthracite coal duff and bituminous coal slack and the use of iron ore imported from Spain, iron production finally ceased, probably in June 1874, and the works was dismantled in 1888.

Illustrations include a cross-section and a table of dimensions of No 1 Blast Furnace reproduced from a report of 1863 and a plan of the works site based on the 1887 Ordnance Survey. An appendix reproduces an inventory of iron making plant etc drawn up in 1872.

Other chapters cover the coal industry and transport.

APG

A Rook, R P Lowery, R D A Savage and R L Wilkins: An Iron Age mirror from Aston, Hertfordshire. *Antiq J, 1982,* **62,** *18-34.*

Gives details of working technique, analyses in Ant J, 1983, **63,** 30.

CBA

B G Scott and P J Francis: Native copper in North-East Ulster; a contributory factor in the establishment of the earliest Irish metalworking? *In Irish Antiquity (ed D O Corrain), 1981, 28-41.*

CBA

M G Spratling: Metalworking at the Stanwick oppidum; some new evidence. *Yorks Arch J, 1981,* **53,** *13-16.*

I M Stead: The Cerrig-Y-Drudion 'Hanging Bowl' (with an appendix by P T Craddock), *The Antiquaries Journal, 1982,* **62,** *(2), 221-234.*

The conclusions to this study are negative and there is doubt whether one or two vessels are represented but a reconstruction of the design allows the conclusion that it is one of Britain's most important pieces of Early Celtic art. The fragments are all of tin bronze and the trace elements are remarkably consistent, suggesting that the pieces all come from the same stock of metal.

ECJT

G Warrington: The copper mine at Alderley Edge. *J Chester Arch Soc, 1981,* **64,** *47-73.*

G C Whittick: Roman lead ingots from the Mendips (description, metallurgy, and technology). *Somerset Archaeol Natur Hist, 1981,* **125,** *87-92.*

CBA

J P Wild: A find of Roman scale armour from Carpow. *Britannia, 1981,* **12,** *305-6.*

J H Williams, M Shaw et al: Excavations in Chalk Lane, Northampton (prehistoric, Saxon, medieval), *Northamptonshire Archaeol, 1981,* **16,** *87-135.*

Pedestal-type crucible. CBA

D H Cadwell: The Royal Scottish Gun Foundry in the Sixteenth Century, in:- *From the Stone Age to the Forty-five, studies presented to R B K Stevenson . . . (ed Anne O'Connor and D V Clarke), 1983, 427-449.*

CBA

D Austin: Colliford Reservoir, Bodmin Moor (tin mill). *Cornish Archaeol, 1981,* **20,** *221-222.*

CBA

S C Clark, H Owen-John and J K Knight: Medieval iron working at Trelech: a small salvage excavation, with a list of early bloomery sites in the Monmouth-Trelech area. *Monmouthshire Antiq 1981-2,4, (3-4), 45-49.*

CBA

A G Credland: Some swords of the English Civil War with notes on the origin of the basket hilt. *J Arms Armour Soc 1982,* **10,** *196-205.*

CBA

D Fox and C Bowman: A 15th century clay mould found in Scotland and the Master E S *Pantheon, 1982,* **40,** *223-229.*

CBA

G C Whittick: The earliest Roman lead-mining in Mendip and in North Wales: a reappraisal (of its date). *Britannia, 1983,* **13,** *113-123.*

CBA

Anon: Big Ben and the cast iron roof tiles. *Foundry Trade Journal 1983,* **155** *(3272), 335. Illustrated.*

The cast iron tiles have been in service for almost 130 years, and are one of the earliest industrial applications of hot-dip galvanising. About 20% of the surface now shows rusting, but otherwise the original hot-dip zinc coating is still largely intact. The tiles are to be blast-cleaned, and then probably zinc sprayed and repainted.

