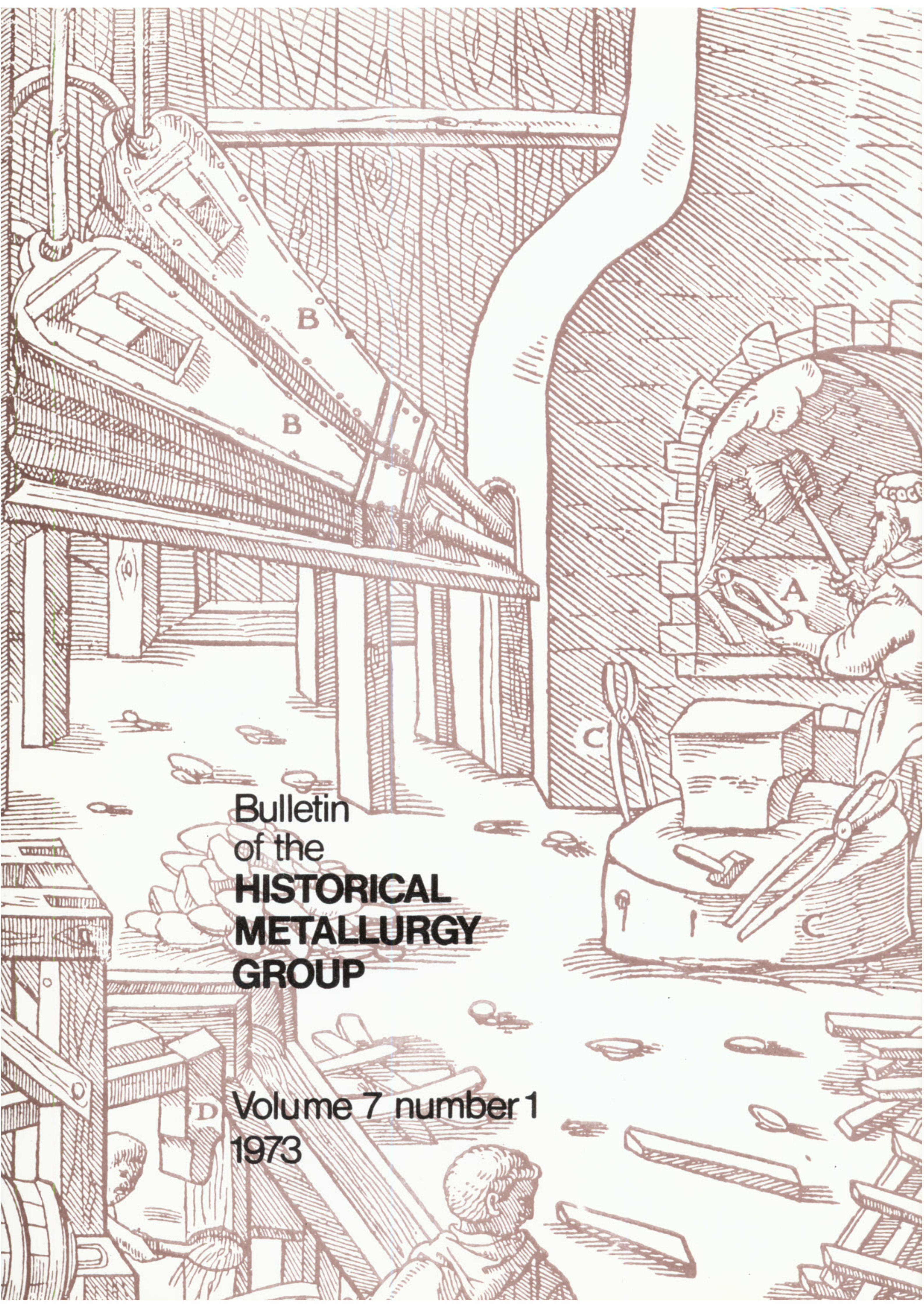

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Casting copper and bronze into stone moulds

by R F Tylecote

Two sets of stone moulds were made from York freestone – a fine grained but rather soft sandstone. The matrices were based on two Middle Bronze Age rapiers, a short one 38.5 cm long (A) and a longer one 45 cm long (B), both from the River Thames.

The stone-carving was done by a sculptor who worked with modern steel chisels and found no difficulty. There is no doubt that this operation could have been done equally well with bronze chisels. The dimensions of both the matrices were based on the rapiers themselves and this left no surplus metal for cleaning-up and working apart from the extra thickness that resulted from warping or bad-fit of the two half moulds. Set (A) had diagonal vents like the Knighton mould *(Fig 1)*; the other had none.

Figure 1 – One of the Knighton moulds after Evans[1]

CASTING

First a small melt of cathode copper was made in a plumbago-clay crucible with a charcoal cover in a gas-air injection furnace. This was poured into an open stone mould for a small flat axe which had been heated to 200°C and dressed with lamp-black. As expected the casting gassed violently and was useless. But it did prove that lamp-black was a suitable dressing for a stone mould as no sticking was experienced.

The mould was redressed by brushing-on more lamp-black *(soot)*. The "gassed" axe was returned to the crucible and remelted without the charcoal and with the addition of a small amount of copper oxide. This was cast as before with much better results. Some blow holes were present and more oxide would have been desirable. Obviously, it is better to ensure over-oxidation rather than the presence of hydrogen. This conclusion is in agreement with the structure of most copper artifacts. This result would correspond to the "sunk set" *(under-poled)* stage in copper refining and would result in an oxygen content exceeding 0.1%.

An 8% tin bronze was melted under charcoal in the same furnace; the charcoal was removed and more tin was added to make the tin content up to 13.6% – the mean value for the Middle Bronze Age. The two-part stone rapier mould (A) was dressed with soot and placed in an oven heated to 200°C. The two halves were clamped together, supported vertically, and a runner-bush of surface-dried "green" moulding sand was placed on top so as to allow the metal to be poured into the small 3 mm diameter ingate connecting with the tip of the rapier.

The fit of the two halves of the mould was not perfect and daylight could be seen between them. Preventing this would have meant very high clamping pressures which was felt undesirable. Obviously a certain amount of warping had occurred during heating to 200°C. The edges of the parting line could have been sealed with clay but it was felt best to try casting without sealing. As it happened, very little metal entered the gap between the two half-moulds and a perfect fit was not needed. Nor may it have been all that desirable, as the gap allowed air to leave the mould cavity.

The casting (A1) appeared to be a good one apart from three cavities which could have meant its rejection under modern conditions. After cleaning-up, however, it was seen that there were a lot of small cold-shuts along the cutting edges and it would seem that it would be better to form the sharp edge by forging rather than direct casting. This may explain the signs of working seen on rapier blades. *(Fig 2A)*.

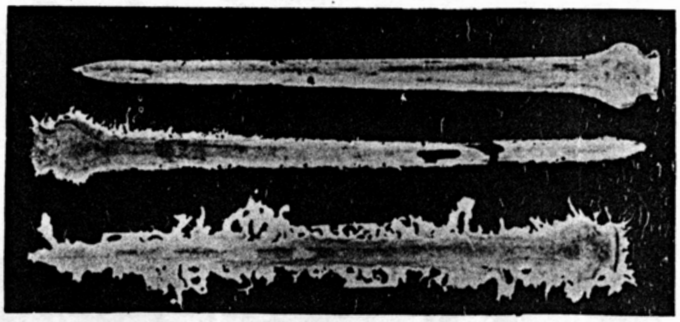

Figure 2 – Experimental castings

A *(top)* Rapier A1 after trimming

B *(centre)* Rapier A2 showing holes near the top *(pouring)* end

C *(bottom)* Rapier A5 as cast with shims, showing "flash" at edges which is later trimmed off

Two further attempts were made which were both relatively unsuccessful. *(Fig 2B)*. The reasons perhaps were; (1) the two halves of the mould fitted **too** well – shims were to be inserted to prevent this in the next cast. Not only does a bad fit let the air out quickly but it effectively thickens the thinner sections of the mould and therefore facilitates running; (2) the pre-heat temperature was only about 100°C which is possibly too little. The runner-bush causes too great a heat loss if made of green-sand, particularly if the pouring stream comes into contact with it.

HARDNESS AND MICROSTRUCTURE AFTER CASTING

No. A1 – *Fine, cored structure with alpha-delta eutectoid. No slag – no cavities. Hardness 134 HV5. A good casting. (Fig 5).*

No. A3 – *Much the same as above, perhaps slightly larger grain size but many cavities now as there was no feeding from the runner when the metal stopped running. Hardness 132 HV5. (Fig 6).*

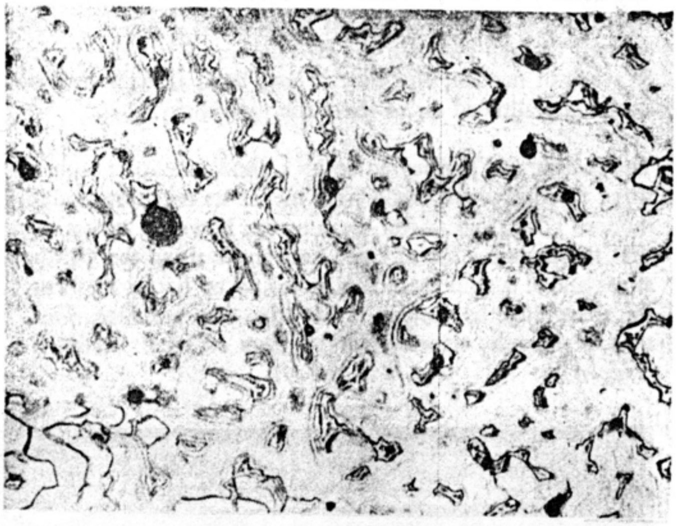

Figure 5 – Microstructure of A1 as cast X500
Fine, cored structure showing pools of alpha-delta eutectoid

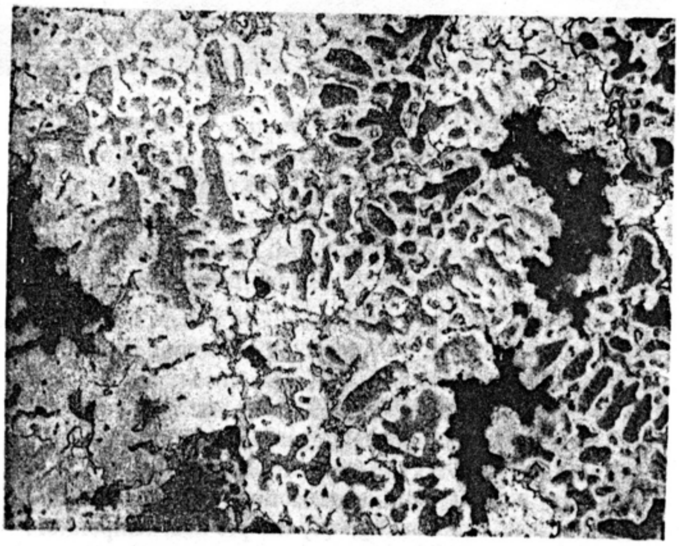

Figure 6 – Microstructure of A3 as cast X250
Showing shrinkage cavities

The second one of the two unsuccessful casts (No.A3) was short due to mis-running but, after fettling to give a **blunt** 1.5 mm thick edge, was used as a basis for forging experiments. In fact it was 25 cm long after fettling – a length well within the range of length of Irish dirks and rapiers. *(Fig 3).*

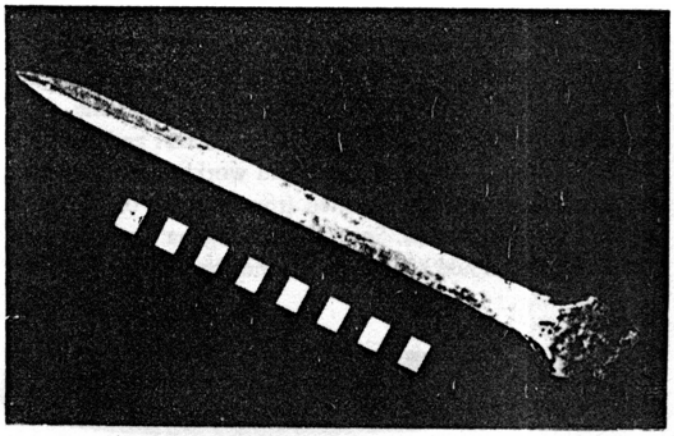

Figure 3 – Blade A3 after trimming and hammer hardening

After casting, the thickness of the two rapiers, A1 and A3, were checked with a micrometer along the spine as it appeared but they were not quite reproducing the contour of the mould. In fact the results made it clear that they were the same, apart from the fact that No. A3 (in which the two half moulds were clamped in the centre only) was slightly thicker than No. A1 where the clamping was at the two ends and not so tight. The maximum thicknesses were about the same as one of the Irish examples shown by Allen, Britton and Coghlan[2] (0.35 cm).

Two more castings were made in mould, A, preheated to 200°C. The first (No.A4) was made with the two halves clamped near the top. This was mis-run near the clamped region giving a rapier in two pieces, the bottom of which was usable after fettling. The second (No. A5) had steel shims 0.65 mm thick inserted between the two halves of the mould and the two halves were clamped midway between the two sets of shims. This arrangement proved very effective giving an extensive but uneven fin or "flash" all the way round and, of course, resulting in a blade thickened by 0.65 mm. The metal tended to run through the gap in two places and this may have been the reason for slight porosity near the clamped region. *(Fig 2C).*

It seems that air or gas tends to collect near the top of the mould where the section is thinner and that venting of the top is more important than the bottom. In a vertically cast mould the air can collect in the space above but must leave rapidly as the mould is filled.

A second series with the mould sloping at an angle of 60° was made with mould B. The mould was preheated and supported in a gas-fired furnace and the preheat temperature was very high – about 300°C. A runner bush of pottery clay was moulded over the top of the two parts of the mould in order to permit satisfactory pouring through the top of the sloping mould. Shims were used as before and of course this mould had no vents cut into it. The mould had been allowed to dry for several weeks after assembly but, when pouring, the dried pottery clay spalled dangerously and it was obvious that this type of runner-bush was unsatisfactory.

A new type of runner-bush was made from a mixture of sand with about 20% of clay having a much higher permeability than the clay one. This was pre-moulded, dried and fitted to the top of the preheated stone mould with the aid of a metal sleeve *(Fig 4)*. At first this was positioned in a sand bed at an angle of 60° without shims. The metal ran only about 2/3rds of the way down and failed to fill the butt. But it was clear that the running arrangements were now very satisfactory especially when care was taken to seal the join between the metal sleeve and the stone with a clay lute. By this time the top of the mould was suffering from spalling and had to be trimmed and shortened so that the maximum length of the casting was only 43 cm instead of the original 45 cm for this mould.

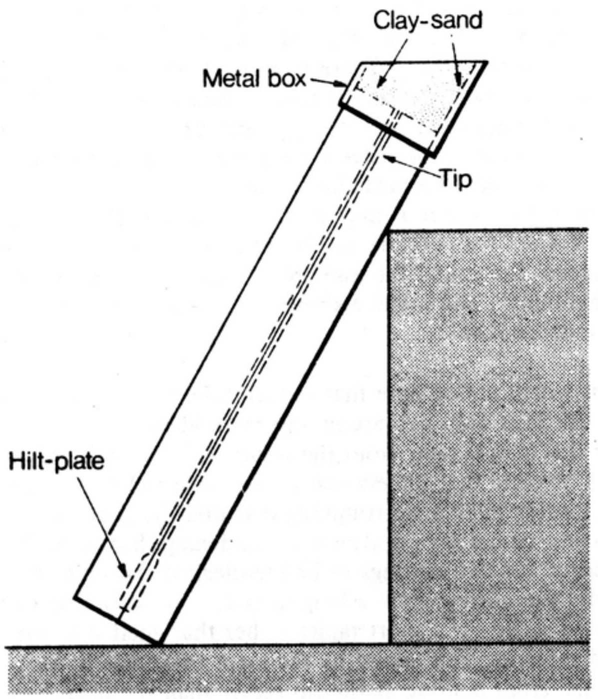

Figure 4

The next cast was made with 0.65 mm shims and the mould preheated to less than 150°C; but the metal was well superheated and a very successful casting was made.

HAMMER HARDENING OF THE EDGES

After casting and trimming blade A3, it was homogenised by heating it in a charcoal hearth to make forging easier. This removed the coring of the cast structure and should have converted it to a more or less equiaxed structure with more of the tin in solid solution. Hammer hardening was carried out with light blows from a ball-pean hammer. But in order to prevent the blade running away from the hammer the opposite edge had to be supported with a stop in the manner shown in Fig 8. After working, annealing and reworking a section was removed from the edge near the tip of the blade *(Fig 7)*. It was found to have a hardness of 224 HV2.5 and consisted of equiaxed and twinned grains with a high density of deformation markings. There was now no residual porosity and the yield point had been much increased by the cold working as shown by the blade's increased resistance to plastic deformation by bending.

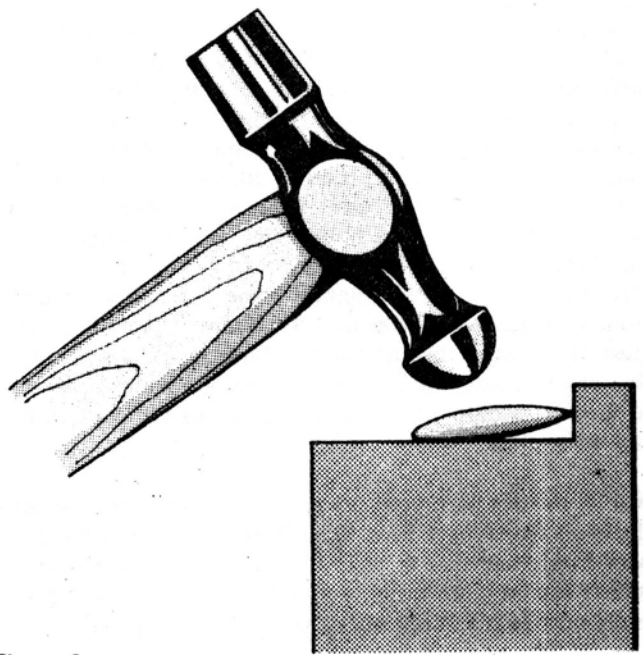

Figure 8

CONCLUSIONS

The problems were not those expected. There are no real metallurgical problems in casting this sort of tin-bronze; it has a low melting point and if the charcoal is removed from the surface at the right moment no gas should be present. Apart from spalling difficulties which were probably due to the use of only a moderately refractory stone, casting in stone moulds is a positive delight compared with sand casting once the problem of avoiding the static bubble that forms in the top of the casting is solved by the use of a sloping mould.

The main trouble is to get the maximum degree of venting with the minimum loss of metal. No doubt experience helped the early smiths and shims were added until the optimum situation had been obtained. Shims could have been made from clay, mica or slate.

By themselves the grooves cut into one of the two halves of mould A were insufficient and superfluous as the same effect could be got by the use of shims. It looks as though the vents cut into the Knighton mould were merely an experiment on the part of the smith unless the stone from which the Knighton mould is made is a great deal more permeable than that used in these experiments.

One must remember that the matrices used were based upon the actual artifacts themselves and that the moulds themselves might have been deeper, and the surplus metal resulting removed by fettling and hammering. The critical position seems to be 2/3rds of the way up the blade when the metal is poured from the tip, and one cannot help feeling that if the mould had been made to give a slight thickening in this region there would have been less difficulty in running. The surplus metal could have been forged away giving a slight lengthening of the blade. The thicknesses of the recorded rapiers shown in Table 2 suggest that our blades are on the thinner side of the range; it is noteworthy that our thicknesses are on the blades as cast while those of the rapiers in museum collections are blades that have been forged and polished. It would seem therefore that 0.38 cm is the thinnest blade that can be made from a straight tin bronze in a stone mould. This does not mean that such a thickness is the thinnest piece of metal that can be made, but is that that can be used as a runner to feed other parts of a casting such as the hilt-plate in the case of a rapier.

Not all moulds have been designed to be run from the tip of the blade; some have been filled from the hilt end but it would not seem that there is any advantage in this. The runner can be more easily removed from the tip, and either end works satisfactorily once the conditions are right.

One of the most striking conclusions from the metallurgical point of view was the high degree of homogenisation obtainable in what was a 13.6% tin bronze. This is the theoretical limit of solubility of tin in copper and the intention of the homogenisation treatment was to approach this figure, with little liklihood of actually attaining it. In fact no alpha-delta eutectoid is visible in the structure shown in Fig 7 and all the tin seems to have gone into solid solution. This fact clearly assisted the improved workability of the material

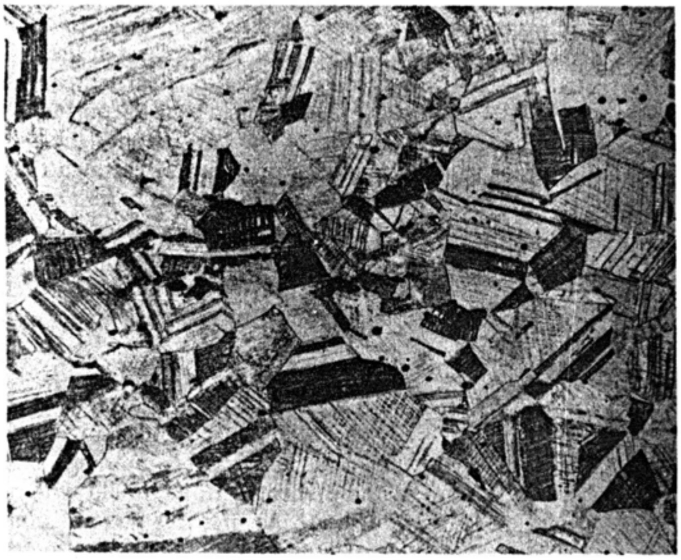

Figure 7 – Microstructure of blade A3 after homogenisation and hammer hardening X250

and enabled us to get the high hardness of 224 HV from the cold worked edges. This is much higher than the highest *(164)* yet recorded *(Table 2)*. This aim has probably been assisted by some loss of tin in melting and it is probable that the actual tin present is no more than 12%.

Metal cast in stone moulds is completely unoxidized on the surface, unlike that in sand or open moulds, and needs no cleaning apart from fettling *(cleaning off the surplus metal "flash" at the edges)*. There is no tendency for the metal to stick to the stone and it would seem that this is one of the least important problems of early casting. Dressing of the moulds was not necessary for every casting. Probably five or so could be made before resooting was necessary. Mould temperature is important, as it affects fluidity but the correct temperature can be ensured by building a small charcoal fire round the assembled mould. The degree of "shimming", and metal and mould temperatures, are all interdependent.

It is worth noting here that out of 1100 rapiers from the British Isles only two are in any sense identical. The reason for this is now clear from the results of this work. While it is possible that rapiers cast in the same mould may be reasonably alike after trimming it is unlikely that such a likeness would persist after cold hardening. But it would be unusual for two castings to be identical; if the smith had a badly run casting from a long mould, it is likely that he would settle for a short rapier rather than melt it down and recast it. This would be the main advantage to be gained from pouring at the tip rather than the butt. Next time he might be luckier and get a full length casting.

TABLE 1

Experimental Results

Series	No.	Preheat °C	Results
I Vertical mould	A1	200	Good cast but cold shuts; length, 38 cm
	A2	100	Mis-run; holes near centre. length, 38 cm
	A3	100	Mis-run; reduced to 25cm and forged to harden edges
	A4	200	Mis-run
	A5	200	Shims added; good casting 38 cm long
II Inclined mould	B1	300	Clay runner; spalled
	B2	200	Clay-sand runner; mis-run
	B3	150	Shims added; good casting 42 cm long

TABLE 2

Comparison with early rapiers

Provenance	Length	Maximum Thickness cm	Maximum Hardness HV	Tin %
Thames, Battersea PR 1488	52.6	0.65	104	10.98
Ireland, PR 1884, 119, 268		0.58	150	13.93
Ireland, PR 1884, 119, 269		0.65	124	8.80
Ireland, PR 1884, 119, 270	25.3	0.35	144	6.2
Ireland, Wexford, PR 1884, 119, 271		0.52	75	6.63
Farnley, DN 239	–	–	124	12-15
Corbridge, N'land DN 238	34	–	164	10
A3 This report	25	0.46	224	13
A1 This report	38	0.43	–	13
B3 This report	42	0.38	–	–

ACKNOWLEDGEMENTS

I have to thank the Adult Education Department of the University of Newcastle upon Tyne for their enthusiastic support of this experiment and particularly **C B Burgess**, Staff Tutor in Archaeology. The moulds were carved by **Marie Wraith** and the cold forging was done by **Richard Langmack.**

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2 I M Allen, D Britton and H H Coghlan. **Metallurgical Reports on British and Irish Bronze Age Implements and Weapons in the Pitt Rivers Museum.** Occas. paper 10, Pitt Rivers Museum, Oxford, 1970.

3 C B Burgess *(with an Appendix by R F Tylecote).* **Bronze Age Metal Work in Northern England,** c1000–700 BC. Newcastle, 1968.

FIGURES

1 One of the Knighton moulds *(after Evans[1]).*

2. Experimental castings –

A Rapier A1 after trimming.

B Rapier A2 showing holes about 2/3rds of the way up near the top *(pouring)* end.

C Rapier A5, as cast with shims showing "flash" at edges which is later trimmed off.

3 Blade A3 after trimming and hammer hardening.

4 Arrangement for casting with a sloping mould.

5 Microstructure of A1 as cast (X500). Fine, cored structure showing pools of alpha-delta eutectoid.

6 Microstructure of A3 as cast (X250). Cored structure showing shrinkage cavities.

7 Microstructure of blade A3 after homogenisation and hammer hardening. Equiaxed grains showing twinning and heavy deformation markings. (X250).

8 Arrangement used for hammer hardening.

A note on slag from the first American blast furnace

by M M Hallett

The first iron blast furnace in America was erected in the middle 1640s on the River Saugus some ten miles north of Boston, Mass. The works have been fully restored as a museum piece, including the blast furnace and forges, and the whole history of the enterprise has been described by E N Hartley.(1)

The period is one of interest in the history of iron making as it was at about that time that the benefits of the use of limestone in blast furnace operation began to be recognised. Tylecote(2) quotes Boate(3) as reporting the use of limestone in blast furnaces in Ireland in 1652. Yarranton's blast furnace, erected in 1652 in Worcestershire, produced a slag containing 20% of lime(4) but it may well be that this was due to the use of a limey ore rather than to the deliberate introduction of limestone. Hartley(1) quotes a voyage by John Smith(5) in 1614 along the cost of Massachusetts, in which he thought that he saw abundant ironstone and deduced that the cliffs were limestone because of their similarity to the coast of Devonshire. Without discussing the accuracy of these observations, they might be held as indicating an awareness that limestone was desirable as a flux.

Nevertheless, the only flux that seems to have been used at the Saugus works was a gabbro from the peninsular of Nahant. This is well documented and many pieces were found on the site.

Gabbro is a series of complex plutonic rocks in which the composition generally ranges between 45–50% SiO_2, 16–30% Al_2O_3, 2.5–12% MgO, 9–16% CaO, with a metallic iron content running up to 10%. The iron ore used at the furnace was bog iron ore and such a flux is not one that would have been employed if there had been any knowledge of the effectiveness of limestone. The general metallurgical knowledge available at Saugus would have been the same as that in Europe, because the Saugus operation was under the control of well known English ironmasters.

The opportunity was taken of a visit to the Saugus site to collect some samples of the blast furnace slag. One could not say positively that the samples came from the blast furnace, because the site had been disturbed in reconstruction but the slag pile concerned was by far the largest in the vicinity and was in a position natural to the furnace. The slag was fairly heavy with a considerable amount of gas holes and was generally dark grey to brown with some green tinges.

Two pieces were analysed, one lighter than the other, and the results are shown below:–

Sample	CaO%	MgO%	FeO%	Al_2O_3%	SiO_2%	Fe%
Light	10.86	14.6	4.0	12.10	47.32	0.5
Dark	10.98	6.7	6.93	16.59	44.82	0.5

The slag is a complex alumino-silicate of a generally acid character. Comparison with the range of analyses quoted above for gabbro shows that the slag is of the composition that would be expected if gabbro had been used. The missing elements were not determined but the appearance suggested that manganese was present in substantial proportions and this element is well known to be a normal constituent of bog iron ore.

It appears that the gabbro acted in very much the same way as did the old ferrous silicate bloomery slags of medieval and Roman origin used in early blast furnace practice, as these passed almost unaltered through the furnace merely dissolving the gangue of the ore. These findings suggest that recognition of the use of limestone occurred not earlier than the second half of the 17th century.

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A report on the manufacture of steel in Yorkshire and a comparison with the principal groups of steelworks in Europe (Part 1)

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

Monsieur le Play was Professor of Metallurgy at the School of Mines in Paris. During 1836 and again for some lengthy period in 1842 he visited Great Britain and particularly the South Yorkshire region, studying the steel industry and he published his findings in a report which was included in the "Annales des Mines" in 1843 (4me. Serie, Tome III, pp. 583-714). This gives a very clear picture of the operations in the Sheffield steelworks and as such first became of interest to the present translator. It is however, much more than that as it deals with the situation in the steelmaking countries of Europe, at a time when Britain had developed an enviable position as leader in the technological field, and Professor le Play had a shrewd eye for the economic aspects of steel production.

The report falls into three sections of almost equal length and it is proposed that the translation of one section shall appear in each of three successive issues of this Journal. The first section consists of the Introduction and the chapter on the Manufacture of Cementation Steel in Yorkshire (covering pages 583-626 of the original report). The second section will comprise the second chapter which covers the working down of the blister steel, the production of shear steel and the manufacture of cast crucible steel (pages 627-671 of the report) whilst the third covers the state of steel manufacture on the Continent and particularly in France in 1842 (pages 672-714 of the report).

A note should be added here on the units of weight, length and cost used in the report. These are given in the normal metric system but obviously in most cases are translations of the figures given in this country. It has seemed reasonable, therefore, to give these all in British units as applicable at the time (thus all prices are quoted £ s d). Footnotes which are included in the French text will be identified by the original notation, namely (1), etc; footnotes which are the translator's comments will be marked by asterisks. With reference to Plates, there are two of these in the original text; one, the original Plate XII, covers cementation steel manufacture and will be reproduced complete in connection with Part I whilst the other, originally Plate XIII, covers crucible steel manufacture and will accompany Part II. The original plate numbering will be kept throughout. The figures in parentheses alongside the text represent the original pagination in the report.

