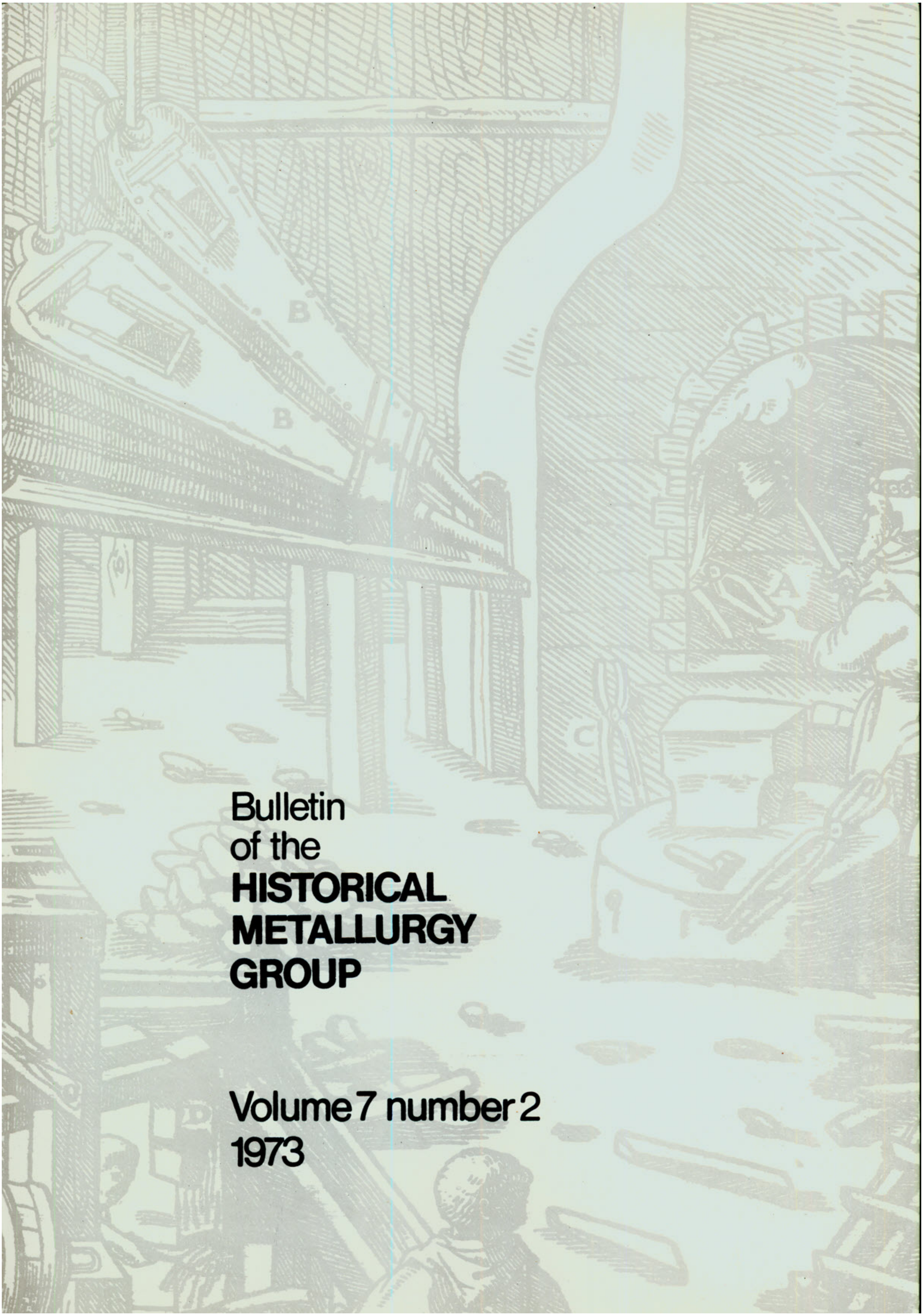

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The Manufacture of Jewellery during the Migration Period at Helgö in Sweden

*by Kristina Lamm** ©

INTRODUCTION

In the middle of the first millennium A.D. Scandinavian art metal work reached a remarkable level. The great number of high-class artifacts in the museum collections in Scandinavia give eloquent evidence of the experienced technique and the independent creativeness of the craftsmen at this time. Though these articles give us a great deal of information of the character of the art, the style and its development, they tell us very little about how, where and under which conditions the artifacts were made, for the simple reason that the workshops where they were produced have never been found.

Now, quite new possibilities have arisen through the discovery of a large workshop site on Helgö, about 30 km west of Stockholm. This allows us to form an opinion as to how a prehistoric workshop was organized and functioned and what were its products as well as the technique used.

Thousands of fragments of moulds for jewellery, costume accessories and weapons together with an immense quantity of other waste products from the workshop clearly show the importance of the production on Helgö.

Besides almost 50 kg of mould fragments and about 300 kg of complete and fragmentary crucibles, other important find-groups have been unearthed in the workshop, e.g. metal ingots and more or less finished products, fragments of gold, silver and bronze, slags, pieces of clay furnace linings and tuyeres. An interesting find-group is some small rectangular plates of tempered clay with upward-turned rims with a visible coating of oxidized metal on the inner surfaces *(Fig. 1)*. Analyses have shown that these coatings have high contents of lead and silver which might indicate their use for the extraction of silver by cupellation.

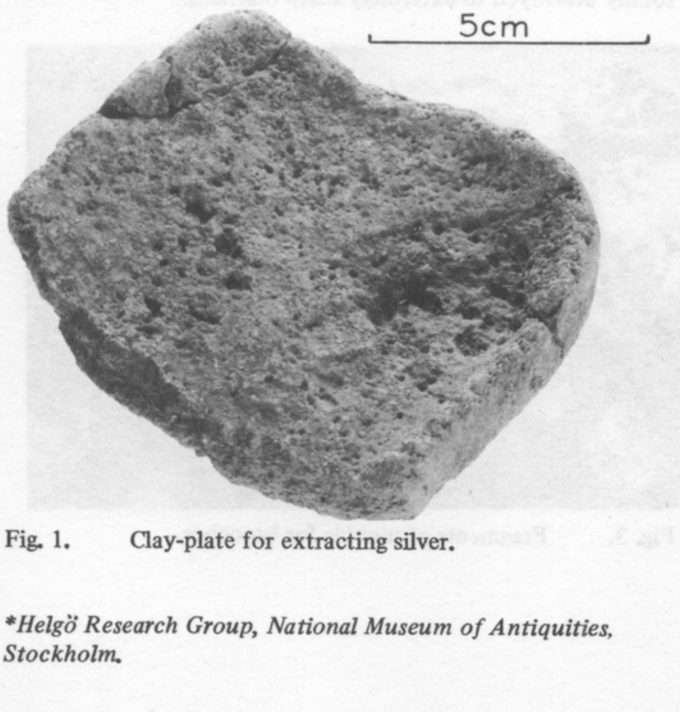

Fig. 1. Clay-plate for extracting silver.

A small hoard of gold artifacts, consisting of three gold spirals and a solidus, has also been found within the workshop. This find together with crucible fragments with melted gold drops stuck onto them, whetstones with traces of gold remaining, melted drops of gold, as well as a great many gold rods, gold threads and some semi-manufactured articles, prove that the goldsmith's work played an important part in the workshop manufacture.

Most of the workshop finds have been made within the area where the investigations started in 1966. So far, it is only partly excavated. There are, however, indications that the whole area, which covers almost 10,000 square metres, has been used for metalwork, both for blacksmithing and for casting in bronze and precious metals.

According to the material so far discovered, the casting activities extended over about 400 years from the Migration period to the beginning of the Viking period. The first 200 years of this period are represented by overwhelmingly rich material, while in the later period the material is considerably less abundant.

This extensive manufacture was obviously not intended merely for use on Helgö but, from the outset, was meant for sale. Moreover the selling of these products does not seem to have been limited to the immediate surroundings of Helgö – not even to the Mälar district. Objects directly corresponding to the moulds have been found in North Sweden, on Gotland, and in Finland. Through the workshop finds on Helgö a clearer view of the connections between these regions around the Gulf of Bothnia has appeared and the outline of a prehistoric East Scandinavian trade can be seen.

But the trade on Helgö did not only comprise their own products; many imports, which have been found there since the archaeological investigations started in 1954, indicate the importance of the site as a trading centre in central Sweden.[1]

Many objects from far and near have come to light on Helgö – a Buddha statuette from north India, a crozier head from Ireland, a Coptic bronze ladle from Egypt, to mention the most famous ones – but also other imports from the Roman Empire from the Germanic territories south of the Baltic and from the British Isles.

Work on the material from the recently discovered workshop started with the publishing of a first volume of a catalogue raissonée, which appeared in 1972.[2] The moulds for three different categories of objects have been discussed in this publication. The purpose

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was to discern the character and the extent of the production and the diffusion of cast products of these three types. The technical aspects of this material have not yet come up for discussion as the intention is to deal with these questions at a later date. Work on these aspects has, however, already begun. One aim is to try to reconstruct the structure and composition of the original moulds. As all the moulds are now in such a fragmentary state it has been extremely difficult, not to say impossible in the case of some of the objects, to get an idea of the original shape of the moulds. But in the case of those object groups which are more abundantly represented in the mould material it has been possible to make fairly reliable reconstructions. Another aim has been to try to get an insight into the casting technique used in the workshop on Helgö.

An account of the results so far achieved in these investigations will be given below as well as a short presentation of the larger material groups from the workshop — the crucibles and the moulds.

THE CRUCIBLES

The crucibles are made of clay, tempered with finely ground quartz, and virtually all of them are lidded. The lid is fastened to the bowl by a surrounding outer clay casing. This type of crucible is always provided with a handle protruding from the rear edge. The outer surface is more or less vitrified and is of a greyish or greenish-grey colour, often containing reddish areas of cuprous compounds. *(Fig. 2)*

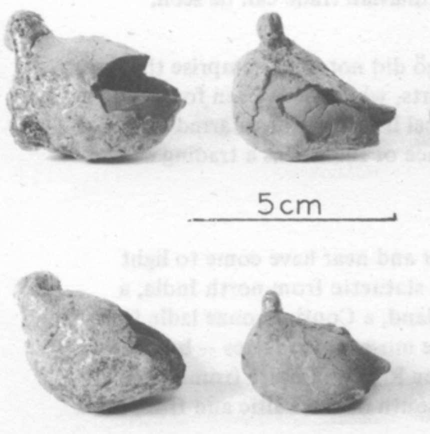

Fig. 2. Lidded crucibles.

Lidded crucibles have also been found in some other places in Sweden and Norway and around the Irish Sea.[3] They all seem to belong to the middle of the first millennium AD. On the Continent, this type of crucible is extremely rare.

During the Viking Period the lidded crucibles seem to go out of use in Scandinavia. In Birka, the Viking Age commercial town and workshop centre in central Sweden, quite another type of crucible has been used, i.e. an open crucible with an elongated form.

Amongst the large quantity of crucible fragments from Helgö only 9 open-type crucibles can be distinguished with certainty. These are, however, of quite another type from the Viking Age crucibles; they are much smaller and some of them are remarkably shallow. A couple of them seem to be of exactly the same type as some crucibles found on the 6th century site at Garranes, Cork. In contrast to the Helgö specimens which are made of clay, the crucibles from Garranes are made of stone. They are supposed to have been used for glass or enamel.[4]

As two of the open crucibles found on Helgö have drops of gold remaining in them it might be that this type of crucible was especially intended for melting gold. On the other hand the lidded crucibles were also used for this purpose as there are melted drops of gold on not less than 87 fragments of this type.

THE MOULDS

Undoubtedly the most interesting finds from the Helgo workshop are the moulds; all of them are made of clay mixed with quartz — the same material used in making the crucibles. *(Fig. 3)* They are all fragmentary, as they have been broken into pieces when the cast product was taken out. The majority of them are now quite impossible to classify, as the matrices are completely obliterated. The remaining mould fragments represent everything from almost totally destroyed to extremely sharp matrices.

Fig. 3. Fragments of moulds for brooches.

However, as the fragments generally are quite small, the moulds with well preserved matrices are also very difficult to classify.

The most frequently represented artifact-group in the mould material is represented by the 6th century square-headed brooches. Up to now 635 fragments of moulds for this brooch-type have been unearthed, belonging to at least 211 brooches. The importance of the mould material from Helgö can better be understood by the fact that the minimum number of types of square-headed brooches, made on Helgö, are about four times as large as the corresponding cast brooches which have so far been found in the whole of Sweden.

Other cast products from the Helgö workshop are represented by a substantially smaller amount of mould fragments. On the other hand the assortment of types was quite considerable.

The Migration-Period material, which, as mentioned above, is so dominant in the workshop, is to a great extent typical of the fashions of the epoch in Scandinavia. The workshop had not only a great assortment of different articles to offer their customers, but also a great many variations of the same article. The customer, who intended to buy a square-headed brooch had at least 29 different types to choose from. The great variations in the decoration ought to have been enough to satisfy all tastes.

Casting in piece moulds was obviously the technique preferred on Helgö, while the use of the lost-wax method cannot be established with any certainty.

The majority of the fragments belong to piece-moulds, made of two fitting pieces, but objects with undercuts in decoration and design have been cast in multipart moulds. The separate mould-parts were held together by an outer casing of clay, in principle the same type of construction as the crucibles.

The square-headed brooches are the main examples of casting in two-part moulds *(Fig. 4)* The mould is divided in such a way that one half, here called the front portion, forms the entire obverse side of the brooch, while the other half, the back portion, forms its reverse side.

These brooches, which are the best examples of jewellery found belonging to the 6th century in Scandinavia, have a very rich and forceful ornamentation consisting of more or less stylized animal figures. The ornamentation covers the whole surface of the brooch. Every detail of this exuberant ornamentation has been cast in the mould and has not been worked-in afterwards on the cast object.

(In the reconstruction drawing, Fig. 4, the detailed ornamentation is not drawn, only the contours and the framework of the brooch).

The back portions are always plain, which applies not only to the moulds for this type of brooch but is a feature characteristic of all kinds of moulds. The front portions on the other hand have a gently rounded exterior. In the back portions there are cavities for the pin attachment and the catch-plate.

A remarkable fact is that dowels and holes for registration are extremely rare in the moulds. The moulds for small square-headed brooches are provided with only two dowels, placed in the middle of the mould on each side of the bow of the brooch. Moulds for square-headed brooches, larger than the depicted item *(Fig. 4)* are sometimes provided with more, but smaller, dowels.

To prevent the two mould-halves slipping against each other, the outer edge of the back portion of the mould was made convex while the edge of the front portion was provided with a corresponding concavity. This feature makes dowel location practically superfluous.

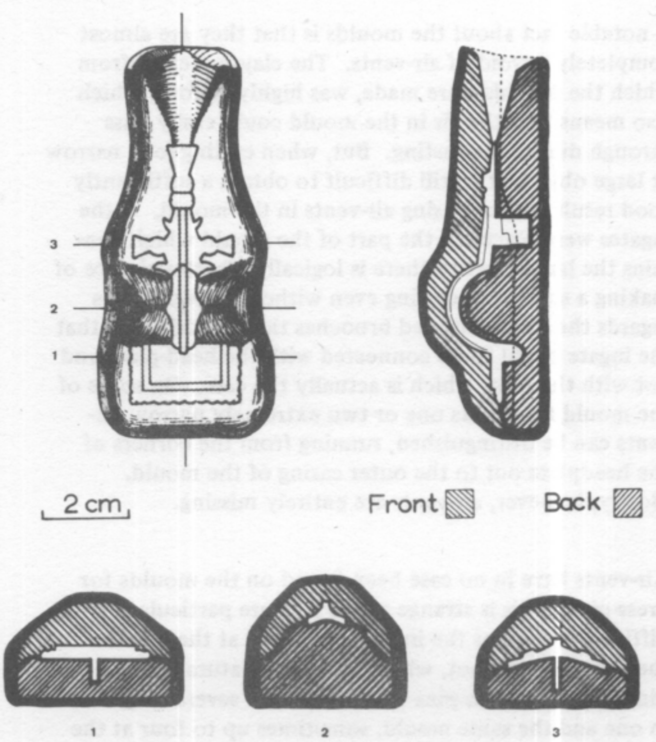

Fig. 4. Reconstruction of mould for square-headed brooch. The broken line on the section above to the right marks the joint between the two halves of the mould.

The runners of the moulds also were made in such a way that the two mould parts fitted into each other. The half on the back portion was provided with two out-drawn flaps, while the front portion had corresponding depressions *(Fig. 5)*.

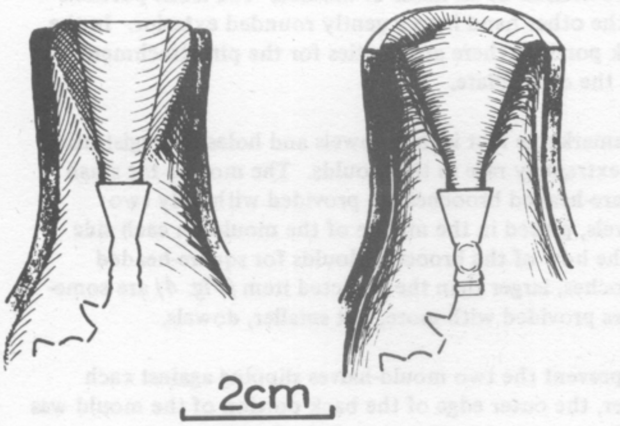

Fig. 5. Detail of runner on back *(left)* and front portions of the mould *(right)*.

A notable fact about the moulds is that they are almost completely devoid of air-vents. The clay material, from which the moulds were made, was highly porous, which also means that the air in the mould could easily pass through during the casting. But, when casting long narrow or large objects it is still difficult to obtain a sufficiently good result without using air-vents in the mould. If the ingates were placed in the part of the mould which contains the largest cavity there is logically a better chance of making a successful casting even without air-vents. As regards the square-headed brooches this should mean that the ingate ought to be connected with the head-plate and not with the foot, which is actually the case. On some of the mould fragments one or two extremely narrow air-vents can be distinguished, running from the corners of the headplate out to the outer casing of the mould. Mostly, however, air-vents are entirely missing.

Air-vents have in no case been found on the moulds for dress-pins. This is strange as the pins are particularly difficult to cast, as the ingate is situated at the base of the pin-shaft and not, which was more natural, at the pinhead. The dress-pins were often cast several together in one and the same mould, sometimes up to four at the same time *(Fig. 6)*. The moulds generally lack dowels and the mould-halves were held together by curving the outer edge so that the ingate halves fitted into each other. In some exceptional cases the moulds for this type of object are supplied with dowels.

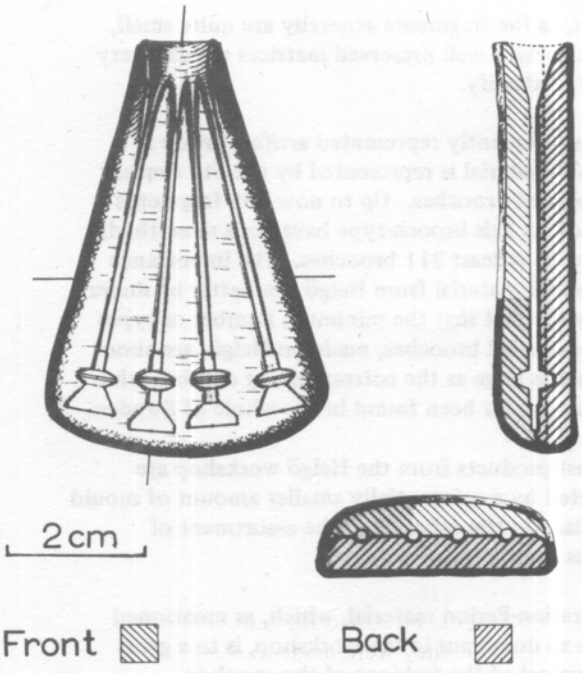

Fig. 6. Reconstruction of mould for dress pins. The darker part of the front portion indicates that part of the reconstruction for which parts have been found, while the lighter part cannot be confirmed by any preserved moulds.

THE CERAMIC MATERIAL

A mineralogical and chemical investigation has been made on the crucibles and the moulds from Helgö. This was intended to give an answer to two main questions:- the composition of the ceramic material and its provenance.

The investigation revealed that the clay material was tempered with very fine-grained quartz, which probably had been artificially crushed and sifted. The percentage admixture was more difficult to determine – values of 30 to 40% and 50 to 60% were obtained. The analysed fragments of the moulds also showed the addition of fine-pulverized charcoal.

The analyses indicated that both moulds and crucibles were probably produced from local clays and that the quartz too was very likely of local origin. The analyses also showed that the firing temperature of the crucibles had been greater than 900-1000°C.

As the results of the quartz analyses were so variable, practical tests were made in which the clay was tempered with 10% to 60% of quartz. With small amounts, the material does not attain a sufficiently refractory quality and with the largest amounts the material becomes too loose and crumbles to bits. Furthermore, it loses its plasticity and cannot be modelled any longer. 30-40% has turned out to be the best proportion for the moulds. With more than 40% quartz, it is impossible to get the fine detail shown by the Helgö moulds. In the crucibles, on the other hand, it is possible to have up to 50-55%. The higher the proportion of quartz the better the refractories of the crucibles. To increase the strength of the crucibles a further addition of 5-10% chamotte is made in the form of fine-ground, used, crucibles.

Another way to increase the strength of a crucible is to roll or dip it in ground quartz. This can best be done at the last moment in the process before the clay has hardened. A crucible, so treated, can stand a temperature of up to approximately 1600°C. This has possibly been the method used in the Helgö workshop and is indicated by the fact that the outer casing of the crucibles generally has a coarser structure with higher quartz and larger grain-size than the bowl. This difference in structure between the bowl and the outer casing is not due to the fact that they were made of clay with different proportions of quartz. A crucible made in such a way splits during drying as the shrinkage characteristics vary with the proportions of quartz.

RECONSTRUCTION OF THE CASTING TECHNIQUE

In order to get a deeper insight into the technique used at Helgö, experiments have included every detail from the mixing of the clay to the production of the finished product. The reconstruction of the process is based partly on the above-mentioned ceramic analyses, partly on detailed comparisons between the original material and the replicas which were made during the experiments. The purpose of the experiments has been to find the simplest possible mode of procedure in every stage of the process, i.e. the quickest way from pattern to finished product.

The experiments have clearly shown that the bronze-founders at Helgö had a highly developed technique. The ceramic material seems perhaps to be quite simple from our point of view – but it has got a plasticity, a porosity and a refractory quality, which has astonished the ceramists as well as the art founders of today. It is fully comparable with some modern foundry materials.

The reconstruction of the casting process can of course not be proved but must be regarded as quite possible. It is in complete accordance with observations, which have been made on the moulds and crucibles found on Helgö.

The first step in the process was the mixing of the clay material. For the experiments, clay from the Mälar area was used - the same kind of clay as the ancient founders used on Helgö.

The clay, which had to be completely dried before it could be used, was first weighed, crushed into pieces and then put into water. If, instead, the water is added to the clay, it forms clods which are difficult to disintegrate. When the clay was completely dissolved, after approximately 10 minutes, the supernatent water was poured away and the fine-pulverized quartz was added, about 40% for the moulds and about 50% for the crucibles.

The crucibles were made after the clay had been worked until it had reached a pliable consistency. A bowl was first formed and then a lid was folded over the outer edge of the bowl. A handle was formed in one side of the crucible and an opening in the other. The outer casing was then formed by painting on another layer of more fluid clay but with the same proportion of quartz. It was important that the clay for the outer layer of the crucible did not have the same solid consistency as the clay for the bowl and the lid, because if this were the case the crucible would split.

The making of the moulds is almost as simple as the making of the crucibles. Experiments have shown that it takes merely a few minutes to produce a mould once you have the pattern to hand.

It is obvious that the bronze founders at Helgö used a flat surface as a support when they formed the back portion of the mould as these parts were always flat when found. The back portion was therefore the first half of the mould to be made. They pressed down the pattern into a well worked lump of clay which was rolled out on the work-table. The pattern could either be of metal or of organic material such as wood or bone. Before the pattern could be used it had to be carefully sooted, or else it would stick on to the clay.

The next stage was the modelling of the runner either by hand or with the means of a conical pattern. Again, the pattern must have been well sooted so it could be detached from the mould. The back portion was then supplied with some notches for the dowels.

After that the front portion of the mould was formed by pressing down a piece of clay over the pattern. At the same time the clay was pressed down into the notches in the back portion thus forming the dowels. But it was of great importance not to forget to soot the back portion with the pattern remaining in it before the front portion was put on. If several pieces were used, each piece had to be sooted separately.

When the front portion was ready, the two halves of the moulds were separated from each other. The pattern had then given a perfect impression to the mould.

The pattern had to be taken away immediately, otherwise the mould would crack, as the clay shrinks a little when drying. After that the ingate channel was formed.

The two halves were again joined and the outer casing of the mould applied. Before casting could be done in the mould, it had to dry for at least 24 hours. It was absolutely necessary that moulds and crucibles were perfectly dry at the time of casting otherwise they would crumble. Also they could not stand too rapid an increase of temperature in the hearth. Before they could be placed in the strong heat in the middle of the hearth they had to be gradually heated on the edge of the hearth.

After this it was time for casting. In order to understand better the situation of the ancient founders on Helgö we used for all our casting experiments one of the already excavated hearths within the workshop area at Helgö.

The hearth, which has been used, is double, i.e. it is divided into two parts. *(Fig. 7).* This is a most practical construction, as it is possible to keep different temperatures in the different parts. In one, the crucible is heated and a constant temperature of 1200-1300^{o}C is required for melting bronze. In the other part of the hearth the mould is warmed and here the temperature is considerably less. The moulds ought to have a temperature of 700-800^{o}C when the metal is poured in. If they are colder than this the metal solidifies before the mould has been completely filled.

When the metal has been melted the crucible is lifted from the hearth with a pair of tongs and the metal is quickly poured into the mould, which at this stage should be sufficiently heated. When the mould has cooled, the two halves can be separated by tapping the mould at the parting line. In most cases the two halves can be separated without breaking.

But the object is far from finished at this stage. Even though the impression in the mould is extremely sharp, not even the most skilled foundry-worker is able to get a casting which is perfect throughout. The relief decorated objects, which had such a leading position in the production at Helgö, required a careful and time-consuming grinding and polishing.

Fig. 7. Double hearth in the workshop area.

APPENDIX

The composition of the metal from Helgö

The composition of the copper-base material so far analysed is given in the Table. The first two groups represent ingot material and it is notable that almost all of the analyses have a higher content of zinc than tin. On the other hand, the other two groups which represent used material mostly have a higher proportion of tin to zinc. This may be due to a loss of zinc on remelting or the addition of tin before casting. No doubt the position will become clearer when further analyses are made on material from the workshop area and the brooches themselves.

NOTES AND REFERENCES

1 The material from Helgö is published in :-

W. Holmqvist, B. Arrhenius and A. Lundström: **Excavations at Helgö; I** Uppsala, 1961

W. Holmqvist and B. Arrhenius: **Excavations at Helgö; II.** Uppsala, 1964.

W. Holmqvist, K. Lamm and A. Lundström: **Excavations at Helgö; III.** Uppsala, 1970.

2 W. Holmqvist, K. Lamm, A. Lundström and J. Waller: **Excavations at Helgö; IV. Workshop, Part I.** Uppsala, 1972.

3 The most important find-place for this type of crucible outside Scandinavia is Dinas Powys, Glamorgan; L. Alcock, Dinas Powys. **An Iron Age, Dark Age and Early Medieval Settlement in Glamorgan, Cardiff, 1963.**

4 R. F. Tylecote, **Metallurgy in Archaeology.** London 1962, p.139.

TABLE

Composition of Helgö Copper-base alloys (Weight %)

	Cu	Zn	Pb	Fe	Sn	Ag
Bars						
7172	82,4	15,4	2,0	0,2	0,02	~0,2
8528	76,3	19,6	0,4	0,8	0,01	~0,03
8532	76,2	8,1	9,0	0,3	3,8	~0,03
9831	70,5	21,9	4,2	0,2	0,05	~0,5
Rods						
2883	77,0	12,8	1,5	0,5	4,6	~0,2
3394	61,1	5,6	16,7	0,3	6,1	~0,2
8831	93,5	0,04	0,3	0,7	0,4	~1
Runners						
9603	60,0	5,5	1,3	1,4	12,0	~0,7
9626	76,7	0,5	1,3	0,8	15,5	~0,7
Dress Pins						
9470	60,0	0,2	0,3	0,5	2,2	~0,7
Grave 43 (11)	63,0	1,0	0,2	0,4	12,5	~0,3
Grave 43 (12)	73,2	8,0	0,2	0,3	7,1	~0,3

Ancient Clay Furnace Bars from Iran

*by J.W. Barnes**©

INTRODUCTION

Whilst geologically surveying the country surrounding the Kushk zinc-lead mine in central Iran during the 5th CENTO training programme in geological mapping techniques in 1970, Mr. Taghi Parsa of the Geological Survey of Iran noted an accumulation of baked clay bars on the floor of a valley some 3km northeast of the mine *(Photo 1)*. Later the writer and his CENTO colleagues briefly visited the site and collected samples from it.

Photo. 1. Clay furnace bar fragments littering the surface at the Kushk furnace site.

Wertime has reported similar "fire bars" from smelting sites at Saavand, 80km east of Kushk *(1968, p. 933)*, and he mentions that because of their high zinc oxide content they are used by villagers even today as a medicament for healing sores. Tylecote too has found them *(1970, 287ff)*; at Deh-Qualeh, 200km southwest of Meshed where he says they were in such quantity that the whole village was built on them; he also saw more at Saicha, 150km southwest of Kerman. However, although smelting methods used in Iranian villages had changed little over the centuries until relatively recently, there is now no surviving memory of what the bars were used for. Whatever purpose they served in smelting was apparently discontinued long ago, perhaps because of the lack of a market for the material they were designed to produce. Wertime *(loc. cit.)* suggests that they may have been parts of the "grates" *(sic)* Marco Polo saw being used to recover **tutty**, or **tutiya** *(i.e. zinc oxide sublimate**)*, near Saavand in the later 13th century on his journey to the Orient. Tylecote, however, has another explanation which he bases partly on the writings of Hamd-Allah Mustawfi, a 14th century Persian: he suggests that the zinc ore used for tutty production was "pelletised" in bar-like form and what we now see are the spent remains of the bars after furnacing, equivalent to the **spodos** of the Ancients *(Tylecote, 1970, p. 287-8)*.

There is thus general agreement that the bars were used in the production of zinc oxide, but opinions differ on just how they were used. The results of the investigation reported here tend to confirm that they were in fact condensing surfaces for the collection of tutty, not an early attempt at pelletisation.

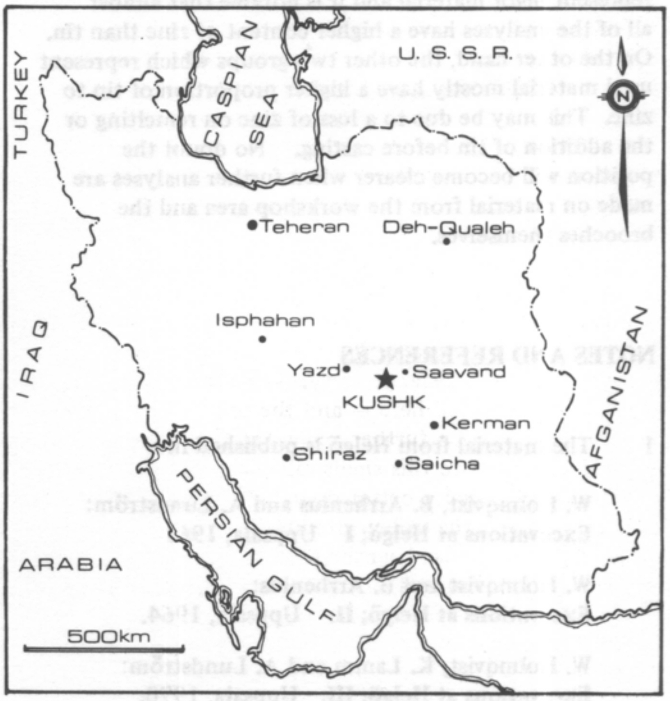

Fig. 1. Index map of Iran.