F Barlow: Ironmaking in the blast furnace a hundred years ago. *Refractories Journal. Sept./Oct 1983,* **58** *(5), 18-20.*

Briefly reviews typical profiles, sizes and preformances. The nature of the refractory lining is emphasised. Hot blast stoves are described.

APG

Simon Hughes: The mines of Talybont. Part 2 from 1800 to the present day. *Industrial Archaeology. Winter, nominally 1981,* **16** *(4), 290-307. Illustrations pp 339-340.*

Appendices list the output of lead ores, blende, copper ore and silver for the period.

APG

C McCombe: Whitechapel's Bells ring loud and clear. *Foundry Trade Journal, 1983,* **155** *(3270), 228-242 (illustrated).*

After tracing the development of the enterprise and describing some of its more famous achievements, the techniques used for moulding and tuning the bells at Whitechapel today are described.

APG

J Peatman: Abbeydale Industrial Hamlet. *Industrial Archaeology, Winter, nominally 1981,* **16** *(4), 318-329. Illustrations pp 341-343.*

Briefly reviews the historical development of the site, and outlines the process of crucible steel making and scythe making.

APG

A Graham: Sydling St Nicholas excavations. *Proc Dorset Nat Hist Arch Soc, 1982,* **104,** *131-135.*

Details of 15th century bell mould for the church shows that it was an example of the later clay pattern type (ie not lost-wax).

ECJT

EUROPE

Anon: Ancient Mines and Foundries in France. *Table ronde du CNRS, Université de Toulouse-Mirail, 1980, Paris 1982, 329pp (in French).*

The volume comprises papers on mining non-ferrous and precious metals as well as iron mining and smelting. Among the latter are: J-M Pailler: Mines and Metallurgy in the French-speaking literature 1789/1960, 5-13. P Galliou: Mines and metals in the West of Gaul, 21-32. Iron ore and slag distribution maps of Brittany, furnaces at Kermoisan. F Deroche: Investigations into iron making within the Leuci tribal territory, 133-138. Gallic and Gallo-Roman iron mines and slag heaps in the East of France, Chavigny, Camp d'Afrique, Saint Die, Nancy, Liverdun, Puvenelle (19th century exploitation of slags), La Bure, Pierre d'Appel, etc. A Bouthier: New data on the use of iron ore in NW Nievre in the Gallo-Roman period, 139-156. Large slag heaps at Bois Marillier-Saint Amand, Thorins La Luysaya, etc, some of them industrially exploited, smelting sites, slag in foundations of Roman villas. C Peyre: Iron at Minot: mines, mining fields, bloomery heaps, and pseudotoponymy of the mine, 157-177. Shafts and galleries, slag heaps, and ore washing plants, problems of chronology Gallo-Roman period to Middle Ages. S Benoit: Historical note on mining activity at Minot, 178-182. From the La Tene period until about 1600. R Sablayrolles: Importance and problems of studying ancient smelting sites: the example of the Montagnes Noir, 183-190. Information on one of the most important iron smelting centres of the Gallo-Roman period in south-western France, programmes and research possibilities. R Halleux: New texts on ancient metallurgy, 193-204. Among others, notes on steel carburization and quenching in ancient texts. P-L Pelet: Investigations into the metallurgy of iron in the Jura Vaudois, NW Switzerland, 205-214. Summary of intensive excavations of La Tene and Roman sites, comments on bloomery furnace types and properties. C Domergue, A Rebiscoul and F Tollon: Bloomery furnaces of the Gallo-Roman period at the Montagnes Noir and their production, 215-236. According to scattered indications shaft furnaces about 200cm in height and 45 cms in diam were constructed. Estimated slag volume in the region 7-8 millions of tons, estimated daily production during three centuries 4-20 tons of iron. M Mangin: Characteristics and functions of the iron metallurgy at Alesia, 236-258. House blocks in the Alesia oppidum (occupied from the 1st century BC until the 4th century AD) yielded simple open hearths; roasted iron ore finds lead the author to suggest a small-scale, rather retarded iron production (and working). Metallography of several implements and bars. R F Tylecote: Metallurgy in Punic and Roman Carthage, 259-278. Smithing slags and plants in the Punic period, bipyramidal iron bars, iron smelting outside the city (Sbeitla, Roman). J R Maréchal: Thermodynamics of Gallo Roman slags, 305-318. French terminology for metallurgical waste products, analytical approaches to non-ferrous and iron slags.