The translator has considered that it is more suitable to present the text as near as possible to the style of the original rather than to attempt to convert it to a polished form of English; in this he is at variance with the Editor's opinion and he accepts responsibility for the overall presentation.

***Natural steel – was produced from high manganese pig iron by controlled reduction of the carbon by oxidation in charcoal fired hearths.**

INTRODUCTION *(583)*

Two groups of European Steelworks

The steelworks of Europe are divided into two principal groups of about the same order of importance on a production basis but which are distinguished by essential differences in technical and economic conditions.

Conditions for the Existence of Steel Forges for the Production of "Natural Steel"

The works producing "Natural Steel"* employ processes which are parallel with those generally followed on the Continent for the manufacture of bar iron. The iron ores treated in such works must have certain special characteristics which are not to be found in ores other than the spathic iron carbonates; it follows, therefore, that the works producing natural steel are to be found near to such deposits. These ores, as well as the intermediate products used in the production of the crude steel, must be worked exclusively with vegetable fuel, so that works of this type are necessarily restricted to territory which year by year furnishes the timber. *(584)*

In a continual endeavour to overcome these limitations and to extract the maximum possible amount of ore with the required characteristics, the workmen have been led, on the one hand, to concentrate the blast furnaces and the necessary combustibles near the ore mines and, on the other hand, to transport some distance, towards the forests and the water power, and preferably in the direction of the consumer market, the pig iron for conversion into steel. Besides this, the mountainous terrain which hides the principal beds of spathic ore in Europe does not permit the gathering together of a numerous manufacturing population in any one place. This circumstance has equally contributed to the dispersion of the steelworks around the orefields which provide the raw material.

Four Principal Groups of Steel Forges for Natural Steel

Under these conditions, there are four groups of steel forges which deliver to commerce about two thirds of the raw steel produced on the Continent between them and which are enumerated below in their order of importance:

1. The Central Alps Group, of which numerous works are scattered throughout Styria and Carinthia, around *(585)* the inexhaustible orefields of Eisenertz and Huttenberg.

2. The Rhine Group, established along the Sieg, the Moselle, and the Sarre, etc., near to the orefield which is characteristically called Stahlberg, and of which several

works spread as far as Lorraine and Alsace, in the same sedimentary basin, seeking the streams, the forests and, above all, the markets.

3. The Isere group, of which the works fed by the orefields of Allevard and St Georges d'Heurtieres are spread along the numerous tributary streams of this valley.

4. The Thuringian Group, of which the principal orefield is known, like that in the Rhine Group, under the name of Stahlberg and of which the works are all situated in the mountainous region, rich in forests and water power, known as Thuringerwald.

Conditions for the Existence of Cementation Steelworks

The steelworks of the second group produce "Cementation Steel"* employing bar iron as the raw material.

The iron ore deposits which are capable of giving bar iron suitable for converting into cementation steel are much more numerous than the mines for natural steel; one could, if pressed, consider the deposits as unlimited in number. Nevertheless, when one looks at the origin of the iron which feeds the principal groups of cementation steelworks it is recognisable that the provision of such iron is restricted to a very small number of deposits in the Scandinavian mountains, the Ural Mountains and the Pyrenees and to certain works that smelt these ores there exclusively with wood charcoal.

Cementation, since it does not involve any loss in weight of its raw material, unlike the manufacture of natural steel, does not need to be carried out near to the ore deposits. The principal groups of cementation steelworks, on the contrary, for reasons which can be stated in a few words, tend to develop in totally different conditions. *(586)*

Bar iron suitable for steel manufacture sells at a price above that for other sorts of iron; the works producing this type of iron thus have a natural tendency to carry their annual production as far as the limits of the forest resources will allow. With respect to both the provision of fuel and the availability of water power, these operations are found in almost the same conditions as those for producing natural steel and the necessary extra fuel for the conversion of their own iron into steel is not available in these countries.

In truth, cementation itself only involves a very small consumption of fuel, but this operation, so important from a technical point of view, has not, with respect to the supplies and expenditure which it calls for, other than a very secondary place in the field of the steel industry. The most essential parts of this industry are those which have the object of converting the raw cemented bars into marketable products and one will see, in the following part of this report, that these operations give rise to considerable consumption of fuel.

Two further very important circumstances tend to isolate the cementation furnaces from the countries which produce the steel iron.** *(587)*

It will be shown in this report that mineral fuels exhibit, at equal calorific power, a decided superiority over vegetable fuels in the working of cementation steel; the major forges in Sweden and in the Urals, which have indefinite supplies of wood fuel, find their conditions less favourable than those in the coalfields of Western Europe for the conversion of their iron into steel.

The merchant bars, produced by the steelworks, are to some extent worked down for immediate consumption by a multitude of small workshops which, at the same time, also work down bar iron; the distribution of such establishments, over the face of Europe, is determined for them by the population. In all cases, however, the greater part of the production of the steelworks serves as raw material for extremely varied industries which cannot develop advantageously other than in locations where the fuel, the motive power and the manufacturing population are collected together: such are the industries which exist to produce scythes and sickles, files and rasps, saws, edge tools of all kinds, cutlery, ironmongery and the like. These works, which constitute the dominant industry in certain districts, require, in general, the same economic conditions as the other major manufacturing industries, such as silk, wool, cotton, and so on. They differ from these latter, however, in that they cannot achieve all the desirable perfection unless the working of the steel is done in intimate relationship with the metallurgist who produced it. Often, in effect, each class of products using steel as raw material requires subtle differences in the quality of the steel; in certain cases, as, for instance, in the manufacture of files, the rigorous observation of these subtleties is so important that it is always an advantage to have the manufacture of the steel and its working down carried out in the same works. It is for this second reason that the cementation steelworks, instead of being established near the orefields and the works which produce the bar iron, have developed by preference in the manufacturing districts where they find their principal markets. *(588)*

* **Cementation steel – is another term for "blister steel" formed by the surface carburisation of bar iron (wrought iron) by heating in closed vessels in contact with charcoal.**

** **"Steel iron" is such bar iron as is suitable for conversion into steel.**

A REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE (PART 1)

To sum up, the countries where the cementation steelworks tend to develop are those which can import the steel iron from Sweden and from Russia, using economic routes of communication, which are abundantly provided with mineral fuel, where the agricultural resources permit the development of a large manufacturing population and, above all, provides a vast market into which they can pour their products.

Conditions for the Prosperity of the Steelworks in Yorkshire

The parts of Yorkshire (Sheffield, Attercliffe, Marsborou g*) in which is concentrated the principal steelworks of Great Britain provides in large degree all these conditions for prosperity. It is joined by good navigable waterways (totalling approximately 110 miles) and by a railway to the port of Hull, situated in the largest open bay on the east coast of England, facing the Baltic Sea and best *(589)* placed, therefore, to receive iron from Sweden and Russia. The terrain is formed from one vast coalfield, one of the richest in England, from which the coal, obtained at a low price from mines of shallow depth, is eminently suited to the many facets of the maufacture and working of steel. To the east of the manufacturing district are the plains and fertile fields of York and Lincoln, crossed by numerous waterways which permit the transport at low cost of the necessary food for the working population. Finally, the internal nagivation routes and the port of Hull ensure to the steelworks of Yorkshire economic communications with all the workshops and all the ports of the United Kingdom and open to them a market, both domestic and foreign, more important than that available to any other region in Europe.

Several other parts of Great Britain also offer advantageous conditions for steel manufacture; thus, at the beginning of the eighteenth century and more recently, several steelworks established themselves on other coalfields situated close to the sea, notably near Newcastle on Tyne, Liverpool, and Bristol. But these attempts have not been able to sustain an important production centre, since none of these localities has combined to the same degree as Yorkshire the favourable conditions which have previously been indicated.

On the contrary, the steelworks of Yorkshire have expanded in such fashion that to-day they produce eight tenths of the total quantity of steel made in England. They greatly *(590)* exceed, in this respect, each of the other groups of steelworks in Europe. At the same time, with the materials at their disposal, they could produce, if required, more steel than all the continental works together. Furnished with unlimited resources of fuel, assured of finding in Sweden and in Russia a large provision of steel iron, they will quickly take a further great stride forwards should the growth of the market respond to the potential of their production facilities.

Division of the Report into Three Sections

Such is the general situation of the steelworks of which I propose to describe the fundamental operations. I shall devote two sections to the principal object of my researches: in the first I shall describe the industry which has for its object the conversion of bar iron into raw cemented steel; in the second I shall signify the diverse methods in which this steel is converted into marketable products and I shall deal particularly with the production of cast steel, an industry which has recently seen a very great extension in England and which is, however, the least known of all the works methods in metallurgy.

I shall summarise, in a third section, the actual state and the possible future of the manufacture of steel in the many countries of Europe. After having dealt specially with those considerations which apply to the French steelworks, I shall indicate those measures which appear to me to be appropriate for the acceleration of their development.

PART I – MANUFACTURE OF CEMENTATION STEEL IN YORKSHIRE *(591)*

This operation, one of the most simple in metallurgy, essentially consists of the carburisation of bar iron under the prolonged influence of a high temperature in the presence of charcoal. The materials are always shielded by refractory and impermeable walls from the adition of the gases from the hearth where the necessary heat for the reaction is produced.

Following the order which appears to me to be the best for the description of all metallurgical industry, I will deal successively with description of all metallurgical industry, I will deal successively with

1 the plant and equipment for the process;
2 the raw materials and fuel
3 the personnel
4 the method of working
5 the production, consumption and cost of manufacture per ton of raw steel

1 THE PLANT AND EQUIPMENT

The cementation furnace is the principal part of the plant. Over a century and a half it has had numerous changes in its shape its dimensions. The old furnaces, in which less than 5 tons of iron were treated during one operation, have

*Masbrough, a suburb of Rotherham, then a village with a long tradition of cementation steelmaking, possibly going back to about 1660.

been progressively enlarged and, at the present time, are being constructed to hold up to 40 tons. It appears to me that these have passed the most convenient limit for economy, and, above all, ease of working; many furnaces are charged with only 10 to 12 tons. Those which are preferred, even in the works where business is not lacing, only hold 15 to 20 tons. *(592)*

All the furnaces consist of two equal sized rectangular chests separated by a flue and surrounded on almost their entire surfaces by the combustion gases. These gases, after having slowly circulated round the chests, leave the combustion chamber by openings situated at the base of the arch, on the periphery of the chamber.

Cementation Furnace commonly employed in Yorkshire

PLATE XII makes known the arrangement most common in Yorkshire and represents a furnace in which is cemented at one time some 17½ tons of iron. I shall deal specially with the details relative to the construction of this equipment, which fulfils all the conditions for giving good cementation and which is notable for a very low fuel consumption.

The chests are constructed either of refractory bricks or from carefully cut quartz sandstone. The materials for both these kinds of container are plentifully found in the coal measures which form the terrain of this part of Yorkshire. The vertical walls in stone are ordinarily six inches thick; those in brick are made of two courses horizontal wall forming the base of the chests is ordinarily one and a half times the thickness of the vertical walls; in the brick chests it is formed of three courses of brick laid flat. The bond between the joints is always made with a thin layer of refractory clay.

Formulae giving the Dimensions of the Cementation Chests *(593)*

In making a comparison between furnaces of markedly different sizes, I have been led to state that these dimensions can be deduced by a very simple relationship to the quantity of iron worked in each campaign. Firstly, I have established by experimental work that, unless the success of the operation is to be compromised, each chest can only be allowed to contain 36% of its internal volume of iron.*

The longer dimension of the internal opening in the chests, which I shall call the **length**, is always horizontal and its cube varies in the same proportion as the weight in the charge or the volume of the chest. This length is ordinarily 9'-2" in a furnace of 10 tons capacity and rises to 11' -0" in the furnace of 17½ tons capacity represented in Plate XII. This diverges a little therefore from the numerical law which I am going to give, because there is some convenience in giving a standard length for cementation bars.

The **thickness** (I give this term to the least dimension of the interior) is sometimes vertical and sometimes horizontal; it is the dimension which varies least and ordinarily remains between 27" and 36". In those furnaces where the charge does not exceed 24 tons, this dimension again varies roughly as the cube root of the charge; beyond this limit it grows at a little lower rate.

To sum up, the comparison of a large number of cementation furnaces has led me to the following empirical formulae, with whose aid one can determine very approximately the chest dimensions for furnaces in which the charge may vary from 10 tons to 24 tons. *(594)*
P here represents the total charge in tons and v, 1 and e represent respectively the interior volume, the length and the thickness of the chest:

$$v = 1.1 \times 10^4 P \text{ cub ins} = 6.4P \text{ cu ft}$$
$$1 = 51.5 \sqrt[3]{P} \text{ in}$$
$$e = 12.5 \sqrt[3]{P} \text{ in}$$

For the furnace shown in Plate XII the measured dimensions are

v = 107.5 cu ft   1 = 11'-2"   e = 2'-10"

For a furnace where the charge is only 10 tons, inspection has given the following values:

v = 62.3 cu ft   1 = 9'-2"   e = 2'-4"

General Arrangement of the Chests

The six rectangular faces of each chest are exposed, as has already been stated, to the action of the flame except at the points of support which are essential for five of them and above all on the bottom face, to give the chests a suitably stable condition. This last face rests on masonry supports, of square section, leaving between them gaps of square section, all perpendicular to the length of the chests.

In the furnace shown in Plate XII, in which the chests are made of sandstone, the supports and the intervening gaps are 9" per side. The vertical walls of the chests are supported by sixteen bulkheads *(Fig 1)* carried up to the full height of the chests between these and the surrounding *(595)*

*The old Sheffield tradition gives the figure of one third the volume; Boussingault in 1875 gives data which gives two values of 35–36%.

outer wall and having a thickness of 4½". Seven other partitions *(Figs 1, 2 and 3)* are placed between the chests above the firebox; and sometimes the central one, thicker than the others, goes right down to the level of the grate and divides the fire into two portions.

On the furnaces which are constructed in brickwork, the solid blocks and the flue holes situated between the chests are usually of 4½" side or the middle dimension of the brick; the points of support are formed from dovetailed bricks laid edgewise in the masonry of the circumference; they are placed in quincunx (one at each corner and one in the middle) and separated on the same horizontal line by two lengths of brick or 1'-6".

Arrangements and Dimensions of the Firebox

The two chests are placed at the same level and in a symmetrical manner with reference to the central flue which separates them. This is always the same length as the two chests. The size of the flue, c, or the distance between the two chests varies with the weight P of the charge roughly according to the law given by the formula

$$c = 6.9\ \sqrt[3]{P}\ \text{in}$$

This formula does not give exact results except for furnaces with charges between 13 and 24 tons. The coefficient decreases for larger furnaces and increases for smaller *(596)* furnaces, particularly where there exists a central dividing wall between the two chests, separating the flue into two parts. The furnace represented in Plate XII shows agreement between the observed and calculated dimensions at a flue width of 1'-6". The wrought iron bars, five in number, are about 1¼" square in section; they are supported by five cross beams in cast iron above an ash-pit having the same width as the flue and some 2'-5" high.

The upper face of the firebars is 15" below the lower part of the flues built below the chests. Along the axis of the flue there are openings in the opposite ends of the furnace, 18" wide and 12" high, the threshold being 12" above the firebars. These are used for charging the coal and are closed during the working of the furnace by cast iron doors.

Form and Dimensions of the Combustion Zone and its Openings

The enclosure around the chests and the firebox, in which the fuel develops its heating effect, is composed of four vertical walls, surmounted by two depressed vaults joined together in cloister arch formation. The form and dimensions of this enclosure are intimately tied to the dimensions of the chests and the hearth. The vertical walls are six inches from the outer walls of the chests; the springing of the vaults is exactly at the level of the top face of the chests; their common height usually varies from 2'-10" to 3'-4"; in the furnace shown in Plate XII it is 3'-0".

This height is necessary for workmen to enter the *(597)* furnace easily when they are charging the chests or taking out the steel.

The open interior of the furnace is thus rectangular and has the following dimensions:

Side parallel to the flue	13'-2"
Side at right angles to the flue	11'-6"

There are always six openings at the springing of the vaults, set three and three *(Figs 1 to 4)* in the two sides of the furnace. The two largest, set on the same axis of the furnace and above the charging doors, serve for the entrance of the workmen; four smaller openings, set symmetrically over the small ends of the chests, are for the introduction of the iron bars and the removal of the bars of steel. All these doors are hermetically sealed during working by blocking up with bricks and clay.

Two yet smaller openings *(Fig 5)* of at least 4½" square section are made on both sides of the furnace, around the middle of the vertical dimensions of the chests. These are the ends of small channels, by means of which the workmen may withdraw test bars, placed for that purpose during the charging of the chests, during the course of the cementation and on a number of successive occasions. These bars permit judgement of the progress of the cementation and the recognition of the moment when the operation is finished.

The flame, after having circulated around the chests, leaves the combustion zone through eight openings *(Figs 1, 2 and 3)*, arranged two by two on each of the four vertical *(598)* walls. These openings, which distribute the flame in a uniform manner, are made at the level of the top face of the chests and at the springing of the vault; they are square, with a 6" side and communicate through flues of the same section to six vertical chimneys each 8" square, rising only a few inches above the level of the vault.

Tower Carrying away the Combustion Gases

A large tower *(Figs 1, 2, 3 and 4)* fixed on solid foundations and constructed in common brick, carries away the gases issuing from the smaller chimneys. This has almost a conical form and a circular horizontal section; its principal dimensions, which vary from one works to another, are as follows for the works specifically represented in Plate XII:

External diameter at ground level	26'-6"
Thickness of wall at ground level	1'-9"
Internal diameter of top cylindrical orifice	1'-8½"
Thickness of wall of top cylindrical orifice	4½"
Height of conical portion above ash-pit	36'-3"
Height of cylindrical part	4'-0"
Total height of tower	40'-3"

The diameter of the tower at ground level is always determined by the condition that the furnace and its chimneys have to be contained by it. The whole space between the furnace and the tower, up to the springing of the vault is filled with communal masonry (Figs 1, 2 and 3). Two opposite openings (Figs 1, 2 and 4) are made in the tower, along the axis of the flue and giving access *(599)*
to the furnace. They are 6 feet wide and, starting at the level of the ash-pit rise 5 feet above ground level; in all they are 11'-3" high.

General Arrangement of a Cementation Steelworks

Cementation furnaces are sometimes isolated and sometimes in groups, to the number of two to five in a single works.* Usually the cementation steelworks comprises two furnaces and one of the best arrangements I have seen, in this case, is shown in the line engraving reproduced here

The two furnaces are contained in the same rectangular building *(Figs 6, 7 and 8),* 107 feet long and 34'-6" wide. In front of the charging doors and along the major axis of the shop are pits of the same width as the openings in the towers, which project 4 feet into the shop beyond the bulk of the latter. There are 4 foot wide passages set between the walls of the shop, the towers themselves and the outer pits; the two pits in the centre of the shop are 30 feet apart.

It is advisable to raise the wall plates for the roof to a suitable height above ground level, about 15'-6", so that the workmen can handle the bars of steel iron easily and place them on end for the length of the wall. A door 9 feet wide permits vehicles to enter into the middle of the shop and to minimise as much as possible the cost of transhipping the iron and steel; it is on these grounds that one reserves a considerable space between the furnaces. This space is also necessary to store the steel and the iron, to weigh it, to cut the bars into *(600)*
convenient lengths, to heap and cart away the coal ash from each station; in short, that is, to carry out conveniently all the operations which will be described in the following paragraphs.

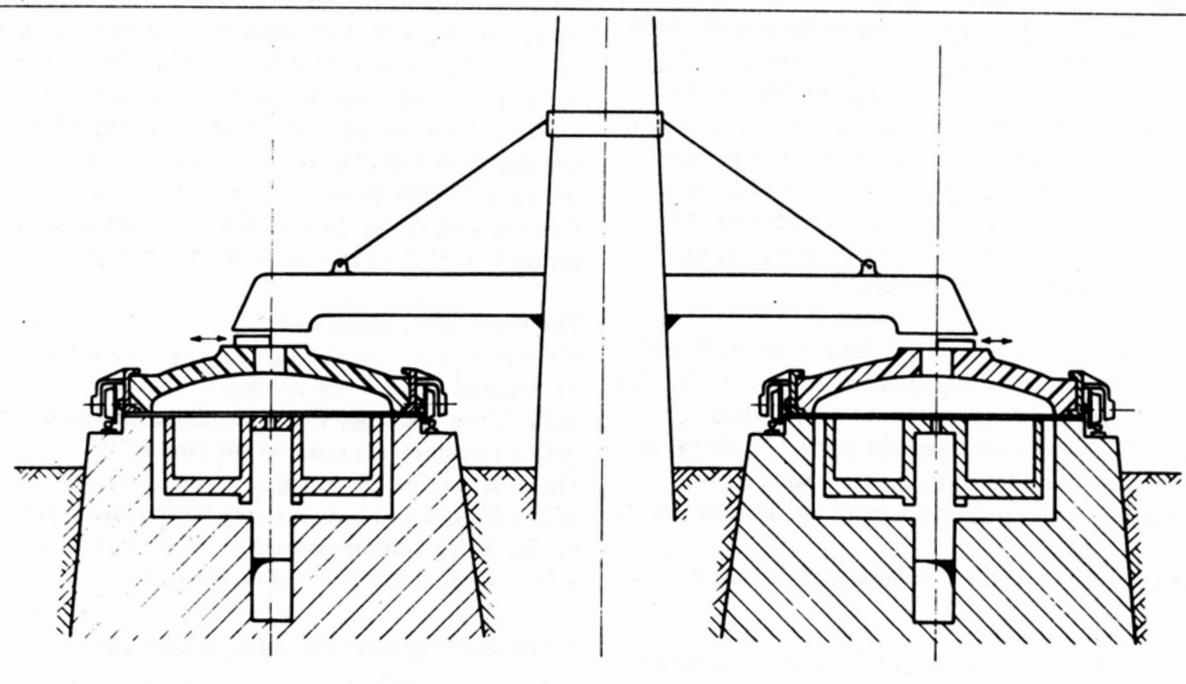


PLATE A. REALISATION OF CHIMNEY-TYPE CEMENTATION FURNACE AS DESCRIBED IN THE TEXT

*The Holmes works, erected in the year Le Play was last in Sheffield, had a group of six furnaces.

A REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE (PART 1)

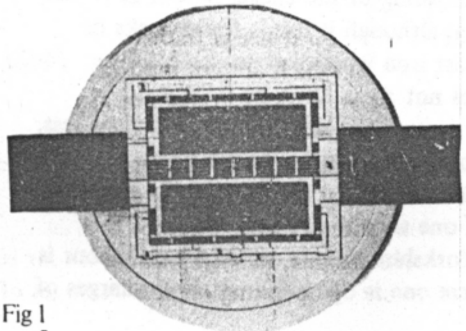


Fig 1

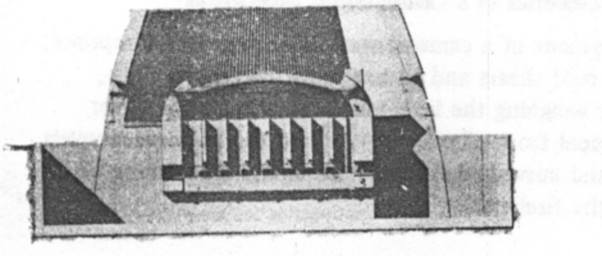


Fig 2

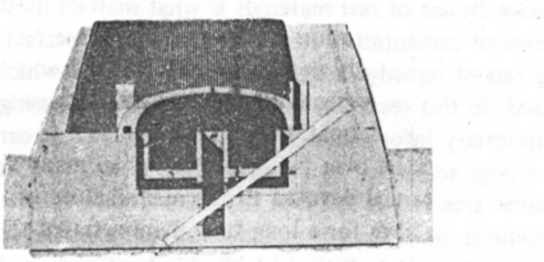


Fig 3

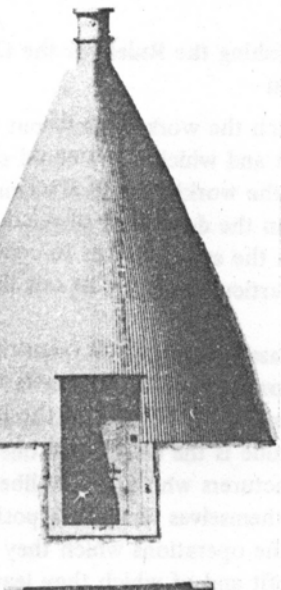
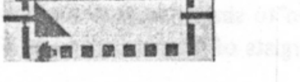


Fig 4



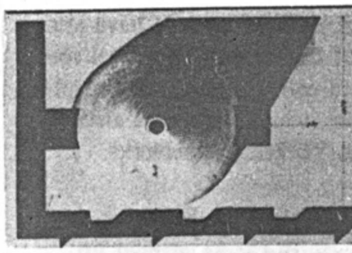


Fig 6

Fig 7

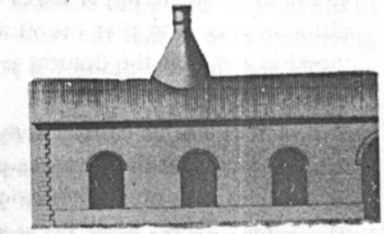


Fig 8

GENERAL ARRANGEMENT OF CEMENTATION STEELWORKS

(derived from Plate XII being page 592 of Annales des Mines le Series Tome III) *(712)*

This shows all the details of a cementation steelworks of two furnaces in each of which one could work at any one time 17½ tons of iron and the total annual production of which could rise to 700 tons of steel.

Fig 1 **Horizontal section of cementation furnace at the level of the upper surface of the chests**

Fig 2 **Vertical section of the furnace on a plane passing through the axis of the firegrate**

Fig 3 **Vertical section along a plane perpendicular to the fire grate and at the longest horizontal dimension of the chests**

Fig 4 **Vertical projection of the tower surrounding the furnace and of one of the two openings made in this tower for giving access to the furnace. Vertical section of the pit made around this opening down to the level of the ash pit.**

Fig 5 **Vertical section of one of the cementation chests, following its longest horizontal dimension. One sees here the arrangement of the blocks on which the chest rests and the flues arranged between these blocks for the circulation of the flame. One can also see equally well the passages which allow the withdrawal of the trial bars during the progress of the operation.**

Fig 6 **Horizontal projection of a cementation shop with two furnaces**

Fig 7 **Transverse section through the same shop following a vertical plane perpendicular to the longest dimension of the building and taken at the same distance from the two furnaces.**

Fig 8 **Vertical projection of the front of the same shop.**

The Less Common Chimney Furnace

I have seen, as an exception in Yorkshire, and I have also found in the neighbourhood of Liverpool and Bristol some cementation furnaces built on a totally different principle from those previously described, which, as I have already said, belong particularly to the Yorkshire steelworks.

The chests, the firebox, the flue holes and the outer surroundings are arranged in exactly the same manner up to the limit of the upper edges of the chests. The differences arise in that the vault covering the chamber is movable and that the draught is produced by a chimney.**

The vault is still in cloister arch form but is much more depressed than in the furnaces previously described; its height does vary more than from 15½" to 21½". The bricks making up the vault are arranged on a cast iron frame, itself supported on four small wheels, riding when required on parallel bars of iron. One can remove the vault easily when it is necessary to empty the chests; it is replaced in position in the furnace before lighting up the fire, luting the space between the fixed and moving parts with clay.

The chimney always has a foundation independent from that of the furnaces; these, two in number, are usually arranged symmetrically on either side of the chimney. The *(601)* combustion gases always exit from an orifice in the centre and in the top part of the movable vault and pass to the chimney by a fixed horizontal flue, suspended above the furnace by iron stays attached to the rafters of the shop. One could imagine that, with this type of arrangement, the combustion gases would tend to pass straight from the hearth to the horizontal take-off flue without heating the circumference of the chests; one obviates this tendency and prolongs the heating action of the flame by closing completely, by means of a horizontal partition fixed at the level of the upper edges of the chests, the gap between them above the firebox. The flame thus has to circulate in the space, 6" wide, between the chests and the periphery; in addition, the exit of the flame is retarded by reducing the width of the flue hole at the level of the upper edges of the chests to about 1½". The chimney always produces an excess of draught within the furnace, except on lighting up; the combustion is not, as in Yorkshire, regulated by working on the fire bars, but by opening an orifice in the horizontal take-off, which gives access to a greater quantity of air, thus enabling the restriction still further of the combustion rate.

This method of construction appears to me to be advantageous in several respects. It lends itself more easily to the charging and unloading of the chests as well as to the control of the firing; although it needs frameworks of wrought iron and cast iron which are not used in the *(602)* other system it does not seem likely to involve any considerable initial costs. Fuel consumption is a little less, provided the workmen are attentive to the regulation of the fire and the provision of fuel to the firebars. In effect, it appears to me that one should give preference to this furnace, over the Yorkshire one, in works where labour is low priced and where one is operating on small charges of iron.

Other Accessories in a Cementation Steelworks

The equipment of a cementation steelworks also comprises an anvil, cold shears and hammers for cutting the bars, scales for weighing the iron and steel, wheelbarrows for bringing coal from piles in the yard to the furnaces, shovels, straight and curved firerakes for charging, cleaning or riddling the firebars.

2 RAW MATERIALS AND FUEL

A judicious choice of raw materials is what matters most in the success of cementation steelworks. The most perfect working cannot remedy defects present in the iron which is to be used. In this respect, the manufacturers, possessing all the necessary information from innumerable trials carried out on a large scale over two centuries by so many workers in the same area and devoted to the manufacture of the same products, have for a long time demonstrated the various qualities which distinguish the kinds of iron used in Yorkshire.

Difficulty in Establishing the Rules for the Choice of Cementation Iron

The knowledge which the workers daily put to profit in the practice of their art and which alone could serve as a complete basis for the working of steel cannot at this time be considered within the domain of science. Among *(603)* the obstacles which the savant has to conquer in this field of study I would particularly point out the following:

The artists of all classes and in all countries are, in general, little disposed to communicate to others the results of their experience; among the bulk of the industrialists of Yorkshire this attitude is the established one. Moreover, such of the manufacturers who do show liberal intentions in this respect are themselves rarely in a position to give enlightenment on the operations which they only direct for commercial profit and of which they leave the technical direction to simple workmen. These latter are truly the metallurgists of Yorkshire and it is only among

****A realisation of this type of furnace can be found in Figure A. Earlier chimney furnaces were reported in Sheffield by Gabriel Jars (1767) and Gustav Broling (1797).**

them that one can gather the elements of steelmaking. But there, as elsewhere, there is barely a common language between the workman and the savant; it is, for example, extremely difficult to determine in many cases what qualities a workman means when he says that an iron has "body", is "sound", "strong", "tough", etc; all of these, however, are expressions which have a very precise meaning and which distinguish properties which are perfectly clear to the workman handling the iron. What increases the difficulty in this sort of study is that the expressions do not always have the same significance to two different workers attached to two different branches of the steel trade. Finally, to arrive at a result worthy of confidence, it is necessary to know how to guard against the inexact observations of the workmen, to guard against the exaggeration with which they regard the importance of certain properties, essential perhaps for the speciality they produce, but entirely secondary *(604)* for the steel industry as a whole.