Kushk zinc-lead mine

Kushk *(Fig. 1)* lies 150 km east of the city of Yazd, itself an ancient lead producer, almost at the geographical centre of Iran. To the east and southeast of Kushk are other ancient lead mining towns at Taerz, Kuhbanen and Saavand. Kushk itself is little more than a desert locality but the present mine is of moderate size and is operated by Bafq Mining Company in which both RTZ and Simiran Company participate. Mining has now been developed to 110 m below the surface on a strati-form ore body which is part of a moderately dipping shale formation underlain by rhyodacite and overlain by a thick succession of tuffs and dolomites. Modern mining

** **Tutiya**, *from the Persian word for smoke, or derivatives of it, was the common term for zinc oxide in most European languages from at least the start of the middle ages, and probably from long before: "tutty" was the English version. Metallic zinc was of course unknown at that time and a metallic origin for tutty was not suspected.*

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dates only from 1947 and there is no evidence of any ancient workings to be seen: if any ever did exist they have now been obliterated by recent mining without having been recorded.

The ore is a sphalerite-banded shale with galena, and these sulphides persist almost to the surface with only a thin soft yellow-brown jarosite oxidation zone at the top. Ancient miners would have had little difficulty in mining sulphide ore but it would have been predominantly a zinc ore with local enrichments of galena which could, however, have been hand-sorted to a lead-rich concentrate with relative ease. A zinc concentrate with only a minor amount of finely distributed lead sulphide could also have been produced by picking.

The furnace site

The site where the bars were found lies some 3 km from Kushk mine over steep ridges and any easier route is at least twice that distance away. If Kushk was the source of the ore smelted here – and the only other known occurrence is even further away – the advantages of transporting the ore to this small valley are not apparent, unless it provided a better draught for smelting. A spring at the head of the valley provides water and a small stand of timber has been planted there; but if vegetation was once more abundant there is now no sign of it.

The bars occur over an area 20-30m in diameter where they form a slight mound on the floor of this arid valley. They are plainly visible on the mound surface and the thickness of the deposit is clearly deeper than the 30cm or so exposed by digging with a prospecting pick.
No bar was found unbroken and from the frequency of the different shaped fragments it is assumed that most

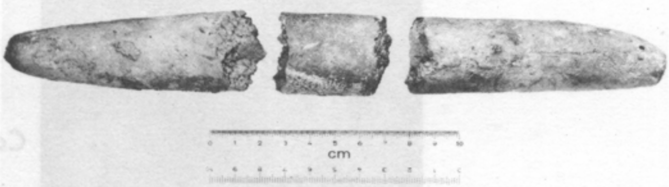

Photo. 2. Furnace bar reconstructed from three typical fragments. Some centre fragments are longer than the one shown, but many end pieces are shorter. This reconstruction probably represents a typical bar.

were broken into three to five places. Reconstruction *(Photo 2)* suggests that the bars were originally about 30 cm long which also accords with Wertime's estimates of 28-36 cm for the bars he found at Saavand *(loc.cit)*. They are roughly cigar-shaped with a relatively consistent 3 cm diameter and appear to be made from sandy gravel of up to 3 mm grain size, with a clay binder. The surface of the bars tends to roughness but is not powdery and there are patches and areas of vitrification *(sometimes only on one side of a bar fragment)* forming a very thin skin very much less than 100 um thick. Although the bars were presumably supported in the furnace by ledges or in notches, or rested on each other, they show no signs of ever having been fused to their supports although furnace bricks from the site have been fused together. Thin sections of materials which were examined under the microscope show little vitrification but as the gravel from which the bars were made contains grains from the volcanic rocks of the area, some glass is naturally present. Thin sections do, however, show some rounded areas of brown glass containing abundant laths of sodic oligoclass, showing that there has been preferential melting of certain constituents – almost certainly rhyodacite fragments. Otherwise the bars contain recognisable rock fragments, including sandstone and occasionally shale. It is interesting to note that muscovite still survives in some shale fragments, indicating that temperatures were probably not greatly above 800^{o}C, when it would be resorbed. There is certainly no evidence to be seen under the microscope that the bars were made from ore, but if they were, the presence of muscovite would suggest that the bars were fired at temperatures well below that needed to sublime zinc oxide. As a whole there is evidence that these bars have been in some furnace but there is no evidence that they have been subjected to the very high temperatures one would associate with the hearth of even a primitive lead furnace, nor would the bars have the strength to support a furnace charge at either high or low temperature. For this reason "furnace bar" has been substituted for the term "fire bar" used by Wertime. Bar fragments from the Deh-Qualeh site, kindly provided by Dr. Tylecote, did show extensive vitrification, but the fact that most bars from Kushk at least, are not vitrified, indicates that they did not need to be subjected to very high temperatures to serve their designed purpose.

A hand-sized fragment of furnace brick with red-speckled black vesicular slag attached was also collected from the site, but apart from a few similar pieces of slag, there is little other sign of the original furnace itself.

Microprobe examination

Before analysing the bar fragments for their chemical composition, samples from the edge, from an intermediate zone 8 mm from the edge, and from the core of a bar fragment were qualitatively examined by microprobe in conjunction with the Cambridge Stereoscan electron microscope *(Photo 3)*. Results showed a sharply defined zone of zinc enrichment in the first sample penetrating for 40 um from the outer surface of the bar, with a zone of lower enrichment about 50 um deep behind it. It was difficult to determine whether there was any zinc in the other samples, but if there was, it was in very small amounts and largely obscured by background "noise". Lead showed a low-grade enhancement for some 150 um in from the bar edge, with lesser enhancement further inwards, but rather high background "noise" made the results difficult to assess. Copper, if anything, was slightly higher at the bar centre, but this has little significance as the Kushk ores are virtually copper-free.

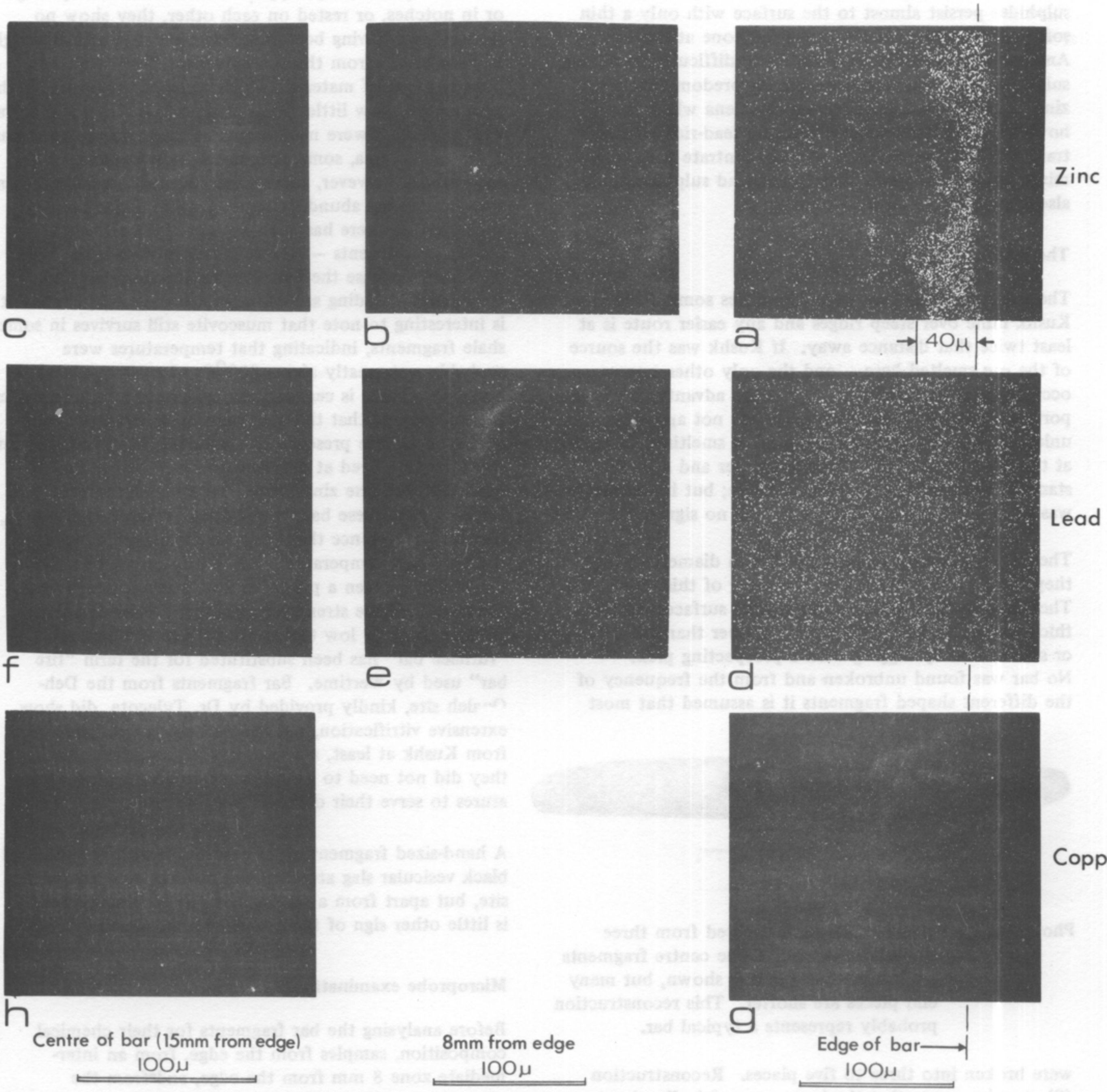

Photo. 3. — Microprobe photographs showing zinc, lead and copper distribution in the furnace bars from Kushk. Photo a, b and c show zinc concentrations at the bar edge, 8 mm from the bar edge, and at the centre of the bar, respectively. Photos d, e and f show lead concentrations in the same parts of the same bar, whilst photos g and h show copper at the edge of the bar and at the centre only.

Microprobe examinations were also made of Tylecote's bar fragments from Deh-Qualeh. One bar was fairly well vitrified and showed no recognisable minerals under the microscope except for quartz, the remainder being a greyish isotropic glass with indeterminate brown patches *(of glass?)*. It also showed a very fine grained zone 40 um thick at the outer edge. The other bar was almost completely vitrified and full of gas vesicles. Its outer surface had apparently melted to produce an uneven crinkled surface with upstanding reticulate ridges. The microprobe showed that in both bars there was once again a zinc enriched zone at the outer surface, but here well over 100 um thick, and showing no sharp cut off. Zinc decreased inwards and in the case of the second bar had dropped to an almost constant level within 1 mm of the outside skin *(Photo 4)*.

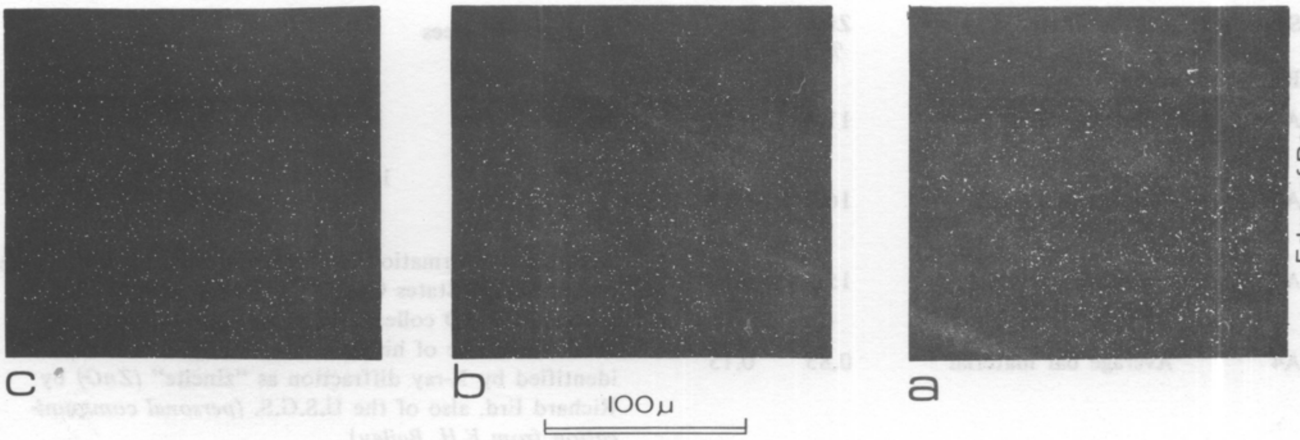

Photo. 4. – Microprobe photographs showing distribution of zinc in different parts of a highly vitrified furnace bar from Deh-Qualeh (collected by R.F. Tylecote). Photo **a** shows a strong zinc concentration penetrating for more than 100 um in from the edge of edge of the bar; photo **b** covers an area 1 mm in from the edge; photo c, 5 mm in. Patchiness of distribution, particularly noticeable in **a**, is probably due to surface irregularities caused by the remains of gas vesicles.

Analysis

Guided by the results of microprobe examination, samples were taken from three Kushk bar fragments for X-ray fluorescence analysis as shown in Figure 2. These samples included scrapings no greater than 0.5 mm deep taken from different parts of the surfaces of bar fragments A and C, including both vitrified and unvitrified material. In bar B, however, a sample was taken to a depth of 2 mm around the periphery of the bar. Samples were also taken from the cores of bar fragments B and C, and again, in fragment B, material was taken from the zone intermediate between core and outer surface. A semi-section was cut from the end of bar A to represent the composition of average bar material. Fused brick with adhering slag *(the junction between the two was obscure)*, and a piece of the glassy slag itself, were also taken. Samples from the Del-Qualeh bar fragments were also taken to determine their average composition. The samples were analysed by XRF by Mousa Al-Atia of the Department of Geology, University College, Swansea, and the results are shown in Table I.

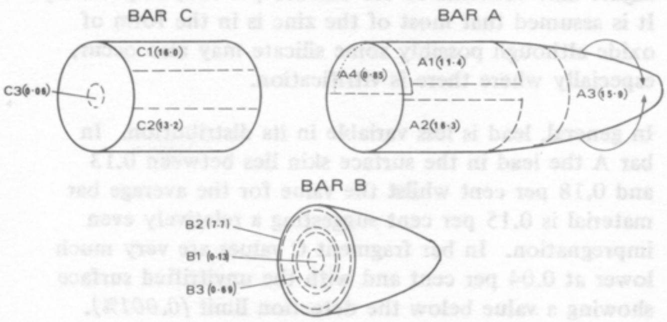

Fig. 2. Location of samples taken from bars for analysis. The zone sampled in each bar is shown by broken lines.

TABLE I

X-RAY FLUORESCENCE ANALYSIS OF IRANIAN FURNACE BARS

Analyst: Mousa Al-Atia

Specimen	Material	Zinc %	Lead %
Bar A			
A1	Unvitrified skin: scrapings to ½mm deep	11.4	0.18
A2	Part-vitrified skin: scrapings to ½mm deep	16.3	0.13
A3	Part-vitrified skin: scrapings to ½mm deep	15.9	0.17
A4	Average bar material	0.85	0.15
Bar B			
B1	Core of bar	0.13	n.d.
B2	Outer 2mm of surface of bar	7.7	0.04
B3	Inner zone of bar	0.69	0.04
Bar C			
C1	Unvitrified pale skin: scrapings ½mm deep	16.0	n.d.
C2	Vitrified dark skin: scrapings 1/4mm deep	13.2	0.04
C3	Core of bar	0.06	0.04
Brick/slag			
D1	Slag with some brick	7.2	0.05
D2	Slag	3.2	0.05
Deh-Qualeh bars			
DQV	Completely vitrified bar - average material	1.8	–
DQ2	Partially vitrified bar - material	1.2	–

A partial chemical analysis was also made by R. Rees *(of the same department)* of a semi-section of bar A for alkalis by flame photometry, and for alumina by colorimetry. The results are shown in Table II.

TABLE II

PARTIAL CHEMICAL ANALYSIS OF FURNACE BAR 'A'

Analyst: R. Rees

Na_2O	K_2O	Al_2O_3
2.55%	1.00%	15.61%

Additional information has been provided by E.H. Bailey of the United States Geological Survey, one of the writer's CENTO colleagues, who removed protruding crusts from one of his own samples. This crust was identified by X-ray diffraction as "zincite" *(ZnO)* by Richard Erd, also of the U.S.G.S. *(personal communication from E.H. Bailey)*.

Analytical results

Analyses in general confirm the findings of the microprobe examination. Only the outer skin of the bar fragments show any great zinc enhancement and gave values between 11 and 16 per cent metal. Where a 2 mm deep sample of surface was taken *(sample B2)* zinc content dropped to 7.7 per cent, presumably because of dilution by material containing lower amounts of zinc deeper in the bar surface. Figures for the inner zone and the core of this bar *(B2 and B1)* suggest a progressive decline in zinc towards the core. The average bar material *(A4)* gave a figure of 0.85 per cent zinc which is consistent with the other results. The more vitrified bars from Deh-Qualeh show higher zinc contents of 1.8 and 1.2 per cent respectively. It is assumed that most of the zinc is in the form of oxide although possibly some silicate may also occur, especially where there is vitrification.

In general, lead is less variable in its distribution. In bar A the lead in the surface skin lies between 0.13 and 0.18 per cent whilst the value for the average bar material is 0.15 per cent suggesting a relatively even impregnation. In bar fragment C values are very much lower at 0.04 per cent and with the unvitrified surface showing a value below the detection limit *(0.001%)*. In bar B lead in the outer and intermediate zones is a consistent 0.04 per cent, but was not detectable in the core. Most surprising of all the analyses however, are those for the slag, with only 0.05 per cent lead in both samples in contrast to 7.2 per cent zinc in sample D1 and 3.2 per cent in D2.

Experimental evidence

Obviously the best evidence of how these bars were used would be to reproduce bars with similar characteristics. Tylecote attempted this by making a very small bar from willemite mixed with a little natural ochre and some clay, and retorting it at 1150°C *(personal communication).* He collected the zinc oxide sublimate from the retort and satisfied himself that pelletisation as described by Mustawfi in the 14th century could produce recoverable tutty. The present writer, although disagreeing with Tylecot's conclusions, decided to follow his example by making two bars from the type of materials available at Kushk. One bar was made of crushed shale and crushed rhyodacite from Kushk, mixed with sand and blue glacial clay from Swansea; the other from the same clay mixed with Kushk sphalerite *(note that zinc oxide minerals at Kushk are rare).* Like the "natural bars", they were made cigar-like, about 15 cm long and 2 cm diameter at the middle, and it may be noted that this tapered form was more difficult to make than a simple cylinder with rounded ends. Could shape have any significance?

The bars were oven dried, then cut in half and one half of each bar was heated in a tube furnace to 850°C, the other halves to 1000°. In each case temperature was raised gradually over four to five hours to allow the escape of water vapour and of sulphur dioxide. The bars were then held at their maximum temperature for four hours. After cooling, thin sections for microscope study were made from the bars *(now a terracotta colour)*, and slices taken from microprobe examination. Under the microscope the zinc-bearing bars showed no resemblance to the bars found at Kushk, but those made from rock fragments did show many points of similarity. In particular, shale fragments were almost identical to those seen in the Kushk, even to remnant flakes of muscovite. That muscovite did survive in the experimental bars suggests that temperatures over the theoretical 800° *(above which the muscovite should be resorbed)* need to be sustained for far longer if all the muscovite is to break down under these conditons; thus the survival of muscovite is not a wholly reliable indicator of temperature. Rhyodacite in the bars had recrystallised but had not melted to the globular outlines seen in the Kushk bars: it now formed patchy brown glass with poorly formed felspathic areas and in some cases there was even evidence of a lath-like texture developing in which the *(untwinned)* laths gave a slightly oblique extinction *(albite-oligoclase?).* The better developed felspar laths seen in the Kushk bars may have been the result of a longer period of heating — and probably in particular a far slower and longer cooling period — than a laboratory tube-furnace can give. Still, the results strongly suggested that the "natural bars" were made from rock fragments and clay, and not from pelletised ore.

Experimental work was now taken a stage further and several new bars were made and oven dried. These were 7 to 9 cm long, 1 cm in diameter and, as it was now assumed that composition was not a critical factor, made of sand and clay only. Two ovoid pellets of ore and clay, each containing 4g of sphalerite, were also made as this appeared at the time to be an easy method of charging ore to the furnace. The pellets were placed in one end of the tube-furnace, whilst four bars *(Nos. II to V)* were arranged at the other. One bar *(No. V)* was half in and half out of the heating zone, the others placed almost touching each other in a line towards the furnace end *(see Fig. 3).* A water-jet vacuum pump was attached to draw air and fumes emitted from the ore pellets over the bars. As before, temperature was built up slowly to get rid of water and sulphur dioxide, and was finally raised to 1100°C for four hours. Copious fumes were emitted but ceased long before heating was stopped. Bar III was found to have a faint white coating and the two bars to either side had a white coating on their ends adjacent to it.

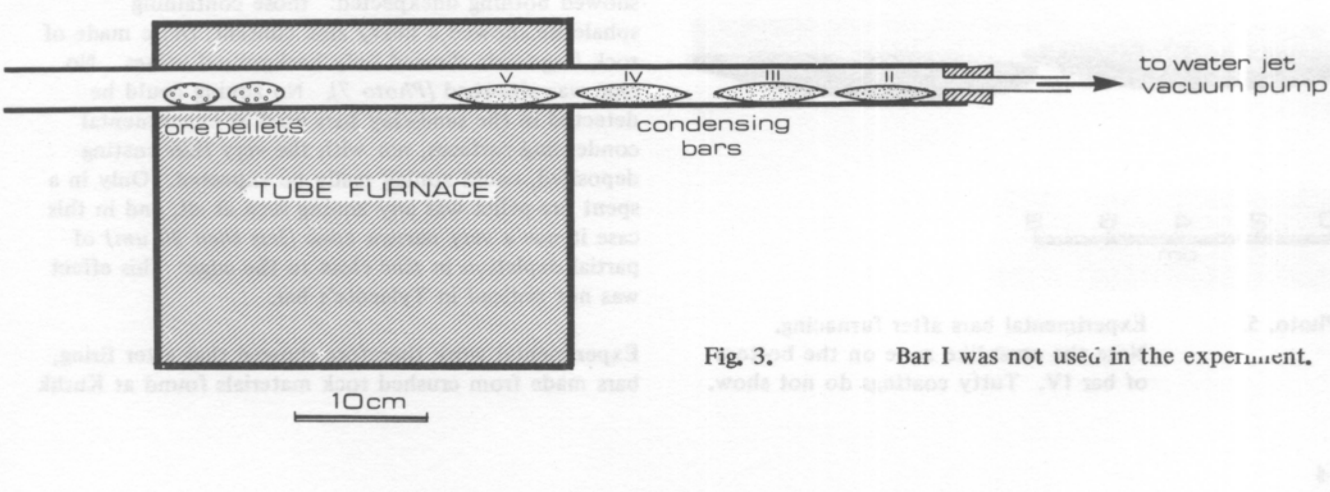

Fig. 3. Bar I was not used in the experiment.

The whole process was then repeated using the same bars but with the ore pellets replaced by a vitrosil boat containing 22g of sphalerite. Temperature was raised slowly to 1140^{O} and fuming ceased two hours later. On cooling more noticeable white deposits were found, and more widely spread, but still not affecting Bar V *(see Photo 5)*.

In general the coatings were very thin but adhered strongly, for they did not rub off. Such longitudinally arranged bars probably offer too little resistance to air flow for any appreciable crust to be built up but on the lower surface of Bar IV a greyish-white crust up to 1 mm thick had accumulated, largely by soaking into the bar material *(Photos 5 & 6)*. The thin coatings, with some 0.1 to 0.2 mm of bar material, was scraped off all affected bars and aggregated to provide a sample large enough for analysis: the grey crust was also chipped off. XRF analysis *(Table III)* showed that the coatings, although much diluted by bar material, contained nearly a quarter of a per cent of zinc, but the grey crust contained very little (0.04 per cent). The grey material appeared to be mainly an impregnation of sulphur compounds, probably formed by the reaction of clay minerals in the bar with SO_2.

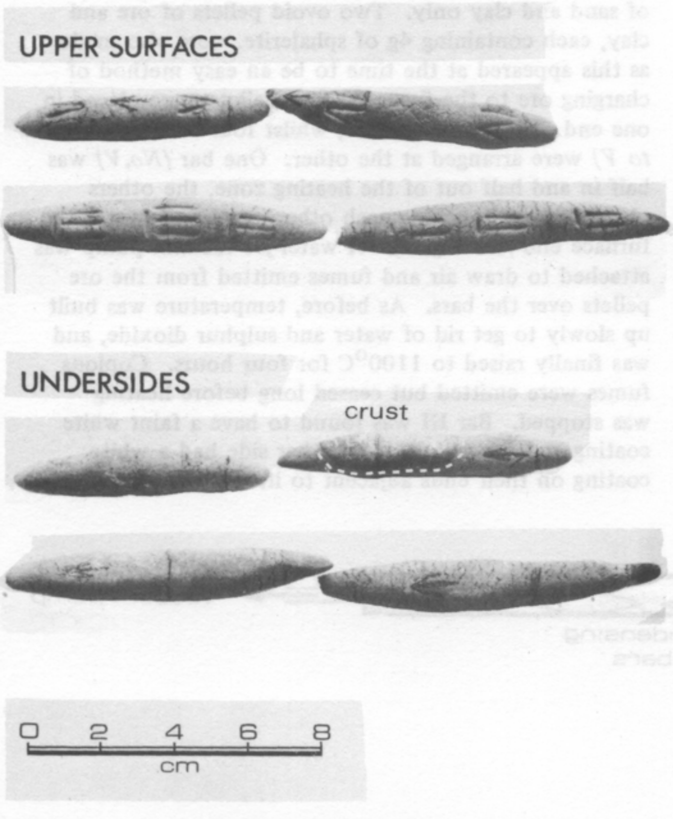

Photo. 5. Experimental bars after furnacing. Note the crust-like zone on the bottom of bar IV. Tutty coatings do not show.

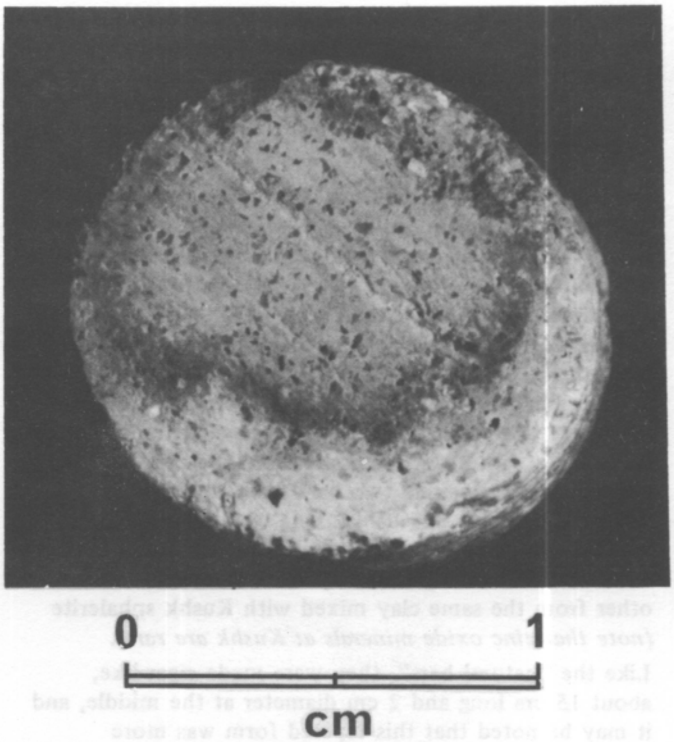

Photo. 6. Cross-section of experimental bar IV, showing the impregnated crust of sulphurous material at base.

Microprobe examinations of the experimental bars were not entirely satisfactory largely because the material was too friable to make properly polished surfaces, whilst impregnating materials used to try to overcome these difficulties did not withstand the electron beam. The best experimental materials were the ore pellets. Tylecote's experimental bar, although harder and more vitrified than the writer's, was cellular due to gas vesicles and therefore also not a very satisfactory sample.

None of the writer's experimental bars showed any zoning. The half bars furnaced at 850^{O} and 1000^{O} showed nothing unexpected: those containing sphalerite showed a heavy zinc content; those made of rock fragments showed only background values. No zinc was absorbed *(Photo 7)*. No zoning could be detected in the sand-clay bars used as experimental condensing surfaces, nor with the very thin coating deposited, could zoning really be expected. Only in a spent ore-pellet was any zoning seen at all, and in this case it was a very narrow zone *(less than 20 um)* of partial depletion in zinc close to the edge: this effect was not noticed in Tylecote's bar.

Experimental work therefore showed that after firing, bars made from crushed rock materials found at Kushk

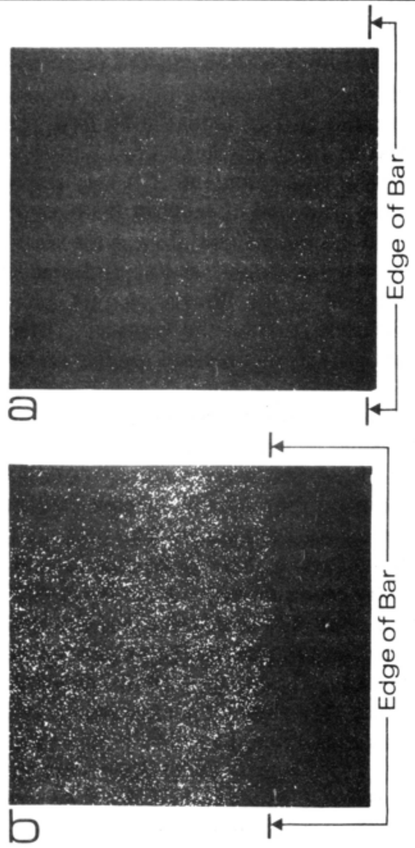

Photo. 7. Microprobe photographs for zinc in a: an experimental bar made of clay and rock material from Kushk, furnaced at 1000°C; b in a *"spent"* bar made of sphalerite and clay furnaced at 1000°C.

resembled microscopically the 'natural bars' found there, but that bars made from ore and clay did not. None bore any microscopic resemblance to the more vitrified bars which Tylecote found at Deh-Qualeh, nor would any similarity be expected. Microprobe examination provided no useful information except that the only zoning seen, that in the ore pellet, was the reverse of the zoning in the Kushk and Deh-Qualeh bars, i.e. it showed slight depletion in its outer skin. Chemical evidence was inconclusive in that some zinc oxide did condense on the bars exposed to zinc oxide fumes, forming a hard adherent, but very thin, coat: given a great deal more vapour; a much longer time, and an arrangement of bars which would impede the flow of fume, would a thicker crust build up? The sulphurous encrustation, first though - joyfully - to be tutty, at least does indicate that encrustations of some sort can build up to a considerable thickness on bars.

TABLE III

X-RAY FLUORESCENCE ANALYSIS OF EXPERIMENTAL FURNACE BARS

Analyst: Mousa Al-Atia

Material	**Zinc** %
Scrapings from surface of bars	0.24
Crust from bottom of Bar IV	0.04

DISCUSSION

How were these bars used? The work done does not support Mustawfi's observation that the bars were made of "moistened" ore *(Tylecote, 1970, p.287)*. Presumably he saw bars made of moist materials, probably grit and clay, placed in a furnace, and later he saw them taken out coated in tutty "*. . . in the shape of the bars, like sword sheaths . . ." (ibid):* perhaps we can excuse this non-technical observer for assuming the tutty came out of the bars which must therefore have been made of ore. Marco Polo was no more of a technologist but he does say that the ore was heaped on the blazing fire of a furnace which had a grid above on which the tutty condensed *(Latham, 1972, p.69)*. This at least conforms with the chemical evidence which shows that the bars are rich in zinc only in their outer skin and the very minor enhancement in zinc content in the interior of the bars can easily be accounted for by diffusion.