CPSA

R Barker: Bronze cannon founders: Comments upon Guilmartin 1974-1982. *The Int Journ of Naut Arch, February 1983,* **12** *(1), 67-74.*

A critical study of Guilmartin's work regarding technical appendices and the development of foundry technology for early guns.

Author

C Bonnet and M Martin: The lead model for an Anglo-Saxon brooch from Saint Pierre, Geneva. *Archaeol Schweiz, 1982,* **5**, *210-224.*

CBA

I Burger and H Geisler: Archaeological sources relating to iron smelting in the region of Kelheim. *Erwin-Rutte-Festschrift, Kelheim-Weltenburg, 1983, 41-56. (In German).*

Renewed research activity following the earlier work by P Reinecke and H Behaghel and others in this iron ore region. New excavations of La Tène period elongated domed furnaces, one at Altessing-Unterau, and three at Neuessing-Weihenmühle.

CPSA

A Burnett and P T Craddock: Early Italian currency bars. *British Museum Italic Seminar, 1982, Ed J Swaddling.*

Z Bukowski: Phases of the process of spread of the experience in iron in the Lusatian Culture region. *Kwartalnik Historii Kultury Materialnej, 1982, 3-4, 313-322. (In Polish, English summary).*

Another in the series of articles on this subject. The author identifies the following phases in the process of introduction of iron and iron technology from the south: BD and HB both with sporadic occurrence of iron objects: HC/HD with possible local iron working of imported metal; and HD/LA with eventual additional local smelting on a small scale. The whole process covers the 13th-5th centuries BC.

CPSA

Z Bukowski: The earliest iron objects on Central Europe and the beginning of the metallurgy of iron within the Lausitz Culture area between the Odra and Vistula rivers. *Archeologia Polski, 1981/2,* **26**, *321-401. (In Polish, German summary).*

Catalogue of the Late Bronze Age (HB_3), iron objects in Poland and Czechoslovakia. Local iron smelting did not begin until the Hallstatt D period. Pre-La Tène iron production in the Holy Cross Mountains has not been attested up to the present.

CPSA

G M Burov: On the problem of the lower dates of the Debyazhsky culture. *Sov Ark 1983 (2) 34-50. (In Russian).*

The Late Copper-Bronze Age in the North-Eastern fringe of the European part of the USSR corresponds to the earlier Ozyag stage of the Lebyazhsky culture. Date late 2nd to early 1st mill. BC. The copper used in this culture had natural traces of tin, lead and arsenic with gold and negigible silver content; in some cases they used low tin 'bronzes' (0.5% Sn). The adjacent Seima-Turbino complex of the Kanin Cave sanctuary used a metal containing, as a rule, arsenic or antimony tin bronze with higher concentration of silver; gold was usually absent, while copper and tin bronze contained lead and arsenic in comparatively small proportions. Table of analyses.

Author (abridged)

C Eluere: Prehistoric Goldwork in Western Europe. *Gold Bulletin, July 1983,* **16** *(3), 82-91.*

The author discusses the centres producing gold artefacts during the BA based on the archaeological study of the prehistoric gold of France and the information derived from methodical and technological investigations. Selected illustrations show the methods of fabrication from various areas in Europe. Schematic representation of the silver, copper and tin contents of gold alloy artefacts found in different regions throughout Western Europe are given.