On the other hand, the questions raised concerning the choice of iron used in the cementation steelworks are extremely complex and it would not be possible to deal with all the details involved within the simple framework of a simple report; I shall confine myself, therefore, to show briefly the facts which long research and a number of favourable circumstances have already allowed me to record.

Classification and Current Prices of Iron used in Yorkshire

The starting point for all studies relative to the qualities of steel iron should be a comparison of the commercial values of these irons. It is far from the whole truth, as can be seen from an overall consideration, that the market price should be an absolute means of classification for every important property, but it forms, if one can express it that way, the most precise common yardstick which one can use to appreciate among the different irons the useful properties. I have put together in the following table the results which I have gathered together on this subject in Yorkshire in 1836 and 1842 and which I owe to the goodwill of people well placed to know the commerce relating to iron in Hull and in Sheffield as well as the situation with regard to the Swedish, Norwegian and Russian forges which provide these markets.

The manufacturers of Yorkshire in addition work irons produced in England by very varied methods but which, with one exception only, all permit of the simultaneous use of coal and wood charcoal. These irons, of which *(605)* the quality has improved in recent years, compete with the lowest grades of Swedish iron, but they are only used for a few purposes.

Current Prices of Swedish, Norwegian, Russian and English Irons used in the Yorkshire Steelworks

SWEDISH AND NORWEGIAN FORGES

Lofsta and Carlholm (Upsala Lan)	£35. 0.0 per ton
Gimo and Ranas (Upsala Lan)	£31. 0.0
Osterby (Upsala Lan)	£30. 0.0
Forssmark (Stockholm Lan)	£28. 0.0
Stromsberg and Ullforss (Upsala Lan)	£28. 0.0
Gysinge (Gefleborgs Lan)	£27. 0.0
Wattholma (Upsala Lan)	£26. 0.0
Hargs (Stockholm Lan)	£26. 0.0
Shebo and Ortala (Fahlu Lan)	£25. 0.0
Oster Rusoer (Nadenaes)	£24.10.0
Elfkarleo (Upsala Lan)	£21. 0.0
Sorforss (West Norrlands Lan)	£21. 0.0
Hedaker (Westeras Lan)	£18.10.0
Backaforss (Elfsborg Lan)	£18.10.0
Soderforss (Upsala Lan)	£18. 0.0
Norberg (Gefleborgs Lan)	£17.10.0
Hedwigforss (Gefleborgs Lan)	£17.10.0
Dadran (Fahlu Lan)	£16.10.0
Rishyttan (Fahlu Lan)	£16. 0.0
Catherineberg (Gefleborgs Lan)	£15.10.0
Thurbo and Wikmanshyttan (Fahlu Lan)	£15.10.0
Awesta (Fahlu Lan)	£15. 0.0
Ludwika (Fahlu Lan)	£15. 0.0
Swana (Westeras Lan)	£15. 0.0
Amoth (Gefleborgs Lan)	£15. 0.0
Strombacka and Swabenswerk (Gefleborgs Lan)	£15. 0.0
Tjarnes Nedre and Robertsholm (Gefleborgs Lan)	£15. 0.0
Hamarby (Gefleborgs Lan)	£15. 0.0
Storforss (Carlstadt Lan)	£15. 0.0
Quarntorp (Carlstadt Lan)	£15. 0.0 *(606)*
Friedricsberg (Carlstadt Lan)	£14.10.0
Fagersta (Westeras Lan)	£14.10.0
Sikforss (Orebro Lan)	£14.10.0
Melderstein (Norrbottens Lan)	£14.10.0
Snoa, Anderforss, Ericsforss (Fahlu Lan)	£14.10.0
Spjutback (Carlstadt Lan)	£13. 0.0
Larsansjo (Westeras Lan)	£13. 0.0

RUSSIAN FORGES

Nijni-Taguilsk (Perm)	£19. 0.0
Katav-Ivanovsk (Orenbourg)	£17.10.0
Jourzen-Ivanovsk (Orenbourg)	£14.10.0
Neviansk (Perm)	£14.10.0

ENGLISH FORGES

Bagbarrow, Sparkbridge, Nibthwaite (Lancashire)	£17. 0.0
Lowmoor (Yorkshire)	£16. 0.0
Tividale (Staffordshire)	£15.10.0
Bowling (Yorkshire)	£15. 0.0

Physical Properties of Steel Iron

All the irons from the North which are sought by the manufacturers of cementation steel are distinguished by their grainy structure, compact and with a brilliant blue-grey colour somewhat resembling that of zinc. One sees most often in the transverse section of a bar all the features of a very pronounced lamellar structure and very rarely that of a fibrous structure. In this latter case, when nicked cold, instead of breaking with an almost flat *(607)*
fracture, it tears away in fibres composed of a number of superimposed plates. The surface of these plates is a slightly silvery matt white colour; their edges, when distorted after breaking cold, present a silky gleam similar to that given, under the same conditions by the fracture of refined copper. It is extremely difficult to break the bars cold, even when heavily nicked with a steel chisel.

Qualities Sought in Iron for the Manufacture of Steel

The essential property of these irons is that they give, by suitable working, a product having in the highest degree the useful properties of steel, that is to say they are capable of taking on a high hardness on heat treatment and a vivid brilliance on polishing, welding easily, showing high resilience and being capable of reheating many times without resuming the ordinary qualities of wrought iron. This essential property appears to me to be closely tied to the nature of the ores from which the iron is made, for on going back to the origin of the irons classified as the highest grades in this respect, I have established that they all come from a very limited number of beds of iron ore. The quality of the fabricated articles, that is to say the property they have of being more or less hard, sharp, polished, resilient, and so on, measures in this way the grade of the raw materials and, in part, their commercial value. One can imagine that this should be so since, on the one hand, the cost of the fabrication of the steel object remains constant, regardless of the nature of the iron and, on the other hand, the selling price of the object increases with the perfection of the raw material from which it is made. This property, which I propose to call "Steely *(608)*
predisposition"* distinguishes the irons previously mentioned from the bulk of the merchant irons of Europe and finds itself developed to its highest degree in the premier grades from Sweden, Norway and Russia.

A second and most important property is the regularity of distribution of all the elements within the body of the iron. The defects given by the lack of this quality show themselves during the successive working operations on the steel and in a more or less prompt manner, according to the quality of the iron and the nature of the working. The most general and most decisive symptom is that given by the raw bars after they have undergone cementation. These bars should preserve their former shape, their surfaces perhaps covered with many small lumps which appear to be caused by the action of a gas which is developed in the body of the iron when it has acquired a certain degree of softness in the cementation furnace;** but it is essential that these kinds of blisters shall have very small dimensions (less than 3/8") and shall be distributed uniformly over all the flat surfaces of the bars. Large blisters and, above all, large fissures distributed irregularly over the bars are a sure symptom of lack of uniformity. The workers often characterise this defect in different ways, saying that the iron "lacks body" or is "sick".

This property is not perhaps independent of the nature of the iron ore, for it is developed to different degrees in irons derived from different ores but made by the same *(609)*
methods. It is always much more easy to show that the smallest differences in metallurgical treatment of identical ores are sufficient to establish pronounced differences in this respect in the quality of irons.

The enormous differences in price which exist between the best grades of Swedish, Norwegian and Russian iron appear to depend above all on defects in uniformity and when one follows with care the manipulations carried out on raw cemented steel in various shops one is not slow to understand why the workers pay such importance to this particular property. Experience shows that the walls of the major cracks formed during cementation can only be brought together with extreme difficutly under the influence of the forging operations to which the steel is submitted before putting it into service. Very often, in the same areas as these cracks, there are irregular segregations which are shown up by the presence of grey or black stains which the workers designate as "flaws". These flaws, which cannot be seen on the surface of the forged bar, nor on the rough finished articles (cutting tools, files and so on), are brought to light by the final operations (polishing or machining) so that one does not recognise the advisability of rejecting the object until one has carried out all the labour involved in its manufacture at a total loss. There exist in certain qualities of iron which possess the "steely disposition" to a high degree but which give steel *(610)*

***The actual words are "propension aciereuse" the property described would appear to be that generally referred to as "body".**
****It was not until some 35 years later that Dr Percy proved that the blisters were formed by the action of carbon on the slag stringers just below the surface of the iron, the carbon monoxide pressure being capable of raising the metal surface into the blisters.**

which is flawed in such a manner that the amount rejected is at least one third of the sum total of the product. One imagines that the losses in material and labour involved in these rejections would markedly cheapen the raw material, even though the unrejected products occupy the same rank as those of the most highly prized grades. The English irons which are now employed in Yorkshire ordinarily recommend themselves on account of their uniformity; it is on these grounds that the steelworks seek them for certain applications, although under the heading of "steely disposition" they lie below the more common grades of Swedish and Russian irons.

I repeat that this property plays a most important part in the grading of steel iron. Many facts, carefully collected with regard to the several grades which I have followed on a comparative basis through a multitude of successive operations, have permitted me to affirm that this single cause establishes a difference of 30% in the prices of these grades although in other respects they show themselves entirely identical.

Among the other properties which the workers seek among the steel irons I would single out again uniformity of texture. The workers have often indicated as equally good for the manufacture of steel those bars which show a single structure, be it sub-lamellar, coarse grained or even fine grained with traces of fibrous structure, but it is of advantage if each particular structure persists throughout the whole length of the bar. Experience proves that, in the contrary case, the different parts of the bar take on differing degrees of cementation during conversion into *(611)* steel, from which it follows that, in order to give a certain level of homogeneity to the steel subsequently it is necessary to use a more prolonged forging operation and, as a result, very considerable expense.

I shall have occasion many times in the following part of this report, and particularly in the second part, to return to these properties of irons and to postulate the cause of the enormous differences in price which exist between the various grades.

Shape and Dimensions of Cementation Bars

The bars of steel iron, apart from some exceptional cases, always have a flat form which, for a given cross sectional area, lends itself much better than a square or round form to the progress of cementation. The bars should always have a sufficiently large section so that the quantity of iron contained in the chests may be as great as possibile; one does not depart from this rule except for vary special manufacturers. The section of the bars rarely goes below 1 sq in; often it rises to 3 sq in. The thickness ordinarily varies between 5/16" and 13/16" and the width between 2¼" and 5½".

Cementation Mixture employed in Yorkshire

Many workers have assured me that the complex cementation mixtures indicated in most of the works which deal with steel manufacture and also in English technologies have never been generally employed. In their opinion, the bizarre recipes given on this subject, as well as the alleged fluxes necessary for the melting of steel have often been given with the aim of putting one off the scent *(612)* of the real difficulties of steelmaking. The only reagent which I have seen charged with the iron in the cementation chests is crushed wood charcoal, part in the powdered condition and part in small pieces, the largest of which rarely exceeds a volume of 1/8 cu in.

This charcoal is made from the branches and small debris arising from the woods used for timber within a radius of 20 miles from Sheffield; the dominant species is the oak. In the state in which it arrives at the works, the charcoal is already in quite small pieces and weighs around 20 lb per cu ft; it costs on average £2.3.6 per ton. It has often been tried, without success, to use the calcined charcoal from a previous operation as cementation medium; ordinarily, one may diminish the expense slightly without appreciably altering the carburising properties of the medium by mixing a fourth part of calcined charcoal with the new charcoal.

Coal employed in Heating the Furnaces

Coal is the sole fuel used in Yorkshire, be it for the cementation or for the other branches of steel working.

One seeks, for preference, the very gassy coals which agglomerate in the hearth without fusion or puffing up. A mixture of fines and the small pieces remaining after sorting out the lumps is used. This mixture, after transport rarely exceeding 5 miles, costs from 8/0d to 9/0d per ton, according to the position of the works and the choice of the coal. One can use, if absolutely necessary, fine *(613)* coal of inferior quality which does not cost more than 4/0d per ton delivered to the works, but the conduct of the operation is then unduly complicated without corresponding benefit; the economy obtained will be more than balanced by the much greater length of operation and troubles caused by irregularities in the steel. These kinds of coal, abundant in Yorkshire, are only used for the heating of steam boilers.

Analysis indicates the following composition for a variety of coal considered as being very suitable for heating cementation furnaces:

Material gasified by calcination in a closed vessel	36.9%
Carbon, residual to the calcination	56.7%
Argillaceous ash, slightly ferruginous	6.4%

3 PERSONNEL IN A CEMENTATION STEELWORKS

The working of a cementation furnace requires the cooperation of two workers. Their work consists of preparing the bars, charging and discharging the chests, helping the workmen bringing in the raw materials and carrying away the products and finally charging the grate and controlling the fire throughout the whole of the operation. The working of a single furnace is not sufficient to employ two workmen full time; in the ordinary way, three workmen can keep two furnaces on full output. A works which has two furnaces continually active keeps three workmen who give about 320 effective days work per annum; they employ besides this the casual supplementary labour of a helper who furnishes around 130 days work per annum. *(614)* The average cost of a day's work by these various workers is 2/10½d.

4 METHOD OF WORKING IN A CEMENTATION STEELWORKS

Preparation of the Bars

The workmen begin by cutting the bars for cementation to suitable lengths, always 2" less than the longest dimension of the chests. Without this precaution, the bars, which expand more than the refractory material of the chests, would invariably crack the latter.

Charging and Preparation of the Furnace

The furnace long since cold, having had any repairs made which may be necessary, one of the workmen enters to proceed with the charging of the chests, whilst the other remains outside to bring up the iron and the cementation mixture. One places firstly on the bottom of each chest a layer of charcoal three inches thick; then one lays in the iron in one of two different ways with new layers of charcoal. Sometimes one places the bars flat and in horizontal beds, almost side by side, separated by layers of charcoal ⅜" to ⅝" thick; sometimes one places the bars in horizontal rows placed on edge with only a few sixteenths of an inch* of charcoal between them. These layers are separated by horizontal layers of charcoal about ⅜" thick. Short lengths of bars are carefully placed end to end and broken up where necessary in such a way that the layering of bars and charcoal shall be kept as regular as is conveniently possible and such that the volume occupied by the iron shall be as large as possible. When the level of the four small openings is reached, one places there pieces of bar of a kind which can be easily withdrawn, so as to be able to judge by their appearance the *(615)* progress of the cementation. Finally, the charging of the chests is always completed by a layer of charcoal three inches in thickness which should remain a few inches below the top level of chests.

The chests so filled are hermetically sealed by a method as simple as it is effective: on top of the last layer of charcoal one lays a bed of 4" of a sort of mortar derived from the powdery debris which deposits itself in the troughs of the wheels where one polishes and sharpens the cutting tools and a multitude of cutlery objects.** This material, abundantly provided by the workshops of Yorkshire, is composed essentially of powdered quartz mixed with particles of steel oxidised on their surface; by the action of heat it coagulates and softens without liquifying.

The chests being thus prepared, one cleans the flues which allow circulation of the flame from within to the circumference of the surrounding wall; one closes with bricks and clay the two doors and the four charging openings; one fills the passages leading to the trial bars, first with charcoal and then with clay; one puts the five fire bars on their bearers having replaced if necessary any of these found damaged and then one proceeds to light up.

Heating Up

Heating up should be carried out with much discretion when the furnace is new or when part of the structure has been renewed; but in the ordinary case one pushes the fire more rapidly at this stage than at any other of the operation in order to raise the chests as soon as possible to the red *(616)* heat at which the cementation takes place. For the furnace shown in Plate XII this heating up lasts around 24 hours and in this period one burns in a unit of time an extra quarter as much coal over the normal consumption.

Management of the Fire

The competency of the workman shows above all in the regulating of the fire in such a way as to maintain continually a bright red heat which lends itself best to cementation, without exceeding it and without ever allowing the grate to become empty. This temperature corresponds very closely with the end of the fusion of copper; it is never sufficiently high to vitrify the bricks or

*Literally "a few millimetres"
** Usually termed "wheelswarf"

the clay which holds them together. In the most usual furnaces in Yorkshire there is no damper to vary the draught so that the workman can only control the fire by the care which he gives to the firing of the grate. This is always filled to the level of the sills of the charging doors. The thickness of the ignited fuel is thus 12" in the furnaces whose working I have particularly described and for coal of the analysis which has been reported above; it varies a little according to the furnace dimensions, the state of the draught and, above all, the quality of the coal.

It is important that the thickness of the bed of burning fuel should not diminish too much or the furnace will cool down too quickly; it is proper therefore that successive charges should be made hour by hour. The workman clears the bars twice a shift when the coal is high in ash content and he repeats this operation very often when the temperature of the furnace tends to become *(617)*
lower than desired; finally, he partially clears the grate when the temperature becomes unequal at the two ends of the furnace.

I have said that the depth of the fire bed covering the grate rises to 12" when the fire has just been charged and with the quality of coal given above. A very careful fireman can achieve a certain economy of fuel by reducing this depth to 10" or even 9", but in such case the charges have to be more frequent and the furnace is more prone to cooling following an oversight by the workman. In Yorkshire, where the fuel is of low price and where the work is almost always without managerial supervision of the workers, these refinements are never observed and it is not unusual to observe intervals of two hours between successive charges.

On the other hand, these considerable intervals between charges of fuel have the clear result of lowering the cost of labour and, in this respect coal, which remains alight longer than wood and which, in a given volume, gives a much greater weight of combustible material, is much better than vegetable fuels for the heating of cementation furnaces.

The cementation furnaces in Yorkshire are so well suited to the operations carried out in them that, despite the slight imperfections in the management of the fire, the consumption of fuel does not exceed 15 cwt per ton of raw *(618)*
steel, a remarkable result in an operation where the substance to be heated is separated by a thick envelope of low conductivity from the hearth where the heat is produced. In the cementation of the 17½ tons of which I have followed all the details, where care has been particularly paid to the firing and in which the fire has lasted 8 days, one burned the first day some 31½ cwt of coal and an average of 26¾ cwt on each of the following days; the total consumption was brought up to 11 tons or 5/8 ton per ton of raw steel produced.

One maintains the fire for a number of days proportionate to the transverse section of the bars and to the degree of cementation which one wishes to give them. For a charge of 17½ tons the length of firing varies between 5 and 9 days; it is ordinarily of 7 days, but it is necessary to consider that the cementation proceeds further after one has ceased to charge fuel, during the period of cooling.

Putting Out the Fire

One finishes the operation by cooling the furnace more slowly than one heated it up. To this effect, one allows the clinker to accumulate on the grate in such a manner as to stop it up. These precautions have at the same time the object of using the accumulated heat to best advantage and also the prevention of rapid changes of temperature which would shorten the life of the refractory structure.

The furnace having cooled below a dull red heat, one progressively opens the different orifices to hasten the cooling by means of fresh air. Ordinarily one can *(619)*
proceed with the unloading of the furnace eight days after one ceases to provide fuel for the hearth. The raw steel is taken out through the same six openings which served for its charging. The last part of the operation, including the repair of any parts slightly damaged, can possibly be done in one day. The furnace is now in a condition to receive a new charge.

To sum up, the cementation of 17½ tons of iron requires on average the number of days given below:

Charging, sealing the chests, cleaning the flues, closing doors and openings	1 day
Heating	7 days
Cooling	8 days
Discharging, minor repairs	1 day
TOTAL	**17 days**

It is necessary besides to take account of the fairly considerable time necessary for the receipt and delivery of the iron and the steel, the fuel, the cementation medium, the refractory materials and so on, the weighing of the materials, the preparation of the bars which go to make a charge, the major repairs to the furnace, and so on. Thus a furnace of this capacity, maintained at the maximum activity which the nature of things will admit, does not receive more than 20 charges per year.

Physical Properties of the Raw Steel

The physical properties of the iron are completely changed by cementation. The malleability which is shown by the good grades of steel iron to the highest degree is completely destroyed in the raw steel, to the point where the bars will break if one throws them down from a small height *(620)* on the the edge of an anvil; one can break them in small pieces by simple blows with a hand hammer.

The surfaces of the best forged bars become very uneven; they are covered with blisters and one can also see quite clearly the imprint of fragments of charcoal with which it has been in contact.

One can see even in the best kind of raw cementation steel numerous small fissures in the transverse fracture, ordinarily parallel to the wide faces of the bar. In common steels, these fissures attain considerable length and reach the surface of the bar.

The fracture is always lamellar; the facets are considerably larger than those seen in the iron; their largest dimension often exceeds 3/8"; their surfaces, instead of being flat and brilliant, are grainy or scaly and reflect the light but poorly; the fracture itself is less brilliant than that of lamellar iron.

Finally the colour itself is greatly altered; the bluish tint has disappeared and is replaced by a greyish white colour.

5 PRODUCTS, RAW MATERIAL CONSUMPTION AND COST OF FABRICATION

Annual Production of a Cementation Steelworks

A cementation furnace maintained at maximum activity can convert annually some 20 chargcs of iron into steel. A steelworks of average size consists of three furnaces designed to receive different weights of charges, say 12–15tons, 15–18 tons and 18–22 tons, such that the annual production of the three furnaces can rise *(621)* to 1000 tons.

But in ordinary circumstances and above all in the state of constraint which has been present in the steel business in Yorkshire these last few years, the works are far from attaining the production corresponding to full activity. Thus in 1842, the 97 cementation furnaces in Yorkshire distributed between 33 works have produced in all 16250 tons; thus a works with three furnaces has produced on average only around 500 tons and this has reduced the production of each furnace to 165 tons.

Many large producers of steel articles prepare in their own works the steel which they consume. Assured of an immediate market, they can easily determine for a long period the materials and personnel which are necessary to them, and thus they obtain an average production which is greater than that just indicated.

But most cementation steelworks are run by small manufacturers whose only industry is to convert iron into steel at an agreed price. These manufacturers are placed in less favourable conditions to make best use of their means of manufacture, their profits are less and they are more acutely subject to the effects of the variations which affect the whole of the steel industry.

Observations on the Calculations of Manufacturing Costs

Before indicating the costs involved in the production of raw cemented steel in Yorkshire, I am going to *(622)* insist on the appropriateness of including this type of information in studies of practical metallurgy to set forth the principles which, in my own opinion, should serve as a basis of calculation for the cost of manufacture.

The industrial arts cannot exist except under conditions which assure an agreed profit to the manufacturer; perfection in industry does not consist in consuming minimum raw materials, fuel or labour but in manufacturing at as low a price as possible the products of an agreed quality. The choice of method is a problem which remains undecided as long as one pays respect only to accepted techniques and ordinarily admits only of a solution when one considers these latter in the context of the economic conditions peculiar to each locality. The calculation of the cost of manufacture is the sole means of appreciating in each particular case the fitness of a metallurgical method; it is, therefore, there where it is necessary to seek the confirmation of existing facts and the improvements which one can bring to bear.

It seems at first sight that a calculation of manufacturing cost should give, for each particular case, a large quantity of incidental or arbitrary data little suited to the characterisation of a metallurgical method. It is certain at all events, that if one is content to make these

calculations in the manner set out by the manufacturers themselves one almost always finds that some works placed in almost similar technical conditions have very different cost prices. The special object of this report does not allow me to lay stress on the causes of these anomalies; I will limit myself, therefore, to showing means of rendering these calculations comparable *(623)*
and also to furnish to metallurgy the means of precision which it has lacked heretofore.

A metallurgical enterprise comprises two subdivisions which are ordinarily quite distinct and in Great Britain occasionally are completely separate: the commercial enterprise, which buys the ores or the working materials and sells the fabricated products and of which the profits should cover the costs, the advance of moneys and the unfavourable hazards involved in buying and selling, and the business proper, of which the profits should cover the costs which relate directly to the metallurgical operations. The first rule which the metallurgist should impose upon himself is to separate as far as possible these two kinds of costs. Thus, in the present state of the steel industry in Yorkshire, an industrialist who combines the two offices of merchant and manufacturer ought to deduct in the first place for cost and profit, over and above the price of the iron, about £4.15.0 per ton of raw cemented steel. On the other hand, the manufacturer proper, whose only work consists of converting iron into raw steel, only receives about £1.8.0 per ton in the ordinary way. The costs and profits to be attributed to each of the subdivisions are thus:

For the manufacturer	£1.8.0 per ton
For the merchant	£3.7.4 per ton

and one easily comprehends that the cost of the manufacture thus calculated better characterises the metallurgical method than if one has confused with it, as the manufacturers often do, a larger or smaller part of the costs relative to a purely commercial operation.

As for the manufacturing costs, they divide *(624)*
themselves into two categories; the first, which I shall propose to call **special costs**, covers the consumption of materials and labour, that is to say they remain almost constant, whatever the scope of the manufacture, for each ton of product; these are the most characteristic elements of the method used and one cannot give them in too much detail. The second, called **general costs**, almost constant each year, whatever the manufacture, vary for each ton of product in inverse proportion to the production in any given period; one can only calculate this second category of costs after having determined the size of the annual production. I would add in this respect, as in all others, that the calculated manufacturing cost only represents the real state of things in the region which one wishes to describe if one accepts as true the average data relative to the majority of the works therein.

To apply the principles which I have just laid down, I will take the case which, according to that which I have set do down earlier, is the most usual in Yorkshire. I shall suppose that it deals with a cementation steelworks in which the only business is working the iron which is sent for that purpose for the benefit of others. The establishment to which the details which follow specifically apply contains three furnaces; having good customers at its command, it has ceased work in these last years a little less often than most works and has made annually some 600 tons *(625)*
of raw steel. Three workmen, together paid some £3 per week, have been employed through 50 weeks, Sundays and holidays included. It has been necessary, moreover, in order to carry out several urgent tasks, over a temporary period of about 5 weeks, to take on an assistant paid 15/0d per week, working only six days per week.

The cost of manufacture and the profits for a works placed in such a situation are given in detail in the following table:

COST OF MANUFACTURE OF ONE TON OF CEMENTATION STEEL IN YORKSHIRE

Special Costs	**Consumption in materials and days work**	**Costs of materials and days work** Items	**Total**
Iron for Cementation	2220 lb		
Charcoal at £2.3.6 per ton	123 lb	2. 4½d	
Coal at 8/6d per ton	1680 lb	6. 4½d	14. 5d
Labour at 2/10½d per day	2.03 days	5. 7½d	
General Costs			
Industrial Capital: rent of works or interest on capital at 5%		3. 4d	
Floating capital: interest at 6%		6½d	
Maintenance of plant: bricks, clay, iron for tools, labour of specialist workmen		2. 4½d	
Management and supervision: exercised without cost by the head workman		Nil	13. 7d.
Miscellaneous costs: taxes and licences, carrying of letters, office costs, etc		1. 6d	
Profits		5.10d	
		TOTAL	**£1.8.0**

The average price of the irons employed in Yorkshire *(626)* for steel manufacture is about £18.5.0 per ton (or in round figures, 45 francs per 100 kg). The nett cost of one ton of raw steel produced from iron of this type can thus be established at £19.8.0, that is to say:

Iron	2220 lb at £18.5.0 per ton		£18.0.0
Coal	1680 lb at 8/6d per ton	6. 5d.	£ 1.8.0
Labour	2.03 days at 2/10½d per day	5. 7½d	
Other Costs		15.11½d	
		TOTAL	**£19.8.0**

This conversion cost of £1.8.0 per ton of steel remains constant, except under special circumstances, whatever be the state of the trade. This is in consequence of the separation of interests which exist between the different types of industry which contribute to the manufacture of the ultimate products of the steelworks of Yorkshire. This real diversification of work has a very happy influence on the whole of the steel industry and prevents those disastrous variations in price which manifest themselves in so grievous a manner in the iron works, for example, whose products have, during this last six years, undergone a reduction of some 63% in price. (1)

FOOTNOTE (1) – The same merchant irons which would have sold in 1836 for £12 per ton only sell today for £4.8.0 per ton. I learn that in August 1843 the current price of wrought iron, on board ship from Wales, has fallen to £4 per ton. I learn also that a very considerable delivery of iron has been made recently, for cash, at £3.16.0 per ton.

END OF PART ONE

A visit to Sweden

by R F Tylecote

Sweden is to many people synonymous with metallurgy and to be invited to attend a conference on the migration period without any metallurgical content would indeed be a surprise. It so happens that one of the most important sites of the period, at Helgö, about some 20 km to the west of Stockholm has yielded a substantial number of crucibles and moulds. This site has been excavated for many years by the State Historical Museum under the direction of Professor Holmqvist and it became the focal point of the conference. The conference itself was held at the castle of Hässelby which is a Nordic Adult Education centre in the suburbs of Stockholm. It is not my intention to describe the whole of the conference but to give some account of the more metallurgical aspects.

One of the most important papers was given by Dr Christina Lamm on the subject of the copper-base alloy finds at Helgö and the techniques for making them. The principal artifacts were moulds for brooches and the finding of these has settled the point of origin of the brooches themselves which is highly satisfying to the archaeologist.

The crucible fragments all relate to the "beaked" type of integral-lidded crucibles so common on both sides of the Irish Sea in the sub-Roman and Early Christian periods. This type of crucible is small (about 5–20 cc capacity) and made by forming a crucible bowl and adding a lid in such a way that the sides of the lid were smoothed down over the crucible leaving a small "beak" for filling and pouring. The moulds were mainly two-part clay moulds sealed after removal of the pattern with an outer casing of clay surrounding and uniting the two parts. No signs of a pattern were found on the site and it is possible that the original pattern was made of hardened wax and the moulding done by pressing on to it two pieces of clay meeting at the parting line. The pattern could be either removed and reused or melted out as in investment casting. Later, an actual finished brooch may have been used.

The moulding material consisted of clay, 30–40% quartz and probably some charcoal. The moulds had good porosity which was improved where necessary with air vents which terminated at the junction of the inner piece mould with the outer covering envelope.

Moulds and crucibles had both been made of local clays which could stand temperatures between 1000 and 1600°C. When the brooches themselves were used as patterns they were connected to the runner cup by a down gate of wood.

Before use the moulds were sooted with a candle as a parting medium.