Experimental evidence has shed some light on the problem, but only to a limited extent. Tylecote's home-made bar of pelletised ore did produce sublimate and left a "spent" vitrified bar externally very like the vitrified bar he found at Deh-Qualeh, but microprobe examination did not show any high zinc content in the interior of the Deh-Qualeh bar. His results did not, however, explain Mustawfi's statement that the bars emerged from the furnace coated in tutty, an observation apparently substantiated by Marco Polo. The writer's experiments showed that rock fragments mixed with clay did produce a ceramic bar which was microscopically like those found at Kushk: presumably the Kushk bars were made of local gravels bound with clay. Condensation tests, however, were less conclusive, but taken as a whole the bulk of all the evidence very much supports the theory that these bars were expendable condensing surfaces used for the collection of tutty.

Chemical analyses show that the materials from the Kushk site have been enriched in zinc, but they contain little lead for materials found so close to zinc-lead ores. The small amount of lead in the slag is particularly important for until these analyses were made it had been assumed that the bars were merely part of a modification made to a normal lead furnace so that by-product tutty could be recovered. Indeed, at Saavand litharge was found, indicating that lead was both smelted and desilvered there, and Wertime *(loc. cit.)* justifiably considered that any tutty collected was a by-product of lead smelting. But, were these bars for the direct collection of by-product tutty, or were they part of a secondary refining process? At Kushk the low level of lead in the slag shows that whatever was smelted there, it was not lead-rich. We must now assume that this site was for the treatment of zinc ore from which galena had been picked by cobbing and careful hand-sorting; or it was for refining a zinc-rich secondary product from another process, such as the residues and flue dusts from a lead furnace. Whatever the raw material, the end product was evidently tutty, the only zinc compound possible in the circumstances, and it may be noted that Kuhbanen *(and probably other parts of the Saavand-Yazd-Taerz area)* was once an important tutty producer, exporting it even as far as India *(Forbes, 1964, p.262-3).*

The bars at Kushk may thus be assumed to form part of a zinc oxide collecting plant which, whatever may have been the case elsewhere, was treating zinc-rich material. The bars are not strong enough to support a charge themselves, nor at Kushk do they show the vitrification expected in ceramic bars from the hearth of a furnace, so it must be assumed that these bars were used only in the upper parts of the furnace where temperatures were only high enough to cause thin and patchy vitrification. There they were exposed to zinc vapour from the furnace below which condensed on their surfaces to form a crust. As temperatures in the upper parts of the furnace were relatively low, there was little diffusion of zinc into the body of the bars and the main zinc concentration now found is in their outer skin. Some vitrification of the surface may have occurred at the very beginning of the process, and some sublimate may have reacted with the ceramic material to form zinc silicate, but the accumulation of refractory zinc oxide on the bars probably tended to protect them from further vitrification. However, as seen from the bars collected by Tylecote at Deh-Qualeh, some may have been overheated at times and so suffered extreme vitrification.

Although the ores may have been hand-picked the tiny scattered grains of galena which occur in the Kushk ores could not be removed. Some lead were therefore present in the furnace fumes and was absorbed by the bars to give a relatively uniform impregnation throughout each bar fragment with just a slight enrichment which the microprobe shows in the outer zone *(Photo 3):* this is consistent with the behaviour of lead vapour and part of it may even have reacted with bar material to form silicates. Lead contents differ in the various bar fragments and it is emphasised that these samples were collected at random from among many thousands of fragments and are not pieces of one single bar. They were probably used at different times, when the lead content of the furnace charges differed, or were used in different parts of the furnace. Tutty condensing on the bars probably contained similar amounts of lead.

Just how the bars were arranged in the furnace flue is now impossible to determine. Did they rest in niches or sockets in the flue walls, well separated one from another, or were they merely stacked criss-cross fashion directly on top of the charge? Why also are they never found whole? Presumably the bars were broken in removing the crusts of oxide from them which Mustawfi said coated them like sword sheaths, particularly as experiments suggest that the tutty adheres to the surface strongly. The huge deposits which are now found suggest that they were expendable and even if usable more than once, had only a very short life. Presumably they formed the gratings that Marco Polo described as *"... of small bars set close together..."* to which *"The smoke or vapour ... attaches itself ... and as it cools becomes hard" (Forbes, 1964, p.271).* According to Marco Polo *(ibid; and also Latham, 1972, p.69)* the bars were of iron, but how reliable were the details of his observations, for his whole description of the production of tutty takes only seven lines of print in Latham's version? * Perhaps iron bars were used at some time, and perhaps expendable clay bars were found to be cheaper, or more convenient, or were an earlier material.

Nothing was found during the writer's very short visit to the Kushk site by which the nature of the charge fed to the furnace could be determined. If it were a zinc-rich hand-sorted concentrate we must presume that the site was for the exclusive production of tutty, established because the available ore was zinc-rich. Unless pre-roasted, the charge would have been sulphidic, for the

**There appears to be some difference between the accounts of Marco Polo's observations given by Forbes and those given by Latham on this subject. Forbes' account is longer and more detailed than Latham's, although both presumably originated from the same text. Forbes gives Paracelsus and Biringuccio as references: perhaps these gentlemen improved upon the original text.*

oxidation zone at Kushk is insignificant, a fact confirmed by Burnol *(1968, p.63)* who visited the mine before modern mining was under way. Unless the ore was roasted first, difficulties such as the crusts the writer encountered in experiment would probably have occurred. There is however, the possibility that the site may have been used to process flue dusts and residues from another furnace - possibly a lead furnace - so as to produce refined zinc oxide of a quality suitable for making brass. Brass-making was probably the main use for Persian tutty and much of the furnace residue and dust from a first smelting may well have been too impure for this until refined. Certainly it would have been too contaminated for its secondary use in medicine. That even the Ancients had a keen knowledge of the variable qualities of zinc oxide sublimates is apparent from their extensive terminology. Dioscorides, in fact, not only mentions two main classes - white **pompholyx**; and **spodos**, black *"as though it were a scraping and flaking of the floors of the furnaces of the brass workers" (Forbes, 1964, pp.263-4)* - but he further subdivides them on quite small differences of colour and crystallinity under such terms as **botryites, onychitis, placodes, zonitis** and **ostracitis** *(op. cit., p.270).* Although by the 13th century Albertus Magnus manages to confine himself to only three varieties - **tuchia** from **tutiya**, **cadmia** which he sometimes confuses with smithsonite, and **succudus** *(Wyckoff, 1967, pp. 249-50)* - there was obviously considerable empirical knowledge of the substance in the past despite the fact that zinc metal was still unknown.

Finally, why and when did smelters in Iran stop using these bars? Was it because the supposed iron gratings seen by Marco Polo displaced them? Did outlets for tutty dry up because consumers found other sources closer to home? Were deposits of smithsonite/pure enough to replace the more expensive tutty in brass making found? Massive bodies of smithsonite running at 33 per cent zinc occur in the deeply oxidised zinc ores at Shah Kuh, near Isphahan, another occurs at Angouran, near Tabriz: others occur elsewhere in Iran but none in the Yazd-Taerz area with the possible exception of poor quality material at Taft, near Yazd itself. Were these bars in fact unique to eastern Iran, where smithsonite is rare or of poor quality? They have not been reported from western Iran, nor have they ever been found in Turkey, a country rich in zinc ores, many of them oxidised to smithsonite at surface.

The question of when is even more difficult to answer. Even in Europe cementation methods *(i.e. 'smithsonite methods')* of brass making persisted until the middle of the last century, and no doubt they were used even longer in less developed metallurgical areas such as this. All that can be said is that there is now no record of when and how the bars were used, despite long metallurgical traditions in the villages where they are found, and despite the fact that bars which still remain are used medicinally even today: usage was sufficiently long ago that no memory of it now persists. At Kushk enough time has passed so that the furnace itself has disappeared except for small fragments of fire-hardened brick with adhering slag, whilst the thousands of bar fragments form a deposit of soil and bar-fragment conglomerate. In this arid part of central Iran it is impossible to say how long it would take to achieve this condition.

ACKNOWLEDGEMENTS

First may I commend the keen observation of Mr. Taghi Parsa, Museum Curator of the Geological Survey of Iran, who discovered this site. I should also like to thank in particular Mr. Mousa Al-Atia of this department for his great help in analysing the samples by XRF, Mr. Richard Rees for other analyses and also Miss Christine Nicholls for help with the microprobe. Professor Hugh O'Neill, formerly of the Department of Metallurgy at Swansea, kindly read the original manuscript, whilst correspondence and specimen material from Dr. Tylecote stimulated in particular the experimental work. In addition I should like to acknowledge the hospitality of the Bafq Mining Company, near whose property the bars were discovered, and the Central Treaty Organisation *(CENTO)* who financed the geological programme during which the site was found.

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Irish Prehistoric Gold-Working; some Geological and Metallurgical Considerations

by Stephen Briggs, James Brennan,** and George Freeburn.**** ©

'It has been asserted that the gold of which our Irish ornaments are composed was brought from India by the nomad Kelts who finally settled in Ireland; by some it is supposed that it was procured from Gaul; and by others that it was imported from Spain by the Milesian colonists. Others, again, imagine that it was derived from Africa; in fact, our manufactured gold has been assigned to every gold-producing country in the world of ancient times, but our own.' Wilde, 1862[1],

It was with the above statement that nineteenth-century Ireland's most distinguished publishing antiquary ended his treatise on the gold objects in the collection of the Royal Irish Academy. His grasp of the problems of pre-history were sound for his day. Many still are sound. Wilde was at the time taking exception to the then generally-held view which was expressed by him above.

But a hundred years later, the origin of the metal for the fabrication of gold objects in prehistoric Ireland was still obscure. And it was in order to attempt a solution to this problem that the Römisch-Germanisches Zentralmuseum at Mainz published their third investigation into the origins of metallurgy dealing only with prehistoric gold from Europe. Edited by Dr Axel Hartmann of Stuttgart, the publication contains over 500 analyses of artifacts found in Ireland[2]. Hartmann's treatment of these analyses has been received both optimistically[3] and cautiously.[4,5]

The present article sets out first to examine the geological background of gold in Ireland (*Part 1*), describe a preliminary geological survey carried out by two of the authors (*Part 2*) and discuss the implications of Hartmann's metallurgical groupings (*Part 3*).

PART 1

The Geographical and Geological Distribution of Gold in Ireland.

This has been recently discussed and summarized by Reeves[5]. The following is a slight amplification of his work.

The Wicklow Deposits

The Wicklow deposits are well-known from numerous accounts both in geological and archaeological literature.[5,6] As has been recently pointed out by Jackson,[7] most of the deposits which were exploited in the 18th and 19th centuries were from placer deposits within fluvio-glacial gravels. Nowhere has gold yet been found in situ or a 'mother lode' located.[8]

The assays made during the 19th century of a number of rocks from this region, suggest that the gold may derive from rocks of different geological epochs. A quartz vein in the Cambrian quartzite of the Bray Series on Bray Head was demonstrated to be auriferous by Dr. Francis Codd.[9] South of Bray Head, Gerard Kinahan recognised small specks of gold in black sands deriving from the Silurian slate[9] whilst O'Reilly[10] noted its presence as 2 dwts per ton from volcanic rocks in the Dublin area. Gravels of the River Dodder at Ballinascorney and Rathfarnham have been observed to contain some gold particles[9] whilst G.H.Kinahan[11] notes that both the Liffey and Slaney Valleys are mentioned in the Annals as having been worked for placer gold. In 1970, James Brennan recognised some gold particles while panning the River Slaney near Enniscorthy (*unpublished investigation*), and there are references to probable gold occurrence in County Carlow[9] so it would appear that the area from which gold may be recognised from stream samples in the South East of Ireland could cover hundreds of square miles.

Two source rocks exist from which most of this Wicklow gold could derive. Firstly, there are two parallel belts of Silurian and Ordovician rocks running roughly NE-SW some 68 miles on either side of the Leinster Granite. The inner zones of the two Silurian belts form mineralised aureoles next to the intrusion. Most of the rivers flowing out of the Wicklow mountains, both East and West, cross this mineralised zone at some point, and it is therefore hardly surprising that so many of those rivers yielded positive results when gold was sought.[12]

The best-known gold finds in the Croghan Kinshella area, south of Aughrim, are located on the flanks of a ridge of volcanic rocks, where these rocks have altered and mineralised the Silurian shales. It therefore seems more likely that the gold derives from lodes within this aureole than from the actual granite, as was supposed by Charlesworth,[13] though it is not absolutely clear what he means by 'near the margin of the granite.'

The second probable source rock in Wicklow is the Cambrian quartzite at Bray investigated by Dr Codd, where a quartz vein network may contain gold.

References to Gold elsewhere in Ireland

In the Southwest of Ireland, G.H. Kinahan[11] records the reputed occurrence of gold among the copper lodes in yellow Devonian sandstone at Crookhaven. This occurrence is strengthened by its recognition in copper ores from County Cork.[14] Lewis's mention that gold ore was known from Ardpatrick, Co. Limerick, more likely refers to a piece of prehistoric artifact than to a mineral occurrence.[15] The West of Ireland has little tradition of native gold, and less evidence. One tradition suggests its existence at Feakle, Co. Clare, and the number of topographical names using Or and Orra must be dismissed as of no geological significance until proved other-

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wise.[9] The rumour that in 1863, a 6 lb nugget, besides many smaller ones, was found at Crossmolina, Co. Mayo, has not yet been substantiated.[9]

There are two references to supposed gold sources in the North Midlands. A mine in the neighbourhood of Manorhamilton and Lurganbuoy, Co. Cavan, is marked on the O.S. Geol. Survey Sheet 44 as a 'Gold Mine' and noted on the accompanying memoir. It was certainly the seat of silver, copper and lead mining, but it seems strange that neither Kinahan nor later writers record any mention of gold from it, though it enjoyed 4 years of industrial activity between 1842 and 1846.[16] During recent investigations by the Tara Mining Company, gold has been recorded accompanying an occurrence of antimony and arsenical pyrite in Co. Monaghan.[17]

From nearer the North Coast there is a nugget in the Ulster Museum. This, labelled 'Inishowen', has been submitted to the Stuttgart Laboratory for analysis and was acquired from Seaton P. Milligan (*Museum No. 737, 1916*).

From County Antrim, Lewis twice notes the occurrence of gold: at Skerry, Ballymena[18] and at another site near the base of Slemish Mountain. Both finds were from a 'Greenstone'. The Glendun River also traditionally produced gold[11] and the tradition is confirmed by a Mr Collins of the British Portland Cement Company, who picked up some grains at the confluence of the Glendun River with the Owenaglish in 1954.[17]

Besides these, there is a newspaper account of June 15th 1826, in the **Enniskillen Chronicle and Erne Packet** describing how a 'quantity of gold . . . mixed with extraneous matter . . . in the quantity of 1½%' was found by labourers while preparing the site for a gasometer at Lisburn. This is less likely to be a geological freak than the site of a goldworking area of an unknown period.

Gold Deposits in the Sperrin Area

Perhaps the earliest reference to the occurrence of fine alluvial gold in Ireland, is that of Gerard Boate, who in 1652, mentioned that particles had been found in the Moyola River.[20] Probably following his authority, Sampson confirmed Boate's statement, though was reluctant to accept that the gold flake in his possession was in any way indicative of its general occurrence.[21] Some five years previous to this, the Rev. John Graham had also noted its supposed presence in the Moyola and described how the 'common people who live near the river, have a tradition corroborating this report of Dr Boate . . .' None of these people have ever found any gold in the river.[22]

However, one of the most remarkable statements ever written on Irish gold, with the object of attracting prospective investors in Irish mining, was that compiled and published by New Industrial Issues Ltd., on 14th October 1935.[23]

This pamphlet, of 24 pages, two maps and numerous illustrations, combined quantities of incomprehensible jargon with the prospects of infinite financial reward. The recorded facts of there having been gold workings in Wicklow, and of the existence of large numbers of prehistoric gold artifacts from elsewhere in Ireland were stated, and numerous writers of varying authority were quoted in order to draw the attention of the investor not to Wicklow, but to Northern Ireland.

Turning, on p 10, to the North of Ireland, the leaflet describes how a Mr Heiser searched for, and found, gold at 8 different locations within Counties Derry, Donegal and Tyrone. There deposits were found to contain gold in quantities ranging from 3 to 48 grains to the cubic yard. All the gold was found by panning, and nowhere does the compiler describe a primary source for the mineral. Explanations of the origin of alluvial gold within the article are not very illuminating (pp 15, 16) even to someone who knows the geology of the area. The credibility of much of this statement is doubtful, and the company concerned does not appear to have enjoyed the remarkable future which it predicted for itself.[24]

Despite the dubious nature of the document, it is possible to ascertain that gold was successfully panned for at a handful of locations. These were in the Mourne River and Basin, and at its confluence with the Derg (p 23), at the Owenkillew and Glenelly confluence (p 24), in the Cabry Valley in Co Donegal (p 23, 24), the Faughan River and the Faughan Vale in Co Derry (*where there is still tradition of gold having been found*), and it was probably also recognised in small quantities from other localities in the Foyle Basin.[23]

The widespread nature of the occurrence of gold in the Sperrins, Antrim and Donegal, suggests that it may be derived from a variety of Moinian and Dalradian metamorphic rocks, or in the contact zones between Palaeozoic sedimentary rocks and Caledonian intrusive igneous rocks.[25]

Gold Deposits from other localities in the British Isles

Calvert and Hunt have written comprehensive, though dated accounts of the gold deposits of these islands.[26,27]

In Scotland, the Sutherland Goldfield of Kildonan is perhaps the best-known and richest deposit in Britain.

The nature of its occurrence in this area suggests that its recovery, even in modern times, would be restricted to hand panning.[28]

Wales is better known for Roman Mining, both in the North, around Dolgellau, and in the South, at Dolaucothi, a site which has recently become better known through the work of Jones and Lewis.[29] Whereas the Romans recovered their gold here from a complex mining system, it seems likely that earlier activity in the area was restricted to simpler methods of recovery.[29]

Gold is also known from the tinstreams of Cornwall, though only it occurs in minute quantities.

The existence in Ireland, of two major zones of mineralisation from which gold may have been won in prehistoric times can now be demonstrated. Other sources of gold in the British Isles have been mentioned above, since it seems more likely that prehistoric man would use resources close to hand, rather than deliberately import raw materials from the continent. Hartmann[30] omitted to mention any other resources from the British Isles, than the Wicklow deposits.

Only systematic stream sampling will confirm or disprove old traditions of gold occurrence in areas of heavy mineralisation, and only many analyses of these samples would illustrate the true range of trace elements with which we are comparing our prehistoric examples.

PART 2

The Recovery of Gold from the Sperrin Area, 1967 - 1971

With the historic background and the known fact that the late George Barnett of Owenreagh had successfully panned for Moyola gold during the present century[31], two of us, (*J.B. and G.F.*), began a systematic programme of investigation of gold occurrence, by river panning in the South Derry - North Tyrone area in late 1967.

The panning of light gravels and muds on the edges of rivers was attempted using a shallow steel bowl, as recommended for mineral collection elsewhere.[32] It was soon discovered that the best locations for gold particle recovery are those where the heavier grains of gold have sunk into the bedrock of the river. Sampling was hindered in the deeper streams, where lack of deepwater equipment, or the existence of bare, unfissured bedrock made it virtually impossible to locate and examine sediments. Better results were achieved by collecting particles from between paving stones beneath bridges.

Once collected, the yellow grains were kept in small bottles of water, for examination. The morphology of grains from different locations was found to differ markedly. Those found lower down the streams, (*for example from around Newtown Stewart*), being more flattened, suggesting to the authors that they had travelled some distance from their source or sources. Higher up the rivers, (*for example along the Owenreagh River*), the grains were more angular and solid, suggesting their possible closer proximity to a primary deposit.

In order to ascertain from which local rock type the gold may have derived, one of us, (*J.B.*), carried out a simple chemical test on several samples of pyrites in bedrock from a variety of geological and geographical horizons within the area under investigation. This method was qualitative only, but did illustrate the local existence of native gold from a wide variety of geological horizons. (*See Appendix 2*).

It has not been found possible to trace any vestiges of early mining or placer workings in the Sperrin area, and therefore it seems more likely that Barnett panned here for the metal, if, indeed he knew this source.

It may be suggested here, that even within the richest auriferous area of Wicklow, some panning must have been done in order to locate placer deposits and their nuggets. And since finding nuggets tends to be a hit and miss business, the prehistoric metallurgist may soon have discovered that it was simpler to collect small particles at a consistent rate, in a hardened hide, or in a wooden pan, than it was to walk miles and wade fathoms, searching for elusive pebbles.

This local survey has demonstrated the possibility of small-scale recovery of particles from rivers draining wide areas of Central Ulster. The defined area has been noted to coincide roughly with a high concentration in the distribution of gold lunulae of the Early Bronze Age.[33] It is here suggested that some of these ornaments may have been made of alluvial gold recovered in like manner, and that here, and elsewhere, prehistoric man is more likely to have collected his gold by panning than by looking for nuggets *(pace Tylecote[34])*.

Dr. McKerrell[35] has kindly analysed a sample of this Sperrin gold from Trinamadan Bridge, Co. Tyrone (*Irish Grid ref. 493 867, sh 4, 1"*). The composition is: Au 90, Ag 9.8, Cu $<$ 0.1 and Sn $<$ 0.01%. The two latter figures were the detection limits for the run and are realistic at the 2 sigma level. He writes "In terms of the Stuttgart groupings this is undoubtedly group L; low Ag, very low Cu and Sn. The lunulae grouping." The significance of this analysis will be discussed below.

A further sample of Sperrin gold has been sent to Stuttgart for analysis.

PART 3

Trace Element Analysis and Gold

Hartmann has described 6 main groups of gold artifacts from Ireland on the basis of chemical trace element analysis[36]. These 6 groups are L, M, OC, MC/NC and PC. Of these, it has been suggested that groups OC and MC/NC may well be of intentionally alloyed gold containing silver and copper, whilst there is only one artifact of group N metal.

Our examination here concerns only groups, L, M and PC, since the view was expressed that one of these, group L, was probably of Wicklow gold, another, group M, was almost certainly not of Wicklow gold, and that Group PC may even have been imported from the Upper Rhine. It is quite possible that these views may, at some future date, be demonstrated to be correct. However, in the meantime, it is felt necessary to examine closely the evidence upon which they are based.

Groups L and M

The following table, taken from Raftery's summary[3], illustrates the relative percentages of the major trace elements in these two groups[37]

Copper %	Tin%	Silver %
Group L; 0.1 to 0.25	usually less than 0.1	12.5
Group M; 1.1	0.16	between 7 and 21

The reader is referred to the original tables for fuller data.

However, there is some doubt of the value of recording relative percentages of silver and copper within the gold. Tylecote[38] dissents from the view that gold which has weathered for a long time has some of its silver dissolved from it, as against recently released natural gold, including mined gold, which will tend to be higher in silver. He points out that there is little evidence to substantiate this theory, and he considers that the silver content of early gold is natural, ie present in its original percentage.

There can be little doubt but that the silver content of early gold is natural. But even this does not preclude that some of its silver content may have dissolved since it left its primary source and before its collection. Silver does dissolve during weathering, the black tarnish of silver oxide being seen on the surface of the gold which contains it. The silver content of stream samples is therefore likely to be reduced in this manner (*as suggested by Hawkes*[39]).

It therefore follows, that within one river, particles deriving from the same source will contain progressively smaller amounts of silver, as they are battered and washed away from that source. There could consequently be a wide variability of silver percentages in samples from the same stream. Only a systematic programme of collection is likely to determine such variability, and in the meantime, it seems doubtful that the percentage of silver in these analyses of early ornaments is significant in either geological or archaeological terms.

Comparisons of scratch analyses from placer nuggets with similar stream provenances may also be of limited value. If only the outer layer is scratched, it may give a false impression of the actual percentages of trace elements within that nugget, since the outer skin is likely to have lost, through weathering, at least some of the less durable elements - for example copper and silver. Indeed, the low percentages of silver and copper may be accountable to such weathering.

Dr. Tylecote[38] has cautioned that in alluvial gold, there is a good chance that copper would be dissolved by the action of the water. The demonstrated differences in copper content between groups L and M may not be particularly significant for this reason.

A comparison of differences in tin content between these two groups is confusing. Here again, Dr.Tylecote[38] has issued a cautionary note about its use as a trace element. "Stream or alluvial gold may contain tin because the tin mineral (*cassiterite*) is heavy, and, if present, will pan out with the gold and be incorporated when the gold is melted under reducing conditions."

Simoëns[40] has surveyed the tin resources of the South-east of Ireland; it is yet unknown from the Sperrin area. Systematic sampling may reveal its presence there. It does, however, seem strange, that group M, which contains slightly more tin than group L, should be the only group which is thought to come from outside Wicklow, *(but still in Ireland)*, the only area in which we have yet any positive tin occurrence.

Slight traces of nickel were detected in about 15% of group M, but were not considered to be characteristic. Since nickel is not a well-known metal from Ireland or Britain, this may prove to be one of the few diagnostic elements, but only when we have a fuller knowledge of its geological occurrence. *(Cole[41] notes traces of nickel in association with copper in Co Galway; Davies[42] notes its association with iron at Moel Hiraddug in Flintshire; there is a small nickel lode in Tyrone (Pers. Inf.)).*

Besides suggesting that groups L and M may be from different sources Hartmann has suggested a chronology into which they could fit.

Conveniently, L comprises many objects of the lunula class, and is proposed as of the Early Bronze Age. Group M comprises a number of objects from hoards and there it is proposed belong to the Bishopsland Phase of the Middle Bronze Age[43]. This chronological division seems sound on both archaeological grounds and upon the basis of the analytical groupings proposed in SAM 3.[2] However, the implied geographical groupings, discussed above, appear to suggest on the grounds of this chronology, that Middle Bronze Age populations were collecting gold in completely different areas to those in which the First Metallurgists had found it. This view must be questioned, both on grounds of the limitations of the analyses, and on account of the paucity of analyses of native gold available from Ireland and elsewhere, when compared to the large number of extant analyses of artifacts.

Group PC

Category PC is characterised by the existence of a small amount of platinum, and seems to comprise metalwork ascribable on archaeological grounds to the La Tène period. Raftery notes that platinum-type gold does not appear in Ireland in the raw state and, in pointing out that it is found in the area of the Upper Rhine, is tempted to think its occurrence in artifacts from both this area and Ireland, as indicating cultural or even ethnic contacts. Whereas nowhere does Raftery state that such Irish articles derive from the Upper Rhine, this is inferred in the statement. However, both he and Dr Hartmann agree that this fact is not demonstrated, and that the origin of group PC must as yet remain an open question.[3]

The analysis of artifacts of this class revealed the presence of up to 30% silver, with some 5% copper and 0.3% tin, whilst the diagnostic element platinum averaged 0.01%.

Tylecote records that natural gold may contain as much as 38% silver.[38] It does seem likely, however, that in the case of group PC, silver would be alloyed to gold when the latter was in poor supply. Distinguishing alloyed silver from natural silver within the gold is spectrographically impossible. To counteract the whitening effect of the silver upon the gold, a small amount of copper would be added. The average of 5% copper observed in this group was probably added for this purpose.

The presence of such a tiny percentage of tin could indicate that methods of alloying and refining were becoming very sophisticated, as was the art style during the La Tène period. Another possibility is that placer deposits were being worked, thus obviating the picking-up of adventitious particles of heavier elements.

The presence of platinum is more difficult to explain, unless it, too, was accidentally included in mineral collection or deliberately added as a hardening factor during working. It is far less probable that the platinum was contained in the silver or copper additives, than in the original gold, since it is far more frequently associated with that metal.[44]

The possibility that platinum-gold may be found in Ireland should not be overlooked. There is a tradition that platinum occurs in the Wicklow Mountains.[45] This tradition is partly confirmed qualitatively by its appearance in a list of the elements recognised in the general area of the Wicklow gold working.[46] No mention is made of its mode of occurrence in relation to the gold. It remains possible that platinum may be recognised elsewhere in Irish gold deposits and it should be pointed out that it would take very little to contaminate the gold in such tiny amounts as those recorded by the analyses.

Within the British Isles, platinum has been recognised in Northwest Scotland, where its proximity to the primary occurrence of gold should be noted.[28] In Shropshire, it has been reported from the Bunter sandstones, into which it is proposed that it found its way from the older rocks of North Wales.[42] This being the case, it is not improbable that the platinum may come from roughly the same area as North Welsh Gold. *(The inference is the present authors').*

Therefore, it is suggested here, that whereas it is not altogether impossible that the gold of which Iron Age artifacts were made was in fact imported, that this possibility could well disappear, when the gold resources closer at hand, which we know from the scattered literature, have produced analyses. Certainly, it is premature to infer on present evidence that a large proportion of Irish Iron Age gold artifacts was either made abroad, or that the metal was imported from abroad.

The two main questions which it may be hoped to answer by detailed artifact analysis concern its origins and the method by which it was fashioned. Before any attempt can be made to ascribe objects to origins, detailed knowledge of ores, their content and distribution, must be available for comparison with analyses of artifacts. And before any conclusions may be reached about methods of manufacture, there should be detailed analyses of different parts of the same object.

Firstly, then, the need for the systematic examination of ore deposits will be discussed. In other fields than that of prehistoric gold metallurgy, the need to analyse ores has been realized, and that need is being slowly met.[14] Yet Hartmann has analysed some 500 Irish artifacts, but only presented a handful of ore analyses.[47] This is the more surprising, since in 1939, having brought together 14 ore analyses from all over the British Isles, Otto had to admit that there were then too few ore analyses to permit of useful comparison with analysed artifacts.[48]

Secondly, Hartmann has not offered any detailed studies of any single artifact even though the value of such studies has long been appreciated. In 1938, Plenderleith analysed in detail eight objects belonging to the National Museum in Dublin.[49] Using optical spectrometry, Plenderleith produced 22 analyses of the eight artifacts and was able to determine local variation in artifact composition.

It is unfortunate that Hartmann omitted to mention Plenderleith's work in his otherwise comprehensive bibliography of analyses in the literature,[50] since these analyses, though only qualitative, are an important landmark in the study of prehistoric gold metallurgy. In his study, Plenderleith managed to note several trace elements which were not included in Hartmann's survey *(Table 1)*.