ECJT

V D Gopak and S P Pachkova: Iron artefacts from the Kruglik settlement (Bukovina). *Sov Ark 1983 (2), 231-236. (In Russian).*

Knives and sickles, carburized and welded iron-steel. One sickle has a well developed 'white' residual ferrite line at the junction of the high carbon core. Measured hardnesses do not exceed 274 HV.

RFT

H Hamann: A smelting experiment using bog iron ore in a reconstructed Iron Age furnace in relation to the interpretation of the excavation results in the Geest. (In German). *Die Heimat (Neumunster), 1982,* **89** *(11-12), 413-419.*

A slag-pit shaft furnace of the Scharmbeck type was tested using bog iron ore with 36.8% Fe and commercial beech charcoal. Consuming 16 Kg ore, 30 kg charcoal (4 kg for furnace preheating) and 9.5 kg sand during about 8 hours under induced draught, the experimenter obtained metal grains in the slaggy mass (unweighed). Fine and coarse perlitic structures indicate a steel with up to 0.71% C.

CPSA

R J Harrison and P T Craddock, with an appendix by M J Hughes: A study of the Bronze age metalwork from the Iberian Peninsula in the British Museum. *Ampurias (Barcelona) 1981,* **43**, *113-179.*

A discussion on the various alloys used in Iberia from the unalloyed copper, arsenical-copper and, lastly, highly leaded tin bronzes during the Bronze Age showing that the ancient smiths in Western Europe understood and controlled the compositions of their metals from at least 2000 years BC.

Authors (abridged)

B Jovanovic: Rudna Glava: The oldest copper mines in the Central Balkans. *Bor-Beograd, Muz Rudarstvai Metalurgije, 1982, 155pp.*

CBA

L Lodowski: Lower Silesia at the beginning of Middle Ages (6th to 10th centuries AD). Ecological and economic basis. *Warszawa-Wrocaw-Krakow-Gdansk 1980. (In Polish, German summary).*

Chapter IV of the work, dealing with Handicrafts, contains a paragraph on the technology of iron (pp 150-155). Sources for studying the metallurgy of iron remain uninvestigated for the most part. Preliminary reports on slag blocks and iron smelting in Zukowice suffer by reason of their unresolved metallurgical problems and uncertain interpretations. Some metallographical analyses of iron artefacts suggest that the level of the blacksmith's work was not high (iron with elevated phosphorus content). Tongs from Zukowice are shown in Fig 35.

CPSA

I Martens: Recent Investigations of Iron Production in Viking Age Norway. *Norwegian Archaeological Review, 1982,* **15** *(1-2), 29-44.*

The paper is focused on settlement and economic aspects of the early metallurgy of iron in Norway. Smelting activities were carried out predominantly in areas which were peripheral to agrarian settlements and formed part of the process of exploitation of mountain resources. The iron-making communities were economically dependent on the outside world. Survey of excavations, comments on trade goods as reflected in hoards of pre-Viking and Viking periods.

CPSA

H G Niemeyer: 'Phoenician' pot bellows? A hoard from Toscanos, Spain. *Der Anschnitt, 1983,* **35** *(2), 50-58.*

Phoenician double tuyeres? A comparison with similar material from other sites (Carthage etc) of the same period (8th-5th cent BC).

ECJT

R Pleiner and D Bialekova: The beginnings of metallurgy on the territory of Czechoslovakia. *Bulletin of Metals Museum (Sendai, Japan), 1982,* **7**, *16-28.*

Short outline of the development of metallurgy in the very centres of Europe from the Chalcolithic period up to early medieval Slav technology. Principal sources for studies in presumed mining of copper ores, casting bronze, introduction, working and smelting of iron (bloomery furnace types, blacksmith's types, hoards of axe-shaped bars, metallography of implements). Reference to basic literature.