In the course of the conference we were taken out to the site of Helgö itself to see a demonstration of the casting process arranged by Dr Lamm and assisted by J E Tomtlund, Ralph Ohlsson and Pär Hallindar. Two hearths were used and the moulds were pre-heated in one hearth while the crucibles were being heated in the other. Both hearths consisted of a ring of stones and a hollow in the ground filled with charcoal and they were blown with bellows and tuyeres. Additional air could be producted when necessary by additional blowing on top and proved very effective for getting the last few degrees before pouring. What was rather surprising was that it was necessary to heat the moulds to much the same temperature as the metal. The crucibles took about twenty minutes to fill through the small openings. The metal used were small pieces of tin bronze although it is now known that the alloys originally cast were brasses and gun-metals.

Once the metal was melted, the crucibles were manoeuvred in the hearth so they could be quickly extracted and poured into a waiting mould ready in its hearth at a red heat. When removed the crucible cooled on the outside to a black heat but the contents remained molten and were quickly poured into the mould. It could be seen that the inside of the crucible was still red hot after emptying and it was clear that the insulating properties of the clay were exceptionally good; no doubt the heat retention was assisted by the lid. No slag seemed to be formed and therefore there was no tendency to close the small opening during pouring. But the crucibles could hardly be used more than once as they had a tendency to fuse and crack on the outside. The artifacts cast in these moulds needed a good deal of touching up but it is thought that this was also the case with the original artifacts since the detail in them is so very finely cut and it is assumed that such detail could not be obtained by direct casting.

The beaked type of crucible disappeared in the Viking period and was replaced by open flat-bottomed and spherical types. It is noteworthy that some of the fragments found contained traces of gold.

There was no sign of iron smelting on the site – no ore, no smelting slag nor signs of roasting but only smithing furnace bottoms, and it is thought that iron was brought to the site from elsewhere as a considerable number of iron artifacts were found. These comprised the usual knives and weapons and oddly enough, padlocks. All these and many from other sites had been radiographed and the prints transferred to 5 x 5 cm slides so that it was a simple matter to run through 74 radiographs with an automatic projector. These comprised the usual suite of Migration – Viking period iron-work including pattern-welded swords of various types – some with inscriptions and hilts, others with an inlay of silver or copper base alloy. Spearheads were also shown, some were pattern-welded and inlaid. As the padlocks were badly corroded it was only by radiography that their manner of functioning could be elucidated.

A metallographic display was also arranged mainly showing the work done on the ferrous artifacts. By British standards some of the knives were oddly shaped but many were steel-cored with plates of iron welded to either side – a technique typical of the Migration and Early Medieval periods.

Hans Drescher, a well known authority on early moulding techniques, also gave a paper summarising his work on Roman moulding techniques. Many of his examples were taken from the Iron Age to Roman site of Magdalensburg in Austria which has yielded tuyeres, crucibles and furnaces.

Dr Berthold Schmidt described the examination of chieftain's graves in Thuringia which produced ironwork such as spearheads and spurs. A rather large crucible was also found which it was suggested might have been used for cupellation as it was contaminated with Ag and Pb. Jutta Waller reported the finding at Helgö of a number of gold brooches and pieces of moulds. The latter seem to have been part of piece moulds in which ornamental panels for the heads of large pins were assembled rather as in the Chinese manner to form complete moulds.

On the Thursday morning there was an intensive session on ferrous metallurgy with contributions by Pleiner (from Prague) Piaskowski (Krakow), Bielenin (Krakow) and the writer. Pleiner, who has written a book on European black-smithing, discussed the smithing techniques used in the prehistoric and medieval periods and the conclusions to be drawn from metallurgical investigations. He showed an example of an 9th century iron plough-share with a steel insert. No shares nor coulters from Britain have yet been examined for this sort of thing which should be expected considering the intense wear on such implements. The welded joints between iron and steel were good and clearly the material had a low arsenic content. On the other hand Bavarian and Bohemian knives both showed signs of arsenic enrichment on the weld interface.

Dr Piaskowski discussed the variation in the phosphorus content of iron with date showing that it was high during the medieval period. Bielenin and the writer discussed the same type of furnace – the pit-type shaft furnace in which the slag runs into a pit immediately below the furnace shaft and not to the front as in most developed types. This type is well known in Poland and North Germany reaching into Jutland and just making East Anglia. It was suggested that it ought to turn up in Sweden and it was pointed out that examples had, in fact, been recently found in Western Sweden.

Dr Eric Tholander, well known for his work on forging, discussed the difficulty of distinguishing between smelting slags on the one hand and smithing and finery slags on the other. He claims that reduction slags (eg smelting) usually contain small grains of metallic iron while slags arising from oxidizing processes such as smithing and fining do not. Certainly one would not expect a bloom being reheated to shed metal but rather scale, while during smelting grains of reduced metal might fail to join the bloom and be tapped with the slag. But surely finery slags are likely to contain metal?

In the afternoon Dr Lena Thålin and Sven Modin dealt with the techniques of making pattern welded swords and spears and their classification. Both pattern-welded swords and non-pattern-welded swords had welded-on edges of carbon-steel. There are of course many variations on the pattern-welding theme ranging from alternations of high phosphorus iron and low phosphorus steel and simple horizontal piling, to steel cores covered with pattern-welded bars. The spearheads were never as well made as the swords. One of the inscribed *(Ulfberht)* swords consisted of a steel edge welded to a simple piled core. This agrees with the absence of pattern welding in British swords of the Viking period. The piling was made of high and low carbon material more or less well diffused. Lena Thålin gave some analyses for Ni and Co which showed some groups with high Ni and Co, while others were high in Co only. It is hoped that analyses for these elements will help archaeologists to provenance the weapons themselves by correlation with Swedish ore bodies.

Finally Dr Hans Aust gave a description of iron smelting sites at the mouth of the river Weser in North Germany. These seem to be early *(? EIA)* and contain charcoal-making heaps, lumps of iron ore, smithing hearths and furnace bottoms *(slag lumps)* weighing as much as 130 kg and some tuyeres, although no furnaces have yet been found.

After the conference at Hässelby those interested in the technical side of ferrous metallurgy met in the Metallurgy Department at the Royal Technical University, Stockholm, to continue their discussions. These started with those members who had carried out actual smelting experiments comparing their results and attempting to reconcile their differences. Most of these experiments have already been reported in the technical and archaeological press.

Tholander reported the examination of 4 or 5 blooms containing an average of 0.1% C. But these had a high carbon, hyper-eutectoid plus graphite, skin, and Tholander thinks that it is possible for the blooms to have become carburized in the smelting furnace after their formation and later sealed with slag. His main interest however, was the classification of the slags themselves into homogeneous two-phase, three-phase and multi-phase, and smithing slag which is essentailly slag and scale.

Dr Inga Serning spoke about her excavations in Dalarna *(central Sweden)* which she was to show us during the weekend. These sites were dated to between the 7th and 12th centuries and the free standing furnaces were incomplete. The furnaces had been about 50 cm in diameter and the remains were 50 cm deep with slag tapping holes. In south-east Dalarna the furnaces were similar giving evidence of slag tapping into shallow pits, and furnace bottoms. The slag pits were about 20–30 cm in diameter and 2–4 cm deep. The metal mostly had a carbon content of less than 0.5% but one bloom contained 1.4% carbon. The phosphorus content was mostly less than 0.1% but one site gave 0.2% in the iron and 0–0.3% in the slag.

The next day we went to Dalarna staying at Grängesberg, the site of one of the large Swedish iron ore mines. From here we visited the site of the copper mines at Kopparberg near Falun where we saw the enormous open pit and the Dalarna Museum. This mine was the source of Swedish copper, and much of the world's, from 1200–1800 AD. We then visited the early iron smelting sites of Dala Flodo *(Dykmiran)*, Gryssen, Kråkbodarna and Sunnangang.

On the next day we saw the blast furnace at Loã in Orebro county which is being restored by the Grånges Company. Loã has been the site of iron smelting since the 14th century. The present furnace was rebuilt between 1768 and 1850. It now consists of a brick shaft with an incline for loading. Like most northern furnaces the charge floor is totally enclosed with a part of the roof left uncovered to let the gases out. For this reason it does not look much like the English idea of a blast furnace. The power was supplied by a timber built race from the river and all this is now being restored. Until 1872 the magnetite ore was brought in on sleighs to a steam driven crushing plant. Later it was rowed across the lakes of Sorsjon and Norrsjon to Rallsa.

This furnace is going to be unique as it has adjoining it what must be the only blast furnace gas roasting kiln left in the world. This is very much like that described by Percy as being in use in south Sweden at Finspong in the 1860's. It is a shaft kiln with a tall stack. The gas enters the shaft about ¼ way up, the ore going up an incline onto the charging floor above. The hot ore is discharged above ground level to the tops of the bunkers. It would then be crushed and taken up the blast furnace incline with the charcoal.

We returned to Stockholm to the house of Professor Sven Eketorp, Head of the Department of Metallurgy at the RTS, to witness the first day of the university term. The new students were invited to meet the staff and officers of the student organisations and to partake of roast lamb roasted whole on spits in the open air over charcoal in what seems to be a traditional Swedish way. While all this was going on a demonstration of more direct metallurgical interest was taking place, that of an iron smelt in a prehistoric shaft furnace. This was being directed by Hans Hagfeldt who had done this before in the laboratory but not in the open without instrumentation. It turned out to be an international experiment with much assistance from Messrs Bielenin, Pleiner and the writer who, like Hagfeldt, had done similar experiments. The shaft furnace was built into a slight bank and had an effective bed depth of 80 cm and a diameter of about 20 cm. It was blown by a single tuyere with an air flow of 200 l/min from a vacuum cleaner. The ore was magnetite, very much like that used at Loã. It had been previously roasted but was still magnetic and analysis showed that it contained 80% Fe_2O_3 + Fe_3O_4, but the loss on ignition was only 0.2%. It was crushed on site with a hammer and a stone anvil to a size of −3.5mm. The charcoal was pine and less than 12mm. With 200 l/min air flow the burning rate was 3.0 kg/hr with an ore-fuel ratio of 1:1. Charging was more or less continuous maintaining a level at the top of the furnace shaft.

The charging of ore started at 9.50 am and the first slag tap was 1.3 kg at 12.30 hrs. At 14.00 hrs a second slag tap produced 3.0 kg. Charging of ore stopped at 14.30 after 14 kg of ore had been charged. Some more charcoal was added and then the level allowed to fall. Finally a bloom weighing about 2 kg was extracted from the bottom. This looked pretty solid and contained relatively little slag giving a yield of about 20%. It was all a very successful example of international cooperation and a very good way of introducing the students to the subject of extractive metallurgy.

It remains for me to thank **Professor Holmqvist** for inviting me to take part in the conference at Hässelby and **Professor Eketorp** and **Dr Inga Serning** for their hospitality.

Sites of charcoal blast furnaces at Shifnal and Kemberton, Shropshire, 1972

by Norman Mutton

Summary; the charcoal blast furnace at Shifnal is the earliest in the county of Shropshire dating from 1564, and the second oldest in the Midlands. Although its building is well documented, its history is sketchy and its site was unknown until investigation of a number of sites succeeded in the finding of evidence which points clearly to there having been a charcoal blast furnace in the valley of the Wesley Brook in Shifnal. As the Shifnal furnace was worked in conjunction with forges at the Lizard and as these forges were in use until the early nineteenth century their sites have been investigated also. In the early eighteenth century, probably earlier but this is not definitely established, the blast furnace at Kemberton was used in conjunction with the Lizard forges and with slitting mills and forges in the parish of Ryton. All these sites are within a radius of some three miles of Shifnal and as there is no evidence that the site of Kemberton furnace has been studied recently the opportunity has been taken to investigate there. The need to find and report upon Shifnal furnace in particular was urgent in view of the proposals for the M54 Motorway which will cut through Shifnal parish and through a number of sites which, on general technical grounds, were possible sites for the hitherto unlocated Shifnal blast furnace.

Shifnal Furnace

Location: *Grid Ref SJ 742067 (Manor Mill)*

The site lies in the valley of the Westley or Wesley Brook, one of the headstreams of the River Worfe about one mile south of Shifnal village and something like 1,000 feet north of Shifnal Manor. It has for generations been the site of the manor mill and there is no place-name evidence linking it with the furnace, to my knowledge. (There is clear place-name evidence for the sites of the forges, which are well known anyway, and for Kemberton furnace, and for the Grindle forge). The mill ceased to be used as a cornmill in this century and the buildings were demolished c 1960.

Investigation of the site shows large quantities of charcoal blast furnace debris, slag, partly-roasted carbonate ore, and slag-encrusted lining, covering an area of some 30 yards by 50 yards and extending perhaps another 100 yards along the tail race of the old mill. Some of the slag was granular with 1% Fe. A few pieces of modern hot-blast and cold-blast slags used for the metalling of the lane to the Manor are to be found on the site, but are clearly intrusive.

The water supply is from the partly-silted mill pool which covered more than three acres but which was fed merely by a spring arising about a mile away and not by the brook which runs beside the site. This seems to be the explanation for the known shortage of water in the sixteenth century, which is otherwise difficult to explain as the brook carries a very substantial flow. It is not obvious why this manner of supplying water was chosen in lieu of the more normal practice of damming the whole width of the valley, which is not above 100 yards wide at the mill site, and narrower immediately above it. Another singular feature is that the furnace is so close to the Manor House, even accepting that the Earls of Shrewsbury were rarely resident *(Fig 1)*.

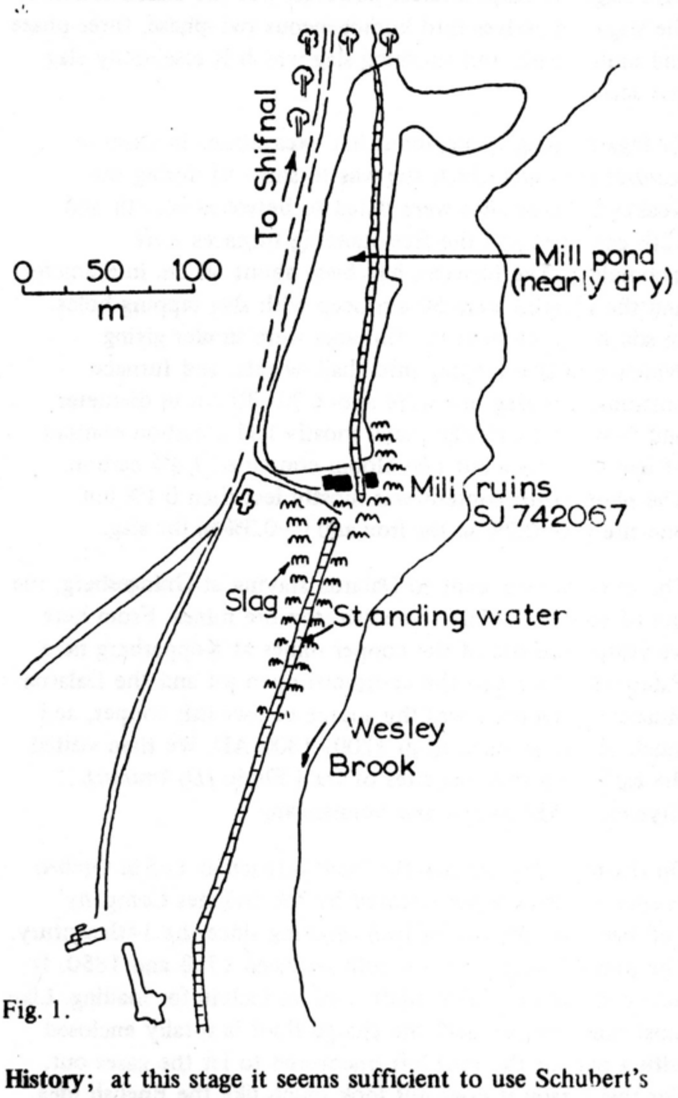


Fig. 1.

History; at this stage it seems sufficient to use Schubert's summary *(History .. p 387)*. *'A furnace was built ..... in 1564, with a forge at Lizard. The forge was still operated during the major part of the following century (sic), but the only evidence of the furnace being continued is in a letter of 1604 ....'* So there is evidence of a life of at least 40 years for the furnace, and of some 250 years for the Lizard forges. A deed of 1783 refers to *"Furnace Pool or Manor Mill Pool"*.

Kemberton Furnace

Location: *Grid Ref SJ 744044 (Kemberton Mills or Kemberton Paper Mills)*

On the Westley Brook, some two miles south of Shifnal furnace, and on the Kemberton side of the brook, the parish boundary between Shifnal and Kemberton running down the centre of the stream. Derelict paper mills used up to the beginning of this century stand on the site, which is in a valley only about 50 yards wide. The water supply is from a mill pond of almost three acres formed by damming the whole width of the valley. There is a substantial quantity of charcoal, slag and other debris under and in front of the paper mill buildings and extending downstream along the tail race and in the brook. A small quantity of widely scattered cold-blast coke slag appears to have drifted on to the site from the roughly surfaced lane leading from Kemberton village. There is place-name evidence for the adjacent part of Shifnal parish and the site is clearly identifiable from 18/19 century maps. *(Fig 2).*

History; Schubert at p. 379 says simply *'Furnace mentioned in list of 1717; in 1728 it was in the possession of Edward Kendall'.* Whilst these dates can be pushed both backward and forward for a few years there is no conclusive evidence, to my knowledge, for either a firm date for construction or for blowing out, although the paper mills on the site were in use not later than 1790. Much more research is needed here.

I am trying to compile a reasonably coherent account of the two phases, 1567–c1640 when a simple furnace/forges relationship seems to have existed, and post c1640 when a much more complex relationship of furnace, forges and rolling and slitting mills can be discerned, with the forges at the Lizard being the link in each case. A sketch map, diagrammatic but essentially to scale, is annexed. *(Fig 3).*

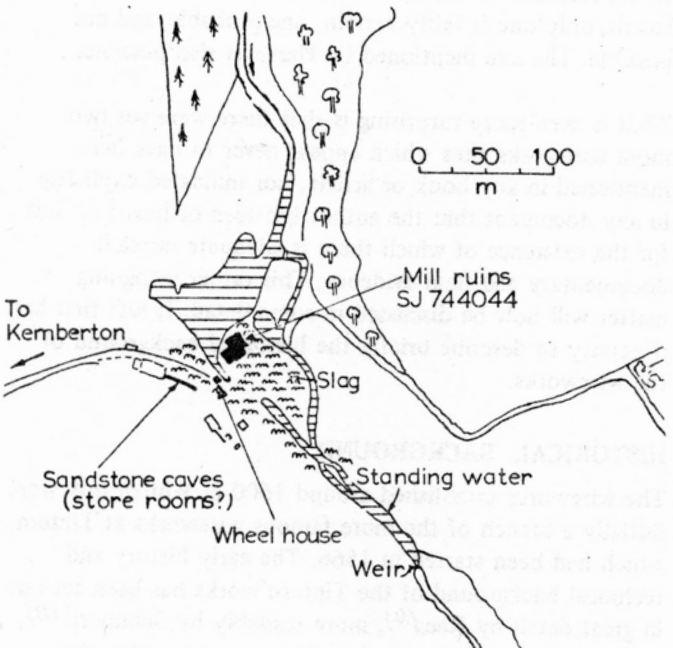


Fig. 2.

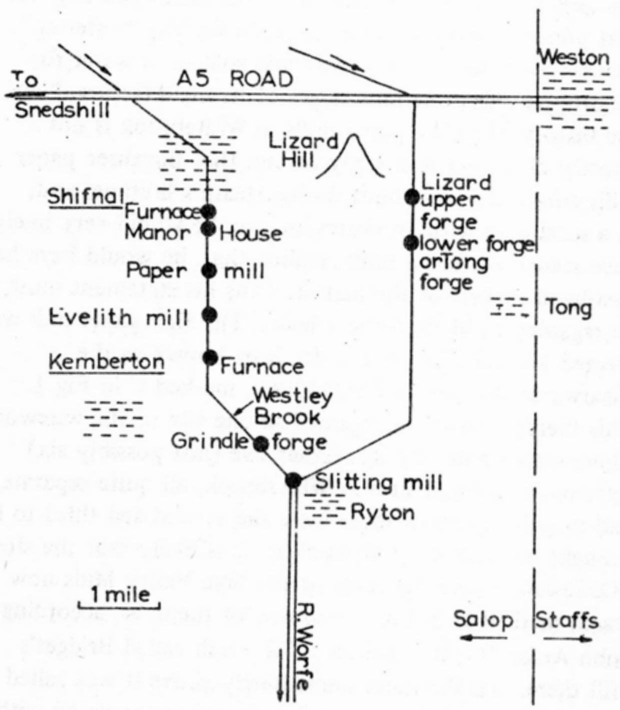


Fig. 3.

The seventeenth century wireworks sites at Whitebrook, Monmouthshire

by D G Tucker

INTRODUCTION

While the existence of wireworks at Whitebrook, between Tintern and Monmouth, in the 17th century is beyond doubt, there is nevertheless a marked uncertainty about their exact location. As they ceased operation around 250 years ago, this is not altogether surprising. The late Mr P G Harris of Monmouth told the author in 1969 that he thought the site was near the mouth of the White Brook *(ie near where it joins the River Wye)*, where on its northern bank he had found traces of iron slag or cinder which might have been waste from the wireworks. This seems a very reasonable theory, as supplies for the works would have had to come by the River Wye, and there was undoubtedly a mill of some sort here *(just opposite the present Tump Farm, at grid reference SO 537067)* well before 1772 because in a map*(1)* of that date there is a reference to the "New Ingen"; there are ruins of a mill still standing there now. This site is marked F in Fig 1.

Charles Heath*(2)*, writing in 1803, stated that three paper mills were erected on the ruins of the wireworks. This proposition has been repeated by Bradney*(3)* *(whose industrial history is, however, very inaccurate)*, by Peacock*(4)* and by Grey-Davies*(5)*, the latter pointing out that ponds would have been required for the "watering" process by which the iron wire was soaked in water for lengthy periods at various stages of its manufacture. Now the history*(6)* of the paper mills in Whitebrook is not entirely clear, but it is fairly certain that the three paper mills concerned were built during Heath's lifetime, and, as a local man with an observant eye, he would very likely have seen them being built. Failing that, he would have had first-hand reports of the matter. Thus his statement must be regarded as likely to be reliable. The first paper mill was erected around 1760 at the site later known as the Clearwater Mill, grid ref SO532067, marked C in Fig 1. This therefore may be regarded as one site of the wireworks. There were eventually altogether five (just possibly six) different paper-mill sites at Whitebrook, all quite separate, and exactly which of these were the second and third to be brought into use is far from clear. It is likely that the site at SO535066, where the ruins of the Wye Valley Mills now stand, marked D in Fig 1, was one of them, as, according to John Aram*(7)*, there was in 1772 a mill called Bridget's Mill there, and the pond immediately above it was called the Paper Mill Pound; there was also a smithy associated with it. One thing is clear; if Heath is correct, there were several different and well-separated wireworks sites.

A possibility for the third wireworks site is suggested by a curious feature in another of Aram's maps*(8)*, shown in Fig 2. Aram was recording the estates in the Manor of Trelech and was therefore concerned only with the land forming part of that estate. He consequently left a blank in the White Brook where a portion of the "Lands belonging to the Old Wireworks" made an excursion northwards across the Brook, as can be seen in the figure. While it is a pity that he did not show what was in this blank, it was almost certainly the embanked pond at SO521071, which still exists in good condition, and which may therefore have been part of another wireworks site, marked E in Fig 1. The pond which now exists immediately above this, at SO519071, was probably not built until required for the paper mills. In between these two ponds is the site of the paper mill known in the second half of the 19th century as Lower Fernside Mill *(the house beside it being later known as Sunnyside and now Traligael)*; but this site was in 1772 associated by Aram only with the "ruins of a cott", and is unlikely therefore to have been the site of part of the wireworks.

It can now be seen that there is still considerable doubt as to the location of the three wireworks sites mentioned by Heath; only one is fairly certain, one probable, and one possible. The site mentioned by Harris is also possible.

What is even more surprising is that there were yet two more wireworks sites which appear never to have been mentioned in any book or article, nor indicated explicitly in any document that the author has seen or heard of, but for the existence of which there is adequate implicit documentary and field evidence. This rather intriguing matter will now be discussed in some detail. It will first be necessary to describe briefly the historical background of the wireworks.

HISTORICAL BACKGROUND

The wireworks established around 1600 at Whitebrook were initially a branch of the more famous wireworks at Tintern, which had been started in 1566. The early history and technical background of the Tintern works has been set out in great detail by Rees*(9)*, more readably by Schubert*(10)*, and in summary form as part of a more comprehensive survey by the present author*(11)*, and thus will not be repeated here. Bradney's account*(12)*, in which he claims that the Tintern works were a branch of those established earlier at Whitebrook, should be ignored. The Whitebrook wireworks would have used the same technical processes as were used at Tintern, the most notable feature being the use of water power for the actual wire-drawing process. Water power would also have been required for blowing the forges, for hammering, and for other miscellaneous purposes. Thus the choice of sites for the works would have been greatly influenced by the need for adequate water power.

While a branch of the Tintern works, the Whitebrook works were owned by the Company of Mineral and Battery Works, and the Company retained their interest in Whitebrook long after they gave up their control of the Tintern works in 1631. The land on which the works were built at Whitebrook was owned by the Earls of Pembroke, whereas that at Tintern was owned by the Earls of Worcester, later the Dukes of Beaufort. It is believed that the Whitebrook wireworks ceased operation around 1720, whereas the Tintern works carried on until the end of the nineteenth century. The Whitebrook works appear to have had 62 working places or "seats" in 1677(13). The buildings must therefore have been fairly substantial.

The Whitebrook wireworks appear to be much less well documented than those at Tintern. For the latter, the large collections of the papers of the Dukes of Beaufort (the Badminton Papers) at the National Library of Wales provide a magnificent source of information. For Whitebrook there is nothing comparable known to the author. The Court Books *(or minute books)* of the Company of Mineral and Battery Works exist in part(14), and are very valuable historically; unfortunately they give no information on the layout or location of the works. The only really useful documentary information comes rather fortuitously from the maps of the Manor of Trelech (referred to earlier) surveyed and drawn by John Aram in 1772. Aram had previously surveyed and mapped parts of the estates of the Duke of Beaufort, such as the Manor of Portcasseg a few miles to the south, and the maps of the Manor of Trelech (Trelleg, as it was spelt then) may well have been prepared because of the impending purchase (stated by Probert (15) to have been in 1774) of the manor by the Duke of Beaufort. The owner, Robert Clive, had purchased the manor from the Windsors, who had obtained it by marriage from the Earls of Pembroke in 1699. Aram's maps are drawn to a large scale (some 5, some 4 chains to an inch) and are reasonably accurate, at any rate by the standards of the time.

Apart from the small pieces of information used in our introductory discussion, there is in one of the maps(16) an interesting item, namely "The watercourse to the old wire works"; this is a leat running at an altitude of about 460ft in a situation totally unrelated to the other possible wireworks sites. It therefore raises the possibility – indeed, almost a certainty – that there were yet other wireworks sites outside the main valley. This particular watercourse, shown as LEAT 1 in Fig 1, leads to what we shall call Site A.

Site A

The data from Aram's map has been incorporated in the author's composite map, Fig 3. The area concerned is above the Manor Brook, a tributary of the White Brook. The high altitude of the leat makes it very unlikely that the works would be 200 ft or so below, in the bottom of the valley of the Manor Brook, and even more unlikely that they would be lower still in the main valley.

Field investigation led to a straightforward identification of the leat, which for about 1200 yards (ie for most of its length) is readily traceable, much of it having been used as a footpath in the past. It is marked as such on the large-scale OS maps(17). It was evidently a substantial leat, perhaps 6ft wide, although it is hard to be sure of the width as the walls are derelict. Where it crosses the walled footpath from Holy Trinity Church up to The Narth it turns southwards and then appears to descend the valley side, but there is little trace of this part of it now. About 70–80 ft below are some very old remnants of stone walls forming a complex of buildings, with comparatively large levelled areas on the steep hillside. There can be little doubt that this was the site of the wireworks. There is a small discrepancy in relating this to Aram's map, for he shows the leat continuing for another 100 yards before turning downwards. However, the lie of the land makes it quite improbable that he could be right in this detail; in any case he was not in any way concerned with the wireworks as such. Thus this amount of error was perhaps possible. So the wireworks site was in this unlikely place, nearly 350 ft above the level of the River Wye – grid reference SO 531066.

The author was unable to trace the leat up to its source, as there seem to be no signs of it above the grid reference SO 521070. Confirmation that the extension of the line of the leat shown in Fig 3 to the north-west as shown in Fig 1 is a correct interpretation of the field evidence is obtained from a clue given in yet another map(18) of Aram's; in a small inset, unrelated to other maps, he shows a small field bounded by "The Watercourse to the Old Wire Works" and showing the watercourse meeting "The Road to White Brook", the field being "An Orchard opposite Pwoolth Blythan". The Tithe Map(19) shows a field called "Pull Blethin" (NB: the word is undoubtedly the Welsh *"pwll"*) starting about 150 yards below the mill pond of the paper mill at grid ref SO519071. There is thus little doubt that our interpretation is correct. If then we extend the line of the leat further as shown in dots in the map of Fig 3, we find it still lying nicely between the 400 and 500 ft contours and joining (or rather leaving) the White Brook at the mill pond shown, which the 6 inch OS map shows to be at an altitude of 461 ft – consistent with our estimate of about 460 ft at the wireworks end. (NB: A fall of a few feet would have been adequate to cause sufficient water to flow in such a wide leat). So we conclude that this part of the wireworks derived its power from the White Brook itself. There is no reason to suppose that the pond concerned existed at the time of the wireworks, however.

A vertical section or profile of the streams and watercourses is shown, purely diagrammatically, in Fig 4, so that the vertical relationships may be easily visualized.

Why were these works not at the bottom of the valley of the Manor Brook, using the power of this brook which presumably was sufficient for the corn mill there? Why place them in such an awkward position, high up on a hillside with no easy access? Transport of material to and from the works must have been difficult and expensive. There can presumably be no other answer than that the Manor Brook was considered too small a stream and too unreliable, and that it was desired to use the water of the White Brook itself.

The remains of the site and buildings (Site A)

The author, assisted by his wife, has made a rough survey of the site which is shown in Fig 5. The physical remains comprise a large number of stone walls and level areas created by means of retaining walls on the very steep valley side. Only two ranges of buildings can now be identified as such – these are marked as 1 and 2 on the drawing – and they are only small buildings. They could have been stores, or other outbuildings forming part of the wireworks, or they could be more recent. The fact that half of a cider-mill base-stone *(or "chase")* lies near building 1 suggests a later agricultural use of the site, and indeed the Tithe Map[20] shows the site as occupied by a cottage 120 years after the abandonment of the wireworks. The large amount of retaining wall providing perhaps 2000 sq ft of flat ground is not likely to have been built especially for agricultural purposes on a barren and rocky hillside suitable only for forestry. The fact that these artificially-created flat areas lie just below the end of the leat makes it almost certain that this was an industrial site, and therefore the site of the wireworks. Presumably there were buildings on these flat areas, probably of two or three storeys; and there must have been at least one water-wheel, but no sign of its location could be found.