Table 1

A comparison of the analyses of Plenderleith with those of Hartmann

Reference Armstrong's Catalogue (1920)	Plenderleith's letter (Maryon[49])	Elements present besides gold: Ag	Bi	Cu	Pb	Sn	Ti	V	Zn	Hartmann's number	Percentages: Ag	Cu	Sn	Ni	Other elements
W 173	J Joint (?)	x		x	x	x				Au 761	ca.17	5.0	0.44	n.d.	sp. Pb
Smaller Tara Torc	K Leaf	x	x	x	x	x	x	x							
	L Leaf	x	x	x	x										
W 192	G Joint (?)	x		x	x	x			x	Au 762	17	4.9	0.40	n.d.	
Larger Tara Torc	H Leaf	x		x	x	x			x						
	I Leaf	x	x	x	x	x									
W 156	O Dark Band	x					x	x		Au 849	ca.20	5.9	0.26	0.01	
	P Body,in gap	x		x	x	x	x		x						
W 158	M Dark stripe	x		x	x	x				Au 936	ca.14	5.9	0.31	n.d.	
	N Body,in gap	x		x		x	x	x							
W 65	Q Joint (?)	x		x			x	x		Au 968	2.5	0.46	0.004	n.d.	0.010%Pt
	R Leaf	x		x		x			x						
	S Leaf	x		x		x	x	x							
W 121	T Joint	x		x		x	x	x		Au 949	ca.13	5.2	0.18	n.d.	
	U Stem	x		x		x	x	x							
	V Rim	x		x	x	x	x		x						

x = the element has been recognised
n.d. = not detected

Despite the obvious drawbacks to Plenderleith's early spectrographic analyses, his inclusion of a wide range of trace elements makes it potentially more useful in the ascription of object to ore, than do quantitative studies which are concerned mainly with copper and silver. Moreover, besides ascertaining minor differences in trace element content from one part of an artifact to another, Plenderleith demonstrated that alloying had taken place in one sample *(W 156; N.M.I; Hartmann, Au 849)*, and Maryon suggested that this alloying may have been modern.[51]

The origins of Hartmann's Group L remain to be discussed. It was suggested by Hartmann that Group L artifacts were derived from Wicklow gold. If they are, we are faced with the problem of ascribing objects – particularly the lunulae – found in the Sperrin area, the centre of their densest distribution, to the Wicklow area. This would suggest that widespread trading of objects during the Early Bronze Age in Ireland. But there are no ore analyses from Wicklow comparable to those of the analysed lunulae, and the only comparable analysis so far available is that from Trinamadden Bridge, Co. Tyrone. We therefore suggest that at least some of the lunula were made locally in the area which roughly coincides with their densest distribution, from stream panned gold.

Hartmann's other Irish groups cannot be easily interpreted in terms of ores, not only because of the lack of ore analyses, but because of the considerable differences between the compositions of analysed artifact and of known ores. These differences are perhaps better explained by local or chronological differences in alloying techniques – a most unhappy explanation in view of its obviating the ascription of the majority of prehistoric gold objects to a native gold source; only to a school of metallurgy. The only way in which it may be possible to ascribe Hartmann's later groups to natural sources, would be by identifying as many obscure trace elements as possible and perhaps even recognising mineral particles included fortuitously in ore collection or manufacture. X-ray fluorescence is the answer, though an expensive one.

Summary

The extent and variety of gold resources in the British Isles has been largely overlooked during an analytical survey of prehistoric gold objects in Europe. A detailed survey of Irish resources, and more briefly of England, Scotland and Wales has here demonstrated the widespread geological and geographical distribution of ores. A programme of alluvial gold collection in the North of Ireland has defined an area of its distribution coinciding roughly with that of densest Early Bronze Age ornament distribution, and one analysed stream sample has a composition similar to that of the lunula, a class of object suggested by Hartmann to derive from Wicklow gold.

These above surveys call to question the albeit tentative conclusions reached by Dr Hartmann and suggest that before any data obtained from artifact analyses may be usefully interpreted, a large quantity of work must be done on the mineral occurrence of gold.

X-ray fluorescence study is the method recommended for future work on both the artifacts and the ores.

Our own views, though open to persuasion from such new evidence as may come to light by future work, remain little changed from those of Wilde[1] with whom we conclude, as we began:

'An examination and comparison of our own *(gold)* with the native antiquarian collection of other European countries confirm the opinion that the gold ornaments discovered in Ireland possess a special character not found elsewhere.'

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APPENDIX 1

Localities at which gold has been successfully panned for between 1967 and 1971

	Townland	River	County	Map No (OS 6")	Results and comments
1	Cabry	Cabry	Donegal	30,31	Poor (hasty investigation)
2	Corick Br. (Dergbrough)	Glenelly/ Owenkillew	Derry	18,19	Moderately large sample. (Some considerable time spent)
3	Lisnamuck	Moyola	Derry	36	Poor
4	Tullybrick	Moyola	Derry	40,45	
5	Attigh Bridge	Owenreagh	Tyrone	18,19	Moderately large

6	Cappagh	Altmore	Tyrone	45	Poor
7	Carrickmore (nr)	Carnowen	Tyrone	36	Poor
8	Greencastle	Owenreagh	Tyrone	19	Moderate result. Unworn grains.
9	Trinmadden Bridge	Owenkillew	Tyrone	11,18	Positive sample with larger than usual size of grains.

Where only two or three grains were recovered, the comment made is "Poor". For results where up to half a dozen grains could be obtained in one pan, "Moderate" is used. A "Positive" sample is one where as many as 20 or 30 grains may be found in one pan.

This grading is in itself no indication of the proportion in which gold may occur locally, but the comment is included in case it should be of use during future work.

APPENDIX 2

The stannous chloride test

Iron pyrites or arseno-pyrites from several localities were broken, roasted and soaked in nitric acid in order to expel all impurities and leave only gold and platinum, should they be present. The samples were then soaked in Aqua Regia creating a solution of auric chloride. Upon the addition of stannous chloride, gold should be liberated and recognised by the precipitation of a purple cloud, commonly known as 'Purple of Cassius'. Rock samples from the following localities reacted positively to this test:

Coneyglen, and the Glenlark River, Greencastle and Carrickmore.

All samples submitted were iron or arseno-pyrites.

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A Report on the Manufacture of Steel in Yorkshire and a Comparison the Principal Groups of Steelworks in Europe

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(Edited and translated by K C Barraclough) ©

PART 2 The working of Raw Steel in Yorkshire – Drawing, Rolling and Forging – the Manufacture of Cast Steel.

Historical Information

The art of converting wrought iron into steel has been known since time immemorial. Amongst all peoples where the art of making and fashioning iron has made progress, one must soon have discovered that this metal will acquire, under prolonged contact with wood charcoal at high temperature, properties similar to those of steel obtained directly by the treatment of certain ores. Without becoming the basis of a special industry, this property would, before long, be put to advantage, as it is still to this day, in many arts associated with the working of iron, notably in the making of agricultural implements.

Cementation so practised had the sole object of steelifying and hardening the surfaces of different objects originally made from wrought iron, but it was necessary to resort to natural steel in all cases where the objects required to be made up entirely of homogeneous steel. Thus, up to the commencement of the 17th Century, the steel forges of the Central Alps, the Rhine, the Isere, and of Thuringia kept the sole privilege of furnishing merchant steel, which the makers of arms, cutlery and cutting tools worked throughout Europe.

The Development of Cementation Steelworks Dependent on the Progess of the Working of Raw Steel

About this time there was commenced in England the cementation of bars of small size; the steel so obtained was only employed at first in the making of objects of low quality. Little by little this manufacture grew and towards 1660 (1) large bars were cemented which were then submitted to a (628) drawing down from a coal fire prior to their use in commerce. This product, to which one gave the name of 'common steel' was sold in square bars about 5/8" per side and gave only a mediocre quality; the central parts of the bars were used for common cutlery and hardware; the ends, more flawed and more heterogeneous, were reserved for edge tools.

Towards the middle of the 18th Century, Crowley of Newcastle gave the cementation steelworks a completely new importance in discovering a method of forging the raw steel by a process similar to that which the Germans had long applied to the raw bars of natural steel. It had already been recognised that the Swedish iron were much more suitable than the native irons for making forged steel; the new industry brought about the confirmation of the superiority of the Northern irons in even more positive manner, such that it was commenced at that time to import large quantities for consumption in the steelworks.

The development of the cementation steelworks was still more accelerated by the gradual rise of customs duty, which was only 1/6d.* at the opening (629) of the 17th Century and which was raised to 18/6d.* in 1690, when the drawing down of steel had increased somewhat. Nevertheless, in the first half of the 18th Century there was imported annually into England some 150 tons of steel from the Rhine and for a long time this was preferred to the forged English Steel which the manufacturers were then selling and which they again sometimes referred to as 'German Steel'.

Information on the Practical Working Down of Raw Steel

The operations to which the raw steel was submitted during this period, and which are practised to this day on a large scale, have the aim of converting it, by means of a series of heatings and forgings, into merchant bars which are more or less refined and welded. These bars themselves in their turn serve as raw materials in the numerous works where one makes files and rasps, saws, scythes and sickles, plates and wires, cutting tools, arms, cutlery, and so on. Sometimes all these working operations are collected together in one building; sometimes, indeed, the works which draw down and forge the steel on a large scale also include the shops where the steel is given its final shaping; sometimes the manufacturers of the steel objects draw down the raw steel bars themselves in small forge fires from which they finally fashion it. But more commonly the two parts of the industry are performed by industrialists whose interests are distinct. The forging of the raw steel is done in establishments having some major importance and having at their command powerful machines operated by water wheels or steam engines, whereas the work which is essentially that of the manufacturer takes place in small scattered shops which total over two thousand in the Sheffield district.

Rolling

The most simple of the intermediate operations is that which consists of reheating once the raw cemented steel bars and passing them repeatedly through the grooves of a rolling mill in such a manner as to bring together and weld the parts fissured during the cementation operation. The heating is carried out in coal fired reverberatory furnaces; one does not start to charge the bars until the furnace is strongly heated, the fire grate full of ignited coal charged a certain time previously and freed by this partial carbonisation

FOOTNOTE (1). I have gathered most of the details relative to this first period of the English steelworks from one of the oldest members of the industry in Yorkshire, Mr. Marshall himself had these traditions from his uncle, John Marshall, who, as I shall show shortly, founded about a century ago one of the premier steelmaking shops in Yorkshire.

***It is not so stated in the text, but this charge appears to be per ton. (trans)**

from the sulphurous fumes which the pyrites mixed with the fuel sets free in the first stages.

This production of rolled raw steel only involves a small expenditure on fuel and labour. The temperature suitable for rolling is much lower than that necessary for forging and the bars, heated singly, are not slow in reaching it. As to the waste involved, it does not exceed 3%.

The nett cost of one ton of rolled raw steel, made from iron at £18/5/0 per ton can be evaluated under ordinary conditions at £22/14/0 per ton, according to the following table, in which, for sake of conciseness, one has not included other than the special costs of fuel and labour:

(631)

Iron	2290 lb @ £18/5/0 per ton		£18.10. 0.
Cost of Manufacture:			
	Cementation		£ 1.10. 0.
	Rolling:		
	Coal 1120 lb @ 8/6d per ton	4.3.	
	Labour 4.56 days @ £3/8/0	13.9.	£ 2.14. 0.
	General costs and profits	£1.16.0.	
		TOTAL	£22.14. 0.

The bars so produced are often passed to the slitting mill; normally the rods which it produces serve in the manufacture of cheap products, composed for the most part of wrought iron, such as the common items of cutlery and tools, in which only the cutting edge is of steel.

It is also in this manner that steel is prepared for coach springs.

Equipment Employed for the Principal Working Operations on Steel

The more homogeneous steel, used to make the medium and best quality objects, is prepared by means of processes which, except for some secondary modifications, are similar to those followed in the Rhenish group of steelworks for the drawing down and forging operations, using coals from the Ruhr and Saarbruck basins, applied to the raw natural steel obtained in that district by the treatment of the spathic iron ores. I have thus found in the arrangements of the hearths and tilt hammers of many works in Yorkshire several details which recall the models which the English industry originally imitated.

The steel is ordinarily reheated in a tuyere hearth, fed with finely powdered coal. The hearth is made up in such a manner that the piece to be reheated is *(632)* always covered by a roof of ignited fuel, without being in contact with it. Sometimes one uses coke fed fires covered with a little canopy of bricks which is movable, the piece being placed between the coke and the canopy; except for their dimensions, these little furnaces show the same arrangement as the tuyere furnaces used in Wales for the preparation of the blooms destined for the manufacture of tin plate. The drawing down is done under tilt hammers whose speed, although moderate in the first place whilst operating on the raw bars, often exceeds 300 blows per minute for bars already submitted to a previous hammering. In Yorkshire these machines are motivated sometimes by water wheels and sometimes by steam engines.

Saddening and Drawing Down

Steel simply drawn down under the hammer is prepared by means of two successive operations. In the first, called saddening, the bars of cementation steel are heated one by one and are then welded under a tilt hammer giving an almost square form but without appreciably reducing the cross section*. In the second operation, one reheats the bar to a white welding heat and draws it down to the different sizes commercially demanded. This steel is scarecely homogeneous, is generally flawed** and can only be used for medium quality work. The working down cost is less than the others; the costs which are involved for the different sizes called for commercially are approximately as follows:

(633)

Iron:	2360 lb @ £18/5/0 per ton		£19. 0. 0.
Costs of Manufacture:			
	Cementation		£ 1.11. 0.
	Drawing Down:		
	Coal 1350 lb @ 8/6d per ton	5.0.	
	Labour 6.0 days @ 3/4d	£1.0.0.	£ 4. 8. 0.
	General costs and profits	£3.3.0.	
		TOTAL	£24.19. 0.

*The French term for this operation is "ressuage", which may be translated as "sweating"; it can also be considered as related to "wash heating". The forging to an almost square form is the literal translation but the operation on a rectangular bar would normally be just to flatten the blisters and consolidate the surface at a relatively low temperature

** This could best be rendered as "roaky" or "seamy".

Single Shear Steel

Single shear steel is similarly produced in two operations; in the first, called welding, one heats up a bundle made up of pieces of bars of raw cemented steel until it attains a white welding heat; then one submits it to the action of the tilt hammer, using care, in order to weld all the pieces together. In order to make the welding quicker and more easy, one sometimes places bars which have already been submitted to a saddening operation below and above the raw cemented bars. The welded bloom is subsequently returned to the fire and is then drawn down to the required size. The nett cost of this kind of steel is more or less as follows:

Iron:	2500 lb @ £18/5/0 per ton		£20. 8. 0.
Costs of Manufacture:			
	Cementation		£ 1.13. 0.
	Single Shear Forging:		
	Coal 2240 lb @ 8/6d per ton	8.6.	
	Labour 8.82 days @ 3/4d	£1. 9.6.	£ 9.11. 0.
	General costs and profits	£7.13.0.	
		TOTAL	£31.12. 0.

Double Shear Steel

Double shear steel is produced in the same manner as the previous kind but with the difference that one uses for the raw material bars of single shear steel, put *(634)* **together in the ordinary case into a single bundle of 12 to 18 pieces. The nett costs should be able to be built up as follows (admitting, as I shall during the rest of this report, that the preparatory work has been carried out in the same works and, in consequence, these have already been burdened with part of the general costs):**

Iron:	2640 lb @ £18/5/0 per ton		£21.10. 0.
Costs of Manufacture:			
	Cementation		£ 1.14. 6.
	Single Shear Forging		£10. 1. 0.
	Double Shear Forging:		
	Coal 2680 lb @ 8/6d per ton	10.3.	
	Labour 8.82 days @ 3/4d	£1. 9.6.	£ 6. 3. 6.
	General costs and profits	£4. 3.9.	
		TOTAL	£39. 9. 0.

Triple Shear Steel

Finally, one produces for the manufacture of certain objects of the highest quality a triple shear steel, for which the nett cost can be evaluated, following the procedure adopted for the previous products, as being £46.0.0. per ton, as follows:

Iron:	2800 lb @ £18/5/0 per ton		£22.15. 0.
Costs of Manufacture:			
	Cementation		£ 1.15. 6.
	Single Shear Forging		£10.13. 6.
	Second Shear Forging		£ 6.10. 6.
	Third Shear Forging:		
	Coal 2680 lb @ 8/6d per ton	10.3.	
	Labour 10.55 days @ 3/4d	£1.15.0.	£ 4. 5. 6.
	General costs and profits	£2. 0.3.	
		TOTAL	£46. 0. 0.

One can evaluate the amount of coal utilised *(635)* **in the production of one ton of triple shear steel as over four and a half tons as follows:**

Cementation	0.94 tons
First Forging	1.12 tons
Second Forging	1.27 tons
Third Forging	1.20 tons
TOTAL	4.53 tons

Independently of these principal products, the steelworks of Yorkshire supply to the works of the district and to commerce several other products of which one can easily conceive the method of production, such as rolled and slit steel, rolled single shear steel, and so on.

Insufficiences of the Preceding Methods of Working

All these workings down of the steel, the fundamental means of which, I repeat, have all been borrowed from the Rhenish steelworks, have in part the objective of cutting up the steel into the sizes adapted to the nature of the many manufacturing industries, but their principal objective is to give to these pieces the malleability and homogeneity needed by the majority of such industries and of which the raw cemented steel is completely devoid.

It is essential to comment, however, that they only achieve this objective in an incomplete fashion and that the raw cemented steel lends itself far less readily to forging and drawing down than does natural steel. Welding requires much time and much fuel and involves, in consequence, considerable cost. The steel, when it is not produced from irons of the first grade, very rapidly loses its steely characteristics in the numerous reheatings to which it has to be sumbitted; finally, the principal cause of inferiority lies in the fact that the forging only imperfectly brings about the removal of the defects of inhomogeneity *(636)* and the flaws which cementation develops in most steel irons. On operating the procedures which cementation develops in most steel irons. On operating the procedures which I have just described, therefore, one finds oneself exposed to the destruction of the steely quality of the product whilst at the same time improving its homogeneity and sometimes with the preparation of a product which, despite its excellent quality, will give numerous scrap objects to the manufacturers who will put it into production.

These considerations, taken together with the details given above, concerning the very considerable costs involved in the forging of the steel, explain very well how the manufacturers of Yorkshire have been led, little by little, into paying so high a price for the premier grades of Swedish iron which, among other advantages, offer them complete security in both respects. They make it equally understandable why the English steelworks, via the route of cementation and forging, could not provide all the first quality steel necessary for the makers of steel objects and why these latter, during the whole of the 18th Century, had to supplement their supplies by means of natural steel from the continent.

Historical Information on the Discovery of Cast Steel

Thus restricted in their scope, the cementation steelworks would only have played a secondary role in Europe if the genius of a simple workman, stimulated by this industrial necessity, had not created a new *(637)* art (1) which gives to cementation steel homogeneity, uniformity of texture and the persistence of 'steely predisposition', the products of which, by the general quality of their properties, place themselves at least in the same grade as the better natural steels; they assure the cementation steelworks, which are provided by their establishment in this new context with unlimited sources of manufacture, an incontestible pre-eminence.* This art has for its aim the production of cast steel; it constitutes in Yorkshire the most important branch of steelworks operations; it is certainly destined to play a very important role on the continent and, in particular, in France. Nevertheless, it is yet confined as the secret of a very small number of workshops. I believe therefore that I am rendering a service to science in publishing here the results of my researches into the past, the present and the probable future of this interesting branch of metallurgy. *(638)*

Benjamin Huntsmann (sic), born in Yorkshire in 1704, applied himself originally to clockmaking in the small town of Doncaster; he made several attempts to fashion from cementation steel the tools necessary to his art and the many different parts which were at that time made, for the most part, by German manufacturers. In 1740, following the success which he had achieved in these trials, he went to settle in Handsworth, a village situated near Sheffield, in the midst of rich coal workings. Here he established the first shop in which cast steel was made in a regular manner; then, to bring himself nearer to Sheffield, which was already the centre of the steel industry, he moved his establishment to Attercliffe, where his descendents still work the same process. He died in 1776 (2).

FOOTNOTE (1). The peoples of Asia, who have opened up almost all the routes which have to day preceeded the European civilisation, long ago prepared several products which can truly be considered as cast steel. Such is the excellent steel provided by the Trichinopoly forges in the south east of the great Indian peninsular. The raw material worked in these forges is an oxidised iron lying in an amphibole formation. The method followed for the making of the iron greatly resembles a direct method which I myself have seen practised in the north of Asia Minor; the iron is subjected, afterwards successively but in the same operation, to carburisation and then to fusion in very small crucibles heated in numbers of seven in a charcoal hearth with four tuyeres. In all cases these workshops, where only a few pounds of steel are made daily, have enormous consumption of fuel and labour, differ so much from the melting shops of Yorkshire, where the means of production are so to speak unlimited, that it does appear to me to be wrong not to say that these have created a new art. It is above all necessary to recognise that the products of the Indian art and its existance were little known in Europe at the middle of the 18th Century.

*It is worth noting that, although le Play had every reason to make this statement in 1842, within twenty years the necessity for the use of blister steel for remelting had passed; it had been replaced by the use of a mixture of wrought and white cast iron, still of Swedish origin however, in the great new River Don Works, built with 384 double hole crucible furnaces but with no cementation furnaces.

FOOTNOTE (2). I myself have noted these dates on the tomb of Benjamin Huntsmann, in the cemetery at Attercliffe; a second inscription recalls that his son, William Huntsmann, died in 1809, aged 76 years. The son and heir of the latter, Mr. Francis Huntsmann, aged 60, was in 1842 directing the establishments founded by his grandfather.

A REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE (PART 2)

Other manufacturers, among whom Walker and John Marshall above all distinguish themselves, soon took up the same method of working and created melting shops at Sheffield and Greenoside**. Nevertheless the new industry, for want of a market, only developed slowly at first. Throughout the whole of the last century it had to contend, on the one hand, with the difficulties presented by the production of the very highest temperature used in metallurgy and, on the other, with the prejudices of customers used to *(639)* demanding from Germany the better kinds of steel which the new industry was striving to produce. But little by little the technical difficulties of the manufacture were overcome; one learned how to recognise and how to prepare the most suitable refractories; working costs, at first excessive, fell each year; stimulated by the low cost of cast steel, the makers of steel articles adapted themselves with success to employing it for all the uses which up till then had been reserved for German steel; very soon they discovered several useful qualities which it developed to a greater degree than the latter.

Influence of the Discovery of Cast Steel on the Progress of Cementation Steelworks

Today the revolution started in Great Britain by the memorable discovery of Benjamin Huntsmann is virtually complete and each day its consequences make themselves more keenly felt on the continent. For a long time now they have no longer imported German steel into England and, on the contrary, the Yorkshire works export annually some 3000 to 4000 tons of shear steel or cast steel in bars, wires or sheets, in addition to an incomparably greater value of steel articles of all kinds. I have established in August 1842 that there were fifty-one steel melting shops in Yorkshire, in which, despite the stagnation in trade, there were converted each week into cast steel some 165 tons of crude blister bar (8450 tons per annum), being around 52% of the total quantity produced by the cementation works.

Actual State of the Art of Making Cast Steel

All the works practise, with but slight modifications, the method of manufacture which I am going to describe according to the same plan which I followed *(640)* in the first section dealing with the cementation steelworks.

1. THE PLANT AND EQUIPMENT

The main part of the equipment is a natural draught furnace, holding two crucibles in which the steel is heated under the cover of combustion gas; the shape of this furnace, its dimensions and its relation to the rest of the shop are shown in great detail in Plate XIII.

****Samuel Walker is alleged to have obtained the secret from Huntsmann by a ruse; at any rate he sets up his works at Grenoside near Sheffield about 1750 before moving some years later to the Rotherham area. (Trans.).**

Melting Furnace – Shape and Dimensions

Each furnace (Figs 2 and 3) is an upright rectangular hole, whose horizontal section is 21½" x 15"; in the lower part is a grate made of five square bars, of side between 1" and 1.3/8"; in the upper part is a rectangular opening of only 13" x 12", whose centre corresponds with the centre of the furnace holes and which joins up with the vertical walls of the latter by small arched faces. The vertical distance between the grate and the furnace opening is 36". Three sides of the furnace chamber are continued to ground level, 67" below the grate; the fourth is left open to allow a large access of air which has to be provided in great quantity to satisfy the needs of combustion. In one of the straight sides of the chamber a rectangular opening, 15" wide and 5½" high is made to allow escape of the combustion gases; this communicates with the chimney by means of a horizontal flue of the same section and 25" long. The top end of this flue is 4¼" below the opening in the top of the furnace. The chimney is occasionally of *(641)* circular section but ordinarily is square with a side of 12". The total height of the chimney above the top end of the flue is 33 feet.

Refractory Materials used in the Construction of the Furnace

The most refractory of bricks cannot withstand the excessive temperatures which must be developed in the steel furnace. To make the walls of these furnaces one employs a sandstone called **gannister***, very close textured, breaking with a very fine sugary splintery grain, formed of pure quartz and on account of this highly refractory. It enters into the construction of the furnaces in two forms.

This sandstone, by reason of its hardness, being used with good effect for the metalling of most of the roads leading to Sheffield, one collects with great care the dust and mud which results from the wear of the causeway; these powdery materials, composed essentially of quartz mixed with traces of animal matter and the fine coal dust which impregnates the ground in all the manufacturing districts of Great Britain, are as refractory as the sandstone itself and are economical to use since they do not require any labour for cutting an erecting masonry. To make anew the walls of a furnace after having taken out the damaged parts, it suffices to pack in the lightly moistened refractory material into the 11" space between the fixed furnace wall and a central wooden core with which one can produce exactly the shape and position which the hole must have.

Unfortunately for the steel melters, one uses here and there for the metalling of the roads certain fusible materials, the admixture of which completely *(642)*

***This would appear to have been the common spelling at the time of the writing of this report. (Trans.)**

destroys the quality of the dust; thus I have seen used in 1842, along part of the road from Sheffield to Attercliffe, in the midst of the region where the melting shops abound, the blast furnace slag from Sheffield Park. Not being always able to obtain completely refractory dust * the manufacturers of cast steel are often obliged to use the sandstone. In such case the wall in contact with the fuel is made to a depth of 4½" with cut stone put together with a little clay; the space of 6¾" between this and the fixed wall is filled with dust of mediocre quality. All the furnaces were made in this way in the shop shown on Figure 2 and which I think I can offer as the best Yorkshire type.

General Arrangement and Dimensions of the Melting Shop

These furnaces, which are never isolated, are arranged in a similar manner in all shops. The number of furnaces grouped together is never less than four and is seldom greater than ten. The chimneys are brought together into the same 40" wide structure with their axes in a straight line; the interval between the two axes of adjoining chimneys is 33". The furnace openings are set in the floor of the main shop, itself set some 4 feet above the level of the yard; the shop communicates with this latter by means of an external flight of steps. During melting the top opening of each furnace is closed by a cover (Figure 4) formed of large bricks held by pressure screws in an iron frame. The shop in the ordinary way is in the form of a rectangle (figure 1), *(643)* one side of which, formed by the chimney structure, has a length determined by the number of furnaces; in the shop with ten furnaces shown in Plate XIII this length is 27'3".

Immediately below this shop is always a vaulted cellar (Figure 3) whose floor, which is at the same level as the bottom of the ashpits of the furnaces, is 4'6" below the yard floor.

In one part or another of the main shop are to be found two small shops, at the same level as the yard. One serves at the same time as a store for coke and refractory clay and as a workshop for the making of crucibles. In the other is the store for raw materials and products and the space for the breaking up of the raw steel. The floor of the melting shop is extended in the latter to its side walls, in front of a small furnace (Figures 1 and 2) in which one raises the temperature of the crucibles to a red heat before putting them into the melting furnaces. Two staircases permit the carrying of the coke and the blister steel charges from each of these shops to the openings of the melting furnaces. A further staircase communicates between the shop and the cellar, where the workers often remain during melting and thus facilitate the constant surveillance which it is necessary to apply to the fire grates. A further staircase is contrived behind the external flight of steps and into this opens a window, giving more light and air below the vault.

The Crucibles for Steelmelting

The crucibles in which the steel is submitted to the melting operation constitute a most important part of the equipment. It has required a long series *(644)* of trials to determine the size and shape of crucible which gives rise to the least consumption of fuel and the minimum loss of raw material. That all the works have arrived at almost complete agreement proves that today the questions are well resolved.

The crucibles are essentially composed of a refractory clay found in the neighbourhood of Stourbridge (Worcestershire) which plays the same part in the metallurgical shops in Great Britain as the clay from Forges in the north of France and that of Ardenne in Belgium. In all cases, since this material, by virtue of the considerable distance which it has to come, costs so high a price in Sheffield, it is generally mixed with its own bulk of a lower quality clay from Stannington near to Sheffield. One adds to the mixture a small quantity of coke dust and powdered fragements selected from old crucible after their use and one prepared from the whole a homogeneous and very compact dough.

Properties of Refractory Clays used for the Making of Crucibles

Comparative trials made by a capable Sheffield manufacturer, who has had the good will to communicate the results to me, have shown that the Stourbridge clay is much better suited to the making of crucibles that all other refractory clays of Great Britain and the Continent. He has not found another which has been able to resist three successive melts whilst the crucibles of pure Stourbridge clay can often resist six melts. It has seemed to me to be of interest to seek the cause of this superiority. The Stourbridge clay, kept in a *(645)* dry place, presents itself in firm lumps which are difficult to break by pressure of the hand and which even resist light blows with a hammer. It is grooved by the nail and takes on some polish when cut with a knife. Its colour is dark brown. Its fracture offers two distinct appearances: certain parts are matt and earthy; others are perfectly smooth and shiny and recall the brilliant surfaces given by certain brown haematites. It pulverises easily under the pestle and the powder passed through a silk sieve is composed to a large degree of particles which are virtually impalpable. The material is completely homogeneous; the small fragments obtained by washing the powder in a small trough are readily reduced by

*Within ten years ganister was being ground and admixed with a small quantity of fireclay and horse droppings by Joseph Bramall of Oughtibridge for sale to the steel makers, who referred to it as "muck" (probably harking back to the original road scrapings) (Trans.).

grinding to an impalpable powder completely identical with that which was separated by washing. The dry clay absorbs very promptly any water with which it comes into contact. It then moves easily under pressure but it does not form a dough like the fat clays used for the making of glassworking crucibles.

Stourbridge clay does not contain other fixed principles* excepting silica and alumina. I have not found in it the least traces of alkaline earths or metallic oxides. It is distinguished above all from most other refractory clays by the high proportion of alumina which it contains. The earthy matter which forms the essential constituent of the clay is intimately mixed with a combustible substance which, on calcination in a closed *(646)* vessel, leaves a residue of carbon; this colours each of the particles of the earthy matter a dark grey and is not completely gassified except under a very prolonged heating. This very intimate mixture of carbon appears to contribute considerably to the increase in the refractory properties of the clay.

I a (999)

I have found in Stourbridge clay the following composition:

Silica	46.1%
Alumina	38.8%
Combined water and combustible matter	12.8%
Carbon produced by heating in a closed vessel	1.5%
Total	99.2%

Stannington clay offers almost the same external characteristics as that from Stourbridge, except that it is not so dark; it is not so homogeneous, for one can easily separate by washing several brilliant plates of mica; it is also more prone than Stourbridge clay to give a dough with water. Calcined within a closed vessel, it gives a rather dark grey residue but heating cannot disperse this colour and it gives no loss in weight. I have found in it

Silica	42.0%
Alumina	40.9%
Magnesia	0.1%
Lime	1.3%
Oxide of Iron	trace
Combined Water	14.7%
Total	99.0%

The mixture which is used to make each *(647)* crucible is made up as follows:

*Oxides

Stourbridge clay, dry and powdered	11 lb. 8 oz
Stannington clay, dry and powdered	11 lb. 8 oz
Fragments of old pots, powdered *	14 oz
Powdered coke	2 oz
Total, per pot	24 lb. 0 oz

One moistens the material with a sufficient quantity of water so that the dough that results agglomerates under pressure and keeps the shape given to it. But it is very necessary that the dough has the homogeneity and consistency of that used for making glassworks crucibles.** When the crucible has been made by the procedure which will be described and when it has been submitted to a dull red heat, one notices that the fracture shows a veritable breccia composed of earthy fragments with a fine coke debris jointed by a small amount of a greyish argillaceous cement. These elements are only feebly agglomerated and are easily broken with a blow from a hammer. I have found that the weight of the preheated crucible was on average 20½ lb.

But this texture is completely modified when the crucibles have been used for melting steel. The dough is converted into a vitreous enamel of extreme hardness which cannot be scratched by a file. It shows a deep black colour which can only be distinguished from the coke fragments embedded into it by their lesser brilliance. The vitreous texture becomes more pronounced and the pores more numerous dependent on the crucible remaining for a longer period at the fusion *(648)* temperature of the steel. In the case of a crucible which has experimentally used for five melts, under the influence of temperature the earthy matter has been transformed into a black, very vitrified and perfectly homogeneous enamel which, on taking out from the furnace, shows itself to be as malleable as a semi-frozen glass.