CPSA

R Pleiner: The beginnings of iron in Europe. *Dialogues d'histoire ancienne. (Besancon). 1982,* **8**, *167-192. (In French).*

Comments on the problem of the penetration of the earliest iron objects into Europe, followed subsequently by the spread of technology. The earliest route for single objects came through eastern Europe during the Bronze Age, meeting the Veneto-Illyrian and Thracian cultures. Later another stream of Graeco-Etruscan and Phoenician influence made its impact in Italy, and two centuries later on the Iberian peninsula. The latter played an important role in Celtic and indeed in European civilization. Eastern imports of the 8th century BC came, in Central Europe into a milieu which was receptive to the technology of working iron.

CPSA

J Piaskowski: Physical-metallurgical studies of ancient iron objects from the Cremation cemetery at Rumia, Gdansk Voivodeship. *Pomorania Antiqua, 1981,* **11**, *117-136.*

Twenty iron objects from the Late La Tène and Roman periods were analyzed. Some show them to be forged from iron with a high phosphorus content smelted in Pomorze (Pomerania), other objects have features of iron from Holy Cross Mountains; nitrides were observed in 4 of these objects. The head of the spear, a sword, a ferrule from the centre of a shield were made of low carbon steel.

ECJT

I Serning, H Hagfeldt and P Kresten: Vinarhyttan. A late Medieval iron production site at Lake Haggen, Norrbarke Parish, Dalarna County, Sweden. *Stockholm 1981, 132pp, 128 figs (In Swedish, but long summary and all figure captions in English).*

Description of excavated sites on the lake shore; early blast furnace remains possible water-wheel system, slag heaps, radiocarbon-dated to the 11th-15th centuries AD. Complex chemical and mineralogical analyses of slag with high silica and low FeO contents, and of ore (low in phosphorus). Metallography of some iron specimens indicated graphitic and ledeburitic pig iron. Vinarhyttan belongs definitely to the earliest European Blast furnaces.

CPSA

H Seyer: Settlement and archaeological culture of Germanic tribes in the Havel-Spree region, in the centuries preceding our era. *Berlin, 1982. Chapter 6.2.1, 35-40. (In German).*

Deals with smelting and working of iron in the region around Berlin, rich in lakes, describes small iron objects and their frequency in the period of the Jastorf culture. Heavy slag blocks and furnace lining fragments are known from Langengrassau, Buchholz, Heinrichsdorf and Glienick. Slag finds also occur in settlement pits (Freyenstein, Schmolde, Lanz). From Rauschendorf there is a small anvil from a Jastorf grave, and an undated hammer. Production of belt-fasteners. The use of iron remained relatively limited.

CPSA

V Souchopova: Metallurgical furnaces from the time of the Moravian Empire near Olumucany (Blansko district). *Z dejin hutnictvi, 10 (Rozpravy Narodniho technickeho muzea v Praze 82), Praha, 1981, 14-25.*

Excavations in forest area 98/1 revealed three types of bloomery furnaces of the Zelechovice type: below ground furnaces with thin front walls (two sub-variants according to hearth shape): and finally free-standing shaft furnaces with flat hearths. Preliminary report.

CPSA

P G Warden, R Maddin, T Stech and J D Muhly: Copper and iron production at Poggio Civitate (Murlo). *Analyses of metal working by-products from an archaic Etruscan site. Expedition, Fall, 1982,* **25** *(I), 26-35.*

G Wetzel: On the pre- and protohistory of the Uhyst area, district of Hoyerswerds. *Hoyerswerdaer Geschichtshefte No 20, Hoyersweda (1982). (In German).*

Near Mersdorf, German Democratic Republic, a rectangular group of 54 slag pit hearths of bloomery furnaces, arranged in four lines, was excavated. They resemble the organized bloomery furnace fields known from the Holy-Cross Mountains, in Poland. This would be the first example in German history. Date: Romano-Barbarian period. Fragments of clay shaft indicate the use of wooden framework.