All the walls are made of roughly-dressed stone blocks without mortar, except where the natural rock of the hillside has been used in situ.

The walled path up to the old leat is interesting. It has stone steps in it, and presumably was the main means of access to the site from the elevated village of The Narth, which was certainly a well-populated village in the 18th century, as indicated by Aram's survey.

Site B

There is a local tradition that the wireworks were on the hillside about a hundred yards south of Wye Valley Mill, and careful examination of the 25-in OS map[21] shows what might be a leat running from a spring, eastwards towards a point just above this site. It runs almost exactly along the 300 ft contour, and its existence is vouched for by an elderly local inhabitant who remembers it as having running water in it when she was very young. Its route can be verified even now by careful field search. Although much of it has disappeared, especially where it ran alongside a lane, there are places where its stone construction is clearly visible. It was between 2 and 3 ft wide, with stone walls.

Below the eastern end of this leat, shown as LEAT 2 in Figs 1, 4 and 6, is a steep path to the site marked B. Just to the left of this path is a patch of sloping ground covered quite deeply with small hard cinders. Just below this, on both sides of the still-steep path, is a levelled area, only about 15 ft wide but giving a total usable area of perhaps 1500 sq ft. Below this again is another levelled area, on which now stand the ruins of a cottage. That this may have been a works site is supported by the fact that there are traces of a gently-sloping road from it down the hillside to the valley road near Tump Farm. This road was clearly shown on the Tithe Map.

The conjunction of the leat, the cinder patch, the levelled areas and the road does give some justification for regarding this as a probable wireworks site. It must have been quite a small unit, for apart from the limited area of the site, the leat was only a small one. Although the OS map shows the leat as fed by a spring, it is of some relevance that there is on the Manor Brook, at an altitude of just over 300 ft, an old dam. There must have been a storage pond here, and perhaps the leat really ran from this. As the pond at the corn mill on the Manor Brook was a very tiny one, this storage pond may have been merely to conserve water for the corn mill, but it is tempting to think it was really for the wireworks. The vertical relationships may be seen clearly in Fig 4.

Further aspects of the history

The existence of a leat or a watercourse cannot in itself be taken as proof of a wireworks site, because there were mills (especially grist mills) in Whitebrook long before the wireworks came there, and some of these had leats. For example, a deed(22) of 1594 leases a mill from the Earl of Pembroke to Thomas Jones of the parish of Trelleck *(sic)* thus:–

"And all that water griste mill .... in the pishe of Pennalte ....uppon a River there called Whitebrooke with all the Watercourses Running from the howse now or late in the tenure of ...... John Phellip to a place where the brooke called Manne cometh .... to the brooke called Whitebrooke.........."

This description is confusing, of course, because one feels the "Manne" brook must be what is now called the Manor Brook, yet this lower part of the Whitebrook valley is in the parish of Llandogo, the Penallt parish boundary being much further up.

The wireworks acquired from the Earl of Pembroke all the water rights in the valley and its tributary valleys, for on 6 June 1607 he leased to them(23):–

"All those water-courses & Brooks which meet together and Runn to Whitebrooke another brooke called Nant Gronow att pullble(?) White brooke & also, the Manny brook & Whitbrook with severall parcells of wast and woody ground & several cottages &c .... "

This lease seems to establish the date at which the wireworks were commenced at Whitebrook as 1607, although Rees suggests they were started in "the closing decade of the 16th century".

There was also interaction between the established mills and the "new" wireworks, for(24).

"One of the Earl's copyholders, having a mill on the site, complained that the new works affected his interests....."

Access to the wireworks from the river Wye was important, since supplies came by river and the wire was exported by river. Thus it was important to the Company of Mineral and Battery Works that the right of way between the river and the works should be maintained. On 11 October 1621 the Company was very concerned(25) about

" .... *a wrong offered to them by S^r^. Richard Catchmay in denying their farmer a way in Bannot tree ham, for the w^ch^ they pay him xx^l^ a year rent ......*"

The way was to the "woorks at Whitbrook", and on 22 October a letter was sent to Sir Richard.

Now Bannot Tree Ham (misquoted by Rees(26) as *"Lane"*) is surely the meadow by the river which appears on the Tithe Map(27) as Burnt Tree Ham, and has the remains of a stone slipway in it. This must have been where boats were laden and unladen; it is marked in Fig 1.

When the wireworks were first built at Whitebrook they were comparatively small, having cost only £900. But when the Company gave up Tintern, they decided to expand the Whitebrook works. At the meeting of the Company on 23 December 1629, Mr Mynne(28) raised objections to this because

1. he feared there might be no timber left in Wyeswood, nor any to be got except in the Forest of Dean, and from there no carriage was possible until midsummer because of the state of the ground – everything had to be carried on horseback,

2. he feared the cost of the new works would greatly exceed the estimated £1000, because "the work already done at Whitbrook cost but 900 pounds" and there was need for as many new works at Whitebrook as they had at Tintern, and these would not be built for £3000.

3. there would be need to remove so many workmen from Tintern and build houses for them

4. everything was dearer than when the Company first built at Whitebrook.

However, the Company did go ahead at Whitebrook.

Mr Mynne's comments are interesting in several ways. The remarks about carriage show that goods were normally carried by wagon, and hence the relevance of the old road to Site B. However, Site A could have had no wagon road, and from the size of the leat one would suppose it was one of the later works. Perhaps by then, carriage by packhorse was accepted. The remarks about as many new works at Whitebrook as at Tintern justify our theory that there were many separate works sites, for this was certainly the case at Tintern.

Mynne's remarks about building houses leads one to wonder whether the development of a settlement such as The Narth *(on the hill above Whitebrook)* was mainly due to the wireworks, and whether the large network of walled path-ways which runs between Whitebrook and The Narth *(and also to Pen-y-fan)* was built by the Company. Certainly this system of paths is fascinating and unusual, and its origin nowhere recorded as far as the author is aware.

Although account books for the period 1672–1687 have survived(29), they treat Tintern and Whitebrook as one unit since both were then under the control of Thomas Foley; they do not therefore help to indicate the scale of operations at Whitebrook, nor do they give any clues as to sites. However, a solitary schedule of material in stock(30) does have separate columns for Tintern and Whitebrook, and from these it is clear that stock held at Whitebrook was roughly the same as at Tintern. This suggests that the scale of operation was about the same at the two places.

That there was more than one site at Whitebrook even in 1609 is suggested by the wording in a note(31) relating to a lease of that date from "Mr Catchmay and Sr Richard Catchmay" granting to the Company "The Mill-close whereupon some of the new works for the making of Wyer are standing".

It would also be wrong to think no development took place between around 1607 and the main removal in 1631, for(32)

"in 1625, Lord Herbert, son of the Earl, questioned the right of the Society to construct watercourses leading to the cutting-house and demanded an increased rent".

All in all, the supposition that there were at least five sites in use by the wireworks does not seem very unreasonable.

ACKNOWLEDGEMENTS

Thanks are due to the staff at the National Library of Wales, the British Museum, the Public Record Office, the Monmouthshire County Record Office, the Herefordshire County Record Office, and the National Register of Archives, where searches have been made by the author. Acknowledgement is due also to the **Duke of Beaufort** for permission to use material from the Badminton papers. The advice of, and discussion with, **Mr H W Paar** and **Mrs Joan Day** have been most helpful.

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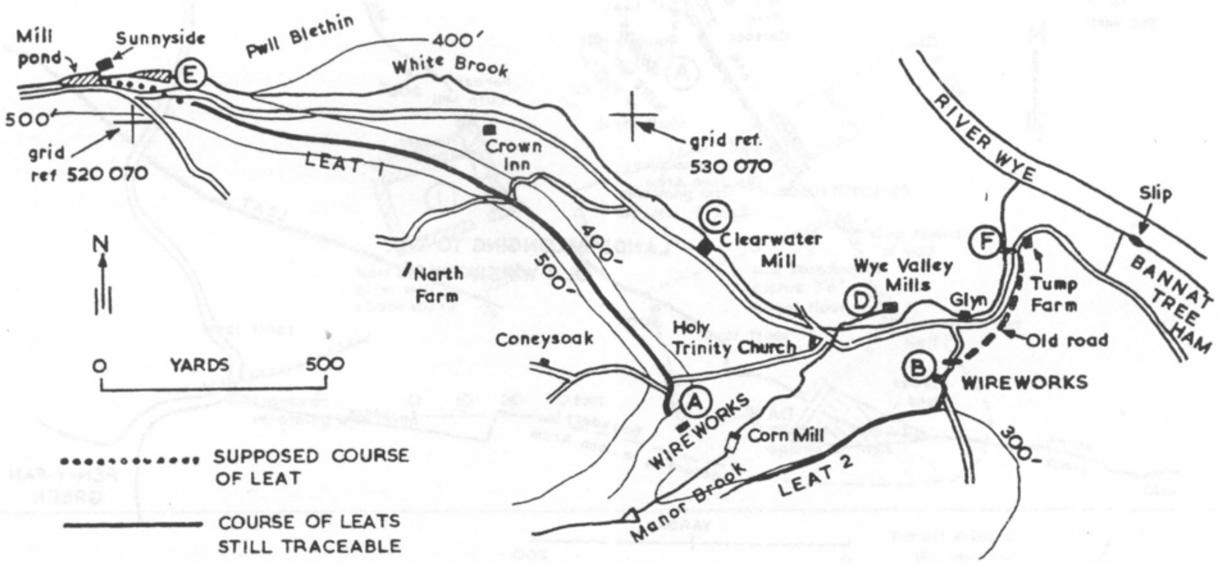


Fig. 1.

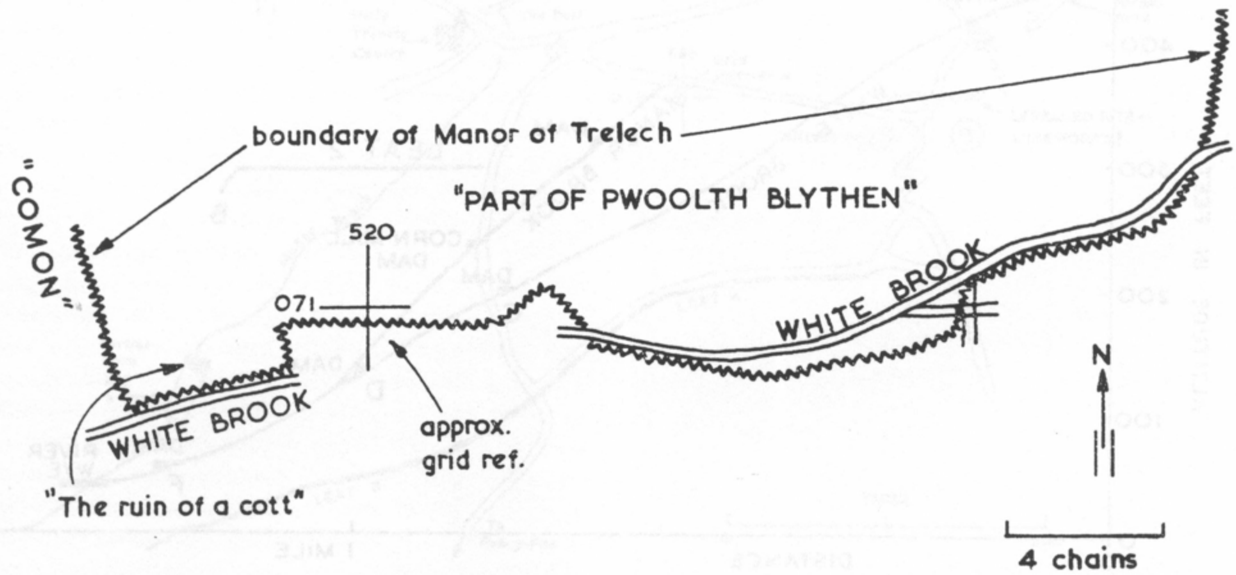
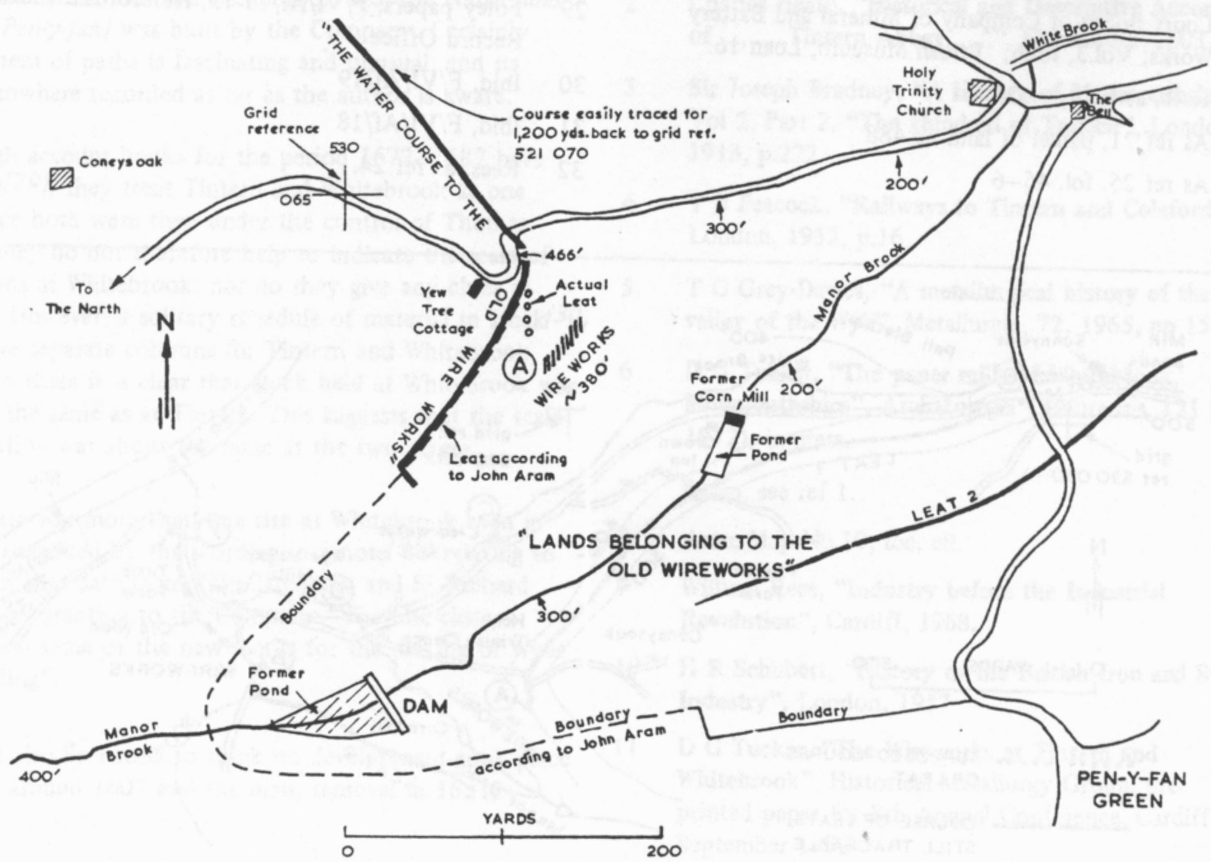
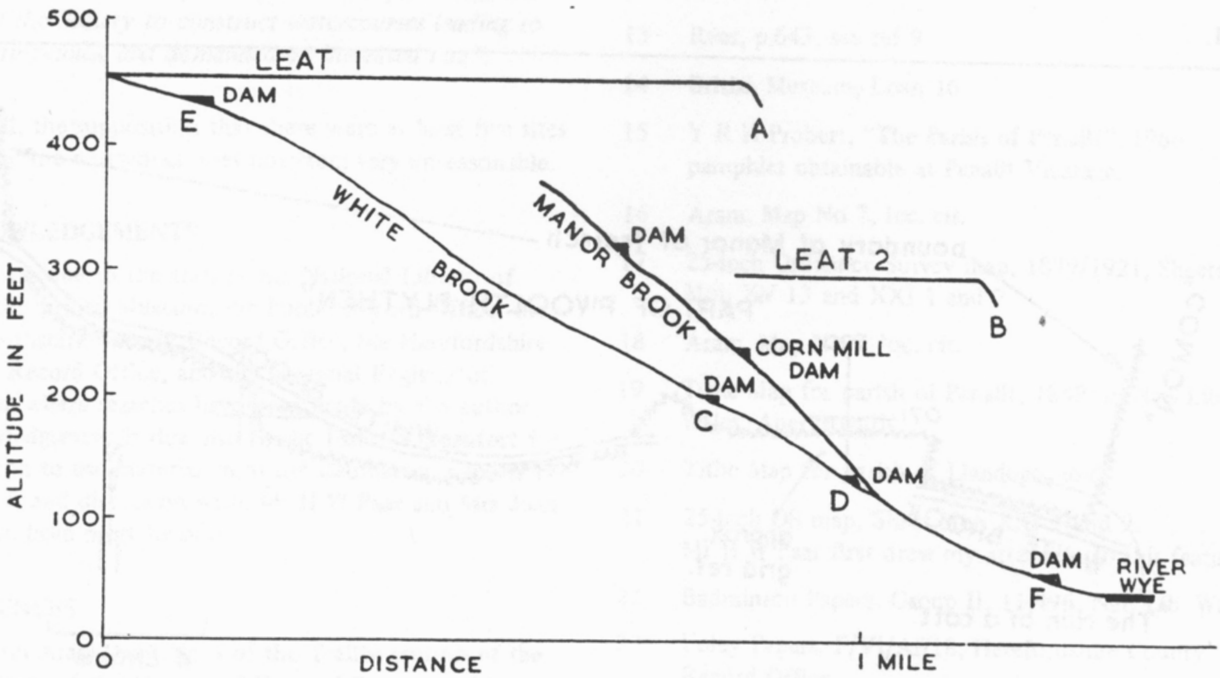


Fig. 2.



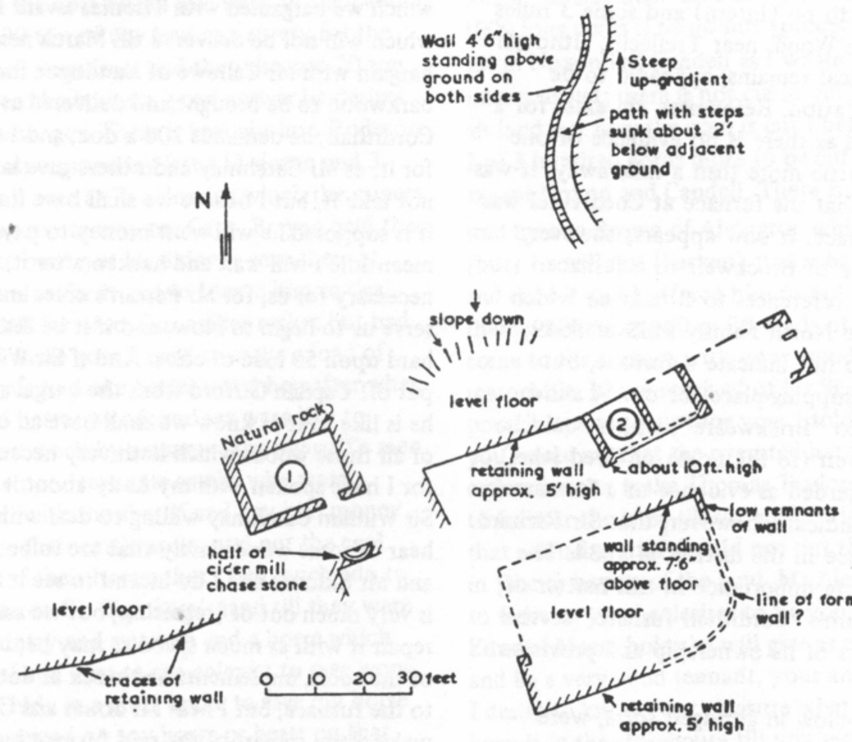
"THE WATER COURSE TO THE OLD WIRE WORKS"
Grid reference
530
065
Coneysoak
Course easily traced for 1,200 yds. back to grid ref. 521 070
466'
To The North
N
Yew Tree Cottage
Actual Leat
(A)
WIRE WORKS ~380'
Leat according to John Aram
"LANDS BELONGING TO THE OLD WIREWORKS"
Boundary
300'
Former Pond
DAM
Manor Brook
400'
Boundary according to John Aram
Boundary
White Brook
Holy Trinity Church
The Bell
200'
300'
Manor Brook
Former Corn Mill
200'
Former Pond
LEAT 2
PEN-Y-FAN GREEN
YARDS
0
200

Fig. 3.



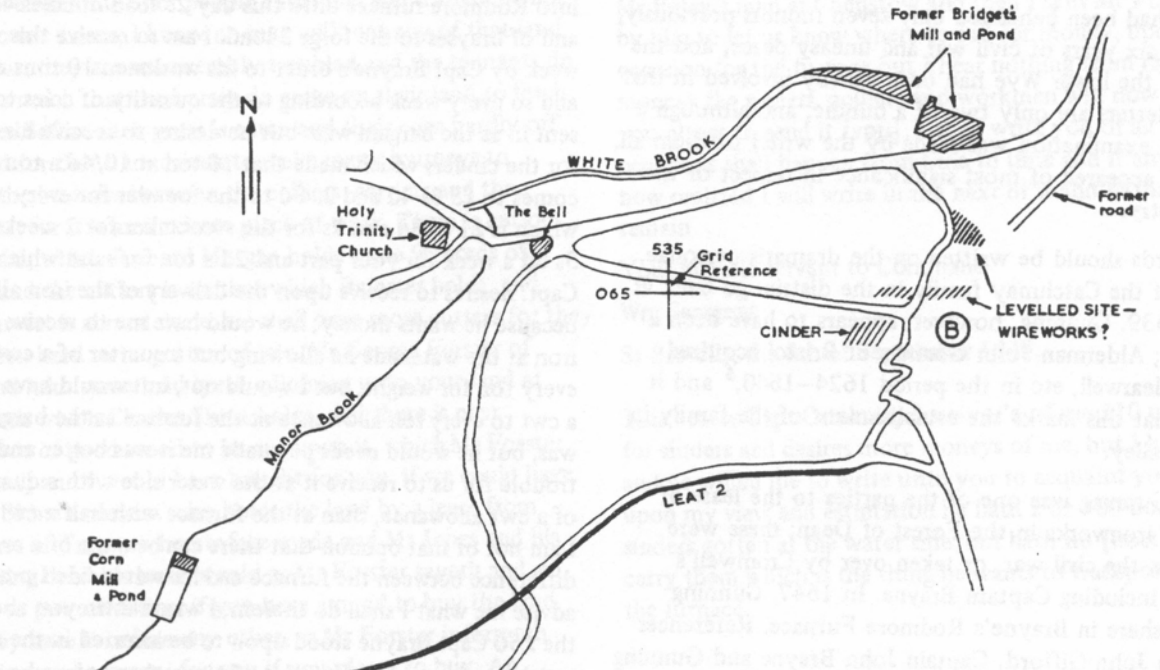
500
400
300
200
100
0
ALTITUDE IN FEET
LEAT 1
DAM
E
A
WHITE BROOK
MANOR BROOK
DAM
LEAT 2
B
CORN MILL DAM
DAM
C
DAM
D
DAM
F
RIVER WYE
0
DISTANCE
1 MILE

Fig. 4.



N
Wall 4'6" high standing above ground on both sides
Steep up-gradient
path with steps sunk about 2' below adjacent ground
slope down
level floor
Natural rock
1
2
retaining wall approx. 5' high
about 10ft. high
low remnants of wall
wall standing approx. 7'6" above floor
half of cider mill chase stone
level floor
line of former wall ?
level floor
traces of retaining wall
0 10 20 30 feet
retaining wall approx. 5' high

Fig. 5.



N
Former Bridgets Mill and Pond
WHITE BROOK
Holy Trinity Church
The Bell
Former road
535 Grid Reference
065
LEVELLED SITE – WIREWORKS ?
CINDER
B
Monor Brook
LEAT 2
Former Corn Mill & Pond
LEAT 2
To Pen-y-Fan
YARDS
0
200

Fig. 6.

The furnaces at Coed Ithel and Trellech

by H W Paar

Two blast furnace sites in eastern Monmouthshire, at Coed Ithel (about 1½ miles north of Tintern) and some 3 miles to the west (in Woolpitch Wood, near Trellech), although presenting generous physical remains, appeared to be totally without documentation. References did exist for a furnace at Brockweir, and as there is no evidence of one there, and Coed Ithel is little more than a mile away, it was a reasonable hypothesis that the furnace at Coed Ithel was known as Brockweir furnace. It now appears, however, that in assigning the name of Brockweir to a furnace. Schubert[1] was misled by references to Brockweir which occur in Hart[2] and in the North Family MSS of 1649, which on examination do not indicate a furnace, but (by implication) only a shipping-place for ore. A third reference[3], by referring to "Brickweare", which could be construed as either Bigsweir (to the north of Coed Ithel) or Brockweir, cannot be regarded as evidence of a furnace at the latter place; it does indicate, however, that Sir Richard Catchmay owned a furnace in the district in 1634. The North letters[4] are of prime importance in this matter of location, because they name "Cordithell furnace" several times, and give particulars of its ownership and provision.

The letters, reproduced below in abridged form, were written to John Gunning, a Bristol merchant, by his agent in the Wye Valley, William Seargent, in September 1649: Charles I had been beheaded only seven months previously, after over six years of civil war and uneasy peace, and the district of the lower Wye had been heavily involved in that war. The letters are only two of a bundle, and although a superficial examination was made by the writer of them all, these two appeared of most significance in respect of the iron industry.

A few words should be written on the dramatis personae. Records of the Catchmay family in the district go back at least to 1339. Gunning, however, appears to have been a newcomer; Alderman John Goninge of Bristol acquired lands in Clearwell, etc in the period 1624–1640,[5] and it is likely that this marks the establishment of the family in the Wye valley.

In 1636, Gunning was one of the parties to the lease of the King's ironworks in the Forest of Dean; these were damaged in the civil war, or taken over by Cromwell's followers, including Captain Brayne. In 1647, Gunning secured a share in Brayne's Rodmore Furnace. References to Captain John Gifford, Captain John Brayne and Gunning will be found in Hart's work.[6]

[Letter sent to John Gunning]

Worthy Sir, Mr Skinner told me he hath written to you what we did in Wales about those woods and 200 load of charcoles which we bargained with Thomas Evans for, at 29s a load which will not be delivered till March next, and I am now in bargain with Mr Callowe of Landogoe for 6 or 800 doz of barkwood to be brought and delivered at the furnace head at Cordithall; he demands 20d a doz; and I offered 19d a dozen for it, as Mr Catchmay and others gave last for it, but he will not take it, but I believe we shall have it so at michlemas, for it is supposed he will want money to pay his rent; and in the meantime I will wait and harken after it, for it will be very necessary for us, for Mr Perkin's coles and that wood will serve us to begin to blow, and if it be 800 doz it will make us hard upon 50 load of coles. And if Sir William Catchmay can put off Captain Gifford from the bargain of his woods which he is like to to, I know we shall have an offer and the refusal of all those woods which lieth very necessary for Cordithall, for I have spoken with my Lady about it and I find her and Sir William Catchmay willing to deal with you for it; I do hear of some woods lately that are to be sold about Trellegge and Mr Skinner and I do intend to see it this week, the furnace is very much out of [repairing] but we are now setting on to repair it with as much speed as may be; I have taken an acct. of the tools, implements and stock as doth remain and belong to the furnace, but I hear Mr Jones and Captain Harbert do make claim to part of the said furnace but Mr [xposer] Catchmay saith they have no right at all in it; There is sent into Rodmore furnace unto this day 25 load of coles 4 sacks and of brayses to the forge 2 load. I am to receive this next week by Capt Brayne's order to his workmen 10 tons of iron and so every week according to the quantity of coles to be sent in as the bargain was: but he desires to receive his money for the cinders which made that 10 ton at 10/4d a ton which comes to £5 3s 4d and 2s 8d to the founder for every ton which is £1 6s 8d and 7s for the stocktaker for 2 weeks at 3s 6d a week for your part and 2d a ton for sand which the Capt. desires to receive upon the delivery of the iron allways because he wants money; he would have me to receive the iron at the waterside he allowing but a quarter of a cwt to every ton for weight, but I would not, but would have half a cwt to every ton allowance at the furnace as the bargain was, but he would needs persuade me it was better and less trouble for us to receive it at the water side with a quarter of a cwt allowance, than at the furnace with half a cwt but I am not of that opinion that there can be a qtr of a cwt difference between the furnace and the water side I pray advise me what I shall do therein; I wrote unto you about the £50 Capt Brayne stood upon to be inserted in the new articles to be paid him the 1st of November before he would sign them and you wrote me that you expected then that Capt Brayne should enter into bond to you for the delivery of the iron according to the bargain he is loath to enter into bond but in respect he stands at present in want of money if you please to pay him the £50 within this week or thereabouts he would deliver you 20 ton of raw iron as a surety for the £50 until you receive all your iron, and then the said 20 ton to be accounted to even the business; your answer he desires therein by the first messenger. There is brought into Rodmore furnace and measured upon monday last 115 dozen and 3 bus [hel] of Clowerwall oare at 7s a doz for which the miners desires their money as soon as may be; Capt. Brayne paid them 7s 4d a doz for the like oare, yet Mr Skinner gave them at Brockwere but 6s 6d a doz for it and so I leave him to deal with them for Cordithall for oare. Our collier makes but bad yeald of our wood for there goes 5 cord to make a load of cole as yet; but he hopes to make better yeald hereafter when he have more dust and better wood; and we were like to come to trouble the last week by reason of the Sherriff's men distrained many of the poor tennants cattle, who were enforced to compound with the sherrif and pay him money before they could have their cattle again, and put the coal carriers in such a fear of their horses that I had much ado to persuade them to come on Sir Baynham's land till they were all gone out of the country and my man and a horse which were there hauling turf and dust to the colepitt to save wood, was driven to fly, and hide in a great brake to save my horse for if they could have seized on any horse or beast on that land the owner must have bought them again of the sherrif; such have been the poor people's fortune, and if there be not some course taken, I know no man will rent any of that land next year, they are so miserably troubled and the tennants do murmur much that the horses do come on their land to fetch the coles before their grass is eaten and their corn hardly off the land for that I am driven to make many journeys to pacify the business between the colliers, carriers and the tennants; for it is an intricate piece of work. There is cut on your land, which Richard Morgan holds some 90 cords of wood, and the cutters is on that which Bainster holds, and now harvest is almost done, we shall have more cutters for they have been hard to be gotten of late. Mr George Forster of Newland hath some land lyeth adjoining unto your land at the marsh which Charles Skine holds, and there is near 100 cords of good wood to be cut upon it, which Mr Forster would sell and I would have bought for you, if we could have gotten Skine's consent who holds the land by a lease from Mr Jones of Treowen heretofore made and Mr Jones and his wife being dead his lease is void as Mr Forster sayeth and do intend to put out Skine; if you have a mind to buy the land you may have it before any other, as Mr Forster informeth me; it is very necessary for you if you please to buy. An answer to this Mr Forster desires; Alexander Thorne intends to cut some 3 or 4 score cords of wood upon his land at Morpurgo Brook speedily and we shall have the refusal of it. I offered him 9s a cord and he will not bate of 10s the whole cord, and he cut and cord it, and so we may have it if you please. Sir Baynham acct of wood will fall very short of 1000 long cords if he do not [procure] some woods to be cut in Noxon and Candell as I wrote to him but have no answer as yet; there is not cut as yet, not 800 half cords on his land but now the corn is cut I believe we shall have some 2 or 3 hundred cords more to be cut; and that will be all except Noxon and Candell. There is a parcel of wood to be sold by one Brown of Alvington which lyeth near Noxon [but] he will not [harken] under 6s 8d a cord and we cut and cord it and I offered him 6s but he will not accept of it; there will be some 60 or 80 cords of 2 foot wood which will come to the furnace with your wood if we may have it reasonable; I have received of Mr Skinner in all forty nine pounds upon account for you. I told my lady Catchmay as you wrote me that she overated her land and that you ordered me to make Thomas Taylors lease but he desired me to forbear the lease till she spake with you or wrote to you for that a small matter should not put the business between you in [shex] having of the land. Mr Alexander Thorne willed me to write to you he desires to be your tennant for the land Edward Morse holds he will give as much for it as any man, and be a very good tennant, your answer he humbly desires. I desire to know your pleasure what to do with the iron to keep it in the storehouse till you send a boat for it or what else to do with it when I receive it; Mr Skinner and I met with Mr Foley's man at Chepstow and then I sent Mr Foley word by him to let us know where to call for money, upon occasion for the furnace but I hear nothing from him since; moneys the miners, colliers and workmen will now expect if you please to send it [vpp]. I shall write you of all things as occasions shall happen from time to time and if any thing be now omitted I will write in the next of it and in the interim remain

Your humble servant to Command

Wm Seargent

St Brevells, the 8th of September 1649.