Method of Manufacture of Crucibles

The manufacture of steel crucibles requires comparatively less labour than for the crucibles used in the glass works or the zinc works. It always takes place by a moulding method, using the equipment shown in Fig.5. This equipment comprises:

1. A cylindrical mould in cast iron (aa), carefully honed inside, slightly conical towards the top, open at both ends, having the height and the external form which has to be given to the crucible;

* This is normally termed "grog"

**It seems strange that le Play should not have described the treading operation applied to the clay; it is just conceivable that it was still considered to be the essential secret in the process and was kept from him.

2. a thick pedestal in cast iron (bb), solidly fitted into a block of wood and furnished with a circular surround on to which the conical cylinder fits by its smaller end; in the centre of the pedestal, corresponding to the axis of the cylinder, is to be found a small hollow mortice in the body of the cast iron, designed to receive the end of the core, of which more below;

3. a core (cc) made from a hard and very heavy wood, coming from the tropical regions, run through with an axle tree of iron (d), whose most narrow extremity fits into the mortice in the cast iron pedestal, whilst the other forms a rounded head designed to take the blows of a heavy hammer. Above this wooden core is a circular plate of cast iron (ee), having the same diameter as the larger end of the cast iron mould.

Following the detail in Fig.5, one can easily understand that when the axle tree of the core is held vertical and is engaged in the mortice in the base by its bottom end, there remains between the core and the exterior mould a gap* which has precisely the shape which one wishes to give to the crucible.

To mould a crucible, the worker begins by smearing a layer of oil over the two parts of the mould and placing the cylinder on the pedestal in the position shown in Fig.5. Next he places in the cylinder the quantity of clayey dough indicated above *(24 lb.)* and introduces by force the central core into the middle of the clay, keeping it in such a position that the axle tree remains vertical and corresponds with the axis of the cylinder. Since the resistance developed by the clay does not allow the core to penetrate very far by the effect of simple pressure, the worker then operates, as has been said, by means of hammer blows using two hands, until the bottom end of the iron axle tree has penetrated into the mortice and the iron disc has come level with the upper rim of the cylinder.

To remove the moulded crucible, it only remains to take out the central core, to close the hole made by the end of the axle tree, to raise the cylinder still containing the crucible above the pedestal, which is invariably fixed to its support, and to place the bottom of the crucible thus uncovered on a circular ring of wood of a diameter slightly less than its base and itself supported on a column of iron (figure 6). The exterior mould held with care and allowed to slip under its own weight is lowered to the floor and leaves the crucible free on the ring. The *(650)* workman gives the final shape to the crucible by shaping the top portion inwards under light pressure and thus giving it the form shown exactly in Figure 7.

The greatest girth of the crucible thus is found some 4" below the level of the opening. The greatest external diameter is 7½", the corresponding internal diameter is 6¼"; the external diameter at the opening is 6¾". The thickness varies progressively from $1^3/16''$ at the base to $^9/16''$ at the top wall.

The cheeses on which the crucibles stand are small cylinders of clay of $5^1/8''$ dimaeter and $3^3/16''$ high. The covers, slightly domed in the centre, have a maximum thickness of $1^5/8''$.

It is essential that the crucibles lose their moisture only slowly after moulding; for this reason, one leaves them several days in the moulding shop; then one puts them on several rows of shelves (Figures 2 and 3) fixed along the walls of the melting shop where the proximity of the furnaces keeps the temperature sufficiently high.

The making of the crucible is very laborious work; a good workman gives up at least six days to make the 108 crucibles needed each week in a shop with ten furnaces run at full output. I find a difficulty in explaining, in a region where labour is of high cost, one has not yet simplified this work by means of a machine whose arrangement presents itself readily to the mind: in which the core would be pressed by a screw travelling through a nut in a system fixed firmly to its base.*

Ingot Moulds for Casting the Molten Steel *(651)*

The steel, when it is brought to the liquid state, is cast into ingot moulds made of cast iron (Figure 8), open at their top ends and closed at the other ends, made in two parts which fit closely the one with the other; these are held together during casting by means of wedges driven by a hammer between the mould and two wrought iron rings. The shape of the ingot moulds varies a little according to the works and the ultimate destination of the product; ordinarily the liquid steel is cast into octagonal prisms of 4 – 5 sq in section and 24" in length. When the moment of casting arrives, one places the moulds two by two in slightly inclined positions, leaning them against the edge of a small pit built into the floor of the shop (Figures 1 and 8).

Other Parts of the Equipment of a Melting Shop

The equipment of the melting shop also comprises the tongs used to pull out the crucible from the fire (Figure 9) and those which are used to pour the steel into the mould (Figure 10), a large sheet funnel with a long shank (Figure 11) used to introduce the charges into the crucibles, the fire rakes for cleaning the firebars and arranging the coke suitably in the furnace, baskets for carrying and charging the coke, hammers for breaking up the bars of blister steel into pieces and a vice and tools to trim the steel ingots as necessary.

***It is not known when such a system was first introduced but the translator has in his possession a photograph of machine moulding by this method as practised at Wm. Jessop's works around 1900.**

Surface Area Required for a Melting Shop

In Yorkshire coke is always made outside the steel-works; one need only consider therefore joining the building to a yard sufficiently large for the putting down of the sandstone and the refractory dusts, *(652)* the old crucibles and the clinker from the furnaces. It is necessary that the vehicles employed in the transport of the coke, the refractory materials, raw steel and cast steel should be able to circulate freely. A total surface area of 4300 sq ft is sufficient for the works shown on Plate XIII.

2. RAW MATERIALS AND FUEL

The raw materials necessary for the manufacture of cast steel are the refractories, whose nature and use has already been described, raw cementation steel and coke.

The raw steel is broken by means of a hammer into pieces of two kinds: one which retains the whole width of the bar and whose length is some 2 to 2¾" less than the height of the crucible, of such a kind that one can introduce them into it by placing them upright and the others are broken into small irregular pieces having for the most part a volume of 0.6 – 1.8 cubic inches. When the steelworks is attached to the melting shop, one charges a certain quantity of cuttings and scrap to the raw steel in the crucibles.

The coke used in most steel melting shops is heavy, very hard, composed of a perfectly vitrified matrix, but riddled with cavities, mostly microscopic and of which the largest scarcely exceeds $^{1}/_{25}$" in diameter. The pieces are furrowed here and there by large fissures. The mean density varies on account of these fissures between 0.75 and 0.92. Submitted to incineration, the coke leaves a clayey residue, which does *(653)* not effervesce on treatment with acid, and which ordinarily is hardly coloured by oxide of iron. The assay of a coke reputed to be of very good quality for steel melting has given me:

Fixed carbon	83.7%
Volatile Combustibles	3.9%
Moisture	1.5%
Clayey cinders, very refractory	10.9%
Total	100.0%

Before being used, the coke is broken by the coke basket filler into pieces whose volume ranges from 4 – 12 cubic inches. The dust and small debris produced by this breaking up and that which remains on the shop floor are used, as will be described below, either in the melting furnaces when lighting up or between two melts in the same campaign, or in the stove where the preliminary heating up of the crucibles is carried out.

3. PERSONNEL IN A MELTING SHOP

The personnel in a steel melting shop vary by reason of the number of furnaces kept in production and this number varies greatly itself in Yorkshire according to the state of trade; I have confirmed, for example, that in August 1842 half the furnaces in Yorkshire were in enforced idleness. A shop with ten furnaces in full production, that is to say for five days a week, needs the bringing together of eight workmen, whom I am going to designate by descriptions which appear to me to explain their functions better than the usual names given to them in the shops;

The Head of the Shop *(Melter)*. He oversees the whole work, breaks the raw steel bars into small pieces with a hammer and prepares the charge for each crucible in a pan, pours the liquid steel into the mould, sees to repairs to the furnaces, and so on.

Two melters *(Takers Out)*. These are specially charged with all the manipulations involved in melting; alone they pull out the crucibles from the furnaces and carry them to the Head of the Shop for teeming.

The Setter-up of Ingot Moulds *(Mould Getter Up)*. He prepares the moulds to the requirements of the head of the shop and takes the solidified ingots out from them; he also assists the melters in charging the furnaces with coke during melting.

The Filler of Coke Baskets *(Coaky)*. He fills the baskets with coke and carries them into the shop; he joins in with the preceding man in assisting the melters with all their manipulations.

The Watcher of the Grate *(Boy)*. This is a child of 10 to 12 years old who stays generally in the cellar to warn the melters when the appearance of the grate suggests that a crucible has been pierced; in addition, he often makes the cheeses with the aid of a mandrel and a cast iron mould; he picks out with a hammer the pieces of old crucibles which, free from vitrified surfaces, can be returned to the mixture, as has been previously reported; he assists the crucible maker when the furnace is inactive.

The Maker of Crucibles *(Pot Maker)*. This employment, as has been said, suffices to occupy all the time of one workman in a shop of ten furnaces in full production.

The furnaces are only fired during the day, these workmen giving a single shift of 10 to 12 hours. The pay for the week usually adds up to £7.8.0* (655)
I did not establish that the remuneration was ever calculated on the basis of the production made.

In addition to the above seven workman constantly attached to the shop, one often employs, when the shop is on full production, another workman to dress the ingots and perform several other accessory tasks.

*This total covers all seven men

In some small workshops with four furnaces, where one only keeps three furnaces lit during three days each week and where one sets out to reduce the number of personnel as far as possible, one only employs two workers: that is, one melter charged with all operations enumerated above and a youth of 14 to 15 years of age who only supports him in those tasks appropriate to his age. I have not found in any part of Europe, other than in England, the workers able to operate alone and without any respite during an entire laborious day's work such as is called for by the operation of three steel furnaces. The wages of these two workers adds up ordinarily to £2.3.0 per week.

4. CONDUCT OF THE WORK IN A STEEL SHOP

The steel furnaces work campaigns whose duration never exceeds five days; this period is often reduced to three days when the works lack a market. Besides, although the furnaces remain alight during the whole of the campaign, these furnaces always work in an intermittent manner and only for ten hours within twentyfour.

Repairs and Lighting Up of the Furnaces

In a shop where one is to melt five days a week, the repair of the furnaces must always be completed by Sunday night. One starts then to warm up each *(656)* furnace with great precautions, so that the skin dries out and only slowly reaches the elevated temperature needed for the melting of the metal. To this end, one throws on the grate some pieces of burning coal which are covered with fresh coke; when this mass of fuel begins to burn, one completes the charge with coke dust; one places in the flue a brick which almost closes it and one covers the opening of the furnace with the lid (Figure 4). There is thus produced, during the night, a slow fire which completely dries out the new skin and raises it gradually to a dull red heat. One repeats the same operation for all the furnaces which one wishes to light up.

The same evening one places on the grate of the annealing furnace (Figures 1 and 2) approximately 2" of small live coke, taken from a coal fire which is always kept alight on the adjacent grate (Figure 2) one puts over it the crucibles which are to be used on the morrow, then one fills the furnace with fine coke arising from the remains from the store or the accumulated cinders from the bottom of the ashpit.

On Monday morning one proceeds to light up; to this end, one shakes off with a rabble the powdery material which one has so far retained in the furnace, one cleans the grate and places thereon the crucibles. The centres of the two crucibles should be in the same vertical plane at equal distances from the two larger sides of the furnace; according to this arrangement, there will be 2"spaces between the two crucibles and between each of the two and the smaller faces of the furnace. *(657)* By placing the crucibles in this manner, the space between them and the larger walls of the furnace is about 4".

One places the covers on the empty crucibles, fills the furnace with fresh coke, unstops the flue* and closes the upper opening. There is produced immediately a very strong draught and in the space of half an hour the furnace reaches a very high temperature.

Charging the Crucibles

One then proceeds to the charging by uncovering the crucibles and introducing the end of the sheet funnel. The Head of the Shop first charges by hand two or three long pieces of steel about 15" long but, to guard the crucible against shock, one of the melters first places a fire rake in the funnel as shown in Figure 11. These bar ends are placed vertically against one of the sides of the crucible and then, in the gap between them and the oppposite side, one piles up small pieces of steel. This arrangement is designed to make each crucible hold the maximum charge. Often, as I have previously stated, one finishes the charge with scrap sheet, steel wire or scrap from divers manufactures.

The total charge for each crucible varies from 28 to 36 English pounds; it is ordinarily 30 lb.

The charge made, one replaces the crucible lids, fills the furnace with fresh coke, closes the top opening by means of the lid *(Fig.4)* and commences the melting.

Conduct of the Firing

To develop and maintain within the furnace the high temperature required for the metling of steel it is *(658)* necessary to choose a coke carefully fulfilling the conditions given above and to observe besides certain rules in the charging of the fuel.

It is not necessary to multiply too much the number of charges of coke, since one doubly cools the furnace on opening up the top aperture, thereby temporarily diminishing the draught, and on introducing a cold body to it. It is better to proceed by large and less frequent charges, short of letting the burning coke fall below the level of the crucibles and thus exposing them at intervals to contact with a completely cold charge of coke. Ordinarily one charges at hourly intervals some 45 to 55 lb. of coke in each furnace. To this end, after having heaped up with a rake the remains of the coke within each furnace, one pours in a new charge gently and in such a manner that it fills as much as possible of the empty space; whilst one worker pours in the coke from a basket, another arranges and piles the pieces

***By removing the loose brick placed in it previously**

with a rake, pulls out those which fall in the flue in order to maintain the full activity of the draught, and piles them up in a slope against the wall of the furnace opposite to the flue. The charge must be rapidly made, in under two minutes.

The coke ash, being refractory, does not tend to obstruct the grate: this requires little attention on the part of the workers. Sometimes filaments of slaggy material, liquidifed by the violence of the fire, fall between the bars, but in such cases similarly the workers are seldom obliged to clear the bars with the rake.

Ordinarily the melting of the steel is complete *(659)* in four hours after charging; the melter assures himself as to the state of the charge by uncovering the crucibles. The workers regulate the charges of coke in such a manner that the upper part of the crucibles are uncovered when the time of casting has arrived; they recharge a little fuel in the furnaces in which melting is not completely achieved and do not pour the metal contained in them until a later time.

Pouring and Casting of the Molten Steel

The pouring of the metal into ingots is done with great speed and requires the bringing together of all the workers; the melter seizes the crucible, to which the cover and the cheese remain attached, with a pair of tongs *(Fig 9)* and places it on the floor within the reach of the Head of the Shop; he takes it quickly with another pair of tongs *(Fig 10)*, removes the lid with a light blow of a hammer, and pours the contents immediately into an ingot mould; the metal is very fluid and throws out numerous sparks, which continue to come out of the mould for some seconds after all the charge has been introduced. The worker cannot lift the full crucible, which weighs about 56 lbs, other than by seizing the tongs with both hands and holding it firmly against the body; his hands and his clothes would immediately be burned under the influence of the excessive temperature of the crucible, if he did not cover them both with numerous layers of wet cloth. The empty crucible is thrown carelessly on the floor of the shop, where it remains until the other crucible has been emptied in the same way. The same two crucibles with the same lids are then replaced empty in the furnace, which one then closes in order to reheat it, after having charged a little fresh coke. One operates successively and without interruption on each of the furnaces in the shop. *(660)*

During these manoeuvres the setter up of ingot moulds must prepare new moulds carefully dried, take out those which are filled, open up those in which the steel has solidified and finally throw the cooled ingots into the yard, all this without impeding the other workmen and without respite.

Three Successive Melts - Intermittent Working

Casting completed, and the furnaces containing empty crucibles once more, one makes a new charge of raw steel, taking the different furnaces in the same order as has been followed for the casting, and one controls the fire as previously. The second melt differs only from the first melt in that, the furnaces having acquired a high temperature, the melt is ordinarily completed in three hours by means.of three charges of coke.

After a third melt, of which the average duration is again of three hours, the crucibles are taken out of service and the operation is discontinued until the following day. To do this, one carefully cleans the grate and walls of each furnace, charges fine coke debris, as one did overnight, closes the opening of the flue with a brick and the upper opening with the lid; finally one places in the annealing furnace the crucibles which will be required next day. At 6 a.m. on Tuesday, one starts to fire up as on the Monday, except that, the furnaces being warmer, one can reduce by a quarter hour the firing which precedes the first charge. One always makes three melts per day and continues in the same manner until Friday evening.

The walls of the furnaces, even though the materials are of the desired quality, are then always too much damaged for melting to be continued in them; *(661)* one uses the daytime of Saturday and Sunday to demolish the internal faces and to rebuild them, as has been stated; then on Sunday evening at 6 p.m. one commences to reheat the furnace to prepare for a new campaign.

Life of Crucibles

The crucibles are not absolutely past being used after the third melt and most of them could be used once or twice more. But in so prolonging their use, one increases the steel losses which take place through accidents which happen unexpectedly to the crucibles; all things considered, it has been proved by experience that the losses of raw material involved more than balance the economies.

In spite of the care taken in the manufacture of the crucibles, these sometime crack or are pierced during working; it can so happen in these cases that the whole of the charge runs out and falls into the ashpit, completely altered in character under the influence of the oxidising medium which it has transversed. More usually, nevertheless, the melters,alerted by the boy, who notices bright sparks falling below the grate, can remedy the fault before the whole charge is lost; to this end, they apply a pad of refractory clay to the exterior of the damaged part and slightly incline the crucible in such a way that it is made to carry more of

the pressure on the sound part of the wall. *(662)*
If the leak persists in spite of these endeavours they have to take out the crucible and save what remains of the contents. These leaks are almost the only cause of the small loss which takes place in steel melting shops.

Another cause contributes to the restriction of the number of melts carried out in the same crucible: this is the gradual shrinking of volume which brings about a corresponding diminution in the weights of the charges. The interior volume of the air dried crucible is 540 cub. ins. and I have found that the volume of a well-preserved crucible which has given three melts has been reduced to 390 cub. ins. The workers in many shops are agreed in affirming this diminution; it continues to show itself in further melts. This remarkable fact appears to me to be attributable to a double cause. The shrinking which occurs with clay on heating under ordinary circumstances is due to the commencement of vitrification which leads to a bringing together of the divers elements; one knows very well that, under the influence of the high temperature of the melting furnace, the clay does not reach the upper limit of vitrification forthwith, as in the other metallurgical hearths; the variations in structure present in the crucibles which have served for one melt, two melts or three melts confirm this explanation well; their texture, looked at under a magnifying glass, is at once more vitrified and less porous when it has been exposed for a longer time to the action of the fire. In the second place, the crucibles, at a high temperature at which they are held, acquire in part the softness of glass and in the same way do not break under sudden shocks; one can understand, therefore, that the pressure exerted by blows and the pressure of the tongs continually has the effect of reducing the volume. *(663)*

Finally, the volume of the charge, when molten, scarcely exceeding 110 cub. ins., it is clear that the shrinking of the clay does not influence the weights of the charges except in increasing the difficulty in placing in the crucibles, in a short time, the solid pieces and clippings which make up the charge. This influence is sufficiently marked to make it necessary to reduce the weights of the three charges made in the same crucible successively from 32 lb. to 30 lb. to 28 lb.*

Whilst campaigns are never prolonged beyond five days, it often happens that, by reason of the imperfect quality of the refractory dust from which the furnace is made, one has to discontinue earlier. Almost always the walls are already sufficiently eroded after three days for the consumption of fuel to have noticeably increased. Thus, whilst the average consumption on the second day of melting is now and then no more than 2½ tons of coke per ton of steel, it often happens on the fifth day that this consumption exceeds 3½ tons. It is for this reason that, when on account of stagnation of trade one cannot run the works at full capacity, one ordinarily reduces the length of the campaign to three days rather than reduce the numbers of furnaces in production.

Physical Properties of Cast Steel

Cast steel clearly takes the shape of the moulds into which it is cast. The weights of the ingots, equal to that of one crucible charge, vary from 27 to 33 lb. Although the raw steel is brittle, the ingots, by reason of their considerable section are difficult to break. *(664)*
The fresh fracture shows a dull grey bluish colour which somewhat recalls that of impure antimony. The whole mass is usually riddled with small cavities of rounded shape with irridescent surfaces and almost always there is in the centre a larger cavity of which the surface is equally irridescent and carpeted with a multitude of acicular crystals.*

Considered in detail, the fracture is grainy, rough and similar to shagreen; but when one makes light reflect from the body of the fracture one sees distinctly a very regular fibrous lamellar structure; the fibres are all perpendicular to the adjoining outside surface, in such a way that their junction sketches out very regularly the two diagonals of the square which results from the transverse section of the ingot.**

5. COST OF MANUFACTURE OF CAST STEEL IN YORKSHIRE

I shall summarise and complete the technical and economic details which I have just revealed by showing, in the following table, all the elements of the cost of manufacture of cast steel in Yorkshire.

This cost, which amounts to £8.10.0 per ton, is ordinarily paid to the manufacturers whose work consists of melting raw steel sent to them for this purpose by other manufacturers. The elements of cost are grouped according to the principles given in the article on raw cemented steel. They refer to a works of average proportions, having a shop of ten furnaces, which, assured of its market, has been able to keep in full production during these last years and in which the production has risen in consequence to 8750 lb. per week, that is to say to about 200 tons per year. *(See Table).* *(665)*

***This explanation given by le Play differs from the more usual one which implies a cutting of the crucible wall at the slag-metal interface so that it is dangerous to fill the crucible again to such a level; a smaller charge thus fills most of the pot but avoids the danger level. This certainly is given as the explanation why, with the larger pot from some thirty years later, the successive charges were 60 lb., 54 lb. and 48 lb.**

***It was a further twenty years before Mushet invented the "dozzle": the heated refractory hollow plug which provided a reservoir of hot metal to fill the shrinkage cavity in the top end of the ingot.**

****From this description it seems he is describing a square ingot whilst his earlier comment was that the moulds were generally octagonal in section.**

A REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE (PART 2)

I have reported in detail in the table the relative consumptions in the making of crucibles because they constitute one of the principal expenses in the steel melting shops. On this subject, I will add that the manufacturers in Yorkshire ordinarily evaluate the cost price of a crucible at 1/1d, whilst the information presented above only brings this price to 9¾d. I have always considered that the price of 1/1d could only be arrived at by adding to the manufacturing cost for the crucible some part of the general costs of the melting shop. Having taken care to verify the information presented above from a number of sources, I believe that I can affirm that the special costs of manufacture do not rise in any shop above 9¾d and that they are still lower in all the large shops. One has also informed me that a number of steel melters buy their crucibles at a price of 1/6d each; these purchases must be the exception, for having had occasion to visit more than twenty melting shops I have not seen a single one which was not provided with a shop for making crucibles. *(666)*

In the conditions which have existed for many years in the works in Yorkshire and in view of the active competition between the makers, the profits are far from reaching the rate shown in the above table in most melting shops. If one supposes, as one has admitted in the first section on cementation steel works, that the annual production was only two thirds of that corresponding to full activity, it is only necessary to make slight modification to the special costs worked out per ton and to the annual sum of the general costs; the cost of manufacture per *(667)* ton of cast steel can then be established approximately as follows:

Special Costs	£5. 0. 4
General Costs	£1. 8. 2
Profits	£1. 11. 6

Total Costs Relative to the Conversion of Iron into Steel

On bringing together the economic data relative to the cementation of iron and to the melting of steel one finds the cost price in Yorkshire of one ton of cast steel made from iron at £18/5/0 per ton can be established as follows:

Iron:	2280 lb @ £18/5/0 per ton		£18.11. 0.
Cost of Manufacture:			
	Cementation	£1. 9.0	
	Melting:		
	Coke 7280 lb @ 13/3d per ton	£2. 3.0	
	Labour 12.50 days @ 2/5½d per day	£1.10.4	£ 9.19. 0.
	Other costs and profits	£4.16.8	
		TOTA L	£28.10. 0.

One can evaluate at 6.20 tons the weight of coal necessary to manufacture one ton of cast steel as follows:

Cementation:	1690 lb per ton for 1.027 tons	1730 lb
Melting:	7280 lb of coke, equivalent to 10/6 x 7280 lb of coal	12130 lb
	TOTAL	13860 lb

The elements of cost price can also be put in the following form, in which I have not presented *(668)* the evidence except for the consumption of coal and labour; I have grouped with the other costs an expense of 3/4d which is required for the carbonisation of 12130 lb of coal:

Iron:	2280 lb @ £18/5/0 per ton		£18.11. 0.
Cost of Manufacture:			
	Cementation	£1. 9.0.	
	Melting:		
	Coal 12130 lb @ 7/4d per ton	£1.19.8.	
	Labour 12.50 days @ 2/5½d per day	£1.10.4.	£ 9.19. 0.
	Other costs and profits	£5. 0.0.	
		TOTAL	£28.10. 0.

Refining of the Cast Steel

The ingots of cast steel always show cavities in their central portions due to the contraction of the liquid metal on solidification. They are, besides, lacking in malleability. One cannot therefore employ them in the manufacturing industries except after submitting, with great precautions, to a series of heatings and drawing down operations, from which derives the kind of steel known in Yorkshire as "cast steel twice refined". The cost of manufacture of a ton of refined bars, with sides of ⅝" to 1¾" can be established on average as follows:

A REPORT ON THE MANUFACTURE OF STEEL IN YORKSHIRE AND A COMPARISON WITH THE PRINCIPAL GROUPS OF STEELWORKS IN EUROPE (PART 2)

Iron:	2500 lb @ £18/5/0 per ton		£20.10. 0.
Cost of Manufacture:			
	Cementation	£1.12.0.	
	Melting	£9. 6.0.	
	Refining Coal 2470 lb @ 8/6d per ton	10.4.	£22.17. 0.
	Labour 20.3 days at 3/3½d per day	£3. 6. 8.	
	General costs and profits	£8. 2.0.	
	TOTAL		£43. 7. 0.

The bars of refined cast steel surpass in general the kinds of steel bars provided from the same *(669)* irons by double forging of the raw cementation steel; they are less roaky, more homogeneous and retain their body better in subsequent working. Finally, thanks to the economics introduced into the manufacture of cast steel, these advantages are only accompanied by a slight increase in the cost price.

Selling Price of Different Kinds of Steel

Before leaving this subject, I shall again reiterate that the cost price of the different kinds of steel of which details have been given in this second section only include what are properly called costs of production, that is to say, those which have to be paid by a merchant who, having bought the raw material, gives it to the steelworks for for working up, whilst reserving to himself the sale of the fabricated products to be made from it. The selling price of these latter includes, in addition to the manufacturing costs, a sum which is always considerable and which recompenses the merchant for his own special costs, the advances of funds for the purchases of iron and its conversion into steel, the unfavourable situations which often affect commercial affairs and so on.

After having compared the current prices proper to different steelworks which work with kinds of iron which approach the average type which I have taken as an example, I believe I can approximately evaluate as follows the selling prices for different kinds of steel made from iron at £18/5/0 per ton:

(670)

Raw cemented steel (Blister bar)	£23.10.0 per ton
Rolled cemented steel	£28.10.0 per ton
Forged cemented steel	£33. 0.0 per ton
Single shear steel	£48.10.0 per ton
Double shear steel	£55. 0.0 per ton
Cast steel refined	£63. 0.0 per ton

In bringing together the detail presented in this second section on the costs of manufacture and of the special qualities on the one hand of double shear steel, obtained directly from raw cemented steel, and on the other hand of cast steel refined, one can easily explain the preference which the users now accord to the latter kind and the extraordinary impetus which has been given in these recent times to the steel melting shops.

The same comparisons lead one to forecast that the steelworks of Yorkshire, placed in the favourable position which this report points out, provided with unlimited means of manufacture, and having at their command the vast market of English commerce, should take on each year still more importance and in their development should follow the progress of the industrial arts, for which both raw and worked steel are an indispensible medium of activity.

Interests which work against the Exclusive Development of the Yorkshire Steelworks

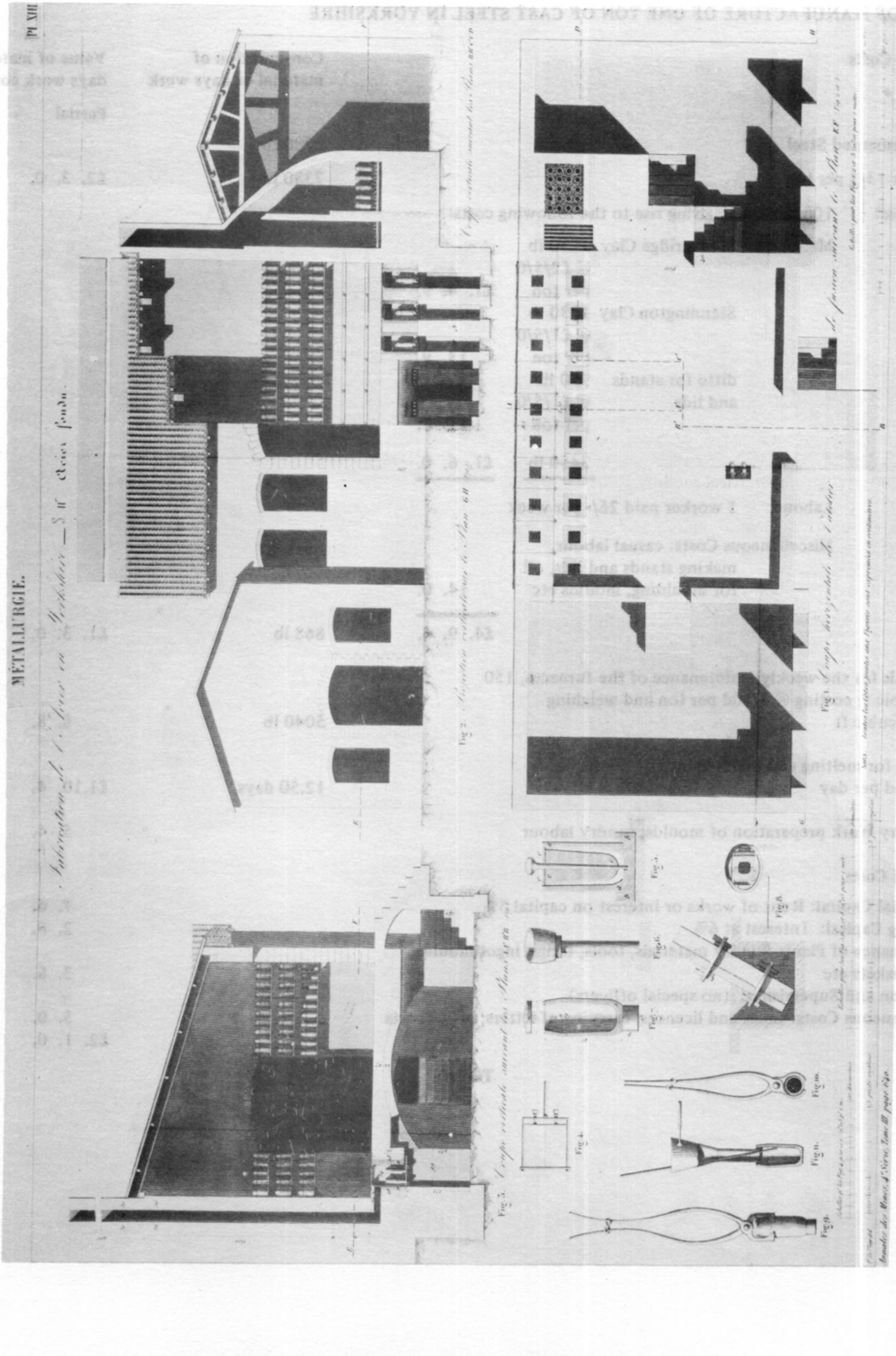
Today every European society tends to assimilate all the branches of industry which their geographic situation, the nature of the ground and the state of commercial relations will allow and this gives rise to the thought that it will not be England alone which will harvest in the new field opened to human activity by the *(671)* discovery of Benjamin Huntsmann. Independent of this irresistable tendency, many interests oppose the exclusive devleopment of the steelworks of Yorkshire. England, not producing its own raw material, cannot ever succeed completely in ensuring a monopoly of this to its manufacturers; it follows still less that England should take exclusive possession of all the foreign markets. On the contrary, there exists on the continent of Europe many localities situated near to the sea, to which the irons of Sweden, Norway and Russia could come almost at the same price as to the steelworks of Yorkshire. Cementation steelworks there could supplement this provision by means of native iron superior to those which England produces; these works could also find there low price fuel and labour and, all compensations having been made for the skill acquired by the English workmen, costs should not be higher there than in Yorkshire.