CPSA

J Ypey: European pattern-welded weapons. *Archaologisches Korrespondenblatt 1982,* **12**, *381-388. (In German).*

A detailed study of European pattern welding of sword blades, based on the author's own smithing experiments. He considers all laminated or piled structures to be damascened. He distinguishes as types, torsion, mosaic, and grid patterns developed by cutting certain levels of the welded-up bar. The purpose of the technique was a decorative one and etching using natural reagents was common. Examples of individual weapons up to 10th century AD.

CPSA

P Hammer and H Klemm: Metallurgical research on Roman denarii, with some conclusions on the technology of their production. *Z Archaeol, 1982,* **16**, *53-93.*

CBA

B G Scott: Goldworking terms in early Irish writings (panning alloying, assaying etc). *Z Celtische Philogie, 1981,* **38** *, 242-254.*

CBA

W A Oddy, M Bimson and S La Niece: The composition of niello decoration on gold, silver and bronze in the antique and medieval periods. *Stud Conserv, 1983,* **28**, *29-35.*

CBA

J Piaskowski: The presence of arsenic in medieval objects made of bloomery iron. *Kwartalnik Historii Nauki i Techniki, 1982,* **27** *(2), 397-410. (In Polish).*

Normally, As is not determined in the analysis of early iron artifacts. This element was found to be present to the extent of 0.2 - 0.25% in some tools from Krivina Iatrus in Bulgaria. It was noted that this amount of As promotes the formation of enrichment bands of ferrite with high As; but no quantitative values are given, although it was noted that the degree of segregation increases with As content. It is believed that the whole of the As in the ore is transferred into the metal. There is an inverse correlation between the degree of carburization and the As content. The micro-hardness of the ferrite with high arsenic varied from 179-256 HV. The % P was in the range of 0.01-0.11.

RFT

J Piaskowski: Metallographic investigation of ancient iron objects from the Koszalin area. *Slavia Antiqua, 1980,* **27**, *231-252.*

Thirteen iron objects of the Roman period were investigated. All had a high phosphorus content. The author has previously shown that in the late La Tène and Roman times bog iron ore was used. There is no evidence that the smith knew how to produce steel.

ECJT

L G Aliyeva and A M Gasanova: On the problem of the unknown metal Kharsini in the medieval written sources. *Me'ruzeler Dokladu (Azerbaijan SSR, Academy of Sciences), 1981,* **37** *(4), 84-87.*

According to the modern historians of chemistry the metal *kharsini* is thought to be brass or antimony. The present authors believe that it is a native metal which contains associated arsenic and antimony as well.

Author

F Delamare: Study of the minting of a counterfeit French gold coin of the period 1775. *Revue de Métallurgie (MES) 1983,* **80** *(7-8), 385-390.*

Neutron Activation Analysis shows that the overall analysis of the coin was 30% gold, 21% silver and 40% copper. Local analysis of the visible parts of the red substrate by microprobe gives 39% gold, 7.8% silver, 54% copper. The yellow surface analysed: 76% gold, 4.9% silver, 1.6% copper and 18% mercury. Auger spectroscopy of the surface layer combined with argon ion bombardment showed that the concentration of mercury rose from zero at the outer surface to about average for the layer at a depth of 10^{-3} mm, but the relative figures for copper, silver and gold were variable. Markings indicated that cast alloy plate had been rolled into strip, blanked, annealed, quenched in water, etched, abraded with fine sand, rubbed with gold amalgam of mercury, and heated to remove about 90% of the mercury by distillation. The edges are then marked with a cord pattern and the blanks coined by striking.

In view of the very high standard of the forged coins, it is difficult to explain the choice of the alloy substrate since an alloy of silver with 5% copper would have been less costly, have the same density as the alloy actually used, and would have been easier to work.

APG

ASIA

Anon: Chinese Founders made Spheroidal-graphite castings 2000 years ago. *Foundry Trade Journal, March 24, 1983,* **15** *(3259), 362.*

A photomicrograph of an ancient pick shows an excellent SG iron structure. Whiteheart and blackheart malleable iron, and decarburised steels made from white cast irons were also used.