This bearer Capt Catchmay have rec'd of me £10 upon acct for sinders and desires more moneys of me, but I have none, and he willed me to write unto you to acquaint you that upon my view and estimation he hath 2 or 300 dozen of sinders gotten at the water side, but hath no [boat] as yet to carry them which is the thing he wants to transport them to the furnace.

[Letter sent to John Gunning]

Worthy Sir, I have bargained with Mrs Callowe of Llandogo for 600 dozen of barkwood for Cordithell furnace at the rate of 19d the dozen being the same rate that was formerly given at the same furnace by Mr Catchmay Mr Skinner and Mr Jones, and to be delivered at the furnace. She would not have sold them under 20d the dozen but that she is to have £30 to be paid for against the [anvil] in Cardiff, which will so give you 3 weeks and for the rest of the money she will not seek till she hath sent in the whole 600 dozen. 200 or 300 dozen she says is cut already which shall be speedily sent in, and the rest as fast as it may be cut and carried, which will not be long, because it lieth very near the furnace, and she wanting money withall will make her hasten the business. She hath promised me 400 dozen more, but she will not take under 20d a dozen for that, as she says this 600 dozen will make [as I reckon] 37 load of coles or thereabouts. I had Mr Skinner's approbation and direction in the business. Sir Wm Catchmay and my Lady both are resolved to [wait] Capt Gifford's bargain for their wood and to take their best chapman and so Mr Skinner and I went to Bixweare yesterday and conferred with Sir Wm about it, and we find him and his Lady very willing you should have it before any, but their price is 7s a cord of 3 foot and 3 inches wood. But it may be something will be abated, because they desires to have £250 before hand presently upon the sealing of the articles and you to lay out the money for cutting and cording and to be allowed it again in the payment for the wood; so that he is at the charge of cutting and cording but only your disbursement of the money in the meantime. So that every whole cord will stand you in 9s 4d a cord, and that wood is more necessary for your work than any, and good wood, but I hope we shall have something abated. Capt Brayne as I hear and partly understand by a note that Sir Wm read to Mr Skinner and I of [a exposition] made him, that if he would send in 7 load of coles to the furnace he should have 2 ton of sow iron delivered him for only 7 load of coles, which 2 ton of iron would yield him £13 which Mr Skinner and I found it to be Capt Brayne's [piece]: but I believe that will not take effect, for it is money that Sir Wm wants, and my Lord [Gray] must have it, and the business must speedily be done before his Lordship goes into [France] he will join with Sir William in the articles for the performance thereof. Sir Wm desires your speedy answer herein for that my Lord is preparing for his journey into [France]. I have rec'd 10 ton of iron at Rodmore furnace this day, and Mrs Brayne hath given order to her clerk to deliver me 10 ton more the next week, which when I receive I will send it altogether to Mr Stephen according to your order. Capt Brayne expects the money for the sinders which made the 10 ton of iron already delivered, and also for the 10 ton to be delivered the next week because his workmen want money presently, and rely upon that to pay them. The 20 ton at 10s 4d a ton comes to £10 6s 8d for cinders, the founder 2s 8d a ton comes to £2 13s 4d the stocktaker demands 3s 6d a week for 4 weeks which is the one half of his wages, but I reckon he ought not to have so much of you in respect there is made at the furnace 15 ton every week or thereabouts and you have but 5 ton a week I reckon you ought to pay him but a third part, seeing you have but a third part of the iron but I will agree with him as well as I can. I could not speak with Capt Brayne prior I receive your letter, for that I could not ask him about the cutting the 4 or 500 cord of wood as you wrote me, nor the £50 upon the 20 ton of iron to be deposited, but I understand by Mrs Brayne that he is badly in debt with so much iron, for I think he cannot spare it, the miners desire to have their money for the ore they brought to Rodmore which is 115 dozen and 3 bushells at 7s a dozen comes to £40 6s 9d. Capt Brayne paid them 7s 4d a doz: when I pay them Harry Symons shall know of it, that he may take up your rents, the colliers and carriers do expect money, and also the cutters which if you please to send by this bearer. I have bought Alexander Thorne's wood at 10s a cord he to be at the charge to cut and cord it, which is [near] cutting of it, and if it will not [be deferred on] ought to cole and spend at Rodmore furnace this blowing or kept till the next, for I [presumed] by Mrs Brayne that if they do blow out, it will be by reason of a [stop] which Capt Brayne hath, and [spent] up the woods in the forest and he intends to make another blast with wood that he shall [have] in the country, and if we cannot spend Thorne's wood there it will be spent at Cordithell. Your tennant Skine is about to cole some wood he hath upon Mr Foster's land near yours at the marsh and will sell it by the load of cole and hath promised me the refusal thereof for you, it will be 5 or 6 load of cole I think. I viewed your woods in Skine's ground in the marsh and I believe it will amount to 40 cord of 2 foot wood or more, and Skine is willing you should cut it if you please; I received the £10 of Capt [Joseph] Catchmay, but I have not been with Mr Vaughan for the boat as yet, but intend to go to him on monday next, God willing. Capt Catchmay keeps his workmen getting sinders still, but he is gone into Wales to his sister Aylway. Mr Skinner hath bought 200 dozen of sinders off Mr Wm Tanner of Monmouth who is to have £5 in hand towards the getting of them. He is to deliver them at Cordithell [Bank] at 2s 8d a dozen and 14 bushel to the dozen. And thus with my humble service rendered, I do take leave and rest.

Your humble servant to Command

Wm Seargent

St.Bre.

21 Sept.1649

To the worthy John Gunning Esq at his house, Coldastun these present.

POSTSCRIPT

It is clear from the above that Coed Ithel furnace was about to resume work after a period of disuse, because the on-site charcoal manufacture was not yet well-established, supplies of ore were being organised, and methods of payment determined. Apparently Gunning had recently taken over the furnace, from references to the practice of the previous owners, including Mr Catchmay (at least two other members of the family are named – Sir William C., and Captain C.).

The reference to a furnace being out of repair points strongly to the one in Woolpitch Wood, as it follows upon a mention of woods at Trellech; it can hardly refer to Coed Ithel, because that was about to be put into use, and it is not reasonable that it would only then be noticed as out of repair, or lacking an inventory, or that doubts about its ownership should still exist. Moreover, the claimants were Jones and Harbert, whereas Coed Ithel is stated to have been operated by Catchmay, Skinner and Jones.

The role of "Mr Foley" is not clear. He was probably Thomas Foley, then 32 years old and busy expanding his father's interests – he purchased no less than 97 properties – land, mills, manors, furnaces, wireworks, etc – in the period 1648–'75.[7]

The North MSS contain other items giving considerable local detail on the iron industry. A manuscript book and entitled "Lady Ann Guning : her Leadger. 1680" indicates the importance of the timber crop in estate economy, for carefully written on the fly-leaf is:–

The measure of cord wood in the Forest of Deane

2ft 2 inches length of the billet

8ft 4 inches length of the short cord

4ft 4 inches heigh of the wood

The long cord is two of these cords.

This acct given me by Mr Morgan squire Winter's man

20 August 1686

The book contains frequent references to the getting, measuring, washing and delivery to the waterside of cinders up to 1707 at least, eg. in 1694 William Ball was paid £13-15s for getting and carrying 110 dozen of cinders to the waterside, and £2-3s-6d for washing and measuring 126 dozen, while for the measuring only of 116 dozen he received 10s. That it was a lucrative trade is indicated by the statements that in 1690–1694 the cost of getting, etc cinders was £85 odd, and in 1694 alone receipts from cinders totalled £163 odd.

NOTE: The transcription of the two letters from the original 17th Century manuscript, with its many flourishes, abbreviations and cramped passages, has left certain words still somewhat uncertain. These are indicated above by enclosure within square brackets.

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The Percy Collection of Metallurgical Specimens in the Science Museum, South Kensington

The Science Museum is anxious to extend into modern times one of its most important and interesting collections and is seeking the help of metallurgists everywhere.

Dr John Percy (1817–1889) was a pioneer of scientific metallurgy. Before the mid-19th century, the metallurgist worked almost entirely in the light of practical experience, virtually unaffected by discoveries made in the physical sciences about the structure of matter. Percy did not himself change all that, but he marked the beginning of a more scientific approach to metals. As Percy remarked in his inaugural address as lecturer (later professor) in metallurgy at the Royal School of Mines in 1851, "experience without scientific knowledge *[was thought]* more trustworthy than the like experience with it". His massive but incompleted textbook is the first that reads as more than a mere recipe book. Parallel with his writing and teaching, he amassed in the course of nearly half a century a collection of some 4,000 specimens illustrating stages in the preparation of metals or displaying some of their properties or applications. He had a wide circle of friends and contacts, well aware of his interest, and a steady stream of specimens came in from far and wide. For example, J H Marshall, a former student of his, wrote in 1875 "Remembering a suggestion of yours to RSM students to the effect that you will always be glad to receive any objects of metallurgical interest that they may come across, I herewith send you something that I hope may be acceptable, viz an old fire-bar from the grate of a domestic kitchen-range". The bar had been curiously split along the fibre. Of greater historical interest, are the experimental pieces of Bessemer steel produced in 1856, recalling the spectacular invention of the process, and its early setback.

On his death in 1889, the bulk of the collection comprising about 3,700 items, was purchased by the South Kensington Museum (later divided into the Victoria and Albert, and Science Museums). A catalogue was compiled by Professor J F Blake based on Percy's own ms notes, and published with a preface by Professor Roberts-Austen in 1892. A small selection of the pieces has been on display in the Museum for many years, and has recently been rehoused in new cases. The bulk has been kept in an outlying store, but when these are brought to the Museum premises in cases soon to be installed, the entire collection will be readily available for students to examine, in a special study room adjacent to the Metallurgy Gallery, construction of which is now in progress.

The collection ceased at an arbitrary point, but the development of metallurgy has continued at an ever quickening pace. The Museum, supported by an Advisory Committee of the Metals and Metallurgy Trust, considers that it would be appropriate for the collection to be augmented by specimens of significance in the subsequent history of the science and technology of metals, and accordingly invites donations of suitable items. The field is now so vast that the Museum must be more selective than Percy needed to be. It would however be important to preserve early, if not the earliest, examples of the more important alloys developed in the last 100 years, including specimens illustrating special properties or the results of subjecting metals to unusual or arduous conditions. Specimens of various stages in the production or purification of metals by processes introduced during this period would also be suitable. Another field would be the introduction of metals new to industry and engineering.

Organisations or individuals who may wish to suggest items or who possess specimens which they feel would make a significant contribution to the Museum's metallurgical collections are invited to write to Mr L R Day, Assistant Keeper in the Department of Chemistry of the Science Museum, South Kensington, London SW7 2DD.

Work in progress. The bloomery at Pippingford, Hartfield, East Sussex

(Grid Ref: TQ 44573126)

This bloomery site has been recently excavated by C F Tebbutt. It consists of a developed bowl furnace built into a pit. The internal diameter is about 60 cms which would make it more like James Money's furnace at Minepit Wood, Rotherfield, than anything else. The lining was made of slag, clay and stones and the furnace has a sandstone bottom with a slope towards the slag tapping pit. Some tap slag was found **in situ** on the sloping sides of the very deep pit in front of the furnace. The front wall was missing but there was room for up to 3 or 4 tuyeres.

A section cut into a slag heap on the down slope side of the furance yielded very little tap slag but some large "furnace bottoms" which could have come from a 60 cm dia hearth. Pottery found with the slag was dated to within 30 years after the occupation, ie 43–73 AD. A 1m wide by 6m long trench cut through the slag heap yielded 1925 lbs of tap slag, 912 lbs of cinder and ten furnace bottoms weighing from 14 to 30 lbs.

The remains clearly represent an early Roman type shown by the presence of the furnace bottoms which, of course, are a feature of the Early Iron Age rather than the full Roman period. The Minepit Wood furnace is also now dated to the early Roman period and is essentially of the same type of developed bowl furnace which was to become the mainstay of the medieval period.

The complete excavation report will be appearing in Sussex Archaeological Collections in January 1974, (Vol 111); it is expected that the Minepit Wood report will appear in the same issue.

BERSHAM IRONWORKS

This, the site of one of Isaac Wilkinson's works to the west of Wrexham in North Wales, is being investigated by John Turley, a lecturer on the staff of Cartrefle College of Education, Wrexham. This site is not far from the modern works of Brymbo, which itself still has an early blast furnace. Thanks to the kindness of the metallurgical Department at Brymbo Steelworks the following partial analyses of some of the Bersham slags have been carried out and the results made available to us.

Location

	River bank			New Furnace		
%	1	2	3	1	2	3
Fe as FeO	11.4	7.1	6.5	27.5	4.5	14.2
SiO_2	42.1	44.3	43.6	37.5	49.8	37.8
CaO	15.4	9.5	20.8	6.3	17.9	22.2
P_2O_5	0.11	0.22	0.11	0.11	–	0.11
Al_2O_3, MgO, MnO	Remainder			Remainder		

These are fairly typical early blast furnace slags with low lime and some iron. *(see Bulletin, 1964,* 1 *(3), 5).* It would seem that most of them are undoubtedly charcoal slags. If the basicity is expressed as CaO/SiO_2 (mol.%), there is a reasonable correlation between it and the iron content. The chief exception is No.3 from the New Furnace site. Bersham was worked from 1649 until John Wilkinson's death in 1808.

TINTERN IRONWORKS, MONMOUTHSHIRE

The National Museum of Wales under the direction of its Keeper of Industry D Morgan Rees and assisted by R G Keen has been investigating the remains of one of the blast furnaces in the valley of the Angidy near Tintern. *(G. Ref. SO 524002).* Although the members of the HMG passed the site last Autumn during the tour in connection with the annual conference, it was not possible to see the remains because of the density of the undergrowth. However, remains have been found and are being surveyed. Meanwhile we have received the results of an analysis of the slag from this furnace supplied to us by Mr Martin Headworth. These analyses were made by the BSC at Llanwern. Two analyses were made from a large lump, the top portion of which had a green-glassy character typical of early blast furnace slag (A1), while the bottom was stony-grey (A2). It seems that this segregation has occurred during cooling and is not the result of two different taps of slightly different composition on the same place.

%	A1	A2
Fe as Fe0	1.02	4.6
Ca0	32.6	34.5
SiO_2	48.4	51.3
Mn0	0.7	0.9
Mg0	13.9	6.2
Al_2O_3	3.1	3.3
S	0.11	0.12

This clearly represents charcoal smelting; the ore was probably from the Forest of Dean, no doubt fluxed with limestone from the same source.

A second sample (B) was also examined but was found to be very heterogeneous containing slag, iron prills and charcoal. Its diameter was about 30 cm.

It is noteworthy that piece A has a higher iron content and is less basic at the bottom, while at the top the iron content is lower and the basicity is higher. The fact that the top is glassy and the bottom not so would suggest that the top has cooled at a faster rate than the bottom leading to downward segregation of the iron.

Five years'activity of the "Comité Pour la Siderurgie Ancienné"

A considerable growth of research in the history of ancient and early iron working has led to a more organized exchange of results among active scholars and research centres all over the world. The interdisciplinary character of problems involve archaeologists, metallurgists, historians and other specialists. An attempt to assist this collaboration was made by establishing a "Comitế pour la sidếrurgie ancienne" on the occasion of the VIIth International Congress of the Prehistoric and Protohistoric Sciences in Prague in 1966. This committee is affiliated to the permanent "Union internationale des sciences prếhistoriques et protohistorique" of UNESCO. Its activity began in 1967 when regular issues of "Communications" started to appear in the journal "Archeologickế Rozhledy", edited by the Archaeological Institute of the Czechoslovak Academy of Sciences, Prague.

Since that time 10 Communications have been published in the above journal: No.1 in the AR 1967 **19**, 782-788; No.2 in 1968 **20**, 522-530; No.3 in 1969 **21**, 243-252; No.4 No.4 **ibidem** 552-559; No.5 **ibidem** 823-830; No.6 in 1970 **22**, 352-359; No.7 in 1970 **22**, 607-615; No.8 in 1971 **23**, 335-346; No.9 in 1972 **24**, 192-201; and No.10 **ibidem**, in the press. The issues contain more than 460 bibliographical items concerning the history of iron from its beginnings up to the Middle Ages. They are divided into several subjects: excavations of furnaces, bloomeries, and smithies; references to important finds including the earliest iron artifacts, hoards, bars, metal worker's graves etc; papers on mining iron ore; metallographical investigations of early objects; studies in the theory of the bloomery process and other analytical studies focused on the chemical composition of steel and slags; reports on experimental smelting; studies in historical development of the iron industry in individual areas of the Old World. The average increase of books and papers during 1966/71 amounts to about 84 items per year. This fact demonstrated the rapid development of studies in the various fields. In addition to bibliographical abstracts, each Communication contains current information on the scientific activity of research centres and individual scholars.

Until 1972, 114 contributing members from 22 countries (7 from Great Britain) were registered as members of the Comitế. In addition, 25 institutions from 13 countries are corporative members. The President of the Comitế is Professor W U Guyan (Schaffhausen, Switzerland) and the Secretary is Dr R Pleiner (Prague, Czechoslovakia). The Secretariat is at the Archaeological Institute of the Czechoslovak Academy of Sciences, Letenska 4, Prague 1.

In 1970 a symposium entitled "Die Versuchsschmelzen und ihre Bedeutung für die Metallurgie des Eisens und dessen Geschichte" was organised in Schaffhausen. Much attention was devoted to the problems of primary carburization of iron during direct process.

The staff of the Comitế will welcome any enquiries from those interested in research or information on the early metallurgy of iron.

Letters to the Editor

From Charles Blick

Maryport Revisited – 30 September 1972

Sir, Last night I went back to Netherhall. It looked just like Mandalay must have looked on that classical return visit – overgrown, derelict, destroyed.

It was 20 years since I was last there when Colonel Guy Pocklington Senhouse had first asked us to discuss the possibility of the preservation of the old Maryport blast furnace. The grand drawing room on the west side – now gone without trace – was still beautifully furnished, and the gin was naturally kept in a cellar at the base of the pele tower which was the heart of Netherall. Before we left, Colonel Guy showed us three rusty pigs of iron in a stone passageway and said that they were from the old Maryport blast furnace.

The next part of the story is all too well known – the Colonel's death, the accession to the estate of Mr Roger Senhouse, The Hall standing empty, the destruction of the old furnace and then the death of Mr Roger. The scramble for as much information about the old furnace as could be found was begun. The report in the September 1965 issue of the JISI was a masterpiece of deduction. As the "one who has kept in touch with the Maryport blast furnace over a very long period", I failed abysmally in recording internal dimensions. I never imagined it could be felled. I had taken many visitors to it and into it, and we used to gaze up at the remarkably and only slightly damaged lining. Dr H R Schubert put out a plea for its preservation (JISI, October 1962). The then Chief Inspector of Ancient Monuments, Mr B H St J O'Neil came to the furnace, agreed it should be preserved and tried to maintain contact with Mr Senhouse in London. It was all of no avail – in the summer of 1963 the furnace was demolished.

Meanwhile Mr Brian Asmore had mounted a rescue operation to salvage the collection of Roman and Celtic altars and inscribed stones found in the adjacent Roman site, and Mr Senhouse had fitted out the Coach House for their secure accommodation since the demise of the Hall now appeared inevitable. Remembering the "pigs" I asked if it might be possible to salvage these. In short – and over a period of at least a year – Mr Ashmore, greatly daring, searched in the dark, in the moving, constantly collapsing, debris of the animate fungi-ridden hall and found all three. The saga of this search is really worthy of a paper on its own, for, after two pigs had been rescued, there was a fire at Netherhall.

The three pigs now rest in safe custody with the collection of altars and inscred stones. Mr Ashmore allowed me to photograph them, and the photograph is reproduced by permission of Mr J Scott Plummer, the new owner. The dates are quite clear – NH 1755, NH 1757, and NH 1769. They have not been analysed and there being no time to weigh and measure them properly, I can only report that they were about 36 in long, and about 70 lbs each.

We are very grateful to Mr Brian Ashmore for locating and rescuing these three pigs of iron from what was a short-lived but large blast furnace of its time.

Yours faithfully,
C R Blick

LETTERS TO THE EDITOR

From Professor Hugh O'Neill

Sir, During the discussion of D G Tucker's paper, at the Cardiff Conference on 'The Wireworks at Tintern' it was said that the object of "watering" iron rods for some weeks before drawing was not clear, and I then suggested that it was to form a coating to assist lubrication. A visit to the firm of Rylands in 1922 showed that descaled rod was held in water to form a rust coating after which a further slaked-lime coating was added. Dearden's 'Iron and Steel Today' states that descaled rods are allowed to form a "sull" coating of rust before drawing and the US 'Steel Wire Handbook' (1965) has a lot to say about coating, the calcium hydroxide acting as a solid lubricant carrier.

Yours faithfully
H O'Neill — 23 November 1972.

i) NH1769 :
length 35"
width of flat surface 3¾"
curved surface 7" average
girth 10¾" average
thickness from flat surface through to the lettered side (excluding short length of taper at each end) 2⅜"
length of letter panel 9"
size of letter 2"

ii) NH1757

length 37½″
width of flat surface 4″
curved surface 6½″ (at one end), with a maximum of 8¾″
girth varies from 10½″ to 12¾″ for most of the length a fair average would be 12⅜″
length of letter panel 9¾″
letter size 1½″

iii) NH1755

length of flat surface 37″
width of flat surface 4″
curved surface 7″ to 7¼″
mean girth 11″
length of letter panel 10½″
letter size 1½″

Book Reviews

Ryndina, N V: Ancient metalworking production in Eastern Europe. *(In Russian).* 1971. Moscow, USSR. University of Moscow Press. 7 x 10½". illus., diagrs., tables, maps, 141pp + 32 plates.

The author of this book was responsible for the examination of the non-ferrous material from the Medieval site of Novogorod and is a specialist in the non-ferrous field of archaeo-metallurgy. The present work covers the Tripolye culture datable to the period 4250–2000 BC and extending from the northern shores of the Black Sea to the basins of the Bug, the Dniester and the Dnieper. This culture covered the Neolithic, Eneolithic, and Early Bronze Ages; much of the material considered is derived from the archaeological work of T S Passek, famous for her work on the Tripolyan settlements. The book opens with a discussion of the methods of metallurgical examination used. Some new analyses are given from which it would seem that the metal used in the early periods could well have come from native copper which has absorbed considerable oxygen in melting. Tin bronzes were introduced in the last phase of the culture. Further chapters cover the metal working production in the early period *(Phase A in Passek's chronology)* and we have a discussion of the techniques used for the making of hammer-axes in which Allen and Coghlan's ideas are accepted. A good many of the artifacts dealt with come from the Karbinsk hoard and the metallographic structures are well illustrated in the plates at the end of the book. The structure of two bead necklaces is discussed, one of which is made of copper beads made to look rather like amber beads, and the other of tubular sheet copper beads like those from Ali Kosh examined by C S Smith.

Another chapter discusses the peak period of Tripolyan metal work, Passek's phases B1 and B2. The material is treated in the same way as the previous chapter and some crucibles are shown. The book concludes with a brief summary of the examination and gives a chart of the various types of artifacts and metals and the phases of the Tripolye culture in which they occur.

Lack of familiarity with the language makes the reviewer reluctant to criticise such a book which clearly covers an important culture in a professional way but it would have been very useful to have more tabulation of the results, particularly the analyses.

R F Tylecote.

Grzelishvili, I A [or Hershelishvili, I A] : Iron working in Ancient Georgia. *(In Russian).* 1964. Tbilisi. Published for the National Academy of the Georgian S S R Institute of History, Archaeology and Ethnography, – The I A Djavashvili Institute. 6½" x 10". pref., diagrs., maps, plates.

The author reviews the deposits of iron ore used in ancient Georgia with the aid of maps and diagrams giving the extent and depth of the deposits. He then discusses the bloomery technique taking examples from the area giving details of the technique used and the construction of the furnaces. The second part reviews the archaeological finds dating from the EIA into the Mid- and Late medieval periods and is well illustrated. The author has carried out a detailed investigation of slags and furnace lining from the sites and discusses the problems of Georgian iron production. Finally we get a breakdown of the output for each period. The slag analyses are tabulated and some show extremely large amounts of copper and sulphur.

R F Tylecote.

Kurt Schietzel (Ed). Untersuchungen zur Technologie des Eisens. *(Investigation on the Technology of Iron).* Berichte über die Ausgrabungen in Haithabu, No.5. With contributions by R Thomsen, F K Naumann and R Pleiner. Published for Schleswig–Holsteinisches Landesmuseum für Vor- und Frühgeschichte Schloss Gottorp, Schleswig. Neumünster,1971. 112 pp. Soft covers: 18 x 25 cm. No price.

This is the 5th report on Haithabu, a Viking period trading centre on the Baltic coast of Schleswig–Holstein. The object of the work was to establish whether iron was worked locally by an examination of the finds of iron objects and slag.

R Thomsen contributes a report on the metallographic examination of four bars and three axes. The bars had been made from several blooms welded together. Three of the bars were found in levels dated to the 9th century and the fourth bar was not stratified; it might have been imported from Gotland where similar bars were found. The surfaces seem to have been carburized to facilitate welding. The welding temperature was above 1147^{o}C, and after welding the bars had been cooled in water. The welds could be divided into four types:– 1) the ideal weld interface which can only be detected when it separates two dissimilar structures; 2) the almost perfect weld showing only as a thin line of oxide; 3) a weld interface containing slag; and 4) a weld interface composed of carburized surfaces.

The bars had been made from ore relatively low in phosphorus giving figures in the range 0.028–0.086%. One of the bars had been carburized and the ends could be used to form the cutting edge of an axe.

Metallographic examination of the three axes showed that they had been made of piled material of varying carbon content so arranged that the highest carbon content was in the centre but it did not necessarily outcrop on the cutting edge. However, the mean carbon content of a section of Axe No.1 was 0.54% and the %P was again low showing that the axe could have been made from the same material as the bars. The hardness varied between 121 and 199 HV1 depending on carbon content showing that no quench-hardening had been used. Axe No.2 on the other hand was of low carbon content and the hardness did not exceed 145; but the P content was in the range 0.1 to 0.5% showing that a rather different ore had been used. Axe No.3 was similar but with an intermediate P content. It is clear that for most of these tools the carbon steel, when present was not used to the best advantage from the structural point of view but it may have had a decorative purpose. The lack of quench-hardening is in keeping with African and indeed modern practice where the ease of sharpening is more important that the actual hardness.

Thomsen's second contribution is on two socketed spearheads. Radiographic examination showed that these had the pattern-welded structures that we now expect from such implements of this period and which have been discussed at length in M Swanton's Durham PhD thesis. The edges had been welded to the blades with a typical scolloped join. For the most part the carbon content was low but one of the cutting edges reached 1.55% C and had been quench-hardened to give a figure of 750 HV. Thomsen gives detailed drawings on the manner of construction of these interesting weapons.

F K Naumann's contribution relates to three draw plates found on the site. On the entrance sides of two were linear grooves containing all four-five holes of the plate. The basic material was piled medium carbon steel with a hardness of about 150–300, but a section through one of the holes showed a quench-hardened structure with a maximum hardness of 900 HV. A third plate had six holes but no evidence of quench-hardening was observed; perhaps this had not been effectively hardened due to its lower carbon content.

One of the most interesting metallurgical finds from this site was half a tuyere stone or "Essestein" of a type known from Snaptun in Denmark. The Snaptun example has been engraved with a man's face in such a way that the tuyere hole lies below the mouth. These stones accepted the bellows nozzle at the widest side of the tapered opening and acted as a protection against the heat of the charcoal banked up against the other side. The Haithabu stone, reported by Thomsen, was broken through the tuyere hole which tapered from 4.5 cm to 1.5 cm at the fire side. The complete stone must have been about 20 x 18 x 7.5 cms thick. The slag found in connection with the stone was a typical small smithing furnace bottom of iron silicate and Thomsen shows how it was related to the tuyere stone.