I shall show in the last section of this report the results of these tendencies and shall give a summary of the actual state and probable future of the manufacture of steel on the European continent. I shall stress such of these considerations as apply to France and shall pursue above all the means by which the French steelworks could put themselves in the position whereby they could serve the needs of the home market and could deliver, under better conditions than in the past, the products whose abundance and low price are more than ever of importance to the industrial arts and the internal economy.

END OF PART TWO

COST OF MANUFACTURE OF ONE TON OF CAST STEEL IN YORKSHIRE

Special Costs		Consumption of material or days work	Value of materials or days work consumed: Partial	Value of materials or days work consumed: Total
Raw Cemented Steel		2280 lb		
Coke at 13/3 per ton		7380 lb	£2. 3. 0.	
Crucibles: 108 per week, giving rise to the following costs:				
Materials: Stourbridge Clay 1230 lb @ £2/5/0 per ton	£1. 4. 9.			
Stannington Clay 1230 lb @ £1/5/0 per ton	13. 9.			
ditto for stands and lids 990 lb @ £1/5/0 per ton	11. 0.			
3450 lb	£1. 6. 0.			£5.10. 4.
Labour: 1 worker paid 26/- per week				
Miscellaneous Costs: casual labour, making stands and lids, oil for moulding, moulds etc	14. 0.			
	£4. 9. 6.	868 lb	£1. 3. 0.	
Materials for the weekly maintenance of the furnaces, 150 150 cubic ft costing @ 3/10d per ton and weighing 131 lb/cubic ft		5040 lb	8. 8.	
Labour for melting and maintenance of the furnaces @ 2/5½d per day		12.50 days	£1.10. 4.	
Auxiliary Work preparation of moulds; sundry labour			5. 4.	
General Costs				
Industrial Capital: Rent of works or interest on capital 5%			7. 6.	
Floating Capital: Interest at 6%			2. 8.	
Maintenance of Plant: Sundry materials, tools, tongs, ingot moulds, coke baskets etc			3. 6.	£2.19. 8.
Direction and Supervision: (no special officers)			–	
Miscellaneous Costs: taxes and licences, carrying of letters; office costs			5. 0.	
Profits:			£2. 1. 0.	
TOTAL:				£8.10. 0.


Pl. XIII
MÉTALLURGIE.

DESCRIPTION OF PLATE XIII

This shows the general arrangement and the details of one of the best steel melting shops in Yorkshire. This melting shop, comprising ten melting furnaces with two crucibles each, can produce 8750 lb. of steel per week or 200 tons per annum.

Fig.1. Horizontal section of the shop on a plan carried 16" above the floor of the shop. One sees in the shop proper the projection of the top openings of the furnaces and the horizontal section of the corresponding chimneys. On the left, and at 4 feet down from the floor of the shop is a building where one keeps coke and refractory clay and where one makes the crucibles. On the opposite side is found the furnace for the preliminary heating of the crucibles and the building serving as a store for the raw blister steel and the cast steel.

Fig.2. Projection and vertical section of the melting shop and the two buildings following parallel planes in the block of chimneys. One section B'C' presents the projection of the grates and ashpits; the other section CD shows the internal shape of the melting furnace in which the preliminary heating of the crucibles is carried out. Both show the arrangements of the crucibles on the shelves placed along the walls of the melting shop where there is a high temperature favourable to the drying out of the clay.

Fig.3. Vertical sections of the melting shop following the two planes perpendicular to the chimney block. One sees here the arrangement of the two crucibles in the melting furnace and that of the flue by which the combustion gas passes from the furnace. One can also see the door which communicates with the platform placed in front of the heating furnace and the three staircases which communicate from the melting shop to the yard, from the yard to the cellar whose floor is level with the ashpits and *(714)* finally from here to the steel store.

Fig.4. Lid closing the upper opening of the melting furnace, at ground level in the melting shop.

Fig.5. Mould employed for the manufacture of refractory crucibles in which the steel is melted.

Fig.6. Column of iron and movable wooden support on which one places the moulded crucible to separate it from the external mould *(aa, Fig. 5.)* after having lifted the whole above the stand, bb.

Fig.7. Vertical section of crucible and vertical projection of lid and base.

Fig.8. Arrangement of the cast iron ingot mould at the time of casting the molten steel.

Fig.9. First pair of tongs used to withdraw the crucible from the furnace when the charge is molten.

Fig.10 Second pair of tongs with which the workman holds the crucible when he is pouring the molten steel into the ingot mould.

Fig.11. Arrangement of the funnel and the fire rake used to charge the crucible.

Book Review

R F Tylecote

Beno Rothenberg. Timna; valley of the Biblical Copper Mines.
New Aspects of Antiquity. Editor, Sir Mortimer Wheeler.
Thames and Hudson, London, 1973. 248 pages;
133 plates; 77 line drawings; Price; £6.00.

This book gives the results of more than 10 years archaeological research under the author's direction. Timna lies near the northern tip of the Red Sea, in the Wadi Arabah about 19 miles north of the Gulf of Aqaba. The Arabah Expedition discovered about 300 previously unknown sites and it has become apparent that the Timna valley was a major centre of copper mining and smelting for a period of 6000 years. Excavations in this area revealed complete copper smelting installations from the earliest period, beginning in the 4th millennium, to the sophisticated technology of Roman times. We now know that throughout the XIX and XX Dynasties of Egypt *(1318-1166 BC)*, the mines were operated by Pharaonic expeditions using the local Midianite tribes as labour. Amongst the sites excavated was a temple dedicated to the Egyptian goddess Hathor, and the last Midianite phase of the temple suggests connections with the Midianite cult of the "brazen serpent" and with the actual tent-shrine – the tabernacle of the desert wanderings of the Bible.

So much for the background of the book itself. Rightly, it deals with the overall picture discussing the metal and non-metallic finds in their environment as they arise. Unusually, perhaps, the author describes the furnaces and discusses their interpretation in considerable detail in the course of the main text. Many would have relegated such industrial remains to some technical appendix. It is true that some of the more technical details, such as slag compositions, are left to a final chapter entitled "6000 years of Metallurgy in the Arabah", but it is difficult to introduce detailed compositions in the text and, since the final chapter deals with material that is still being worked on, this is understandable.

For once, we see an industrial site discussed in an overall manner with the social and technical aspects given their due weight. The excavation revealed not only the smelting furnaces but the living and cult areas. It is interesting to compare such an area to the lead mining area of the Pennines of northern England where, one wonders whether in 6000 years time archaeologists would be examining the remains of public houses, smelt mills and Methodist chapels.

What I shall always remember Dr. Rothenberg for is his work in bringing to light the true scale of the individual smelting installation of the period, demolishing the view previously held by some of the enormous smelters "with rooms full of molten copper". When reading such stories in one's youth one felt that there must be something wrong with this picture; it did not fit with the scale of pre-Industrial Revolution industry whether organised by an Egyptian Pharaoh or an African potentate. It was Dr. Rothenberg's article in the Illustrated London News of 1960 which made me believe that he, at least, had found the right sort of furnace for the period – a hole in the ground. This hole turned out later to be slightly more complex having a most extraordinary resemblance to the developed bowl furnace of Europe in Roman and Medieval times. The date of the Israeli furnace has been corrected from the time of Solomon, a date based on the then rather limited experience of the local pottery, to the XIX-XX Dynasties of Egypt. This was unfortunate in a way for the Israeli tourist industry but good for those who have at least got part of an answer to the question "where did the Egyptians get their copper?"

The local ore is a secondary oxide type, probably peculiar to the region. It occurs as nodular concretions within the sandstone, and, after mineral dressing, was very easily smelted in simple reduction furnaces directly to relatively pure copper. In the Chalcolithic period it is possible that the reduced metal and the slag were mixed and had to be separated by crushing, but from the XIXth Dynasty onwards it is clear that the slag was tapped from the furnace leaving a plano-convex ingot of copper at the bottom. Air was blown into the furnace by means of a tuyere in the back wall to begin with, but later, by the Roman period, this had been moved to the region of the tap hole in the front wall. The author emphasises that the principle of fluxing the siliceous gangue with iron was known from Chalcolithic times, that the tell-tale black slag is the key to all smelting operations, and that crucibles are indications of melting and not smelting.

The author found smithing hearths, crucible fragments and crucible furnaces for remelting the metal on his Egyptian and Roman sites but unfortunately no moulds. A good deal of the artifacts found in the smelting area were pure wrought copper; but a good deal of the temple offerings are now known to be of bronze.
It is almost certain that the bronze was brought to the site as artifacts and that the local people made only wrought copper artifacts from their locally produced material.

This book is well produced with 25 coloured plates; although often thought of as rather a special subject it should appeal to a large range of people, from those interested in the Bible as history to those merely interested in the history of metallurgy. My guess is that it will do much to widen the outlook of both groups. Dr.Rothenberg should be thanked for his masterly synthesis of industry and archaeology in an environment where there has been a tendency to overlook the former.

Work in progress

New Find of Clay Tuyeres at Helgö, Sweden.

Among finds at the Helgö settlement there occurred clay tuyeres with oval-shaped narrow sides together with another type, that with plain narrow sides. Only the specimens of the first group were tempered with quartz. But both kinds show clear traces of slagging and vitrifying on the hot side. It is of interest that quite similar types of tuyeres are known from earlier La Tène and Roman contexts in Central Europe, where they are found mainly in bloomeries. Nevertheless, some specimens do not exclude their possible use in smithies. It is still impossible to state whether the Helgö production centre included – beside smithies – iron smelting sites. The finds and their analogies are described in the mimeographed Annual Reports of the Helgö Research Centre, 197, pp 78-82.

P.Hallinder, Stockholm.

The Famous Hallstatt Iron Ring from Býčí Skála, Moravia, and its Metal.

Through the courtesy of the VUT Research Institute, Brno, Czechoslovakia and in cooperation with some other laboratories, the well-known iron ring from a grave in a Late Hallstatt cave, once considered as a cast iron artifact, has been recently submitted to fresh and complete investigation. The authors, K.Stránský, E.Münsterova (Mrs.), L. Ptácek and A.Rek have given a version of their report in Czech to the Journal "Slévárenství" *(Foundry Industry)*. It is hoped that an English translation will appear in an archaeological journal soon. The examination included an electron microprobe analysis, electron microscopy, metallographic investigation and X-ray diffraction tests. Briefly, it can now be stated that the object in question does not contain any particules of metallic iron. The structure consists mainly of iron oxides, small amounts of copper oxides and, surprisingly, a continuous zone of metallic copper and tin. The X-ray diffraction test confirmed hydrohematite and magnetite. The carbon content was less than 0.30% C. Nevertheless, the occurrence of copper and tin cannot be reliably explained at the present stage of knowledge *(there exist many possibilities)*. One thing may be accepted as certain: the ring never consisted of white or grey cast iron; it may have been forged from low carbon steel sheet. Despite this fact it represents a curious example of the smith's art.

R.Pleiner, Prague.

Metallographic Investigation of Helgö Iron Rods.

About 20 iron and steel rods were examined on behalf of the Helgö Research Centre, Stockholm. Messrs.Sten Modin, Pär Hallinder and Ja-Erik Tomtlund has prepared a detailed report for the Helgöundersökningen Årsrapport, 1972, pp 56-76. The rods *(square, rectangular, and round in section)* were forged from different sorts of wrought iron or steel, sometimes from perfunctorily welded bars or wires. Among the structures martensite also occurs proving that heat treatment had been carried out at least once during the existence of the objects. As to the purpose of the objects there arises the question of material or scrap metal prepared for further use in the production processes. Besides a metallographic investigation, a numerical model to subdivide and classify the iron bars and rods is submitted.

P.Hallinder, Stockholm.

The Editor would like to acknowledge the help he is receiving with the abstracts. He is very grateful to the following who are 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, M.M.Hallett, J.Piaskowski and K.Poplawska. Some of the abstracts are taken from the periodical "Art and Archaeology Technical Abstracts" and we are grateful to the International Institute for the Conservation of Historic and Artistic Works, London and New York, for allowing us to reproduce them. We are also grateful to Dr.R.Pleiner, honorary secretary of the Iron Committee of the International Union of Prehistoric and Protohistoric Sciences for allowing us to reproduce items from the Bulletin of that committee.

WORK IN PROGRESS

Examination of an iron bar from Gretton, Northants.

*by R. V.Riley**

1. Introduction

An examination has been made of a highly corroded iron bar *(approx. 9 x 2 x ¼ in).* This was a piece of one of a hoard of so-called "currency" bars found near Brookfields ironstone quarry. It is an example of one of the heavier parallel-sided bars, flat at both ends, and not the more common tapered and socketed type that form the majority of the currency bars. It is provisionally dated to 100-50 BC.

2. Examination of Sample

2.1 Chemical and Metallurgical Examination

The chemical analysis of the metal is given in Table 1. Metallographic examination showed that the sample was composed of zones of almost carbon-free iron, and regions where the carbon content *(indicated by the presence of grain boundary cementite)* was equivalent to that of a low carbon steel. Some of these zones were bounded by an oxide slag compatible with the bar being formed by hammering a sponge or mass of iron produced by the reduction of iron ore. On a transverse section, the zones were approximately 0.1 in wide by 0.025 in thick. The carbon-free zones were of a coarser ferritic grain size (approximately 60 grains/mm^2) than the carbon rich areas (*approximately 2000 grains/mm^2*) and contained nitride needles. Both regions appeared rich in phosphorus, small islands being produced in relief on etching.

Micro hardness tests using a 500 kg load showed that the carbon rich areas had an average hardness of 171 Vickers *(range 165 to 179 Vickers)* and the carbon-free areas an average hardness of 210 Vickers *(range 192 to 219 Vickers).* This high hardness is probably due to the high phosphorus content as there was no evidence of hardening due to hammering at low temperature, or any evidence of heat treatment such as quenching. The oxide at the surface of the sample was layered and its constitution could well reflect the micro-structure of the previously metallic part of the sample.

2.2 Electron Microprobe Analysis

Qualitative electron microprobe analysis of slag inclusions in the metal showed them to contain silicon, aluminium and iron oxides, and traces of titanium and manganese oxides. Quantitative analysis *(see Table 2)* indicates that much of the silicon in the metal was present as massive slag inclusions.

2.3 X-Ray Diffraction Examination

X-Ray diffraction examination of the outer *(non-metallic)* layers of the sample showed the outer orange coloured layer and the intermediate red-brown layer to consist mainly of α-Quartz, Lepidocrocite *(* γ*-FeO(OH))* and Goethite (α *FeO(OH)).* The thick black layer adjacent to the metal surface was mainly magnetite *(Fe_3O_4).*

3. Discussion and Conclusions

The structure of the bar is consistent with it having been forged down from a bloom produced by the reduction of iron ore in a charcoal furnace employing an air blast. The metal varies in composition with coarse grained carbon-free zones containing nitride needles and finer grain low-carbon zones. The high hardness of the as-forged material is compatible with its high phosphorus content. The variations in composition across the section were clearly unintentional.

It was hoped that analysis of the metal might indicate whether it was manufactured from ore mined in the Corby region. Large scale ore mixing as used in conjunction with modern blast furnace practice yields a product of fairly constant composition with regard to trace element content *(e.g. copper, nickel, arsenic, and tin).* Analytical data for individual ore samples is sparse but figures obtained [1] for ores from the Stanion Lane and Rockingham areas *(Table 3)*illustrate the wide variation of trace elements obtainable. The analysis of the bar metal appears consistent with the composition of the local ores as may be seen by inspecting the "parts to 100 parts iron" section of Table 3. The very low manganese content of the bar sample arises from the stability of manganese oxide and thus the migration of manganese to the slag phase during manufacture; this is supported by the presence of manganese oxide in the slag inclusions.

Acknowledgement

This paper is based on work done at the Research Centre, British Steel Corporation, Corby. I am very grateful to the BSC and my colleagues for their assistance with this report and to the BSC for permission to publish it.

Reference

1. Research Centre Report No. M9/216. 26th Sept. 1940. *(Inf. Retrieval Ref. 4571).*

* Dr. Riley is with the Tubes Division, BSC, Corby, Northants.

TABLE 1
Analysis of the Bar Metal

	%
Carbon	0.25
Silicon	0.31
Manganese	0.04
Phosphorus	0.39
Sulphur	0.029
Chromium	<.01
Molybdenum	<.01
Nickel	0.03
Total aluminium	<.005
Arsenic	0.010
Copper	<.01
Total nitrogen	0.0065
Niobium	<.003
Tin	<.003
Titanium	<.01
Vanadium	<.01

TABLE 2
Electron Probe Analysis of Slag Inclusions

	Silica	Alumina	Iron Oxide
Edge inclusion	27%	5%	67%
Central inclusion	66%	13%	20%

TABLE 3
Local Ore Analyses - %

Source	Stanion Lane					Rockingham
Total iron	38.19	41.78	29.90	25.3	46.20	29.26
Silica	20.35	7.30	10.14	8.23	13.47	8.53
Alumina	5.46	6.10	7.50	4.75	3.21	6.29
Titanium oxide	0.20	0.22	0.24	0.15	0.12	0.22
Manganese oxide	0.27	0.14	0.10	0.10	0.51	0.14
Calcium oxide	3.25	6.55	10.21	17.10	1.10	13.60
Magnesia	1.19	0.93	3.25	2.90	0.50	1.64
Alkali oxides	0.045	0.056	0.024	0.047	0.011	0.023
Sulphur	0.078	0.026	0.867	0.375	0.390	0.419
Phosphorus	0.440	0.801	0.743	0.495	0.206	0.753
Arsenic	0.008	0.015	0.017	0.020	0.031	0.001
Nickel	0.009	0.010	0.008	0.012	0.010	0.008
Chromium	0.010	0.012	0.020	0.005	0.002	Nil
Copper	0.0036	0.0013	0.0034	0.0043	0.0018	0.0023
Vanadium	0.027	0.044	0.080	0.060	0.027	0.028
Zinc	0.0005	0.0002	0.0003	0.0005	0.0006	0.0005
Lead	0.004	0.006	0.004	0.006	0.010	0.004
Parts to 100 parts iron						
Manganese	0.66	0.26	0.27	0.39	0.88	0.37
Phosphorus	1.38	1.90	2.47	1.77	0.47	2.50
Arsenic	0.025	0.036	0.057	0.079	0.069	0.003
Nickel	0.028	0.024	0.027	0.047	0.022	0.027
Chromium	0.031	0.029	0.067	0.018	0.004	Nil
Copper	0.011	0.003	0.011	0.017	0.004	0.004

WORK IN PROGRESS

EXCAVATIONS AT WINGERWORTH IRONWORKS DERBYSHIRE, 1973

by Philip Riden

This note is an interim report on excavations carried out for Derbyshire Archaeological Society between April and August 1973 on the site of Joseph Butler's ironworks at Wingerworth, Derbyshire *(SK 384662)*, 3 miles south of Chesterfield, in advance of destruction by opencast coal and clay mining. The Society acknowledges with gratitude a grant of £100 from Derbyshire County Council and the very generous free loan of mechanical plant by the owners of the site, Shirland Fireclay Co Ltd. The Society is also grateful to those of its members who have helped with the excavation.

The Wingerworth works, consisting at its greatest extent of two blast furnaces, a foundry and the customary ancillary buildings, was opened in 1780 by the firm of Matthews and Butler. About five years later it passed into the hands of Joseph Butler alone, probably a son of the original Butler, who remained the owner throughout the period of the Napoleonic wars. In the slump after 1815 the Wingerworth works was one of several in north-east Derbyshire to go out of blast and by the time of the compilation of the 1823 list the works had become completely defunct.

Like most Derbyshire blast furnaces before the railway age, those at Wingerworth were built on a site where ample supplies of ironstone were readily available near the surface. Butler's ironstone mines stretched away to the south of the works for a distance of over a mile; the stone was brought to the furnaces by means of a railway, built in 1788, which was the first above-ground line in the country to use cast-iron plate rails. Coke for the works was brought by road from Lings colliery, 3 miles to the east; limestone came from a quarry at Ashover a similar distance south-west of the furnaces. Pig from Wingerworth supplied Butler's two foundries, one at Wingerworth and the other at Chesterfield, as well as his puddling forge at Killamarsh.

None of Butler's business records have survived, nor are there any other documentary sources which shed much light on his activities. For this reason, together with the imminent destruction of the site, one of the earliest coke furnaces in Derbyshire, it was felt that excavation might make a genuine contribution to our knowledge of the East Midland iron industry of this period.

Initially an area of 900 m^2 was cleared mechanically to an average depth of 1 m, revealing the general position of the main buildings, casting floor and slag heaps. The works was built beside a small stream immediately beneath a steeply sloping bank, which appears to have been artificially steepened and the top levelled. The base of one of the furnaces, which were built into the bank to facilitate loading, has been located, revealing a substantial structure, some 8 m square, surviving in parts to a height of over 2 m, and built of local sandstone with a yellow clay core. A retaining wall built against the bank has also been partially cleared, as has the base of what may have been one of the walls of the engine house.

The finds consist of a large quantity of salt-glaze earthenware, presumably of local manufacture, and a rail from the tramway on the site. Since this is the first example of Joseph Butler's rails to be discovered it is of considerable interest.

Excavation will continue until the end of September, after which it is hoped to watch the early stages of the opencast operations. A full report will be published as soon as possible after the completion of the work.

Techniques

H.H. Coghlan – Some reflections on the prehistoric working of copper and bronze. *Arch. Austriaca. 1972,* **52**, *93-104.*

The author draws attention to the role of arsenic in early copper where it is often in the range 2-4%. Although Maréchal has shown that 8% As has the same effect as 8% Sn on worked copper, we have little knowledge of the properties in the lower range typified by most of the Cu-As artifacts which were most likely produced from natural arsenical copper ore. Arsenic acts as a deoxidiser like Sn and produces non-porous castings more easily than pure copper. Cu-2.16% As metal from a halberd was annealed at 600°C for ½ hour and then cold-worked by rolling to 87% reduction before cracking occurred. The hardness progressively increased from 60-207 HV5. Some material was hot-forged at 600°C to 85% reduction. It is concluded that the change to tin-bronze was due to the gradual exhaustion of deposits containing the hardening elements, As, Ag and Ni, in easily available surface workings.

Gives examples of bronze axes with their cutting edges hardened to 230-240 HV, i.e. above the maximum hardness attainable with Cu-As alloys. From the point of view of quality, the socketed axes were poor; the castings were bad and the metal soft. The flat axes were good but the hafting arrangements poor. The palstave, on the other hand, with its knee-haft was in all senses an excellent tool. The socketed axe was too light – presumably it was an attempt to save bronze which was becoming more and more scarce. This poses the question; why was there no metal shaft-hole axe until the Roman Iron Age in the British Isles?

He also discusses the zinc question and gives some analyses of socketed spear heads with low lead and 0.05-0.09% Zn from the MBA. Some recent analyses show 3.3% Zn and a socketed axe is known with 1.8% Zn. He does not think that these are forgeries and believes that one cannot use the Zn content, without supporting typological evidence, as an indication of forgery. Unlike the axes, the socketed spear-heads, although highly skilled products, did not have hardened edges.

Scientific Examinations

J.Driehaus. Archäologische Radiographie. ***Düsseldorf, 1968.***

A general instruction on the use of radiography in archaeology. Gives illustrations of investigations of individual objects including pattern-welded swords from Nettersheim and Beckum.

J.Driehaus. Rõntgenuntersuchungen an Bodenfunden. ***Informations-blätter zu Nachbarwissenschaften der Ur- und Frühgeschichte, 1; 1970, Göttingen.***

A short acount of X-ray fluorescence analysis, X-ray diffraction analysis and X-ray photography as applied to investigations of archaeological iron objects.

A.E.A.Werner. The Scientific Examination and Treatment of the objects from the tombs. ***pp.136-140.*** **in** ***The Tombs of Archbishops Walter de Gray (1216-55) and Godfrey de Ludham (1258-65) In York Minster, and their Contents. By H.G.Ramm,*** **et al.** ***Archaeologia, 1971,*** **103,** ***101-147.***

Analysis of the ring from the tomb of Archbishop de Gray showed this to be an alloy of gold with lesser parts of silver and copper. Spectrographic analysis of the chalice from the same tomb gave the following result: silver 88.1, copper 6.62, lead 0.9, gold 0.13, iron 0.5%. The gilding on the inside of the chalice produced traces of mercury, indicating the use of a 'fire' gilding technique. The patten was also mainly silver and had traces of mercury in the gilding. The head of the staff was found to be 'fire' gilded copper.

The chalice from the tomb of Archbishop de Ludham yielded the following composition: silver 91.1, copper 4.02, gold 0.38 and lead 0.35%. In this tomb the staff was principally of wood.

The conservation treatments applied to these items are fully described.

R.Cesareo and others. Rapid nondestructive analysis of ancient bronzes. ***Int. J.Appl. Radiat. Isotop., 1972, 23 (4), 198-201.***

Cu, Pb, and Sn were determined by x-ray fluorescence analysis in 8 standard bronzes and 5 ancient bronze objects of 8th century BC – 13th century AD origin. A 147 Pm-Al source *(45 mCi; bremstrahlung spectrum)*, a Xe-filled gas proportional counter (Be window thickness 0.5 mm), standard electronic equipment, and a 400-channel analyzer were used. The bronze surface was clean; the analyzed area was 5-10 cm^2 *(∼100 thick).* The concentrations were determined by normalizing the spectrum area between channels No.1 and 199 at 10^5 counts. The Cu, Pb, and Sn values of the bronzes are given.

R.Cesareo, S.Sciuti and M.Marabelli. Non-Destructive Analysis of Ancient Bronzes. ***Studies in Conservation, 1973,*** **18,** ***64-80.***

In this paper are described the measurements, carried out on a considerable number of ancient bronzes, using a portable radioisotope X-ray fluorescence *(XRF)* unit. This unit allows, in a non-destructive way, the quantitative determination of copper, zinc, tin and lead in bronzes and brasses, in a measuring time of about 100 seconds. The XRF results are in good agreement with those obtained by traditional methods.

Historical Metallurgy Group Conference 1973

The ninth annual Historical Metallurgy Group Conference was held on September 21st/23rd at Keele University, with the copper and iron of North Staffordshire as its subject. About seventy members and their guests were present. Since the week-end was run at its usual high pressure pace, it was perhaps fortunate that the spacing of lecture theatre, food hall and sleeping accommodation ensured intermittent fresh air and exercise; while also enabling members to appreciate the fine modern campus, with its varied collection of architecture.

On Saturday morning two coaches set off to visit sites connected with the early copper and iron industries of the area. Our first stop was the late 18th century blast furnace at Springwood. The upper part of the brick built furnace is still well preserved, but inside, the fire-brick lining and the packing between the lining and the walls, have completely disappeared. The furnace is free standing and has a round headed tuyere arch on one side.

We then crossed the derelict railway line where it entered Harecastle tunnel and descended to look at the Canal tunnel below. Here also was the now levelled site of the Goldendale Ironworks, where until recently, scrap was remelted to produce a useful range of iron of variable content to suit all requirements.

The main focus of the day was the visit to mines on Ecton Hill, set in very fine scenery, just within the Peak District National Park. The mines particularly flourished in the 18th century under the direction of the Duke of Devonshire. A preliminary look round was followed by a picnic lunch at a nearby public house. After lunch the party returned to Ecton where we wound our way up a pack horse path, past a small isolated stone powder house, to the remains of the Engine House at Ecton Deep Shaft, where a Boulton and Watt winding engine was erected in 1788 to raise kibbles of ore to the Ecton Deep Level. The engine was an 8 HP sun-and-planet wheel engine with a double acting 16 in. diameter cylinder, 4 ft stroke, almost identical with the engine preserved in the Science Museum London. It replaced an earlier horse whim whose position is still marked by a curved stone wall beside the engine house.

It was interesting at this point to look across the hill; I have never seen mineral veins so clearly marked by disturbed ground above them as the ones discernable here. There are three distinct bands of 'gruffy ground' running down the smooth hillside.

The part then descended to the Dutchman workings, clearly defined on the centre of the slope by an isolated spoil heap. It is likely that this mine was the first in the country to use gunpowder for blasting, somewhere within the period 1665 to 1680. There were magnificent views around, and down to the valley and distant dressing floors below; looking upwards to the crest of the hill a substantial beehive shaped hump of masonry marked the position of the Balance Shaft near the Watt engine house.

Later dressing floors, of the 1890 period, still show vestigial remains of two round buddles. Nearby a masonry wall containing three rectangular openings originally fed water to jigs from a launder at high level behind the stonework.

The next place to be visited was the site of the Whitson Copper Works. These had been set up in connection with the Ecton mines, and in 1772 had six reducing and two refining furnaces at work. Various smelters continued in use until 1890, but the works were finally demolished just after the turn of the century. Today all that remain are some buildings made of slag blocks and a few tips of waste slag. Considerable interest, however, was shown in both. May I suggest that if ever the H.M.G. does not know what to do with its members, they could always spend a happy hour on the nearest slag heap!

The coaches then took us on to the firm of Thomas Bolton & Sons Ltd at Froghall. Here the 'cup of tea' we had been promised turned out to be a quite superb cold collation. Also laid out for our enjoyment was a most interesting display of documents and exhibits connected with the history of the firm, including copper wire manufactured at the Oakamoor works for the first successful Atlantic Cable in 1866. The firm of Thomas Bolton, originally established in Birmingham in 1783, came to Oakamoor in 1852 as a result of Alfred, the twenty-four year old son of Thomas Bolton, attending an auction sale of the works in search of some pieces of machinery. He left the sale having unexpectedly purchased the whole concern, from the Cheadle Brass and Copper Company, for the give away price of £7,000. Boltons have always specialized in the manufacture of copper and copper alloys and today are particularly concerned with products for the electrical industry.

The whole of Sunday morning saw a lively session of short contributions by members.

Professor Dr. U. Zwicker of West Germany showed slides using macro and micro X ray fluorescence analysis of copper slags from Cyprus dating back to 1000 B.C. and from Kitzbuhel to 1500 B.C. Also from Lavarone, Populonia, Etruria, and Rio Tinto. Those of us who found the metallurgical analysis difficult could still enjoy the slides as a form of abstract are!

Dr. H.G. Bachmann *(Frankfort)* spoke of new methods of slag investigation, using an electron microscope on Cyprus slags of 1700 - 1500 B.C. to establish the materials used and the types of ores involved. Magnetite crystals like mountains, and Fayalite resembling nothing so much as great waterfalls. Dr.Bachmann used the delightful phrase "to walk within a slag".

Mr J.W. Butler had determined on being the comic relief and presented his audience, in a most entertaining manner, with a small box containing pieces of metal from a World War I Zeppelin, brought down over Billericay in Essex. His request for information on the metal, however, was serious enough, and surely we shall all await with interest any results that members may produce.

Mrs Janet Lang of the British Museum Research Laboratory, spoke of an examination she had made of two iron objects from the Waltham Abbey Hoard in the pre-history department of the British Museum. The hoard was of a type similar to that of Llyn Cerrig Bach, possibly votive in origin, and dating from the late pre-Roman Iron Age or early Roman period. The sword was similar to a La Tene sword in Switzerland, though harder than the one from Llyn Cerrig Bach. Bands of iron were welded together and then forged, producing in parts a thickness of up to 25 layers. The Adze was made up of several pieces of metal, heat welded together and then forged. The metal used for the cutting edge did not appear to be different from the rest but had been hardened.