APG

V A Alexeyev and E F Kuznetsova: Kenkazgan — An ancient copper mine in Central Kazakhstan. *Sov Ark 1983 (2), 203-212. (In Russian).*

This mine was the source of the raw material for the large-scale metallurgical production in the Bronze Age. Tools of ancient miners and fragments of pottery were found. It was estimated that about 600,000 cubic meters in volume of mining with more than 800,000 cubic meters of ore were smelted. It is possible that smelting was carried out in the nearby settlement of Atusa supported by analysis showing the qualitative affinity between the Kenkazgan ores and products from copper smelting furnaces of the settlement. The output of this mine can be compared with Djezkazgan, one of the major centres of ancient non-ferrous metallurgy. Analyses of ores, slags and metal are given.

Author (abridged)

T Berthoud (ed): Production, exchange and utilisation of metal. *Paleorient 1980,* **6**, *99-124.*

S Cleuziou and T Berthoud: Early tin in the Near East; a re-assessment in the light of new evidence from Western Afghanistan. *Expedition, Fall, 1982,* **25** *(1), 14-19.*

G Hongye and H Jueming: Research of Han Wei Spheroidal-graphite cast iron. *Foundry Trade Journal International, March 1983,* **5** *(17), 89-94.*

Details of a research programme which revealed that ancient Chinese foundrymen were producing cast iron artefacts 2000 years ago. The quality of these archaic irons is similar to that of modern industrial grades of spheroidal-graphite irons. Method through heat treatment, described in detail.

APG

P R S Moorey: Archaeology and pre-Achaemenid metal-working in Iran; a 15 year pro-retrospective. *Iran, 1982,* **20**, *81-101.*

J D Muhly: How Iron Technology changes the ancient world and gave the Philistines a military edge. *Biblical Archaeological Review, 1982,* **8**, *40-54.*

Comments on some places in the Old Testament connected with iron some new results of the metallographical investigation of ancient iron (steel) artefacts in Palestine (Had Adir, a quench-hardened pick dating from the 13th/12th cent BC). The Philistines exercised **political** control over the use of iron in Palestine, not a technological monopoly. Splendid photographs in colour of some well known finds connected with the technology of iron.

CPSA

J Piaskowski: Classification of the famous damascene swords. *International Congress of the History of Turkish-Islamic Science and Technology, 14-18th Sept 1981.*

The author proposes his own classification which includes type and thickness of the threads; thick, intermediary and fine, their colour and the grade of steel.

ECJT

J Piaskowski: The technology of gun casting in the army of Muhammad II (early 15th century). *I International Congress on the History of Turkish-Islamic Science and Technology. 14th-18th September 1981.*

In the army of Muhammad II gun-barrels were cast using separately moulded cores. The mould was made in pure, fat, clay mixed with the shreds of hemp or linen. The technology is the same as the one applied in Europe. It is not known where it was discovered.

ECJT

J Piaskowski: Metallographic investigations of iron objects and slag from the Early Medieval Cemetery at Czersk near Piaceczno. *Sprawozdania Archeologiczne, 1981,* **33**, *137-148.*

Five iron objects were examined. Three knives were made by welding iron and steel. All were submitted to heat treatment. The chisel and arrowhead were forged in iron. All objects have a high phosphorus content. The analysis of slag from Czersk has shown that metal of this kind was smelted by local smelters.