The work concludes with a short note by R Pleiner on the smithing slag giving a full analysis which is similar to that of Thomsen's. The free-running temperature is estimated as 1280°C but its formation temperature and the temperature of working were probably around 1180°C. The phases observed were olivine and magnetite with some glass.

This type of report rather than a comprehensive archaeological report is perhaps the best way of publishing the findings of specialists on such subjects as it allows immediate comparison by others interested in the subjects. This example gives a very rich collection of data and this review does not claim to give a full picture of all the work that has been done on the finds and all the conclusions reached. It should be however enough to show that it is well worth reading by all those interested in the subject of early iron working. The Schleswig–Holstein Landesmuseum is to be congratulated on commissioning and making available such a worthwhile collection.

E C J and R F Tylecote.

E T Hall and D M Metcalf (Eds). Methods of Chemical and Metallurgical Investigation of Ancient Coinage. A symposium held by the Royal Numismatic Society at Burlington House, London, 9–11 December 1970. Royal Numismatic Society Special Publication, No.8, 1972. Cloth bound, 7½"x 10", pp 450 + 20 plates. Price £11.00.

In the eighteenth century it was still more or less possible for one man to be in touch with all the boundaries of knowledge. The notoriously exponential growth of data accumulation since those days now effectively inhibits eminence in both the scientific and humanistic fields simultaneously. Any book which, like the one under review, attempts to bridge the gap between the two fields deserves scholarly attention. As it happens, numismatics is a particularly fertile meeting point for the interaction of several disciplines and many of the papers presented at the Symposium on which the volume is based, bear witness to this.

Coins differ from most other ancient artifacts in a number of ways. Because they were meant to represent a standard value, both their weight and metal content had to conform to limits imposed by economic and not technological factors, let alone artistic ones. At the same time, production was on a vast scale – numerous issues were struck by the million – and so techniques were evolved which would have been quite inappropriate to the "one-off" processes characteristic of a pre-industrial society.

The varying availability of the two major precious metals implied, and indeed still implies, that a given object was worth varying quantities of gold or silver in circumstances altering geographically or chronologically. The necessary change was often effected not by the psychologically damaging method of weight reduction, but by the addition of base metal alloying elements which maintained the outward appearances. The economic history of antiquity has largely to be charted from surviving coinages and so now the numismatist is turning to the chemist, the physicist and the metallurgist for help in answering questions central to his studies. This "Special Publication" gives their replies in admirable detail.

Undoubtedly, the most accurate way of determining the metallic contents of a coin is a completely destructive wet chemical analysis. The initial paper, by L H Cope, incorporates the results of many such analyses on issues of the Roman period. He points out the necessity of recording trace elements with as much accuracy as the major constituents, since they can often be conclusive in establishing the source of the ore, a consideration taken up by other contributors. Chemical cleaning prior to analysis may, of course, remove some of the original metal and Cope rightly insists on mechanical abrasion as the preparatory step. The general procedures associated with chemical analysis are by now well standardised but he makes some valuable observations on sampling techniques when one coin is to be subjected to two or more analytical methods. The Roman coinage of the third century AD is noteworthy for the surface-silvering employed by the Mints before putting it into circulation; Cope devotes an interesting paper solely to this topic and, supporting his arguments with experimental observations, demolishes many earlier theories. His own explanations, depending upon the degree of debasement, seem to satisfy practical criteria.

It takes a hardened numismatist to surrender a unique specimen – and in a sense, all are unique – to absolute destruction. Accordingly, the majority of the reports in this volume cover methods which, to a greater or lesser extent, are non-destructive or do not involve "aesthetic damage". Perhaps the most traditional of these uses the measurement of specific gravity. Because of its relative simplicity, analysis by S G determination is about the only one which can be carried out without sophisticated and expensive equipment. Oddy and Hughes discuss the ways in which errors such as those caused by surface tension effects can be compensated for. Although, as they make clear, tertiary and higher alloys cannot normally be dealt with they include a formula to cover gold – silver – copper cases; this, with a few corrections added in an Appendix, has enabled them to supply analyses of the Merovingian "gold" from Sutton Hoo. Their results compare well with a similar set drawn up by Coleman and Wilson and based on analysis by gamma-ray activation carried out at Aldermaston on the HERALD reactor. Among the advantages of this now standard technique, we may note that, if irradiated in bulk, the cost per coin is small and, at the same time, residual radioactivity is insignificant after a few days so that the coins may then be handled with complete freedom. The happy collaboration between those scientists just mentioned and Kent, a numismatist, has permitted a convincing dating sequence for the Sutton Hoo coins; the previous lack of this, so crucial for the whole context of the famous ship burial, has been a standing indictment of the validity of numismatics as a discipline to be taken seriously by medievalists.

In addition to the usual gamma-rays, neutrons may also be used to induce radioactivity in metals and Gordus describes two technqiues based on this phenomenon. The elements whose isotopes are most easily detectable are silver, gold and copper, while others are more difficult and lead cannot be found this way at all. An intriguing departure from normal practice is Gordus's "streak" method. Here a piece of quartz is rubbed against the edge of the specimen, removing less than a milligram which, being on the quartz surface, may then be irradiated as before. Up to 200 coins may be "streaked" in a day in a coin room which they need never leave – the chief advantage of the method. Of course, if the coins have suffered surface enrichment or are inhomogeneous from some other cause, the streak technique will give false answers, but it comes into its own for the detection of "trace" percentages of gold. Gordus shows how groups of coins from the same source in the Sassanian series have a remarkably constant gold content. Departures from the normal figure, not merely in coins but also in table ware and the magnificent silver plates so charactiersitc of this Iranian dynasty, raise doubts about authenticity and may, in combination with other factors, condemn outright as characterstic of modern forgeries.

Another analytical method, based on considerable laboratory experience, is discussed critically by Schweizer – this is X-ray fluorescence or, more specifically, spectrometry using a point source linear X-ray spectrometer. Here, too, surface enrichment can vitiate the results and to overcome the problem, it is usually necessary to abrade a small area (less than 2mm^2) with fine emery. Naturally, the edge is, if possible, chosen in preference, but it is frequently acceptable to take "milli-probe" readings from the face of the specimen. The millprobe defines the position and magnitude of the area to be analysed. Schweizer outlines those factors influencing the accuracy of the techniques, emphasising matrix effects arising from the additional presence of elements not included in the original calibration graph. He concludes with a comparison of analyses by this method and straightforward wet chemical ones. As far as silver content is concerned the difference rarely exceeds 2%.

When dealing with coins suffering from extensive corrosion or where other manufacturing processes have caused appreciable discontinuities in the structure, X-ray fluorescence analysis runs into difficulties which are aggravated by emission of the incident beam on to a curved surface. Charles and Leake show how such problems were overcome in an investigation into the later Byzantine scyphate (or rather "trachy") coinages, recently the subject of an exhaustive study by Hendy. It is heartening to note how much this numismatists' conclusions can be supported by his scientific colleagues. Padfield also publishes numerous analyses of the Byzantine base metal series; these were obtained not merely by X-ray fluorescence but also by electron microprobe techniques, conducted on small fragments drilled from the edge of various examples. He is able to demonstrate once again how trace elements point both to variations in smelting practice and also to different ore sources; nickel, for example, is typical of coins from the North east of the empire. Finally, Cope and Warren compare the probable accuracy of electron probe micro-analysis with that obtained from related methods.

The question of impurities in a group of Anglo-Saxon pence and other contemporary issues is also raised by McKerrell and Stephenson. They correctly assume that lead cupellation formed an essential stage in the production of silver at this period. Then, by employing an analysis based on atomic absorption spectro-photometry applied to 10 mg samples from the coins, they have been able to demonstrate a significant correlation between percentages of trace elements, such as gold and bismuth, and the probable incidence of specific extraction techniques.

The manufacture of glass in antiquity has recently aroused much interest; ways of investigating glass production by studying the lead isotopes contained in various samples, are here adapted to numismatic purposes by Brill and Shields. The authors refer to other works for the methods used in their determination of the relative proportions of the four stable isotopes of lead to be found in a series of coins. From their graphical presentation of the results, there is no doubt that we may pin-point the ore sources geographically according to the isotope proportions. A short paper by Campbell suggests the intriguing possibility of determining alloy ratios by measuring the thermal expansion coefficients of coins. However, no experimental data have yet been obtained to "prove" the theory.

The French research team of Condamin, Picon and Guey has, over the past decade or so, published much important work in the field of scientific numismatics and it is gratifying to record another valuable contribution from them in the present volume. Very frequently we neglect time-dependent changes in metal structures. Preferential corrosion of copper in a silver-copper alloy is only one of the most obvious pitfalls facing the analyst and, in general, surface analysis must be undertaken with such points in mind. A characteristically pithy addendum from Thompson also warns of the age embrittlement suffered by many such coinage alloys.

With a plethora of information originally published in widely disparate forms, it is very convenient to have concluding chapters gathering together analysis data. McDowell writes about pre-Mohammedan India, while Metcalf deals with the vast field of medieval coinage. Facts, not methods, are of course, their main concern. A bibliography of the major relevant publications has been contributed (in French) by Nāster and Hackens. At the symposium itself, a summing up from the scientist's viewpoint was given by Hall and from the numismatist's, by Mattingly; both are usefully reprinted. in the appropriate place in the book.

The lack of a subject index will be regretted by many readers, although the glossary does help the scientist who is not a numismatist and vice-versa. One or two photo-micrographs tend to be rather too dark for ease of appreciation, while polishing scratches have not always been eliminated. These, though, are trifling objections to a work which will be a "must" for the library of all concerned with the interaction of history and technology. The editors, Hall and Metcalf, and the Royal Numismatic Society deserve our sincere thanks.

D Sellwood.

Abstracts

GENERAL

Henri Feer: Métallurgie et Idolatrie. *Fonderie, May 1972, (312), 169–174.*

A fascinating study of the Biblical account (32nd chapter of Exodus) of the construction of the Golden Calf, which dates from about 600 BC, in an attempt to identify the method of construction.

Three hypotheses are stated and examined in the light of diverse transcriptions and translations of the text:–

1. that the calf was cast, and that the moulding was good enough for it to be acceptable with no further treatment;

2. that the calf was cast and then finished by graving;

3. that gold was cast into sheets which were then beaten and formed into shape around a wooden or other combustible core.

Tentative suggestions are made but no conclusion is drawn – perhaps wisely. The author drily expresses the hope that this unusual study, while it might attract the thunderbolts of the theologians, should interest engineers and others engaged in metallurgy!

BRITISH ISLES

Anon: Replica propellor for S S Great Britain. *Foundry Trade J., 1972,* **132** *(2891), 635–636.*

Gives details of foundry techniques used in manufacture of cast iron and mild steel replica of original wrought iron propellor. Illustrated.

Anon: Foundry Craftsmen reproduce Eighteenth Century Casting. *Foundry Trade J., June 8th 1972,* **132** *(2896), 785, 786, 791.*

Describes techniques used to make a replacement flywheel from drawings made by James Watt for a 1786 beam engine in the Royal Scottish Museum, Edinburgh.

T G Grey-Davies. Redbrook-on-Wye. An early Copper-producing Centre. *Foundry Trade J., June 15th 1972,* **132** *(2897), 823–824.*

After the failure of copper works in Cumberland and Staffordshire, John Coster successfully established a copper-works at Redbrook in about 1688, using local and Cornish ore. The Governor and company of Copper Miners in England bought the works and the subsequent history of the Company, including the opening of works in South Wales, and the closing of Redbrook is outlined.

D G Tucker: The embanked ponds of the Penallt-Whitebrook-Redbrook area and their industrial uses. *Severn and Wye Review, Spring, 1971,* **1***(3), 50–58.*

A study of water-power sources in part of the Wye Valley with map, photographs and references. Contains information on the iron-wire works at Whitebrook (modified by Prof Tucker's subsequent paper to the HMG at Cardiff, 1972) and to iron and copper smelting at Redbrook.

T G Grey-Davies: The Goodrich Bomb. *Severn and Wye Review, Autumn 1971,* **1***(5), 117, 118.*

A short account, with illustration of the mortar preserved on Castle Green, Hereford, and believed to be 'Roaring Meg' used in the siege of Goodrich Castle, 1646, having been cast locally.

Anon: A hoard of Roman Pewter. *Illustrated London News, December 21, 1968,* **253** *(6751), 30–31.*

A brief description of a find, consisting of 22 pieces of Roman pewter, discovered in a gravel pit at Appleford in Berkshire. It is the third largest hoard known in England, probably dating to the end of the fourth or early fifth centuries. Roman pewter was a British product, and pewter in the ancient world is known only from south and eastern Britain. HNL

Anon: Roman Pewter Hoard. *Nature, 1969,* **221** *(5176), 127.*

Twenty-three pieces of Romano-British pewter ware together with various iron implements, some potsherds and a few pieces of leather and wood, were discovered last summer at Appleford in Berkshire.

All the pewter is remarkably well preserved, probably because the hoard was originally dropped in a well and has lain submerged in the water ever since. TS

John Coles: Metal analysis, and the early Scottish Bronze Age. *Proceedings of the Prehistoric Society, 1969,* **35**, *330–345.*

The statistical methods described by Walterbolk are applied to the results for the Scottish Early Bronze obtained by spectrographic analysis of metal objects by Junghans, Sangmeister, and Schröder. Using this method of cluster analysis the analyses fall into four groups. The Early Bronze Age is discussed in the light of these groupings. PTC

Mavis Mate: Coin dies under Edward I and II. *The Numismatic Chronicle, 1969,* **IX,** *207–218.*

The capacity and output of medieval coin dies may be calculated based on surviving documents. In the past, a basic difficulty for such calculations resulted, however, from varying interpretations of the word "cuneus" as it appears in mint account records. Some thought that "cuneus" indicated single dies while others interpreted it to mean complete sets of dies. The author settles this fundamental problem based on documents and ascertains that **cuneus** is used to indicate single dies.

The London Mint accounts from 1281 until 1327 contain a double record of the number of dies manufactured as well as of dies used. There are also accounts of the amount of bullion coined at London and Canterbury. In spite of this wealth of information, many variables must be taken into consideration when using this data for average output calculations.

Geneally, two trussels were used for each pile, but ratios of up to 1 : 3 and even 1 : 4 may be noted. Such extreme ratios lead us to suspect that we are faced with instances of rather ham-fisted hammer-men who quickly split the trussels.

The coin output may be calculated as high as 39,031 per obverse die under Edward I but it may drop to a low 23,000 during the re-coinage of 1300 – or even lower – due to the inferior quality of dies.

In a rather hypothetical calculation, the output of a moneyer may be assumed at 2,200 coins a day, or 220 an hour, or nearly four a minute, if the moneyer worked a ten-hour day.

In any event for a normal ratio of one pile to two trussels used, one may assume an average output of 30,000 to 35,000 coins. VC–S

M J Hughes: A technical study of opaque red glass from the Iron Age in Britain. *Proc. Prehist. Soc. 1972,* **38,** *98–107.*

Gives analyses of glasses of this type used to decorate bronzes and shows that there are two varieties. 33 specimens from Britain are of the alkali-lead-silica ("sealing wax red") type with about 7% cuprous oxide and about 25% PbO. In this type the copper is present as red feathery crystals of Cu_2O in the glass matrix. Such were in use during the period 1st century BC to 2nd century AD. This material probably reached Britain by way of trade from the Mediterranean. But it is also clear that a less brilliant opaque red glass was being used in the Mediterranean area itself which had a lower copper and lead content, the former present as minute particles of metal. This was used when large quantities were wanted, ie. in mosaics.

J Brailsford and J E Stapley: The Ipswich Torcs. *Proc. Prehist. Soc. 1972,* **38,** *219–234.*

East Anglia has been a very fertile area for gold torcs of the EIA. This paper refers to two hoards found in the Ipswich area in 1968 and 1970. Six torcs have been analysed for Au, Ag and Cu and it is clear that all but one have been made from natural gold with a silver content of between 10.7 and 18.8%. The single alloyed torc contains 6.3% Cu in the twisted wires and 11.8% Cu in the terminals; this would lower the melting point and increase the wear resistance besides making a better use of the gold.

Stapley examined the construction and found that the bodies were mainly composed of 8-sided "wires". Draw plates are still unknown for this period and he considers that 9 mm dia wires were too large to be drawn at that time. Replicas were made in Ag from a disc ingot cast between iron plates. The disc was forged and then cut into a continuous spiral ribbon with a chisel – a technique described by Theophilus. Another method was to use a slice from a dry tree and to cut a hollow in it to use as a bar mould. Both the cut wire and the hammered ingot could be forged into faceted wires. The existence of a "flash" on some of the original wires suggested that some form of swage had been used in the actual torc wires and such a technique was tried with intermediate annealing. The terminals appeared to have been cast using an investment casting technique which was repeated with a fair amount of success.

Hugh McKerrell and R F Tylecote: The working of Copper-arsenic alloys in the Early Bronze Age and the effect on the determination of provenance. *Proc. Prehist. Soc. 1972,* **38,** *209–218.*

Loss of arsenic from arsenical copper was found to occur only under oxidising conditions. No loss of any practical consequence was observed under non-oxidising conditions up to 1150°C ie. when holding Cu–10% As alloy in the molten state in a crucible under charcoal or nitrogen. The cast metals were found to be very prone to inverse segregation giving high surface arsenic contents which were reduced considerably by working during forging. As the Cu-As eutectic present in these alloys melts at 689°C, much of the forging occurs in the presence of a liquid phase. It is possible to control the final As by noting the evolution of the white arsenic (As_2O_3) fume during working and in such a way achieve low As contents for soft artifacts such as rivets. The losses under such conditions must reduce the reliability of As as a provenance parameter. It seems that other elements such as Sb could also be subject to segregation during casting and surface loss during working, and caution is advised in the use of rigid analytical levels as indicators of provenance.

Anon: Norfolk Foundries – Historical Survey. *Foundry Trade Journal. 1972,* **133** *(2908), 26.*

A historical survey of foundries in Norfolk is planned by the county's Industrial Archaeology Society (Secretary: 2 Mill Corner, Hingham, Norwich, NOR 23X). The intention is to list all foundries in existence from about the year 1800, survey their sites and photograph any remaining buildings. Articles made by these old foundries are to be stored at the Bridewell Museum, Norwich, where the results of the survey will eventually be deposited.

D James: The Statue Foundry at Thames Ditton. *Foundry Trade Journal. 1972,* **133** *(2909), 279–289.*

Started in 1874 by Cox & Sons, a leading firm of ecclesiastical suppliers, the firm underwent many changes of ownership but few changes in equipment so that at final closure in 1939, there was no electrical supply available in the works, and much of the equipment, including the overhead gantry crane and the centrifugal blowers for the cupolas remained "mandraulically" operated to the end. After limited modernisation, industrial castings were made for a period, and then the building was used as a metal store before being sold to the local council in 1971/72. The entire site is now under threat of demolition, but as so much of the original equipment survives, it is suggested that preservation should be considered.

The techniques employed are fully described and discussed, and some of the major products are illustrated.

Anon: Old Pumps. *Foundry Trade Journal. 1972,* **133** *(2911), 362.*

Display at the annual conference of the British Speleological Association, which was held at Sheffield University, the pumps had been brought to the surface from the flooded depths of Knotlowe Mine at Monyash, Derbyshire, which was abandoned about 1875. They consist of an endless chain interspaced with leather washers which forced the water up a wooden pipe.

Anon: Demolition of Old Works. *Foundry Trade Journal. August 17, 1972,* **133** *(2906), 196.*

Demolition work began recently at the Edward Lucas works in Dronfield, Derbyshire, which when founded in 1704 was the first malleable iron foundry in the country. It is hoped that the main archway will be retained. The site is to be turned into a garden. (NB: it is generally accepted that Réaumur first announced the malleablising process in 1722. Abstractor).

L Holden: Bradley & Foster – A History. *Foundry Trade Journal. August 17, 1972,* **133** *(2906), 209–210.*

Outlines the history of ironmaking on the site at Darlaston Green from the first stone-built blast furnace of 1799, through the peak years around 1870 when three blast furnaces, 63 steam engines, 8 rolling mills, a drawing-out forge, and 43 puddling furnaces were available, and nearly 1000 men employed, to the end of ironmaking after the first world war, and the development since 1922 of the present refined-iron foundry and foundry abrasives business.

EUROPE

D L Searle: Mode of occurrence of the cupriferous pyrite deposits in Cyprus. *Trans. Instn. Min. and Met. 1972,* **81B,** *189–197.*

A very useful contribution to a problem of great interest to archaeo-metallurgists involved in the Eastern Mediterranean. The author concludes that the cupriferous sulphide deposits are characterised by three principal zones:– Upper sedimentary horizon, massive pyrite, and underlying stockwork. He believes that there was only one period of mineralization which took place during the interval between the Basal Group and Lower Pillow Lava volcanicity. This means that there may be other hidden deposits sealed by Lower Pillow Lavas; presumably all the deposits known to early man were exposed by weathering. Gives useful tables of copper content and diagrams showing the stratigraphy of present known deposits. He gives a list of minerals occurring in the various horizons. The copper content varies from 0.2 to 4.0% and there is little evidence of secondary enrichment.

G Constantinou and G J S Govett. Genesis of sulphide deposits, ochre and umber of Cyprus. *Trans. Instn. Min. and Met. 1972,* **81B,** *34–46.*

Another very useful paper on the same problem. Since the weathering of the Cyprus deposits occurred under marine conditions the "gossans", if such a term can be used, are quite different from those resulting from more normal types of weathering. From the analysis of the ochres that lie above the cupriferous deposits it is concluded that these are directly derived from the pyritic sulphide deposits by submarine weathering. As they contain as much as 78% Fe_2O_3 and relatively little sulphur they would make much better fluxes for early copper extraction than the more normal gossans with their high sulphur and arsenic contents. On an unconformable horizon above the ochres are sedimentary umbers the composition of which is rich in MnO_2. Since the $MnO_2 + Fe_2O_3$ content is as high as 61% these also would make good fluxes and their use is probably demonstrated by the slags containing appreciable (more than 10%) MnO_2.

This paper also gives some help to those trying to elucidate the mineralogy of Cypriot copper ores. The authors have identified three paragenetic types of pyrite. The Chalcopyrite in the massive ore varies from 1–10% in a single hand specimen. It is present in larger concentrations in the upper parts of the massive pyrite than in the lower, and in smaller quantities in the stockwork. Sphalerite is present in all deposits. Other copper minerals identified were:– covellite, digenite, idaite, bornite, and chalcocite. Galena, tennantite, tenorite, paramelaconite and delafossite have been found but are rare. It is clear that the Cyprus deposits are characterised by the overwhelming presence of copper as a sulphide and the comparative absence of oxides and the total absence of native copper due to the unique type of weathering and the reduced degree of secondary enrichment.

Catling, H W : The Cypriote copper industry. ***Archaeologia Viva, March–May, 1969,*** **2** ***(3), 81–92. Illustrated, with map.***

The copper deposits of Cyprus, which have been worked since the third millennium BC, are located in the western half of the island, mainly along the northern edge of the Troodos Mountains, and are found in two quite different rock formations: one diabase and the other called pillow lavas. The latter which are copper-bearing pyrites, are overlaid with sedimentary marls. The amount of copper in the ore is rarely more than 2–2½%. The slag heaps near Skouriotissa, which date from remote antiquity cover large areas. There is much evidence that ore or ore concentrate was sometimes carried some distance from the mines to near the coast for smelting. Many ancient mining tools have been found.

In the early Bronze Age, trade in copper was limited to the Syro-Palestinian area and to Egypt and some to Minoan Crete, but late in the fifteenth century trade expanded to the Mycenaean world and lasted for about two centuries. This is the time of the introduction of the oxhide shape for ingots of copper of which there were many examples in the Cape Chelidonia shipwreck. Besides exporting raw copper the Cypriotes kept some at home to produce bronze. Several examples of cast tripods from the Cyprus Museum are shown in colour. RJG

E N Chernykh: Spektral'nyi analiz i izuchenie drevneishei metallurgii Vostochnoi Evropy. (Spectral analysis and study of the most ancient metallurgy of Eastern Europe). *Arkheologiya i estestvennye nauki (Archaeology and Natural Sciences), 1965, pp 96–100.*

On the grounds of quantitative spectral analysis of about 200 copper and bronze objects the author draws conclusions concerning the origin of metals of the Eneolithic and early Bronze Age of the European part of the USSR, and indicates the principal stages of metallurgical development in Eastern Europe and adjacent areas from IV to I millennium BC. LV

Karl Loehberg: Untersuchungen an Eisenfunde aus Limeskastellen. (Analyses of iron objects from the Limes Fortifications) ***Saalburg Jahrbuch, 1969.*** **26,** ***142–146.***

An axe which was found in the Feldberg–garrison was manufactured from iron lumps of varying carbon content (maximum 0.4%). For the cutting edge of the blade a harder steel richer in carbon, was purposely used, which was obviously forged at 700-800°C in numerous stages and operations. The hollow for the handle was similarly formed at about 700–800°C.

The cutting edge was not hardened. This is unusual, as the Greeks and Romans were not unacquainted with the quenching method of hardening. It is, however, possible that this method was still unknown at the place of manufacture. On the other hand, it is possible that the cutting edge was yet to be hardened; the circumstances of its finding could account for this, as, according to the conjectures of Jacobi, the object originates from the **Fabrica** of the garrisons and was perhaps buried in its unfinished state. An answer to the question is only to be derived through further examination of iron objects found in the Limes Fortifications. The sliding wrench was forged of soft iron, low in carbon, at temperatures above 500°C. With illustrations. BM

Richard N Frye: Historical notes on Sasanian and Byzantine silver. *Bulletin of the Asia Institute of Pahlavi University, 1969. (1), 36–42.*

The varying use of gold and silver for coins and objects from the Roman through the Byzantine period is discussed and explained. The practice of writing the name of the owner and the weight on silver objects by the Romans, Sasanians and Byzantines, and the systems of weights used on Sasanian silver, are discussed. Illustrated. EWF

Hans Lange: Et bor fra Skanfinavien-udgravningen. (An auger from the Scandinavian excavation). *Kuml. Arbog for jysk arkaeologisk selskab, 1969. 1970. 191–194.*

An examination of an auger from the Middle Ages showed that a bit of fine-grained martensite had been welded onto an iron piece of pure ferrite, with only very little slag present. HBM

Denise Thomas-Goorieckx: Contribution a l'étude du "damas" des canons de fusils de la vallée de la Vesdre. (Contribution to the study of damascening of the gun barrels from the Vesdre valley). *Inst. Roy. Patrimoine Artistique, Bull, 1966. 9, 197–195.*

The industry of damascening gun barrels in the Vesdre valley was lost in the 19th century. It was possible to determine, through different metallographical examinations on a demonstration piece and on original gun barrels, the manufacturing technique and structure. DT–G

E R Caley: Analysis of an Etruscan Bronze. *American Journal of Archaeology, 1970. 74 (1), 98–99.*

The results of the analysis are: (in % by weight) – Copper 69.88; lead 23.8; tin 4.5; antimony 2.0; bismuth 0.5; arsenic 0.1; iron 0.13; nickel 0.07; cobalt 0.01; silver 0.01.

No conclusions are possible until results from additional quantitative analyses of Etruscan bronzes become available. TS

A complete quantitative analysis is given of a sample of metal taken from a thymiaterion ascribed to the third century. ERC

P A Borea: G Gilli: G Trababelli and F Zucchi: Characterization, corrosion and inhibition of ancient Etruscan bronzes. *Annali dell'Universita di Ferrara NS – Sez V, 1971. pp 893–917. 3rd European Symposium on Corrosion Inhibitors, Ferrara (Italy) 14–17th September 1970. 25 figures, 35 references (In English).*

Chemical analyses were made on 67 bronze objects from the Etruscan necropolis of Spina and conserved in the National Archaeological Museum at Ferrara. Percentages of Cu, Pb, Sn, Zn, Co, Fe, Ni and Sb are reported with totals (most to the 3rd decimal place) based on analysis by atomic absorption technique on Perkin-Elmer equipment using nitric-hydrochloric solution of the alloy which was partially neutralized with NH_4OH in the presence of EDTA. Sn and Sb were first separated as metastannic and metaantimonic acid: Cu and Pb were determined electrolytically by classic methods. An electronic probe microanalyzer was used on one of the objects for studying the distribution of the basic elements of the alloy. An XRD–5 General Electric diffractometer with a Zenon No.6 proportional counter was used for analysis of the surface corrosion products. The product most frequently found in the mineralized layers is brochantite $Cu_4(OH)_6SO_4$. Other minerals found were antlerite, chalcanthite, atacamite, paratacamite, covellite, djurleite, tenorite, cuprite, anglesite, laurionite, phosgenite, cerrusite, hydrocerrusite, galena, magnetite and silica. Among these the only one not previously reported is djurleite. The presence of this rare mineral which was found on only one of the objects, was confirmed by thermal analysis. It is concluded that sulphate and chloride are the most corrosive anions. Metallographic studies combined with back reflection photographs on a few of the objects gave information not only on composition, but also on methods of fabrication.

Anon: Giessereibetriebe in Olympia. (Foundries in Olympia). *Jahrbuch des Deutschen archaologischen Instituts, 1969. 84 (3), 1–28. Photographs.*

In the first chapter the author concludes from a study of the technical features of numerous faulty bronze fragments from the site of the sanctuary of Olympia that they are castings and have been made in foundries situated within the boundary of the sanctuary. This has been assumed previously by former authors, although no evidence of such local foundries has hitherto been proved. The author demonstrates with some certainty that temporarily installed foundries produced votive objects, at least in the early period of the sanctuary. Some categories of objects lead to the conclusion that foundries were operating within a limited period of time. Other groups of objects like reproductions of important large-dimensional objects must have been produced in the area of the sanctuary for which they were destined. Foundries located elsewhere which were suppliers of important large objects may also have established – at least temporarily – local branches in Olympia. In a second chapter a description is given of numerous specimens of copper ingots, shapeless masses of gassy bronze, and incompletely remelted parts of deliberately destroyed faulty castings. These specimens are distinctly different from the numerous tiny fragments of destroyed large-dimensional statuary from the period of decline of the sanctuary. Also the foundations of a huge above-ground furnace found in 1937 proves that large statuary casting took place at least during the Hellenistic period of repair of the sanctuary. Two more chapters deal with the technique of casting and Olympian art respectively. BM

Edward Sangmeister: Zur Ausbreitung der Metalltechnik in Europa. (The spread of metal technology in Europe). *Germania, 1968.* **46,** *4–10.*

4421 spectrum analyses of copper objects from Central Europe are used to demonstrate how the geographical and chronological study of "material-groups" of copper can clarify our picture of the spread of metallurgy in Europe. Three figures show the exploitation of different coppers during the successive phases of the Copper Age and EBA. A fourth shows how a material-group (A) can be geographically, as well as chronologically, restricted. The validity of the material-groups set out in Studien zu den Anfangen der Metallurgie, 1 (1968), is confirmed by spectrum analysis taken since then. BAA

Sigrid Dusek: Eisenschmelzofen einer Germanischen Siedlung bei Gera-Tinz. (Iron Smelting Furnaces of a German Settlement near Gera-Tinz). *Alt-Thuringen, 1967.* **9,** *95–183.*

An exhaustive description of the excavation and construction of iron smelting-furnaces with numerous analytical data on the composition of slag residues. 120 references; drawings. BM

Martin Fritz: The Export of iron from Sweden in Early Times (In Swedish). *Jernkontorets Forskning. 1977, Series H. No.2 14–22.*

The possibility of throwing light on the early iron export from Sweden is greatly limited by the scarcity of adequate source material. Only after the mid 16th century are more reliable data available for analysis.