Mr. Norman Mutton spoke of two sites. One the Shifnal Blast Furnace in the Westley Valley, of 1564, which was well documented, but position unknown. He had now discovered the site by slag and furnace lining remains. The other site was that of the Eccleshall Bloomery, of which the site existed, but there was no written knowledge. Extra deep ploughing had turned up a substantial quantity of slag, which suggested it to have been an efficient water powered bloomery.

Mr Philip Riden gave an account of the excavation of Wingerworth blast furnace, Derbyshire.

Mr K.C. Barraclough showed slides of the crucible shop at Abbeydale.

Mr H.A. Chester of Cheadle gave an historical account of the Oakamoor furnace, where references to "my old mines of iron" and "my old forges" go back to 1190.

Amina Chatwin

Abstracts

GENERAL

G.R.Morton and J. Wingrove. The constitution of bloomery slags; Part II, Medieval. *J.I.S.I. 1972,* **210,** *478-488.*

This is the second paper on the constitution of bloomery slags. The first was published in the December 1969 issue of the JISI and dealt with the Roman period. That work showed that the slags were comparatively high in FeO and fell near the FeO end of the quasi-ternary system; anorthite-SiO_2-FeO. *(anorthite is $CaO.Al_2O_3.2SiO_2$).* In this paper the slags were found to fall into two groups. The first, from rich ores, fell into a group on the tie-line anorthite-fayalite but nearer to the anorthite end than the Roman slags. The second group consisted mainly of slags from the carbonate ores of the Coal Measures and the Weald; these contained even more anorthite and were often accompanied by some hercynite *($FeO.Al_2O_3$).* Thus the slags from the rich ores tended to follow the Roman pattern, and there was some overlap with this group, while those from the leaner ores were low in FeO and higher in SiO_2 and Al_2O_3 forming a distinct group. The latter type is due to the improved skill of the medieval operators and the use of higher temperatures; no doubt this was based upon the need to use the leaner ores.

M. Davies-Shiel. A little-known Late Medieval industry. Pt.II. The making of potash for soap. *Trans. Cumb. West Arch. Soc. 1972,* 72, *85-111.*

This most welcome work will do a lot to clear up the confusion between bloomery furnaces and the kilns used for lime and potash making. None of the latter has a slagged surface which is so obvious in a bloomery hearth. Typical examples of potash kilns and lye boiling fireplaces with their pots are well illustrated. A similar work is badly needed on lime kilns. The author believes that in many cases the O.S. cartographers confused **lye** kilns and **lime** kilns.

H.F.Cleere. The classification of early iron-smelting furnaces. *Ant. J. 1972,* **52** *(1), 8-23.*

The paper begins by surveying the different types of iron-smelting furnaces, based on a tentative classification proposed by Coghlan in 1956. The ambiguities in this classification are indicated, together with examples of furnaces that do not fall easily into one of its three categories. On the basis of data derived principally from furnaces of the Early Iron Age and Roman periods from Northern Europe, the author proposes a new classification into two main groups, differentiated by their provisions or otherwise for the removal of molten slag during the iron-smelting operation. Each of these groups is further subdivided, according to the shape of the furnace superstructure and/or the method of supplying the air blast.

Cyril Stanley Smith. Metallurgical footnotes to the history of art. Proceedings of the American Philosophical Society, *1972.* **116** *(2), 97-135.*

An exploration, with 61 illustrations, of the relationship between the structure and physical properties of materials and the aesthetic quality of objects made from them. The artist's fingers physically interacting with matter can no more be neglected than the concept in his mind. Many details are shaped by surface or interfacial tension. Capillarity forms and joins the gold grains in Etruscan jewellery, it restricts the silver drops in Japanese **gama hada**, it determines the spots in Tang dappled ware, in Shigaraki ware and in oil-spot **temmoku.** It forms the glaze on Egyptian frit. It binds the sand or clay in a porous mould and it restrains molten metal. If the balance of interface energy between iron crystals and liquid oxide slag had been the same as in copper, there could have been no iron age, for iron cannot be melted in primitive furnaces and consolidation by welding would have been impossible. The basic relation between technique and design is discussed at length. Thirteen different techniques used in making moulds for Chinese bronzes are listed, each with some effect on the appearance, but the main quality of the bronzes arises from the fact that the decorative details were developed in the mould, not on a model. Worked metals demand a different quality of design from those made by casting, and objects forged integrally differ from those constructed by joining together pre-shaped parts of wire or sheet. The value of metallography in reconstructing ancient techniques is illustrated with a study of Cretan bronze armour made from sheet and wire. The use of etching to produce decorative patterns seems to have begun with carnelian beads in Harappa. It was used on metal in China about 500 B.C. in a process involving mineralization in situ rather than complete removal of metal. It was used to bite designs on armour before its use in the graphic arts. The Japanese sword guard maker used etching to achieve very subtle surface textures based on the internal structure of his alloys, sometimes dendritic crystals, sometimes equiaxed grains but best of all in the two-phase alloy of copper and silver, **shibuichi.** The Japanese sword is the best example of a satisfactory art form based on the inner nature of metal. The texture of the metal itself depends upon intricacies of forging, and the intricately-shaped interface between hard and soft metal follows a pattern of diffusion of carbon and heat under conditions only partially controlled by the smith.

Though based upon the microstructure of materials, the paper suggests that form, in its broadest sense, arises in the mutual two-way interaction between parts and wholes, between imperfections in atomistic structures and historically-based larger ones, between human control and the nature of matter. *"Much of man's exploitation of the richness of materials has come about because he can see them at a scale where a new quality is emerging from the structural hierarchy of quantity."*

H.K. Barton. Charles Babbage and the beginning of die-casting. Machinery and Production Engineering. *Oct 27, 1971,* **119** *(3076), 624-631.*

Babbage, inventor of the mechanical computer and of punched-card programming died one hundred years ago. He required large numbers of highly uniform parts and became a pioneer in the field of pressure die-casting. His dies had integral clamping arrangements, and castings from his horizontal machine were of a quality acceptable by modern standards. The metals originally described as 'Pewter hardened with Zn' were a Pb-base alloy with a near-eutectic antimony content, also containing Zn $\sim$ 1% or Sn-Sb alloys of the 'Britannia metal' type but without Cu or Zn.

Hans Grothe. Brass production by the old calamine process. *Erzmetall (Zeitschrift für Erzbergbau und Metallhüttenwesen). 1971,* **24***(12), 587-592. (In German).*

The calamine process, as used from at least 300 B.C. to about A.D. 1850 involves direct fusion of ground calamine or ZnO, charcoal and crushed copper in a closed crucible at over 850°C. Analysis of antiques shows that earlier brasses contained only 10-25% zinc and never more than 50% zinc. The reason is that at $\sim$ 1000°C Zn vapour over a Cu-Zn alloy with 30% zinc is equal to the partial pressure of the zinc vapour in the reduction process. This is important for dating antiques. From theoretical assumptions as to the absorption and diffusion of zinc vapours and from a study of reports on the calamine process, it is stated that brass could have been produced with 40% zinc in it by increasing the calamine proportion. 12 ref.

BRITISH ISLES

Martin Allbut and Fred Brook. The South Shropshire Lead Mines. *Industrial Archaeology, 1973,* **10**, *40-63.*

A detailed account of the lead mining and associated coal mining between Pontesbury and Pontesford, with some reference to smelting. A detailed schedule of remains in the area is illustrated by maps of all the sites.

Megan O. Coombe. The Industrial History of Hayle. *Industrial Archaeology, 1973,* **10**, *64-76.*

Traces the main events in the rivalry between the Cornish Copper Company and Harvey and Company until the latter bought out the former in 1868 following the financial crisis of 1866 and the slump in the Cornish mining industry. However, the 1890's saw the end of the demand for large Cornish engines in which Harvey & Co specialised, and despite taking up shipbuilding in 1890, the foundry had to be sold in 1903. The East Pool engine, with a 50 ton beam cast in 1892, was at work until 1953, and is now preserved by the Cornish Engine Preservation Society.

Anon. Museum Planned. *Foundry Trade, 1973,* **134** *(2935) 298.*

Planning permission has been requested for temporary use of a blacksmith's shop at Eckington, near Sheffield, dating back to 1700, as a museum of local industry and history, and headquarters, by the Eckington and District Preservation Society.

Anon. Foundry Trade J. *1973,* **134**, *(2941), 511.*

Members of Derbyshire Archaeological Society have been excavating the site of the 1780 blast furnace off Nethermoor Road, Wingerworth, Chesterfield, in an attempt to secure an accurate ground plan before the site is taken over for opencast mining. Foundations have been unearthed, thought to be for the building where the steam blowing engine was housed.

C.F. Tebbutt. A Roman bloomery at Great Cansiron, near Holtye, Sussex. *Sussex Arch. Coll. 1970,* **110**, *10-13 10-13.*

A description of the surface appearance of and of small finds from a 4-acre iron-making site from the Weald. Pottery and a single coin suggest a date for starting operations early in the 2nd century AD. The site lies about a mile from the well known London-Lewes Roman road, which is metalled with iron slag over much of its length. It was probably supplying markets in London and on the South Downs.

H.H. Coghlan. A socketed bronze spearhead from Ellbarrow on Salisbury plain. *Antiq. J. 1971,* **51** *(2), 298-299.*

The examination of a Late MBA spearhead containing (%), 10.1 Sn, 0.5 Pb, c.0.3 Ni and c. 0.2 As. The metal is essentially in its cast, cored, dendritic state but the cutting edges have been hammer-hardened to raise the hardness from 72 to 203 HV5.

D.W.Crossley. A 16th century Wealden blast furnace. A report on excavations at Panningridge, Sussex, 1964-70. *Post-Med. Arch. 1972,* **6**, *42-68.*

The excavation recovered evidence for two periods of iron smelting; there were substantial surviving structures from a blast furnace thought from documentary sources to have produced pig-iron from 1542 until at least 1563 and, superimposed, indications of a later furnace built with major changes in layout at some time after 1563 but abandoned well before 1611. It was possible to compare, in particular, the application of water-power in the two periods and to sample ore and cast iron. The features of the first furnace could be related to references in surviving account books, and thus a yardstick may be offered for future fieldwork on undocumented furnaces of the period. The furnace used local carbonate ores from the base of the Wadhurst clay. The slags contained 20% CaO and very little iron. The lime content could have come from the ore, and there was no need for additional flux if suitable ore was always available. The iron produced was white or mottled with medium silicon *(c. 1%)*, 1% P, 0.6% Mn and 0.15% S. The sulphur came from the ore, probably as $CaSO_4$, which is very stable and cannot easily be decomposed by roasting.

H.D.Ward. 'Best Yorkshire' from West Yorkshire. *JISI, 1972,* **210**, *396-405.*

This paper is essentially a personal account of experiences in the manufacture of 'Best Yorkshire iron' during the last years of its officially accepted existence as the top grade of wrought iron, and advances some reasons for this acceptance. It deals with the raw materials involved, the stages of manufacture up to the final product and its applications in industry. In view of the great amount to labour involved at all stages the human and humane aspects have not been neglected. The Appendix gives a summary of the commercial history of the five accredited makers of 'Best Yorkshire', the names of some now being associated with the most up-to-date branches of ferrous and non-ferrous metallurgy.

G. Beresford. Tresmorn, St. Gennys. *Cornish Arch. 1971,* **10**, *55-73.*

A forge pit was found outside of and to the west of a stone walled house of the 13th-14th century AD. The pit was dug into the ground and was 2 ft wide, 3 ft deep and 9 ft long at the top. Smithing slag was found in nearby ditches and there is no doubt that this was associated with the house. This pit is of a type common in the Roman period for smithing; there are other instances of similar pits in use in the medieval period eg at Goltho in Lincs.

N. Thomas. An Early Bronze Age stone axe-mould from the Walleybourne below Longden common, Shropshire. *pp 161-166.* **In** *Prehistoric Man in Wales and the West; Essays in honour of Lily F. Chitty. F. Lynch and C.B. Burgess (Eds.) Bath, 1972.*

Now in the Shrewsbury Museum. Formerly in Birmingham City Museum A.417'62. Four-sided with matrixes for flat axes on all faces. One face has both a large and a small axe matrix; another, a large axe and a small bar, rod or awl matrix. The depth of the matrices is about 1-1.2 cm. The mould is made of a grit containing felspar and muscovite probably of Carboniferous age. The overall dimensions are 236 x 15 x 11 cm and weight 6.5 kg. The flat faces would accept a cover to reduce metal loss by oxidation. Traces of Cu and Sn were found in the stone and it is concluded that it was for bronze axes of the Migdale-Marnoch type.

H.H.Coghlan. Three unusual implements in the Borough Museum, Newbury. *p.183-188.* **in** *Prehistoric Man in Wales and the West; Essays in honour of Lily F. Chitty. F. Lynch and C.B. Burgess (Eds.), Bath, 1972.*

Gives the analyses of a flat axe from Argyll with a crude round blade containing 4.8% As; an Irish palstave with 12% Sn; and a small stubby socketed axe of Irish origin which had 6% Sn and 2% Pb. Hardness measurements showed evidence of appreciable cold working in the first and the last but very little in the case of the Irish palstave.

G.J. Wainwright and M. Spratling. The Iron Age Settlement of Gussage All Saints. *Antiquity. 1973,* **47**, *109-130.*

This report describes the excavation of a pre-Roman Iron Age settlement south-west of Salisbury in N.Dorset. This site was circular in plan with two pairs of flanking antennae ditches defining the east entrance. An oval working hollow produced bronze slag and fragments of moulds and crucibles, similar to those found dumped in an adjacent pit. This seems to have been the site of a bronze foundry designed for the production of bronze harness trappings. Some small pieces of iron slag were found in other parts of the site. The use of the site continued into the second century AD and a simple iron-smelting bowl furnace was found belonging to this period of use.

The bronze foundry used the investment process for moulding rings and links associated with horse harness. Some bone tools were also found which could have been used for wax carving. The crucibles were the three-cornered, round-bottomed type, typical of the pre-Roman Iron Age in Britain. Iron hammer-scale was found, and small iron implements such as chisels suggested their use for the touching up of the castings.

A small rod ingot 112 mm long and weighing 63.4 was also found. The mould fragments numbered tens of thousands, from mms to cms in size, and this material has not yet been fully examined. But the items cast were mostly three-link bits, terrets and linch-pin terminals. The moulds contained no vents and only one runner each and were made in a uniform fine fabric only one layer thick. The dating of the bronze foundry is given as the 1st century BC. The metal was a leaded tin bronze, typical of the Late Bronze Age with less than 0.2% Zn. This was not unexpected; while the Early Iron Age often shows signs of the introduction of zinc into the bronzes, this is by no means common; and leaded bronzes continued to be common in the Roman period.

Aileen Fox and William Ravenhill. The Roman fort at Nanstallon, Cornwall. *Britannia, 1972,* **3**, *56-111.*

The paper describes the excavation of and finds from a 2.2 acre fort in Cornwall, occupied for a relatively short time in the second half of the 1st century AD. The authors link the finding of fragments of crucibles and of a drop of silver-rich slag with the silver-lead ore deposits that lie only two miles from the fort, and suggest that the military were prospecting in the area. Iron slags also found in the fort seem to have been connected with iron-working rather than smelting. Full analyses of 11 eleven slag samples, carried out by the Brown-Firth Research Laboratories, Sheffield, are published as an appendix.

W.H. Manning. Ironwork hoards in Iron Age and Roman Britain. *Britannia, 1972,* **3**, *224-250.*

The author summarizes the data relating to the many hoards of ironwork discovered in Britain and dating from the Iron Age and Roman period. He classifies them into two groups – those associated with water and those merely buried. He suggests that there was a cult which involved the deposition of votive offerings of worked metal, in particular ironwork, which begins in the Iron Age in SW Britain, and spreads to East Anglia and Kent by the time of the Roman Conquest, when it disappears. A similar practice appears in the far north of England and southern Scotland with the Roman conquest of these areas. Finally, there is a resurgence of the practice in East Anglia and south-central England in the IVth century AD.

J.V.Megaw. Two axes of the fake Glencar class in the County Museum, Armagh. *Ulster J. Arch. 1971,* **34**, *107-108.*

A number of flat, decorated bronze axes have been found containing lead, iron and appreciable zinc. The presence of lead and zinc is rather unusual for Early Bronze Age objects and this fact coupled with the fact that the metal was cast in a two-part sand mould and the decoration cast-in instead of being cut-in suggests that like several others with similar characteristics they must be fakes. Furthermore, although the edges have been sharpened this has been done by grinding and not by hammering; the latter process results in both a sharp and a work-hardened edge.

Barry Cunliffe. The late Iron Age metalwork from Bulbury, Dorset. *Ant. J., 1972,* **52***(2), 193-308.*

The collection of iron, bronze and glass found in Bulbury, Dorset, in 1881 is discussed in detail. It is considered to date to the early 1st century AD. The nature of the deposit is uncertain, but the possibility is examined that the finds divide into three categories : (a) fittings of a male burial, (b) fittings of a female burial, and (c) an ironmaster's stock in trade. Perhaps the most striking find is an iron anchor and chain, 1.44 m overall length.

K.S. Painter. A late-Roman silver ingot from Kent. *Ant. J., 1972,* **52***(1), 84-92.*

The paper describes a late-Roman ingot recently discovered in Kent. It weighs 1 Roman pound and is stamped EX OFF CURMISSI. All such ingots seem likely to have been distributed as imperial donatives to troops in the IVth century. They are related to presentation silver plate and other gifts of this type, and more than 40 silver ingots of this type are now known from the European Roman provinces; the author publishes a catalogue of these finds. The only other stamp by Curmissus *(or perhaps the* **curator missionum***)* is on a broken ingot in the hoard from Coleraine, Co. Londonderry. The composition of the Kent specimen is $95.2 \pm 1\%$ Ag, 4.10% Cu, 0.81% Au, 1.22% Pb, 0.10% Fe. The structure revealed by microscopic examination is of pure cast silver with fairly small evenly-sized grains, and showing no signs of internal stress.

W.H. Manning and C. Saunders. A socketed iron axe from Maids Moreton, Buckinghamshire, with a note on the type. *Ant. J., 1972,* **52***(2), 276-292.*

The socketed axe from Maids Moreton is the largest example of a group of at least 21 such axes found in the British Isles. They can be divided into two classes by the presence or absence of a loop on the side of the socket. The looped form is the commonest and of British origin; the unlooped examples have Continental parallels. The dating evidence for these axes is inadequate, but suggests that they were in use throughout the whole of the pre-Roman Iron Age; the shaft-hole axe appears to have been introduced late in this period. In a note on the method of manufacture, the authors suggest that the body of the axe was formed from a single piece of bloomery iron, the socket being produced by hammering out wings, which were then folded over and completely welded together. The loops were formed either by welding on a separate strip of metal or by making parallel cuts in the metal and forcing out the strip so formed so as to produce the loop.

J.V.S. Megaw, (Appendix by A.E.A. Werner and H. Barker). A group of later Iron Age collars or neck-rings from Western Britain. *The British Museum Quarterly, Spring, 1971,* *35(1-4) 145-156.*

In an appendix A.E.A. Werner and H. Barker give details of the analysis of two of the collars, the Portland torc and one very similar to it but without precise provenance, which was carried out in the British Museum Research Laboratory. By qualitative spectrographic analysis and quantitative polarographic analysis it was shown that the former is a leaded bronze and the latter is a leaded brass. The quantitative results are given in full.

D.M. Metcalf and F. Schweizer. Metal contents of the silver pennies of William II and Henry I *(1087-1135). Archaeometry, 1971,* 13*(2),177-190.*

The percentages of Ag, Cu, Pb, Zn, Au and Sn were measured on English coins of the 12th century to learn if any evidence of debasement or forgery, as described in written sources, would be found. The coins were analyzed by x-ray fluorescence spectrometry using a curved-crystal so that the area of analysis was less than 1 mm square. 21 references.

R.A.G. Carson. Leysdown (Kent) hoard of early Roman Imperial bronzes. *Numismatic Chronicle, 1971,* 11 *(7th Series) 189-197.*

This paper describes a mid-third century hoard of Roman coins which contained 8 contemporary forgeries, which had been made by casting. The paper contains two scientific appendices *(one by A.D.Baynes-Cope and W.A. Oddy and the second by L.H. Cope)* which describe analytical and metallurgical work on the coins which demonstrated that the forgeries were cast in leaded bronze.

J.R. Blunden. The redevelopment of the Cornish Tin Mining Industry, in K.T. Gregory and W.L.D.Ravenhill (Eds.). *Exeter Essays in Geography in honour of Arthur Davies, 1971, pp. 169-184.*

A short summary of the decline of the industry is followed by reasons for its redevelopment. Then there is a brief analysis of the distribution of the mines. The proposals to develop the industry again are studied; the firms concerned are listed. Capital involved, profits and output expected are all noted. Present developments and associated problems are discussed, especially the one of the ownership of mineral rights, and the aesthetic use of the landscape. Possibilities of tax concessions and the new techniques conclude this illustrated and well-documentated article.

D.R. Wilson (Ed). Roman Britain in 1971. *Britannia, 1972,* 3, *299-351.*

Kirkbride, Cumb. : Lead-working furnace, 1.00m x 0.51m internally, with floor lined with charcoal and calcined bone. Bun ingot of lead, lead drippings. Dated AD 80-120.

Binchester, Dur. : Fort containing workshop for iron and copper (timber-built, burnt down at least twice).

Holme upon Spalding Moor, Yorks E.R. : Pottery workshop of IVth century AD, with small iron-working furnace.

Brixworth, Northants : Roman villa, with outbuilding containing crucibles and offcuts of bronze.

Milton Common, Oxon : Ironworking settlement of III-IV centuries AD.

Dymock, Glos : Ironworking area adjacent to Roman road. Bowl furnace 1.3 m in diameter. Dated AD 150-300.

Bath, Som. : Masonry building of c. AD 100, associated with lead working.

Green Ore, Chewton Mendip, Som. : Lead-working settlement with rough floors, metalled paths, cooking pits, lead-smelting furnaces, etc.

Priddy, Som. : Romano-British lead-working area.

Beauport Park, Sx. : Well preserved bath-house discovered in important iron-making settlement. Many finds of tiles stamped with the CL BR mark of the British Fleet indicate close connection between the Fleet and the iron industry of the Weald.

Anon. Investigations and excavations during the year. *Arch. Cant., 1972, 87, 240.*

A brief note on the work done by the Cranbrook Archaeological Society on the site of the iron-works at Hammermill Farm, Biddenden, Kent. The wheel stream and 'dick' have been almost completely exposed, showing a timber shoring and floor to have been used along its length. On the working area of the site, baked hearths and brickwork of uncertain function have been revealed.

J. Radley. Economic Aspects of Anglo-Danish York. *Medieval Archaeology. 1971,* **15**, *37-57.*

This paper records evidence of metal production in Anglo-Danish York. An iron smelting site has been discovered outside the south corner tower of the Roman fortress in levels which may be earlier. Analysis of the slag suggested that a bloomery process was used. Associated with the Danish building below Barclay's Bank was a piece of vitrified furnace lining. Slag has been recorded from Pavement and Goodramgate and a fair quantity of iron work has been discovered from this period.

Bronze is also common in Danish York and is found as coins, pins, brooches and buckles. The remains of two Danish copper smelting furnaces are recorded from Coppergate.

J.H. Money. Medieval Iron-workings in Minepit Wood, Rotherfield, Sussex. *(Appendix by H.F.Cleere). Medieval Archaeology, 1971,* **15**, *86-111.*

Excavations carried out at this site *(TQ 523338)* between 1965 and 1967 are reported. This site proved to be an undisturbed two period iron working area of the 14th to 15th Centuries AD. The earlier period was represented only by a roasting furnace. Of the slightly later period there remained a dump of ore awaiting roasting, a stone-built roasting furnace and a stone and clay smelting furnace with slag heap. The smelting furnace had been enclosed in a partially roofed timber building. There were also found supplies of roasted ore and charcoal, as well as a few pieces of iron and pottery. The groundwalls of a small auxiliary building were also discovered. One of the nearby mine pits was shown to be Late Medieval.

An appendix gives the results of the examination and analysis of the iron ores, slags and cinders, as well as fragments of limestone and structural debris from the furnace.

D.M. Wilson and S. Moorehouse. Medieval Britain in 1970. *Medieval Archaeology, 1971,* **15**, 124-179.
This is a resumé of work on Medieval and Saxon sites carried out in Britain during 1970 :-

p. 130 Thetford, St.Michael's Church (TL 870823)
Bell casting pits of the 11th/12th Century were found in the nave.

p. 132 Wakerley, Northants. (SP 940980)
A clay-built shaft furnace was discovered that had been rebuilt at least three times and probably dated from the Anglo-Saxon period.

p. 139 Westbury College, Bristol (ST 573774)
A post-15th Century lead smelting furnace was discovered.

p. 139 Stamford, Lincs. (TF 040074)
A late 15th Century deposit contained mercury, crucibles and glass distilling vessels.

p. 147 Bristol, (Peter Street) (ST 59087313)
A 15th Century iron working workshop was discovered.

p. 153 Gloucester (SO 830186)
Evidence of copper working was found near Berkeley Street dating from the Late 13th Century and ironworking was indicated throughout the medieval layers by the presence of quantities of slag.

p. 158 Rhuddlan, Flintshire (SJ 025778)
There was extensive evidence of 13th Century iron working. The nature of the slag suggested that bowl furnaces were used.

p. 172 Goltho, Lincs. (TF 116774)
A blacksmith's shop was discovered associated with a 13th Century house. In it were found hearths, forges and a quenching pit.

p. 177 Lyveden, Northants (SP 984861)
A 12th Century ironworking site was discovered, which yielded a furnace, a pit containing maple, oak, hazel and alder charcoal, roasting hearths and large quantities of slag.

p. 178 Chandler's Farm, Hartfield, Sussex. (TQ 471387)
A 12th Century bloomery site was discovered.

G.R. Morton. The Wrought Iron Trade of the West Midlands. *JISI, 1973,* **211**, *93-105.*

This was the 5th John Wilkinson Memorial lecture to the Staffordshire Iron and Steel Institute and it was to be the author's last contribution before his death in May 1972. It has been prepared for publication by Dr. R.J. Bishop.

The rise of the West Midlands Iron Industry is connected with the coal and ore of the Coal Measures and the invention of the steam engine since this area had very little water power. This paper opens with the properties of wrought iron and attempts a definition. The author goes on to discuss the general development of the puddling process showing how the impurities in the cast iron are reduced. Cort, Hall, Rogers and Purnell are given their due place in this picture, and the effect of working and reworking on the mechanical properties of the iron is demonstrated.

The association of Joseph Hall and the Bloomfield Ironworks at Tipton and the origins of the B.B.H. Company are discussed in detail. We are given a valuable table of analyses of tap cinder, bull-dog and slag from a number of Black Country works. The author then goes on to discuss the production of wrought iron forgings for shafts and axles that led to the foundation of the Patent Shaft and Axletree Co.

The peak period for the production of pig iron in the region was 1852-59. But the number of puddling furnaces went on increasing until 1875, after the arrival of the Bessemer process. Attempts were being made between these dates, and even after, to mechanize the process, and the semi-mechanical puddling processes such as Dank's, Casson's and others are discussed in great detail. This part is well-illustrated with sections of the actual furnaces.
We then see the gradual decline of the industry and the import of 'bastard' iron from Belgium after the 1914-18 war (this was faggoted steel and wrought iron scrap). During this period many famous names disappeared; others changed their business to that of steelmaker, re-roller or stockholder.

EUROPE

A.S. Darling and J.F. Healy. Micro-probe analysis and the study of Greek gold-silver-copper alloys. *Nature, 1971.* **231**, *443-444.*

This report describes the investigation of the physical properties and method of manufacture of a typical Mytilenean hekte of the fourth century B.C. The average composition was gold, 37.5%; silver, 55.0%; and copper, 7.5%. It seems to have been made from a bead of cast metal, and the hardness of the alloy varied in the range 247-274 HV on an unprepared surface and in the range 188-243 HV on a polished surface.

Jitka Hralová and Jiri Hrala. A bronze hoard from Brezovice near Chrudim, Bohemia. With consideration of hammers of Young and Final Bronze Age. *(In Czech). Archeologické rozhledy, 1971.* **23** *(1), 3-26 (plates 113-114).*

In addition to the archaeological analysis of the above mentioned hoard the study classifies typologically hammers of the Middle up to the Late Bronze Age date. The richness of shapes is of no chronological use, it depends on the working purpose of the tool *(various kinds of metal stamping and of blacksmith's work).* Chemical analyses of some bronze finds directed to the ratio between Cu and Sn are added.

Anna M. Rosenqvist. Swords with figural inlays in copper-alloys from the 3rd century A.D. in the University collection of northern antiquities. *(In Norwegian). Universitetets Oldsaksamling årbrok, 1971.* **167-168,** *143-200.*

The techniques used in the figural inlays, representing Mars and Victoria, the chemistry of the alloys and the metallography of the grooved pattern-welding in the blades are described. The use of orichalcum in the figural inlays is suggested. The cutting edges of the pattern-welded blade shows layers containing arsenic, cobalt and nickel, possibly representing remains of a solder between the martensitic parts of the edge and between the edge and the middle pattern-welded part of the blade. For comparison 8 other known similarly decorated, grooved Roman swords, three from Poland, one from Britain, one from Austria, one from Germany and 2 Danish swords, are described. *(After the publication of this paper a similarly decorated sword from the same period was found in the museum in Trondheim).*

Rolf-Dieter Bleck. Chemical analyses of a head of Osiris found in Thüringen. *(In German). Ausgrabungen und Funde, 1970,* **15** *(5), 236-238.*

The results of the spectral-analytic investigation of the head of Osiris described by S. Barthel (Alt-Thüringen 7, 293-95 (1965), were: Cu 85.11; Sn 8.00; Pb 4.5; Ag 0.9; Ni 0.05; Co 0,01; As 0.85; Sb 0.15; Bi 0.03; Fe 0.4%.

The results of the analysis are compared with similar alloys known from literature. According to this it is possible that the sculpture is older than S. Barthel assumes *(Third century AD).*

Earle R Caley. Chemical composition of Greek and Roman statuary bronzes. *Art Technol. Classical Bronzes, 1967. 1970, pp. 37-49.*

Edited by Suzannah Doeringer, MIT, Cambridge, Mass. Greek statuary bronzes, the chemical composition of various statuary bronzes *(Sn, Pb, Cu, other metals)*, analyses of bronze coins of Alexander the Great, composition of uncertain Greek or Hellenistic statuary bronzes, analyses of bronze coins of Antigonus Gonatas, analyses of late Hellenistic bronze coins of Athens, composition of Roman statuary bronzes, and the bronze recipes of Pliny are discussed. It is concluded that present knowledge about the chemical composition of Greek and Roman statuary bronzes is still fragmentary; any conclusions based on this knowledge are only tentative. Many more analyses are obviously needed, especially accurate and complete analyses of bronzes of known provenance, 6 refs.

B.Schmidt. Theodoric the Great and the damascened swords of the Thuringians. *(In German).* **Ausgrabungen und Funde.** *1969.* **14** *(1), 38-40.*

Theodoric returned thanks to the king of the Warnen *(a tribe of the Thuringians)* at the end of the 5th century for swords with decorated blades. The translation of the letter is reproduced. In it a polishing powder is mentioned in which one supposes to include infusorial earth. In Thuringia there is a deposit of infusorial earth, in the vicinity of which finds of the fifth century have been made. Damascened swords are not found in the Germanic tribes until the seventh century. An x-ray investigation of Thuringian swords of the fifth to sixth centuries showed that the majority of the two-edged swords are damascened.