ECJT

K N P Rao: Iron and steel technology in India in ancient and medieval periods. *Metallurgist and Materials Technologist, May 1983,* **15** *(5), 245.*

Completes a table of components made in hard and soft Damascus steels, which was cut short in the original article *(M and M T, Oct 1982,* **14** *(10), 468-470).*

APG

I R Selimkhanov: Examination of a fragment of a vase from Tello in the Louvre and the problem of the use of antimony in antiquity. *Lab Recherche des Mus de France Annales 1975.*

N N Terekhova: Forging technology among the Koban tribes of the Northern Caucasus in the Early Scythian period. *Sov Ark 1983, (3), 110-128.*

Metallographic examination of iron objects (illustrated) from different sites of the late 7th - 6th cent BC. A detailed study of technology of tools, weapons and ornaments revealed that different types of steel, as well as welding and heat treatment were known.

Author (abridged)

R F Tylecote: Comparison between Western and Eastern Metallurgical Techniques as deduced from traditional Japanese and Chinese illustrations. *Bulletin of the Metals Museum, Sendai Japan, 1981,* **6**, *1-14.*

The main emphasis of the article is on the non-ferrous metallurgy (mainly copper smelting). As to iron, similarities and dissimilarites in casting and refining techniques are discussed. Japan's position was a different one in relation both to China and Europe, as the result of political barriers between 1639-1853.

CPSA

R F Tylecote: Iron sands from the Black Sea. *Anatolian Studies, 1981,* **31**, *137-139.*

AFRICA

P Darling: Fieldwork surveys in and around Kano State, Nigeria. *Nyame Akuma, 1983.*

L M Pole: Decline or survival? Iron production in West Africa from the seventeenth to the twentieth centuries. *Journ of African Hist. 1982,* **23**, *503-513.*

A detailed study of iron working including discussion on iron of the iron smelting and smithing processes, its marketing and the quality of the iron. Tools made from local iron were usually said to be harder and longer-lasting than those made from imported or scrap iron. Locally produced iron survived over 400 years even though imported iron was cheaper.

J E G Sutton: West African metals and the ancient Mediterranean. *Oxford J Arch 1983,* **2** *(2), 181-188.*

F Willett: Who taught the smiths of Igbo Ukwu? *New Scientist, 14 April 1983,* **98** *(1353), 65-68.*

Casting and smithing in Nigeria reached a high standard from the 10th century AD onwards. It is a mystery where the West Africans found their materials and learned their skills.

Author

AMERICA

R B Gordon: Materials for manufacturing. The response of the Connecticut Iron Industry to technological change and limited resources. *Technology and Culture, Oct 1983,* **24** *(4), 602-634.*

Primary iron production began in the so-called 'Salisbury' district in the 17th century. From 1734, iron making began to concentrate around larger deposits of ore that were conveniently located near sources of waterpower. Charcoal was readily available. Salisbury bar iron became the preferred material for the arms makers of the Connecticut valley, but failure to produce consistent high quality bar iron, and the failure of attempts to produce steel, for reasons which are discussed, led to increasing emphasis on pig iron production. In 1885, Salisbury pig iron sold for a premium of 60% above the price of charcoal-made pig from other districts on the basis of superior quality. Advances in physical metallurgy leading to a better understanding of cast iron gradually eroded the basis of the claims for high quality, and the last furnace was blown out in 1932.

The article is illustrated by numerous microsections and chemical analyses of samples in the Yale Metals collection which was gathered for students at the Sheffield Scientific school.

APG

D A Scott and N J Seeley: The excavation of a pre-Hispanic gold chisel from Columbia. *J American Science, 1983,* **10,** *153-163.*

I Shimada, S Epstein and A K Craig: The metallurgical process in ancient North Peru. *Archaeology (US) 1983,* **36** *(5), 38-45.*

Describes the furnace found near Batan Grande. Assumes oxide ore from the Cerro Blanco mine was used, and that to account for the As content As-rich sulphide had to be brought from further away by trade. The 'batans' are large quern stones that have been used for grinding ore with the aid of hammer stones 20 x 10 cms. They found plano-convex ingots about 8-10 cm dia of Cu-As metal (2-2.8% As) as well as prills. The slag was very viscous and heterogeneous. The material belonged to the period 850-1532 AD.

RFT

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