Osmund iron dominates Swedish iron export during the later Middle Ages and the 16th century. Bar iron gained importance only at the beginning of the 17th century. Total export of osmund iron was a couple of hundred tons per year during the latter part of the 14th century and it rose to three or four thousand tons per year at the mid 16th century. By far the greatest part of the iron was exported from Stockholm, mostly to Lubeck and, especially later, to Danzig. Only minor quantities were re-exported to Western Europe from the Baltic ports of Germany and Poland.

Karin Calissendorff: On the meaning of Osmund (In Swedish). *Jernkontorets Forskning. 1971, Series H, No.2, 5–13.*

An "osmund" was a piece of iron of specific size. During the latter part of the Middle Ages and somewhat later, osmond iron was exported from Sweden in large quantities. It was sold by the barrel and by the hundred. No piece of osmond is known to exist, and for information on quality and size we must rely on written sources. The medieval Swedish material is mostly lost, and for information on osmond and ways of trade we must turn to the records of iron importing countries around the Baltic and the North Sea, especially when concerned with the early period.

It was formerly suggested that the word "osmond" is an ellipsis of the inventor's name or of the name of the place, where osmond iron first was made. It has also been suggested that the latter part of the word is derived from a word for measure. From phonetic and linguistic points of view it seems preferable to consider "osmond" a tautology of two words for mouth. "Osmond iron" might be the name of iron, produced not by the bloomery process, but by a process of higher temperature in which the iron was fluid and came running out of a hole.

Osmond iron is known since the 13th century. The general conception until recently has been that the pig-iron process at this time was unknown in Sweden. In a recently published paper in this series it is supposed that pig-iron production may have begun as early as the 12th or 13th century, at about the same time that mining started and the water-wheel was introduced.

Other kinds of iron were sold by weight and were called Kalmar iron, landiron, botolf iron etc. (material nouns, never omitting the iron). Osmund was a small lump of iron of characteristic size and shape, and this iron was counted in barrels or hundreds of "osemondes".

The price and weight of a piece of osmond iron were regulated by royal decree because of the need of iron as a kind of money. Osmond iron was widely used as money in Scandinavia, especially in paying rents and taxes.

Gunnar Pipping: On the weight and dimensions of Osmunds. (In Swedish). *Jernkontorets Forskning. 1971. Series H. No.2 23–40.*

Osmund-iron was a well-known export of Sweden from at least the mid-13th century until the early 17th century. Osmund-iron is nevertheless a very elusive phenomenon, since no genuine piece of osmund-iron is identifiable with certainty in existing collections and because there is no contemporary description of osmund-iron or of its mode of production.

Osmund-iron was largely used as a currency substitute, especially in paying taxes. The minimum weight of the pieces of osmund-iron was officially regulated. Taxes were paid in osmund-iron by the hundred and not by weight. It is suggested that in the 16th century the weight of osmund barrels diminished, because the number of pieces in each barrel was regulated and kept constant despite the diminishing weight of the single piece of osmund-iron. The Crown compensated the reduced income by raising the equivalent amount by weight instead of the equivalent number of pieces of osmund. This change is implicitly shown in the accounts of the Royal Warehouse from the 16th century in which a barrel of 480 pieces is called a "barrelled barrel" and the equivalent amount by weight or 600 pieces is called an "unbarrelled barrel". According to previous opinions, the accounts show a considerable real increase in taxation. The weight of a single piece was about 0.3 kg.

J Piaskowski: Metallographic examinations of iron objects of Pre-Roman and Roman period found on North-eastern territory of GDR. *Ethnogr. Archaol. Zeitschr. 1969.* **10,** *301, 322. (In German).*

A chemical and metallographic examination of 13 iron objects of the late La Tene – Roman period. 7 objects were made from high phosphorus iron, and the others were made from low phosphorus mild steel.

J Piaskowski: On the iron smelting in bloomery hearths on the territory of Poland. *Kwart. Historii Kultury Materialnej; 1970.* **18** *(1), 37–52. (In Polish).*

The archaeological traces of iron smelting; slag analysis and ethnographical sources show that generally on the territory of Poland in antiquity the ore was reduced in primitive hearths. Only in some big centres such as the Holy Cross Mountains was iron smelted in developed furnaces.

Max Terrier, Claude Judrin and Michel Félix: Fragments d'un char romain provenant de la collection Castellani. (Fragments from a Roman chariot from the Castellani Collection). *Bull. Labor. Musée Louvre, 1968. (12) 4–19. (In French).*

Metal parts from a Roman chariot now owned by the Palais de Compiegne Museum of Carriages, north-east of Paris, have been the subject of ultra-violet spectrographic analysis. The percentage composition of the copper-tin-lead alloy with traces of zinc, antimony, arsenic, iron, nickel and aluminium are tabulated on three charts. The largest pieces consist of sections from two chariot wheels. A sample from one of the hubs registered in addition to copper, 15.9% Sn, 0.80% Pb, 0.57% Sb, 0.08% As, 0.18% Fe, 0.11% Ni and less than 0.01% A1. The highest percentage of Pb found in the bronze was 10.90, and Sb_1 1.20. MR FM

Anon: Czechoslovakia holds first Major Foundry Exhibition. *Foundry Trade Journal. August 3, 1972,* **133** *(2904), 135–136.*

A brief account of a visit to the preserved blast furnace at Adamov, used for casting cannon and shot. A detailed drawing of 1793 still exists. Two other old furnaces remain on the site, but in worse condition. Illustrated by two photographs.

H Modin and S Modin: Metallographic investigations on Early Iron. *Jernkontorets Forskning, 1971. Series H, No.2 41–44. (In Swedish).*

Investigations of different types of iron bars and clamps from Swedish sites indicating the use of various sorts of iron.

U Zwicker, H Rollig and U Schwarz: Investigations on prehistoric and early historic copper slag from Cyprus (preliminary report). *Rept. of the Dept. of Antiquities, Cyprus, 1972. 34–45.*

The slags examined came from Kition, Enkomi, Salamis, Skouriotissa and Limni. Only the slags from Kition (1200 BC) and Enkomi (1200 BC) are stratified. It is concluded that copper mining in Cyprus is dated before 2500 BC. The slags are all iron silicates, and the copper content occurs as matte, complex oxides with iron, complex silicates with chlorine and only in very few cases as metallic copper. It seems that the slags which are stained green have higher copper contents than those that are not and that the copper is more oxidised. Whether this is an original condition or the result of weathering is not clear. The managanese-iron contents indicate that the Limni slags were fluxed with manganese ore and the Skouriotissa slags with iron. Charcoal from the latter site gave a C-14 date of 350 AD and the slag from Limni is estimated as belonging to about 300 AD.

Some interesting trace elements were found; almost all the slags from Enkomi contained Mo. Most slags contained zinc – a metal that is usually associated with Cypriot copper. Many contained Ni and Co.

ASIA

Philip P Betancourt: The Maikop copper tools and their relationship to Cretan metallurgy. *American Journal of Archaeology, 1970,* 74 *(4), 351–358.*

Certain similarities in form between copper implements produced in the North Caucasus and those produced later in Crete indicate that at least some of the metallurgical techniques of the early Kuban cultures were transmitted westward to the region. ERC

W T Chase: The Technical Examination of Two Sasanian Silver Plates. *Ars Orientalis, 1968,* 7, *75–93.*

The author describes the technical examination of two silver plates in the collection of the Freer Gallery of Art (FGA ℍ 34.23 and 64.10). A checklist for this type of examination is given and followed in the rest of the article. One plate was made from separate pieces laid into the body of the plate, while the other is made from a single piece, possibly by carving. A metallograph shows working and annealing in the second case. Both plates are mercury gilded, with portions of the design reserved in silver. This article was an outgrowth of a Sasanian Silver Conference held at the Freer in 1968. Copiously illustrated. WTC

A M Petrichenko and O D Ganina: Castings from a burial ground near the village of Peschanoe. *Liteinoe Proizvod, 1970, (7), 44–6 (In Russian).*

The excavation of 14 bronze vessels, 15 antique vases, an oak canoe and remains of a human skeleton represents a unique find of Greek origin from the 5th century AD. The bronze material was remarkably well preserved without signs of corrosion or crack formation. The chemical compositions of the base metal and of the cast seam were as follows, Cu 89.7, 87.70; Pb 0.47, 1.73; Sn 8.56, 8.90; Zn traces, 0.19; Ni traces, 0; As 0, 0 weight %, respectively. Most objects were made from a bronze sheet by cold forging and welding the seam by pouring molten bronze into the seam. The good adhesion of the welded portion of the base metal indicated a complex method of casting. Some parts of the vases (handles and ornaments) were cast in portions by pouring molten bronze over solidified parts of the object. The technology of casting was apparently well developed and gave good products.

Maurice E Salmon: A Survey of the Composition and Fabrication of Bronze Artifacts from Hajar Bin Humeid. In. Hajar Bin Humeid: Investigations at a Pre-Islamic Site in South Arabia, by Gus W Van Beck et al. Baltimore, Maryland *(The Johns Hopkins Press), 1969, pp 373–386.*

Thirty-three metallic fragments were examined. Ten were completely mineralized. Twenty-three were cross-sectioned before sampling, two were sampled without cross-sectioning and the samples analyzed by X-ray spectrography. All analyzed objects were of copper alloyed with tin and lead but eleven objects were too corroded to yield reliable data on the original composition. Ten objects were examined metallographically. Some evidence for systematic alloying is found. Most objects were cast. Two objects were cold-worked and annealed, one of which (H 667 stratum E) gives evidence of being manufactured of drawn wire. WDR

M N Ragimova and I R Selimkhanov: Chemical study of some ancient copper-lead objects found in the Caucasus. *Dolk. Akad. Nauk Azerb. SSR, 1970,* 26 *(6), 94–7. (In Russian).*

Spectral data revealed that Caucasian Cu-Pb alloys made 3000–2000 BC contained 1.5–6% As and 3.6–14.7% Pb, whereas more recent alloys (2000–1000 BC) contained

2.6.4–19.5% Pb; 0.2–2.91% Sb; 0.89–13.67% Sn; and 0.4–1.4% As. Cu-Pb alloys made during the 1–4 century AD often contained ≥7% Zn.

Donald Hansen, Kate C Lefferts and Shirley Alexander: A proto-elamite silver figurine in the Metropolitan Museum of Art. *Metropolitan Museum Journal 1970. 3, 5–26.*

The first part of the article, a discussion of the silver figurine from the art historical point of view, describes the figurine and ascribes it to the Proto-Elamite period of about 3000 BC on the basis of comparison with a group of small stone figurines and clay seal impressions. This is followed by a description of the techniques used in its manufacture, illustrated by radiographs and detailed photographs. The composition of the silver and of the solder was ascertained by thermal neutron activation analysis by E V Sayre, and P Meyers and S Alexander analyzed the corrosion products by X-ray diffraction. The results are given in tables. KCL

P R S Moorey: Prehistoric copper and bronze metallurgy in western Iran (with special reference to Luristan). *Iran, 1969. 7, 131–153.*

Spectroscopic analyses of 132 objects in the Ashmolean Museum Collection of Ancient West Iranian bronzes, with a historical survey of West Iranian metallurgy to c 1000 BC and the Luristan industry, c 900–650 BC are given. WDR

Karl Jettmar: Metallurgy in the early Steppes. *American Journal of Archaeology, July 1970, 74 (3), 229–230.*

Results obtained from the analyses of copper and bronze implements of the fourth to first millennia BC from the Steppes region of the Soviet Union are used to indicate the origin and diffusion of metalworking in various parts of Asia and Europe. This is an abridgement of an article to appear in Artibus Asiae. ERC RiES

B N Tandon: Micro-chemical analysis emission spectrography and metallographic examination of four ancient metal samples. *Conservation of Cultural Property in India – Proceedings of Seminar II, (1967).*

Results are given of the investigations of four metallic samples of different periods. The major elements were determined by chemical microscopy and trace elements by emission spectrography. Metallographic examinations were also conducted. Results were:– **Mughal Coin:** Copper-Silver Alloy with traces of Sb and As and made by cold working and hammering. **Base of Buddha Statue:** Cu-Sn Alloy with traces of Zn, As and Sb made by annealing after cold working. **A Kushan Coin:** Cu and Sn Alloy traces of Ag, Pb, As and Sb with annealed structure. **A Nalanda Bronze:** Cu and Sn alloy with traces of Ni, Fe, Pb, As and Sb. ASB

Karunakara T M Hegde: Metallographic studies in Chalcolithic objects. *Journal of the Oriental Institute, Sept 1964,* **14** *(1), 84–90.*

Six representatives cutting implements from five different Indian Chalcolithic sites (Chandoli, Somnath, Navadatoli, Ahar and Langhnaj) belonging to 1800 BC – 1200 BC were studied chemically and metallographically. Composition of the Chandoli axe was Cu 95.11%; Fe 1.81%; Pb 1.68%; Zn 0.62%. The metal was found to be homogeneous and slow-cooled after casting.

An axe from Somnath contained Cu 81.86%; Sn 12.82%; Fe 2.57%; Pb 1.21%. Near the butt the metal was in a cast condition not subjected to hot or cold working. The cutting edge of the axe was repeatedly cold worked with intermittent annealing.

An axe from Navadatoli contained Cu 93.17%; Sn 3.26%; Fe 0.63%; Pb 2.28%; Zn 0.21%. The metal was heated above the recrystallization temperature after casting and cold worked and annealed. A chisel from Navadatoli contained Cu 93.20%; Sn 3.12%; Zn 0.38%; Pb 2.06%; Fe 0.57%. The metal has a homogeneous structure, cold worked and then recrystallized.

An axe from Ahar contained Cu 90.92%; Fe 6.48%; Pb 1.62%; Ni 0.31%. The metal was porous and brittle.

A knife from Langhnaj contained Cu 98.12%; Fe 0.61%; Pb 0.28%. The metal was recrystallized and hot worked. OPA

B B Lal: Analyses of copper mirror from Cemetery R 37 – Harappa (1946). *Ancient India, 1947, (3), 125.*

The results of chemical analysis of the borings from the mirror were: copper 81.90%; lead 2.31%; tin 0.34%; silica 0.20%; sulphur 0.64%; zinc traces, iron traces, oxygen (by difference) 14.54%. The mirror is made of copper with 0.34% tin, which was an impurity. Nickel and arsenic were absent. BBL

B B Lal: Chemical examination of anthropomorphic figure from Bisuali. *Ancient India, 1951 (7), 24–25.*

The composition of anthropomorphic figure from Bisauli has been determined by chemical analysis. Qualitative analysis of the borings showed the presence of copper and nickel only. Quantitative analysis results: copper 98.77% and nickel 0.66%, total 99.43%. The small amount of nickel represents only an impurity derived from the copper ore. As Indian copper ores contain generally arsenic or nickel or both, it is concluded that the ore from which the metal was extracted was of Indian origin. The ore may have been derived from the nearest copper mines in Rajputana or Singhbhum. BBL

B B Lal: Chemical analysis of copper and bronze objects from Brahmagiri IB and Megalith II. *Ancient India, 1947 and 1948, (4), 267 and 269.*

A pin with circular section, thinning towards one end from inside a burial-urn in an early stratum of IB (Stone Axe) culture gave, on chemical analysis, copper 44%, tin 9.0%, iron 1.05%, oxidation product 44.48%.

A copper rod from a middle stratum of the IB (Stone Axe) Culture gave on chemical analysis, 94.13% copper and 5.87% oxidation product.

A copper object, possibly a flat axe from a middle stratum of the IB (Stone Axe) Culture, gave, on chemical analysis, copper 44.87%, iron 1.37%, silica 51.40%.

A finger ring from a late stratum of the IB (Stone Axe) Culture gave, on chemical analysis, 98.7% copper, traces of nickel and 1.3% oxidation product.

A bangle from a pit circle, Megalith II, was found, on chemical analysis, to contain 74.69% copper, 15.81% tin, 2.72% zinc and 0.38% nickel with 6.40% oxidation product. BBL

D P Agrawal: Metal technology of the Harappa culture and its socio-economic implications. *Indian Journal of History of Science, 1970, 5 (2), 238–252.*

Metal technology of the Harappa culture is discussed with reference to excavated finds from Mohenjodaro, Chanhudoro, Rangpur and Ahar, and 38 previously published chemical analyses, and author's seven spectrographic analyses of 4 ore specimens from mines, and 2 artifacts and one ore specimen from excavations. The influence of ecology on technology is discussed and the effects of their interaction evaluated for determining the genesis of the Harappa Culture. Forty references. BBL

H C Bhardwaj: The problem of the advent of copper in India. *Indian Journal of History of Science, 1970, 5 (2), 229–237.*

The paper reviews the published material on ancient Indian copper and bronze metallurgy with particular reference to the Indus valley civilization viz-a-viz the contemporary West Asian civilizations. Advent of copper in India is discussed in the light of published analytical data yielded by excavated finds of Harappan copper and copper-base alloys. The problem of the beginning of copper metallurgy in Ancient India has been tackled from literary, archaeological and technological standpoints. The location of probable copper mines exploited by the Harappans is discussed on the basis of chemical and spectrographic analysis of Harappan copper artifacts and copper ores from Rajasthan and Bihar. No technological affinities have been discovered among pre-Harappan, Harappan, Chalcolithic and copper hoard materials. In the absence of any technological resemblances, the copper and bronze age technologies are thought to be independent developments. There is no resemblance between the Harappan and West Asian metal technology. It is concluded that Harrapan metallurgy had no forerunners and had an independent growth. 37 references. BBL

Barbara Stephen: Shang bronzes with ancient repairs. *Annual-Art and Archaeclogy Division, 1961 – 8–14. The Royal Ontaria Museum, University of Toronto.*

Six ancient Chinese bronzes showing evidence of repair in early times are described. The repairs are concluded to be early also because of the lack of more than traces of zinc – a characteristic of early Chinese bronzes. But the repairs show crude craftsmanship in contrast with the high level of competence in the rest of the object. The repairs are significant because they may indicate that the early bronze casters were not the masters of their craft that they were later on, and also that the objects were in use long before burial. NH

Taketsugu Iijima, and Yoshinori Anazawa: Supplementary study and chemical research of ancient iron-smelting furnaces in Ota-shi, Gumma prefecture. *J Archaeological Society of Nippon, March, 1971, 56 (3), 61–80. (In Japanese).*

In 1969 and 1970 the iron-smelting furnaces on the Kanai hill in the Ota city, Gumma prefecture were excavated. The furnace No.1 was found to be situated in an atelier or a smelting cottage, 10 m x 18 m, built on the south slope of the hill. Charcoal used for the fuel was found around the furnace. The slag consisted mainly of wüstite and fayalite with the chemical compositions: total iron 44.23, FeO 45.70, Fe_2O_3 12.46, SiO_2 16.36, MnO 0.65, S 0.139, P 0.164%. Ti-glass and magnetite seem to be absent, and such a slag seems to be formed at a relatively low temperature, 1150–1200°C. Small grains of iron contained in the slag of the furnace No.2 are considered to be semi-pig iron with a rather high content of sulfur and phosphorus. The date of these furnaces is presumed to be late 9th-early 10th centuries, judging from the earthenwares excavated near the furnaces. KY

Kumahiko Hasegawa: Qualities of the archaeological iron utensils in Japan. II. *Shigen Kagaku Kenkyusho Iho, 1969, (72), 55–56. (In Japanese).*

Seventeen samples found in old graves at Abiko City, Chiba Prefecture, were analyzed by chemical, spectrochemical and microscopic methods. The results on minor constituents such as Cu, Mn, Ti, Ni, and Cr were used for discussion on their source materials.

Kumahiko Hasegawa: Qualities of the archaeological iron utensils in Japan. III. *Shigen Kagaku Kenkyusho Iho, 1970. (73), 60–6. (In Japanese).*

Nine samples were analyzed by mass spectrometry, chemical and spectrochemical methods. The sulfur content was used as an indicator of their source materials.

H C Bhardwaj: Rajghat copper – a metallurgical view. *Puratattva, 1968–69, (2), 30–34.*

Six specimens of copper and bronze from Period I, datable to ca 800 BC – 200 BC have been chemically analyzed and metallographically examined. Experimental procedures of chemical analysis are detailed and methods of determination of arsenic, antimony and sulphur are specified. Two specimens are made of bronze, tin, 13.99%, and 7.83%. Four specimens are made of un-alloyed copper with lead, iron, nickel, calcium, magnesium, sulphur, and oxygen impurities, up to 2.–4.5%. The small amount of tin (1.82%) in one of these specimens is said to be an intentional addition.

Sulphur and iron are said to have been derived from the copper sulphide ores associated with iron pyrites; the amounts vary from trace to 0.75% and 0.21% to 2.23% respectively. Two specimens contain 0.09% and 0.83% of lead; the other two specimens contain trace amounts only and the remaining two specimens are free from lead. The nickel content ranges from 0.08% to 1.07% in five specimens; one specimen was not analyzed for nickel. One specimen shows 0.25% arsenic, the other shows trace amounts only and the remaining four specimens are free from arsenic. Antimony has been detected in trace amounts only in two specimens. All these impurities are attributed to the copper sulphide ores.

Metallographic examination of two specimens gave the following results: the bronze coin with 7.83% of tin shows a cast structure with coring; unalloyed copper specimen (sheet) shows hot worked metal, $Cu\text{-}Cu_2O$ eutectic and annealing twins indicate heat treatment above the recrystallization temperature. BBL

John Alexander Pope, Rutherford John Gettens, James Cahill and Noel Barnard: The Freer Chinese Bronzes. *Washington, DC (Smithsonian Publication 4706), 1967. 638pp.*

The Charles Freer collection of 122 Chinese ceremonial vessels has been catalogued along with technical observations regarding each piece provided by R J Gettens. The method of casting with molds and chaplets, the appearance and composition of the bronze and the corrosion products and technical peculiarities of each piece are described in a short technical report. A more complete description of the technical examination of these bronzes appears in the second volume of the catalogue. (see next abstract).

The few forgeries or recent copies in the collection are described and reproduced with details explaining why the piece is not ancient. Also repairs and added inscriptions are pointed out. Detail photographs and some radiographs illustrate the text. LJM

Rutherford John Gettens: The Freer Chinese Bronzes, Volume II, Technical Studies. *Smithsonian Institution. Freer Gallery of Art, Oriental Studies, No.7 Washington, 1969, 257 pp. ill. Bibliog – 8 pp.*

The scientific analyses of the very important Freer Gallery of Art Chinese ceremonial bronzes are presented by the author in this volume of the catalog of the Freer Chinese Bronzes. The collection has been subjected to intense scrutiny between 1958 and 1967. Samples were analyzed by wet chemical and spectrographic methods as well as by X-ray diffraction analysis. The bronzes were radiographed and photographed in detail. Patina (corrosion products) have been determined and photomicrographs of sections are reproduced. Cross sections of study fragments and many photographs illustrate the piece-mold casting technique as well as cast-on parts and repairs. Three hundred and fifteen figures and eighteen tables are given.

Headings of chapters are:

I Bronze: Constituents and beginnings

II Bronze in ancient China

III Composition

IV Fabrication

V Metallographic structure

VI Inscriptions

VII Radiography

VIII Patina and corrosion

IX Fillings, inlays and incised decor

X False patina and repairs

Appendix I The validity of the analytical data

Appendix II Published analyses of illustrated bronzes

Bibliography and Index.

This volume of technical studies supplements the brief technical observations that appeared under each bronze of Volume I. These observations constitute a major contribution to the advancement of investigation into the methods and materials of ancient craftsmen. LJM

Tsurumatsu Dono: The chemical investigation of the ancient metallic culture. *Asakura Shoten, Tokyo, 1967, 242 pp. 1650 yen.*

This book is printed in Japanese, but has an extensive summary in English (56 pp) and the 66 photographic figures are labelled in both languages. Chapter titles: Introduction, The Copper Age and Its Transitional Period to the Bronze Age in Ancient China; The Bronze Age in Ancient China; Metallic Currencies [Coinage] In Ancient China; The Iron Age and Its Period of Transition From the Bronze Age; The Ancient Metallic Culture in the Iran District; Conclusion. The author includes 160 analyses of objects, the majority of which were carried out under his supervision at Tokyo Imperial University. He holds that a copper age preceeded the Bronze Age in China, that the recipes in the K'ao Kung Ch'i of the Ch'ou-li are substantially correct, that the coloured flame reaction was used by the ancient founders for ascertaining the temperature of the melt, and that early bronzes contain more lead than later bronzes in China (with certain exceptions). Many metallographs are included in the plates. WTC

Kumahiko Hasegaw: Scientific studies on the iron making in ancient Japan. *Archaeology and Natural Sciences, 1969, (2), 42–52.*

Mineralogical and chemical studies on the slags and iron wares excavated on the sites of iron making, and working conditions of ancient Japanese furnaces are reviewed and discussed. KY

AMERICA

Earl R Caley and Lowell W Shank: Composition of ancient Peruvian copper. *The Ohio Journal of Science, 1971, 71 (3), 181–187.*

Complete quantitative analyses were made of samples of metal taken from fifteen Peruvian copper objects that came from various sites and ranged in date from the fourth to the fifteenth century AD. Twelve of the sampleswere found to be composed of arsenical copper. One was native copper and one other was apparently native copper modified by heat treatment. Only one sample contained enough tin to warrant classification as bronze. The significance of the results is discussed. ERC

John Witthoft and Frances Eyman. Metallurgy of the Tlingit, Dene, Eskimo. *Expedition, Spring 1969. 2 (3), 12–23.*

The discovery that many of the objects made by the Tlingit Indians in Alaska are of native copper, rather than exclusively of European copper, is used as evidence of communication between various groups of people ranging from Greenland to Siberia. Further evidence for this is the combination in objects of native copper and musk-ox horns. The latter come from farther away than the already known source of copper (the near-by Copper River Basin). In addition, there are trace elements in some of the native copper objects which are not found in the Copper River Basin metal.

The varying physical properties of native and other copper are described. The native copper shows no evidence of stress-hardening, hammering or annealing, or of being worked in a forge. It is pure and has large crystals. The objects, such as daggers, rattles, masks, were worked with stone saws and were successfully protected by a coating of fish-oil.

The article is copiously illustrated. KS

TECHNIQUES

Diana Lee Carroll: Drawn wire and the identification of forgeries in ancient jewelry. *American Journal of Archaeology, 1970,* **74** *(4), 401.*

The presence of striations or drawplate marks on jewelry wire is not always an indication of modern forgery. ERC

P R Lowery, R O A Savage and R L Wilkins: *Scribers, gravers, scorpers, tracers: notes on experiments in bronze-working technique. Proceedings of the Prehistoric Society, 1971,* **35**, *167–183.*

The terminology and use of tools used in metal decoration are described in detail. Using these tools on metal which is then sand-blasted to simulate age and wear, the metal was examined to see the characteristic marks made by the various tools. These were then compared with examples of prehistoric British decorated bronze work.

A detailed discussion of the problems of technical examination is given. PTC

SCIENTIFIC EXAMINATION

Fulvia Marchetti and Pasquale Rotondi: Determination of the origin of some ancient bronzes by neutron activation analysis. *Atti Ist. Veneto Sci., Lett. Arti, Cl. Sci. Mat. Natur, 1968,* **126**, *201–208 (In Italian).*

It is shown that it is possible to use the analytical sensitivity of this method for determination of the percentage of metallic impurity present in trace quantities, and hence to determine the historical archaeological period to which the bronze belongs. The samples were subjected to a thermal neutron flux of 4.5 x 10^{13} n/cm/^{2}/sec for up to 14 hours and the resultant y-radiation analyzed by a 512-channel instrument. The peaks show the presence of the following radionuclides: ^{59}Fe, ^{64}Cu, ^{113}Sn, ^{114m}In, ^{110m}Ag, ^{124}Sb, ^{60}Co and ^{65}Zn. The content of Sn, In, Ag, and Sb is established for 4 samples. Applied to Etruscan bronzes this method shows them to be of low Sn content but with very little impurity. Pb could not be detected. The composition suggests that the metals used were imported from Spain to Italy.

Sherwood F Moran: The Gilding of Ancient Bronze Statues. *Artibus Asiae, 1969,* **31** *(1), 55–56.*

The author reviews various processes used by the Japanese for gilding bronze statues. Three processes were commonly used: (1) Fire gilding, using a gold-mercury amalgam in proportions 1 gold to 5 or 6 mercury. (2) Fire gilding by rubbing the surface with mercury and laying gold leaf onto it. (3) Adhering gold leaf to the statue with a thin layer of lacquer. All three processes are described step-by-step and the appearance of the resulting surface is described. A common misreading of the Japanese term kondo, which means 'gilded' and not 'made from gold and copper', is corrected. The author discusses the composition of the Daibutsu of Todaiji in detail, and ends the article with a general discussion of compositions of ancient bronzes and a bibliography. WTC

A E Werner: Analysis of ancient metals. *Phil. Trans. Roy. Soc. London, Series 1: 1970,* **269** *(1193), 179–85.*

The requirements of analysis procedures in a museum laboratory are considered in general terms. The type of analysis, the nature of the analysis, and various aspects of sampling techniques must be taken into account to ensure that significant results are achieved. 17 refs.

The Editor would like to acknowledge the help he is now receiving with the abstracts. He is very grateful to the following who are now actively participating:–

D R Howard, J W Butler, W Haldane, P S Richards, T Daff, H F Cleere, H W Paar, N Mutton, E Raub, A P Greenough, J K Harrison, W A Oddy, J Piaskowski and K Poplawska.

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