R.J.Hopper. The Laurion mines: a reconsideration. Annual of the British School of Athens. *1968,* **63,** *292-329.*

A summing up of the present state of knowledge of the famous Athenian silver mines at Laurion. The past history, and recent industrial developments in the area are described, together with the results of previous excavations and a survey by the author.

Jaroslav Kundrnac. Discoveries of medieval gold ore mills in Bohemia. *(In Czech).* **Archeologické rozhledy.** *1972.* **24** *(4), 428-432 (plates 486-488).*

This article is based on the research of medieval plants enabling the extraction of gold ore from silica *(the most complete complex in Europe was uncovered at Pisek in South Bohemia)* and on other similar objects in Bohemian auriferous areas. In the Middle Ages gold used to be extracted in two ways: from silica extracted by mining and then crushed by mill stones *(trace amounts of gold in the uncovered fragments of quartz were proven by neutron-activation analysis in a nuclear reactor)* or by placering. Description of the presumed working process based on the finds from Pisek and on historical sources is added.

Hans Grothe. On the history of zinc. *(In German)* **Erzmetall** *(Zeitschrift für Erzberghau und Metallhüttenwesen)* ***Stuttgart.*** *1971,* **24** *(7), 324-329.*

Lazarus Ercker reported in 1565 that a white tin-like metal *(Contrafeth)* separated at the front wall of the lead furnaces then in use at the Rammelsberg smelter plants. Agricola in his 'De Re Metallica' applied the name 'zincum' at about the same time to a calamine ore found in Kärnten. The tendency to retain this name for the ore and not the metal was due to the alchemical esteem for Aristotle's theory of the seven metals which still prevailed in the 16th and 17th centuries. Wneler and Smith reported about 1920-1930 on an early Chinese retort furnace with 120 retorts and a daily calamine ore throughput of 121 kg. In antiquity, zinc was not known as such and only Strabo and Carus may be taken to refer to it in a passage on metallurgy where they mention pseudo-silver *(pseudargyros).* 18 ref.

Bruno Bearzi. Leonardo da Vinci and the Sforza equestrian monument. *(In Italian)* **Commentari,** *1970,* **21,** *3-7, 1 fig.*

In 1490 Leonardo da Vinci began a highly ambitious plan to cast a colossal bronze equestrian monument for the Sforza family of Milan. The project was never completed - it ceased with the invasion of Milan by the French in 1499 - but the remaining documents provide fascinating insight into Leonardo's search to resolve the technical problems of bronze casting on a colossal scale. The most informative documents in this regard are sixteen folios *(thirty written pages)* contained in the two Leonardo codices recently rediscovered in the Madrid National Library. These manuscripts in Leonardo's hand, including some sketches and diagrams, reveal the project with two problems yet unresolved, one of which, the author notes, had already been solved by cannon-makers. More important, the Madrid manuscripts disclose an important technical contribution made by Leonardo. Instead of the more commonly used lost-wax process, Leonardo planned to use a piece-mold, made from the original full-sized model, to form the mould into which the bronze was to be poured. Clay rather than wax was to be used to form the space later occupied by the metal. The author describes this method in some detail and remarks on the ancient origins of the piece-mold for casting small objects, and, consequently, that signs of the use of a piece-mold do not necessarily prove a bronze to be a modern forgery. The use of the piece-mold in casting large figures became the rule with the monument of Louis XIV, only slightly smaller than Leonardo's project, accomplished by Keller and Bouchardon.

Bruno Bearzi. Donatello's casting technique. *(In Italian).* **Donatello e il suo tempo, Florence,** *1968. pp. 97-105, 6 figs.*

Three examples of Donatello's work in bronze are examined from the point of view of casting technique: the doors of the Old sacristy of S.Lorenzo, the Judith and Holofernes group, and the St.Louis of Toulouse. The author, who supervised the restoration of these works, has made new observations regarding the sculptor's procedure, based on his own experience as a bronze caster. The author's observations demonstrate the highly experimental and inventive approach of the artist and give insight into his special manner of collaboration with master bronze founder or calderaio and other artisan-specialists. A plea is made for great caution in the field of restoration of bronzes in order to avoid irreparable errors.

H.Modin and Sten Modin. Metallographic examination for the purpose of determining the structure of Osmund iron objects. *(In Swedish).* **Jernkontorets Forskning.** *1971, Series H, No. 2. pp. 41-64.*

Many of the objects examined are small blooms or pieces of bloom. The structures mostly show ferrite and pearlite and some, high phosphorus ferrite.

Erik Tholander and Nils Björkenstam. Discussions on the question of making Osmund iron from pig-iron. Jernkontorets Forskning, *1972, Series H, No.4, p.1-7 and 8-23. (In Swedish).*

Hans Hagfeldt.
Methods of determining the composition and melting point of prehistoric bloomery slag.
Jernkontorets Forskning. *1971, Series H, No.2, p.1-6. (In Swedish).*

Uses the method of Morton and Wingrove to determine the melting point from the composition by reference to the ternary phase diagram - anorthite - wüstite-silica.

Sven Rydberg. Working Methods and working conditions in the Falun mines in the medieval period. Jernkontorets Forskning, *1972, Series H, No.5 p 1-9. (In Swedish).*

Åke Hyenstrand. Production of iron in outlying districts of Sweden and the problem of Järnbäraland. Early Medieval Studies, *4 (Antikvariskt archiv 46) 1972, 40 pp.*

Deals with the problem of the location of "Järnbäraland" *(Iron-bearing land)* mentioned in West Nordic medieval sources. Concludes that it must be sought in Dalarna in Sweden and suggests the Siljan region which has the largest concentration of primitive iron producing sites of the 12th to 14th centuries. He groups the iron working sites in Dalarna into three types. types. The first, Type A, operated from the Middle Ages to the 16th century on mined ore. The blast furnaces were situated near the stream on the edge of a farming settlement so as to use water-power. They produced pale blue glass-like slags and presumably pig iron. The second, Type B, was based on bog ores and was worked from the Middle Ages to the 19th century. It produced black tap-slag, sometimes with the aid of water driven blowers, and was clearly a bloomery producing wrought iron. The third, Type C, was worked from the earliest iron age into the Middle Ages and produced heavy viscous slag mixed with furnace lining. It is the latter type that was associated with the production of "Järnbäraland".

R.Thomsen. Researches on Iron objects of the Viking period. *(In German). Radex-Rundschau, 1971 (3), 479-486.*

Small fragments of 10 iron tools from Southern Sweden were examined metallographically. Most were low in Si and Mn but contained appreciable P. They are believed to be made from local bog iron ore. One knife contained a piece of eutectoid carbon steel sandwiched between two layers of low carbon iron. The hardness varied from 613 at the cutting edge to 129 HV. The joints between the high and the low carbon pieces showed considerable arsenic enrichment *(about 1% As)*, the light-etching high As ferrite bands having a thickness of about 0.009 mm. There was some slight diffusion of carbon through these bands but far less than would have been expected in the absence of As. The rest of the tools were smithed bloomery iron with variable carbon content. The %P in the rust was about 2.3 times that in the iron.

S.R.B.Cooke, E. Hendrickson and G.R.Rapp Jr. Metallurgical and geochemical studies. *pp.225-233.* **in** *The Minnesota Messenia Expedition; the recon-*

struction of a Bronze Age regional environment. **W.A.McDonald and G.R.Rapp Jr.***(Eds.). University of Minnesota Press, Minneapolis, 1972.*

The authors claim that all the metal used in the LBA in the Peleponese was imported. There are however low grade copper bearing ores in Thrace, and copper bearing slags have been found in this region. But the new mine at Ermioni could have have been worked in early times as it was completely hidden. The slags recovered by the UMME excavation at Nichoria were melting slags. It was estimated that 5 lbs of copper needed 1 lb of charcoal for melting and that 400 lbs of charcoal needed 1 ton of wood. Discusses the use of the "fingerprint" concept for provenancing metal finds. This is based on minor and trace element patterns. The problem of tin sources is also discussed and it is mentioned that out of 310 mineral specimens collected from the Near East in 1967-8 from possible tin bearing areas, not one was found to contain tin.

Some new analyses of native copper, mostly from the New World, are given.

J.Le Goff. The Culture of the European Middle Ages. *(In German).* **München Zürich,** *1970 (based on the original edition, Paris, 1964).*

Stresses the scarcity and, simultaneously, the importance of iron in the Middle Ages; illustrated by several literary sources *(pp.344-347).*

J.P.Lemant. The Merovingian Burial, No.36 from Barbaise. *(In French)* **Revue Hist.Ardennaise,** *1970, 4, 79–84.*

An iron sax with welded-on steel cutting edge.

R.D.Bleck. Chemical analyses of ores and iron slags from the Roman settlement at Kablow, Kr. Königs-Wusterhausen. *(In German).* **Zeitschrift für Archäologie,** *1971, 5 (2), 302-312.*

Fayalite slags and bog ores rich in phosphorus from an old excavation of an iron smelting furnace found at Kablow, North Germany.

M.Lutz. A Roman iron hoard from Forbach *(Moselle). (In German).* **18. Bericht der Staatlichen Denkmalpflege in Saarland,** *1971, 53-56.*

A Roman hoard of tools and other iron objects *(18 pieces)*together with a folded lead vessel and a whetstone.

R.Pleiner. Medieval iron working at Radetice. *(In Czech).* **Vlastivědný sborník Podbrdska,** *1971, 5, Příbram,42-63.*

An excavation of a bloomery complex from the 13th century in Southern Central Bohemia; slag heaps, a roasting hearth, thick stone-walled furnace remains. Analyses of goethite ore, tapping slags and charcoal. Melting tests. The bloomery is one of many similar on the site. In the 14th century iron production had been abandoned and replaced by mining, sorting and roasting of lead ores *(roasting places, heaps).*

D. Gabler. The Roman villa of Szakony-Békástò. Mitteilungen des Archäologischen Instituts *(Budapest), 1971, 2, 57-86.*

The remains of two bowl hearths from iron smelting furnaces do not belong to the villa; they date from the 11-12th centuries AD. Details of tuyeres on pp.80-81.

F.Horst. Hallstatt imports and influence in the Elb-Havel area. *(In German).* **Zeitschrift für Archäologie.** *1971, 5, 192-214.*

Imports of iron to the north-central Europe and the question of the beginning of local metallurgy in the Hallstatt C & D periods. The use of bronze artifacts was up to 80-90% at that time.

A.Obermayr. Celtic and Roman Magdalensberg. Wien 1971. *(In German).*

A popular account of the Austrian excavations of the Celtic and Roman site at Magdalensberg. Information on iron smelting installations *(pp.40-43)*, on steel working according to Schaaber's investigations *(pp.99-101)*, and on iron trade inscriptions *(pp.129-130).*

A.M.Snodgrass. The Dark Age of Greece; An Archaeological Survey of the Eleventh to the Eighth Centuries BC. Edinburgh 1971.

The 5th chapter *(pp.213-395)* is devoted to the use of iron in the relevant period. Inhomogeneity of the spreading of iron civilization in space and time; regression about 1000 BC. The important role of Cyprus and Anatolia. Rich lists of finds dating from the 11th up to the 7th Centuries.

G.Chapotat. Gaullish Vienne. Material from La Tene III found on the hill of Sainte-Blandine. *(In French). Lyon, 1970.*

Metallographic investigations of four iron implements of 1st century BC. Wrought iron, carburization and piling.

J.Alenus - Lecerf: Merovingian graves at Comblain-Fairon. *(In French).* **Archaeologica Belgica,** *1971, 125.*

A craftsman's grave *(No.18)* contained a piece of grey cast iron with 3.02-3.67% C. Metallographic and chemical analyses were made and it was suggested that several tools found had been used for carving the hollows for inlays on iron surfaces.

G.Domański: A Roman and early medieval settlement with traces of smelting at Tarchalice, Wolów district. *(In Polish).* **Sprawozdania Archeologiczne,** *1972,* **24,** *391-438.*

In fact, the above mentioned traces represent the remains of 72 iron smelting furnaces with slag-pits, the largest groups known up to the present day. Situated in two groups they have been under excavation from the beginning of the present century. The author interprets the furnaces perhaps wrongly - as free-standing with no part below ground level.

M.Comsa (Mrs) and C.Deculescu. A hoard of tools and arms discovered at Curcani Ilfov district. Studii si cercetari di istorie veche,*1972,* **23** *(3), 469-473 (In Rumanian).*

A hoard of 11 iron tools *(Incl. blacksmith's tongs)*, 9th cent. AD.

H.Keiling. An iron anvil from a grave of the Jastorf culture from Boddin, Kr. Hagenow. *(In German).* **Ausgrabungen und Funde.** *1972,* **17** *(4), 176-179.*

Extremely small iron anvil found in a pre-Roman grave *(height 2.7 cm).*

I.Martens (Mrs). Msstrond in Telemark - an iron-smelting settlement. *Viking, 1972, 83-114.*

Recent Norwegian excavations yielded evidence of important iron smelting communities dating from the 6th and from about the 8-13th centuries. Houses, two types of smelting furnaces and slag heaps. Earlier furnaces were stone-lined, the later ones clay-walled with stone supports; slag tapping. Radiocarbon dates. Export of iron.

G.Fingerlin. Dnagstetten, a legionary fort on the Upper Rhine. *(In German).* **51-52 Bericht der Römisch-Germanischen Kommission, 1970-1971.** *1972, 197-232.*

The hearth of an iron smelting furnace came to light in the area of a legionary castrum *(beginning A.D.).* Blacksmith's tools.

P.Grim. Crafts and trade in the Pfalz town of Tilleda. *(In German).* **Zeitschrift für Archäologie,** *1972,* **6,** *104-147.*

Smithies are attested by workshop floors, tuyeres, smithing slags *(wrongly called "blooms"),* fragments of tools *(hammers),* and artifacts; 10-11th centuries A.D. *(pp.111-118).*

S.H.H.Kaland. Study on the Viking period of Telemark. *(In Norwegian).* **Årbok 1969.** *Universitets Oldsaksamling, Oslo, 1972, 67-215.*

Discussion of the economy of Telemark during the Viking Period. Iron making at Tinn and Rauland regions, smithing *(pp.161-163).* Statistics of blacksmith's tools found in the province *(p.138).*

O.Lipińska (Mrs.) The results of the 1966/67 surface investigations in the region of the Modrzejowica river, Kielce voivodship. *(In Polish).* **Wiadomości Archeologiczne,** *1972,* **37** *(2), 206-225.*

New finds of slag blocks *(diam. ca. 40 cm)* in the Kielce region dating from the Roman period.

K.Bielenin. Slag-pit type furnaces in ancient Europe. *(In Polish).* **Materiały Archeologiczne.** *1973,* **14,** *5-102.*

A detailed study of the type of the smelting furnace with a shaft and a slag pit. Its spread over Europe, variations, function, grouping in bloomeries and dating. Although the present chronological evidence points evidently to the east Celtic area, the auther leaves the question of its origins open. This paper also deals with the survival of the type after the Migration period.

J.Piaskowski. Metallographic analyses of iron objects from the settlements at Naszacowice, Weitrzno-Bobrka, Jodowniki Podgorne, Zagorowa and Aksmanice. *(In Polish).* **Acta Arch. Carpathica,** *1969-70,* **11** *(2), 329-344.*

A chemical and metallographic examination of iron objects of the 8th to 10th Century AD. Three knives and a fragment were made of low phosphorus iron, the others contained over 0.14% P. Two knives were welded iron and steel, one knife was carburized. The implements were heat treated. The slag contained rather high phosphorus (0.53 - 1.55% P_2O_5), and the concentration of aluminium and manganese oxides was low (*2.46 - 4.20%* Al_2O_3*, 0.13 - 0.61% MnO)*.

J.Piaskowski. Iron working techniques used by Slavs inhabiting the territories between the Odra and Vistula rivers in the 6th - 14th Century. *(In Polish).* **I Miedzynarodowy Kongres Archeologii Slowianskiej,** *1970,* **5,** *281-285.*

Altogether 500 iron implements were examined from 26 archaeological sites dated from the 4th to 14th century AD, and 64 fragments of slag from 10 sites. The Slavs used iron ores with high phosphorus content for producing iron and steel. They hardened tools by carburizing or welding iron with steel followed by heat treatment. Six knives were pattern welded. Similar techniques were used by Slavs in Russia, Czechoslovakia and Bulgaria. The technical level did not differ from that used in Western Europe.

J. Piaskowski. The achievements of research carried out in Poland in the history of early technology of iron. *(In Polish).* **Archaeologia Polona,** *1970,* **12,** *187-213.*

Over 1400 iron implements from over 250 archaeological sites from the 8th century BC to the 14th century AD were examined using chemical and metallographic techniques. The results were subject to statistical methods amongst others. A correlation was found between the phosphorus content of the iron and the slag, and between the hardness of the ferrite and the phosphorus content in the iron.

V.I.Raspopova. Crafts and workshop production at Sogd in the Middle Ages. *(In Russian).* **Sovietskaya archeologiya,** *1972,* **4,** *145-157.*

Twenty nine metallurgical workshops in 6-8th century Sogd: 2 bloomeries, workshops producing iron bars and many smithies concentrated mainly in one of the city quarters *(4 chronological horizons).*

H.Daicoviciu. Dacia and the Roman conquest. *(In Rumanian).* **Cluj,** *1972, pp.169-170.*

Remarks on metallurgical workshops at Szarmisegetusa, Poiana, and in other Dacian centres, Blacksmith's tools *(Fig.37).* Dating 1st century BC to 1st Century AD.

J.Piaskowski. Metallographic examination of early iron objects from the territory of South Poland. *(In Polish).* **Studia z dziejow gorn. i hutn.,** *1970,* **14,** *101-112.*

General review of results of the examination of iron objects dated from the 8th century BC to the 14th century AD on the territory between Carpathian Mountains and the rivers Vistula and San.

J.Piaskowski. Metallographic examination of Celtic brooches *(fibulae)* **found in Polish territories.** *(In Polish).* **Archeologia Polski,** *1970,* **14,** *(2), 387-417.*

The chemical analysis and metallographic examination of 16 Celtic iron brooches. Like some other Celtic artifacts some of the brooches are identified as products of the Holy Cross Mountains. The problem of the influence of Celts on the technology of iron in the Polish territories is discussed.

J.Piaskowski. Technology of metals in "Secrets" by Alexius Pedemontanus. *(In Polish).* **Kwart.Hist. Nauki i Techniki,** *1971,* **16,** *(1) 53-65.*

Polish translation of "Sectreti", published in 1568 which was the first book containing information on metals technology in this language. It describes the powdering of gold and silver, the refining of silver, moulding materials, and the technique of founding of small objects. This information was obtained by Pedemontanus from artisans.

J.Piaskowski. Metallographic examinations of ancient iron objects from Dobrzenkowo, Przasnysz district, Slupsk, Mlawa district, and Kostki, Ostroleka district *(In Polish).* **Materially starozytne i wczesnosrediowieczne,** *1971,* **1,** *171-187.*

The chemical analyses and metallographic examination of 27 iron objects from the 1st century BC to the 3rd century AD. The objects were divided into three groups: low phosphorus *(below 0.20% P)* and high phosphorus *(0.2-0.5% P).* Neither welding of iron and steel nor secondary carburization were detected.

J.Piaskowski. Problem of the beginning of iron metallurgy on the territories of Poland. *(In Polish).* **Przeglad Archeol.,** *1971,* **19-20,** *37-39.*

The archaeological theory that iron was smelted on the territories of Poland in Hallstatt period, based on the shape of objects is recently supported by statistical analysis of the metallographical examinations of implements identified by J.Kostrzewski as local types. They show the characteristics of metal melted in the Holy Cross Mountains. The author criticizes the theory that in the Hallstatt period iron was imported and merely forged on the territories of Poland.

ASIA

Rutherford J.Gettens, Roy S.Clarke, Jr.and W.T.Chase. Two early Chinese bronze weapons with meteoritic iron blades. *Freer Gallery Occasional Papers, 4, No.1. Book. Washington D.C., Freer Gallery of Art, 1971, 77 p. $5.00.*

This paper details the examination of two early Chou Chinese bronze weapons which have remnants of iron blades. While the iron age in China began only in the late Spring and Autumn Annals period *(ca. 600 BC)* these blades date from ca. 10,000 BC. The authors prove that the iron in these two blades is of meteoritic origin; the bronze was cast onto the iron blades. The objects are described. Radiographs, metallographs, microprobe traces, and chemical analyses are given, along with analyses and descriptions of other objects found in the same lot. 29 illustrations, 5 tables and bibliography.

Contents: Introduction; the broad axe (ch'i) 34.10; the dagger axe (ko) 34.11; studies on the oxide residues of the iron blade and iron point; significance of the findings.

Kumanhiko Hasegaw. Quality of ancient iron utensils in Japan. IV. *(In Japanese). Shigen Kagaku Kenkyusho Iho, 1970,* **74**, *44-56.*

Four samples from the Katayama ruins, Suita-shi, were analysed by spectrochemistry and x-ray microanalysis.

Karl Jettmar. Metallurgy in the early steppes. *Artibus Asiae, 1971,* **33**, *(1/2) 5-16.*

A general outline of the influences on metallurgy in the Central Asian area prior to the 3rd Century BC. The author draws on the conclusions of the Sackler Fund Laboratory, the Junghans-Sangmeister-Schröder team at Stuttgart, and several laboratories in Russia to support his conclusions with spectrographic analyses. Bronze and copper technology is emphasized, but iron smelting and forging is also mentioned. This article is a useful and thought-provoking summary of the evolution of metallurgy in this area and its connection with Iran and China. The discussion presented after the delivery of the paper appears as an addendum.

D.Alpin, J.W.Barnes et al. Geological mapping techniques at Küre, Turkey, in 1966. *CENTO 1966.*

Describes field work carried out on the copper deposit at Küre near Kastamonu in Turkey by a CENTO team. It was worked in Greek and Roman times and there are now large deposits of slag which probably represent the remains of operations conducted about 400-1000 years ago in Genoese and Ottoman times. The old slag heaps were found to be a good guide to outcrop deposits. The extraction of sulphide ores is now increasing but the early works probably used the oxodized ores, although the remaining gossan now lies directly on the massive primary sulphide ore. There is some enriched sulphide but this is very thin. There are about 1.5 million tons of slag with 1% Cu near the Bakibaba ore-body. The reserves contain 80% grade pyrite with 3% Cu.

Pieter Meyers. Interim report on the technical study of Sasanian silver objects from the Stage Hermitage Museum and the Metropolitan Museum of Art. *Bulletin of the American Group of The International Institute for Conservation of Historic and Artistic Works, 1972,* **12** *(2), 96.*

This study of objects from The Metropolitan Museum of Art and, most recently, from the State Hermitage Museum in Leningrad, USSR includes visual and microscopic examination, x-ray radiography, metallography whenever possible, major component and trace element analysis by neutron activation, analysis of gilding, niello and solder, identification of corrosion products by x-ray diffraction, etc.

Earle R.Caley. Chemical examination of metal artifacts from Afghanistan. *Transactions of the American Philosophical Society, 1972,* **62** *(4), 44-50.*

Quantitative analyses showed that two of the artifacts were originally composed of smelted copper, three of low-tin bronze, and five of bronze containing very high proportions of tin. Qualitative tests showed that seven of the objects in various states of corrosion still contained unaltered wrought iron, and that eight were composed of completely corroded iron.

Hiroshi Wake. Japanese sword. *(In Japanese). Kinzoku, 1971,* **41** *(1) 166-73.*

The Japanese traditional sword was metallographically investigated. The carbon distribution in the steel, showed 0.60-0.70% at the edge and 0.30-0.57% at the back. The estimated hardening temperature is about 775-800°.

Wan Chia Pao. Notes on the casting of the handles of some bronze vessels in the Yin dynasty. *Bulletin of the Institute of History and Philology, Academia Sinica, 1968.* **40,** *389-396. Diagrams, 2 plates.*

Four types of handle moulds are recognized : *(1)* an integral mould with separate core for the handles of **chüeh** and **kuei**, *(2)* bivalve mould for the handles of **chia**; *(3)* bivalve with a divided two-piece core for the handles of **chia**; *(4)* separately cast handle for mono-handled **ting**.

M.N.Ragimova and I.R.Selimkhanov. Finds of lead objects from the III-I millennium BC in the Trans-caucasus (results of chemical-spectral analysis). *(In Russian). Vop. Istor. Estestvozn. Tekh. 1971. (1) 56-7.*

The elemental composition *(Pb, Cu, Sn, Zn, As, Sb, Ag, Au, Bi, Ni, Co, Fe, Mo and P)* of 4 objects from the III-I millennium BC which were found in the Trans-caucasus, is determined by means of spectral analysis. Two of the objects dated to the III millennium BC, one to the end of the II - the beginning of the I millennium BC. The latest object differed in composition from the other 3 in that it contained 24% Sn while the earlier objects only contained traces of that element.

J.L.McCall and R.D.Buchheit. Metallographic studies of archeological metal artifacts from South Arabia. *Metallography, 1971,* **4** *(3), 189-207.*

Based on metallographical examination, 20 lead-tin bronze and 2 brass artifacts *(around 75 BC - 25 AD)* from the ruins of Timna, South Arabia, were cast by the "lost wax" process. There was 1 wrought and annealed copper artifact. The copper was produced from sulphide ores and the alloys were made by smelting intentional mixtures of copper and tin or copper and zinc ores. The Timna metalsmiths did not intentionally produce any standard alloys or use similar alloys for certain types of artifacts. The use of brass prior to the Roman period was significant.

P.R.S.Moorey and F.Schweizer. Copper and copper alloys in ancient Iraq, Syria and Palestine: some new analyses. *Archaeometry, 1972,* **14** *(2), 177- 98.*

A curved crystal linear X-ray fluorescence spectrometer with an area of analysis less than 1 mm square was used to determine tin, arsenic and antimony in 128 Cu-alloy objects from ancient Iraq, Syria and Palestine which are now in the Ashmolean Museum, Oxford. These analyses showed the gradual introduction of tin-copper alloys into Iraq after about 2750 BC, into Syria a little later, and into Palestine by the end of the 3rd millennium BC though numerous artifacts continue to be of copper or arsenic-copper until well into the 2nd millennium BC at least. With the appearance of tin-copper alloys the percentage of arsenic in the copper objects noticeably declines indicating that the earlier arsenic-copper alloys were deliberately produced under controlled conditions.

Earle R.Caley. Results of an examination of fragments of corroded metal from the 1962 excavations of Snake Cave, Afghanistan. *Transactions of the American Philosophical Society, 1972,* **62,** *(4), 43.*

Qualitative tests indicated that the original metal of three fragments was a simple tin bronze, and that the original metal of six others was probably wrought iron.

R.Pleiner. The problem of the beginning of the Iron Age in India. *Acta Praehistoria et Arch. 1971,* **2,** *5-31.*

Concludes that the Aryans settled in India long before the Iron Age and worked non-ferrous metals. Iron objects first appeared about 1000 BC probably as imports from the West. Changes took place around the 5th and 4th centuries BC with the appearance of slags and hearths. The largest quantities are in NW India but most of this dates after 300 BC. Hardenable steel was traded after the 1st century AD when there were contacts with Africa and Rome.

B.Rothenberg. Sinai Explorations, 1967-1972. *Bull. Museum Haaretz, 1972, Dec. pp.31-42.*

Found copper smelting sites of various periods. In south Sinai a site was investigated at Wadi Sa'al which had been previously reported by Petrie. There were traces of copper smelting of EBA II date on top of pre-pottery Neolithic B settlements. These were adjacent to malachite deposits. The Egyptian site at Serabit was mainly for the purpose of turquoise extraction but remains of copper working enter-prices were found. Ore sources were located in the area of the Wadi Maghara. The largest slag heap was found at Wadi Nasb and there were nearby deposits of oxide ores. New Kingdom faience dated the heaps to 1600-1100 BC, but much of the slag is from more recent times. Traces of native Cu were found in Wadi Ba'ba. But many of the reported copper mines were found to be manganese and turquoise mines.

AMERICA

J.L.McCall and R.D.Buchheit. Metallographic study of archeological artifacts. *Proc.Annu.Tech.Meet., Int. Metallogr. Soc. 3rd; 1970, pp.99-104 Edited by Johnson K.A., Int. Metallogr.Soc. Inc Los Alamos, New Mexico, 1971.*

Metallographic studies of recently discovered Ag-Cu alloy objects in Ecuador indicate that the Ecuadorian metalsmiths in the period 800-1519 AD had a fairly advanced knowledge of metallurgical technology. Interpretations of the microstructures revealed the probable methodology for the fabrication of the objects.

Georg Petersen. Mining and metallurgy in ancient Peru. *(In Spanish). Book. Museo Nacional de Antropologia y Arqueologia, Lima, Peru, 1970, IV + 140 p.*

All the minerals, ores, and rocks available to the ancient Peruvians are listed and described, along with the important localities. Mining sites and procedures are discussed in detail. The ancient metallurgical methods are described, including the manufacture of alloys. Many analyses of ancient metals and alloys are listed, and an extensive bibliography is included.

J.C.Antweiler and A.L.Sutton Jr. Spectrochemical analyses of native gold samples. *U.S.Geological Survey Report USGS-GD-70-003. Book. Springfield, Va. U.S. Geological Survey, U.S.Dept. Commercie National Technical Information Service, as report PB1-94809, 1970, 28 p.*

The authors present analyses of 174 samples of lode and placer gold from 67 localities in the continental United States and Alaska and one locality in Brazil. The samples were analyzed by quantitative spectrochemistry for silver and by a qualitative spectrochemical method for 32 other elements. There are significant differences between the lode and placer samples. The data presented here would be helpful to anyone working on tracing geologic origin of gold artifacts. With references.

C.J.Tesar and Sheila C.Tesar. Recent Chilean Copper Policy. *Geography, 1973, January, (258), pp.9-12.*

This article analyses the factors which caused nationisation of United States – owned copper facilities by the Chilean Government: Chile's high output, U.S.A.'s high demand and the oligopolistic nature of the industry.

After assessing Chile's role in the world copper industry, recent U.S. foreign policy and Chilean socio-economic developments, constraints and inducements to expropriation are reviewed. The paper draws the following conclusions for the government's decision: copper supply and demand, internal economic necessities, Chilean nationalism and political pressures from an anti-capitalistic group.

AFRICA

Saleh Ahmed Saleh, Adel Wageih George, and Fatma Mohamed Helmi. Study of Glass and Glass-making Processes at Wadi El-Natrun, Egypt in the Roman Period 30 BC to 359 AD; Part I, Fritting Crucibles, their technical features and temperature employed. *Studies in Conservation, 1972, 17, 143-172.*

In the Roman period, from about 30 BC to about AD 359, Wadi el-Natrun was probably one of the main centres of the glass industry in Egypt. In this district, the essential materials for glass-making processes, mainly silica and natron, were and are still quite abundant.

Two kinds of crucibles were in use: fritting and melting. The first kind was used for fritting the raw materials of glass to produce glass frit blocks. Such fritting crucibles had a rectangular form which is not usually encountered in other places. Probably this was intended to facilitate the transport of the glass frit blocks produced to glass factories in different places where raw materials were not available. Dimensions for two fritting crucibles are proposed. The body texture is coarse, highly porous and almost loose. These features were intended by the ancient glassmaker to release the frit block easily by fracturing the crucible, which was thus used only once.

The chemical composition is distinguished by a high content of iron oxide, lime, magnesia and alkailis, thus decreasing the resistance of the crucible to corrosion. The mineralogical composition is mainly: alpha quartz, albite, oligoclase, andesine, diopside, augite and a small amount of anorthoclase and other trace minerals.

The crucible material has been found to have been originally made by mixing mud with sand to which an amount of chopped straw was added; after sun-drying the crucible was baked before use.

The temperature employed in this process never exceeded 1100^{o}C, under prolonged heating, the crucible material fuses in the range 1150-1200^{o}C.